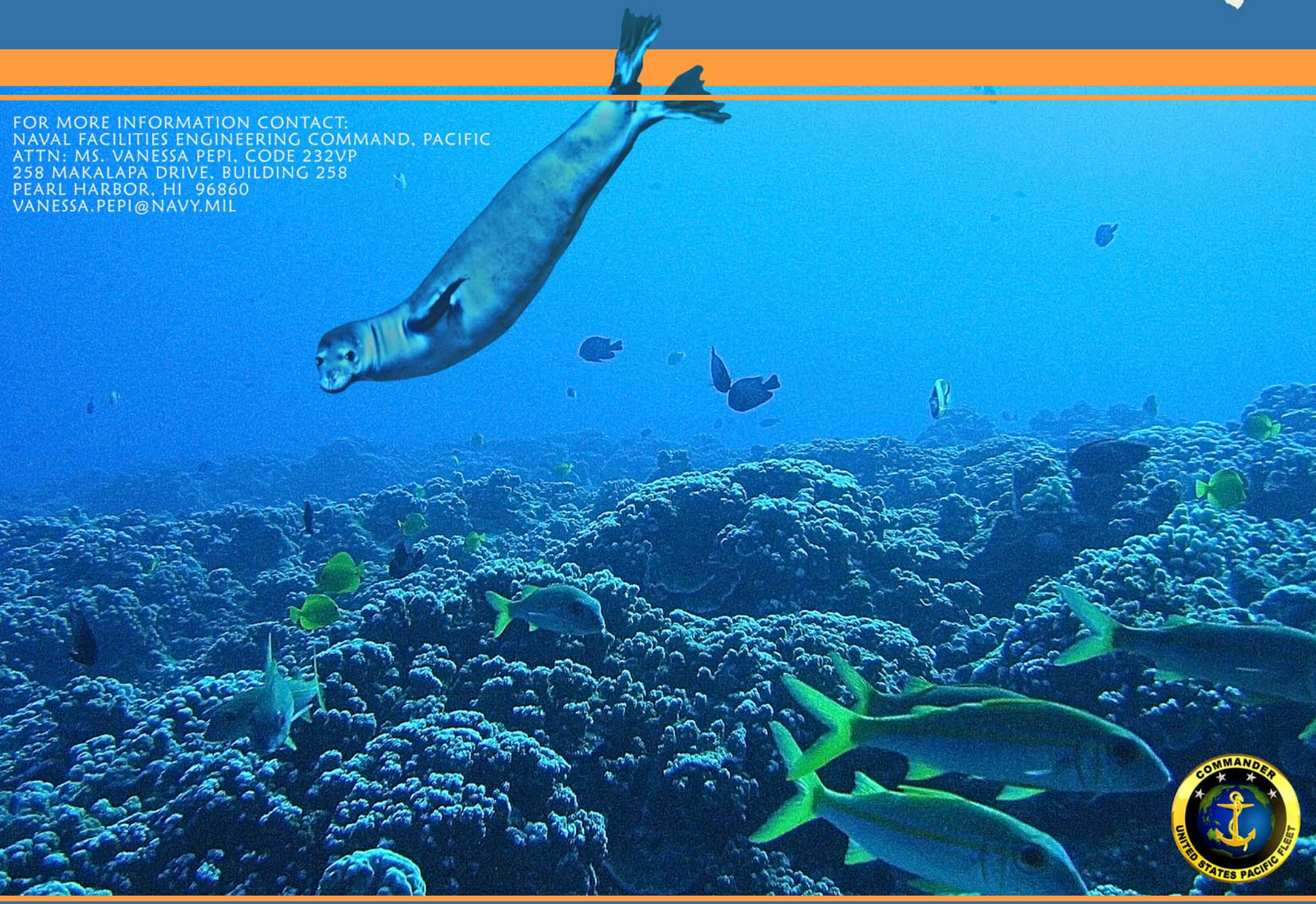
Marine Resources Assessment for the Hawaiian Islands Operating Area



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FINAL REPORT
DECEMBER 2005

MARINE RESOURCES ASSESSMENT FOR THE HAWAIIAN ISLANDS OPERATING AREA

FINAL REPORT

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Title Page Photograph: Hawaiian Monk Seal and Sea Turtle, Hawaii. George H. Balazs, NOAA.

STATEMENT OF PURPOSE

The Navy Commander, United States (U.S.) Pacific Fleet (COMPACFLT) implemented the Marine Resources Assessment (MRA) Program to establish a comprehensive source for information (which could include published information and consultations with regional and/or subject matter experts) concerning the protected and managed resources found in its various marine operating areas (OPAREAs). The information found within an MRA is vital for environmental planning and for use in environmental compliance documentation, for example the description of the affected environment. An MRA is not intended to be used in the place of a National Environmental Policy Act (NEPA) document. MRAs are reviewed by subject matter experts familiar with the region.

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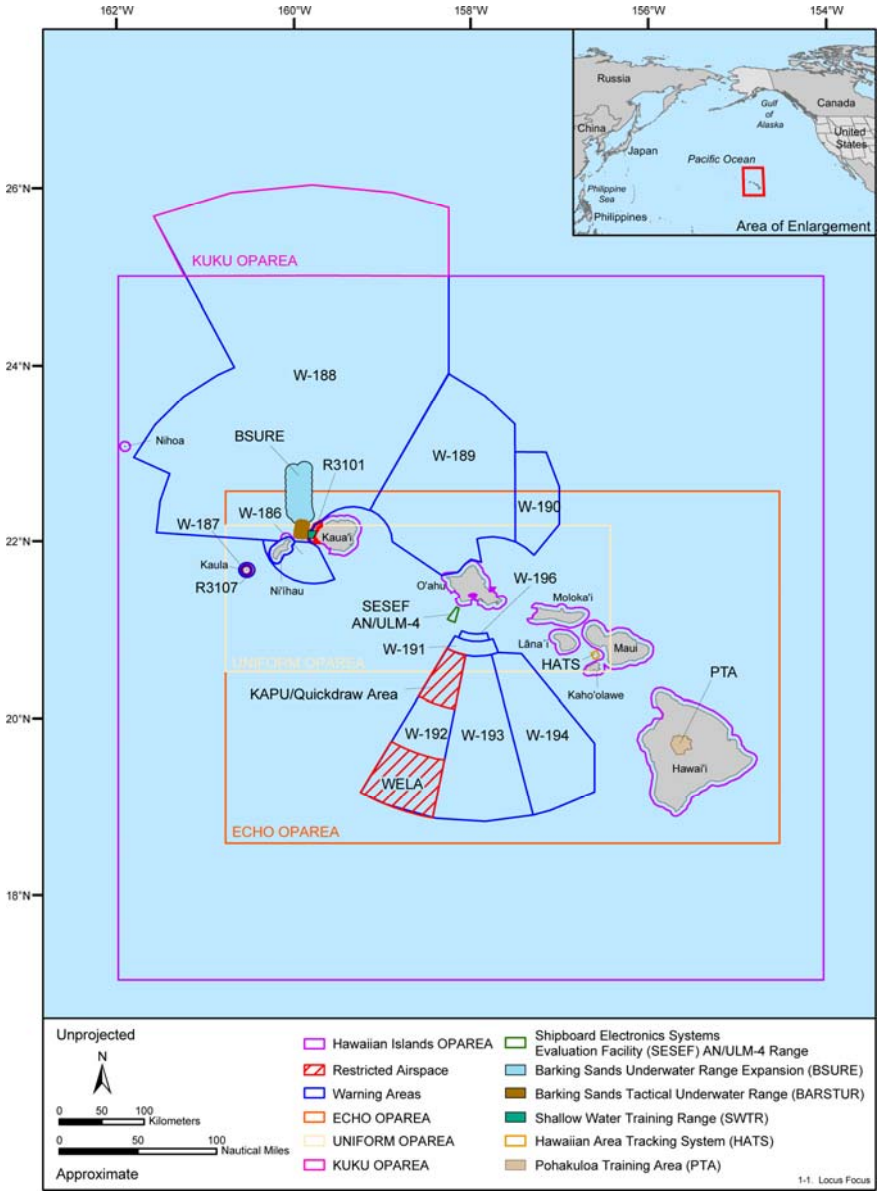
EXECUTIVE SUMMARY

The Department of the Navy (DoN) is committed to demonstrating environmental stewardship while executing its national defense mission. The U.S. Navy (Navy) is responsible for compliance with a suite of federal environmental and natural resources laws and regulations that apply to the marine environment, including NEPA, the Marine Mammal Protection Act (MMPA), the Endangered Species Act (ESA), the Magnuson-Stevens Fishery Conservation and Management Act/Sustainable Fisheries Act (MSFCMA/SFA), and Executive Order (EO) 13089 on Coral Reef Protection. The Navy implemented the MRA program to develop a comprehensive compilation of data and literature concerning the protected and managed marine resources found in its various operating areas. The information in this MRA is vital for planning purposes and for various types of environmental documentation such as biological and environmental assessments that must be prepared in accordance with the NEPA, MMPA, ESA, and MSFCMA/SFA.

This MRA documents and describes the marine resources in the vicinity of the Hawaiian Islands OPAREA. An overview of the Pacific Ocean marine environment found in the central Pacific Ocean illustrates the important physical parameters that may affect the occurrence and distribution of protected and managed marine species. Detailed information is included on the characteristics and life history of protected marine mammals, sea turtles, and seabirds that may occur in the Hawaiian Islands OPAREA and the vicinity. Seasonal variations in protected species occurrence patterns have been identified, mapped, and described along with the likely causative factors (behavioral, climatic, or oceanographic). The probable distributions of nearshore communities such as seagrasses, fishponds, and salt marshes have been assessed. Oceanic habitats including deep rocky and artificial habitats are also described and mapped. An overview of the fish assemblages associated with the waters of the Hawaiian Islands OPAREA as well as fishing activities (commercial and recreational) are reviewed and their occurrences noted. Fish species for which essential fish habitat (EFH) has been designated in the Hawaiian Islands OPAREA are described in detail, including their status,



distribution, and EFH by life history stage. Information is provided on such additional considerations as U.S. maritime boundaries, navigable waters, marine managed areas (MMA), Self Contained Underwater Breathing Apparatus (SCUBA) diving sites, and whale watching activities, in proximity to the Hawaiian Islands OPAREA.

Thorough and systematic literature and data searches were conducted, providing as much relevant information as possible for this assessment. Sighting, stranding, incidental fisheries bycatch, satellite-tracking, and haulout data for marine mammals and sea turtles were compiled and interpreted to predict the occurrence patterns in the OPAREA for these protected and managed species. Predictions of the densities or areas of occurrence for marine mammals and sea turtles are based on available occurrence data (e.g., sighting, stranding, and bycatch records) as well as scientific literature and expert opinion.

The geographical representation of marine resource occurrences in the Hawaiian Islands OPAREA and vicinity is a major constituent of this MRA. A geographic information system (GIS) was used to store, manipulate, analyze, and display the spatial data and information accumulated for the MRA of the Hawaiian Islands OPAREA. Over 145 GIS-generated map figures are included in this assessment; data layers associated with these maps comprise bathymetry, sea surface temperature (SST), protected and managed species' occurrences, EFHs, Navy operating area grids, and maritime boundaries in addition to many others. Metadata (documentation of the GIS data) were also prepared for each GIS file associated with this MRA report. The MRA report for the Hawaiian Islands OPAREA is provided in both paper and electronic form.

REPORT ORGANIZATION

This report consists of eight chapters and four appendices:

Chapter 1 Introduction—provides background information on this project, an explanation of its purpose and need, a review of relevant environmental legislation, and a description of the methodology used in the assessment;

Chapter 2 Physical Environment and Habitats—describes the physical environment (e.g., marine geology [physiography, bathymetry, and bottom sediments], physical oceanography [circulation and currents], hydrography [temperature], and biological oceanography [plankton and primary productivity]) and habitats (e.g., estuarine, nearshore, and oceanic) of the Hawaiian Islands OPAREA and vicinity;

Chapter 3 Species of Concern—covers protected marine mammals, sea turtles, and birds found in the vicinity of the Hawaiian Islands OPAREA, with detailed narratives of their morphology, status, habitat preferences, distribution, behavior, life history, acoustics, and hearing;

Chapter 4 Fish and Fisheries—investigates fish, fishing activities (commercial and recreational), and EFH for managed species that occur within the Hawaiian Islands OPAREA;

Chapter 5 Additional Considerations—provides information on maritime boundaries, navigable waters, MMAs, the North Pacific Acoustic Laboratories (NPAL) sound source, SCUBA diving locations, and whale watching;

Chapter 6 Recommendations—suggests future avenues of research that are necessary to fill the data gaps identified in this project and prioritizes research needs from a cost/benefit approach;

Chapter 7 List of Preparers—lists all individuals who helped prepare the Hawaiian Islands OPAREA MRA report;

Chapter 8 Glossary—includes definitions of the terms used in the MRA report;

Appendix A—contains source information for marine mammal and sea turtle data, data confidence levels, map projection information, and map figures illustrating the sighting survey effort of aerial and shipboard surveys used in the Hawaiian Islands OPAREA MRA;

Appendix B—marine mammal occurrence maps;

Appendix C—sea turtle occurrence maps; and

Appendix D—EFH maps.

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LIST OF ACRONYMS AND ABBREVIATIONS

%	Percent
°C	Degrees Celsius
μm	Micron(s)
2D	Two-Dimensional
3D	Three-dimensional
ac	Acre(s)
AFB	Air Force Base
AFPI	American Flag Pacific Islands
AFSC	Alaska Fisheries Science Center
ATOC	Acoustic Thermometry of Ocean Climate
AVHRR	Advanced Very High-resolution Radiometer
BASSEX	Basin Acoustic Seamount Scattering Experiment
BCC	Birds of Conservation Concern
BMUS	Bottomfish Management Unit Species
BRFA	Bottomfish Restricted Fishing Areas
C	Carbon
CCL	Curved Carapace Length
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CHCRT	Currently Harvested Coral Reef Taxa
CHCRT	Currently Harvested Coral Reef Taxa
chl *a*	Chlorophyll a
cm	Centimeter(s)
cm/sec	Centimeter(s) Per Second
cm/yr	Centimeter(s) Per Year
CMUS	Crustacean Management Unit Species
CNMI	Commonwealth of the Northern Mariana Islands
COMPACFLT	Commander, U.S. Pacific Fleet
CPHC	Central Pacific Hurricane Center
CPUE	Catch Per Unit Effort
CRAMP	Coral Reef Assessment and Monitoring Program
CRC	Cascadia Research Collective
CRE MUS	Coral Reef Ecosystem Management Unit Species
CRE	Coral Reef Ecosystem
CWA	Clean Water Act
CZCS	Coastal Zone Color Scanner
CZMA	Coastal Zone Management Act
d	Day
dB re 1μPa-m	Decibels at the Reference Level of One Micropascal at One Meter
dB	Decibel
DLNR	Department of Land and Natural Resources
DoD	Department of Defense
DoI	Department of the Interior
DOM	Dissolved Organic Matter
DoN	Department of the Navy
DoS	Department of State
DoT	Department of Transportation
DSL	Deep Scattering Layer
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
ENSO	El Niño/Southern Oscillation
EO	Executive Order

LIST OF ACRONYMS AND ABBREVIATIONS
(Continued)

EPA	Environmental Protection Agency
ESA	Endangered Species Act
ESI	Environmental Sensitivity Index
ESRI	Environmental Systems Research Institute, Inc.
FACSFAC	Fleet Area Control and Surveillance Facility
FAD	Fish Aggregating Device
FAO	Food and Agriculture Organization
FCMA	Fishery Conservation and Management Act
FIR	Four Island Region
Fleet	U.S. Pacific Fleet
FM	Frequency-modulated
FMA	Fisheries Management Area(s)
FMC	Fishery Management Council
FMP	Fishery Management Plan
FR	Federal Register
FRA	Fisheries Replenishment Areas
ft	Feet
FWPCA	Federal Water Pollution Control Act
g	Grams
GDAIS	General Dynamics Advanced Information System
GIS	Geographic Information System
GMI	Geo-Marine, Inc.
ha	Hectare(s)
HAPC	Habitat Area(s) of Particular Concern
HDAR	Hawai‘i Division of Aquatic Resources
HDLNR	Hawai‘i Department of Land and Natural Resources
HIHWNMS	Hawaiian Islands Humpback Whale National Marine Sanctuary
HIMB	Hawai‘i Institute of Marine Biology
HLCC	Hawaiian Lee Counter Current
HMS	Highly Migratory Species
hr	Hour(s)
HTML	Hyper Text Markup Language
HVO	Hawai‘i Volcano Observatory
Hz	Hertz
IGFA	International Game Fish Association
in	Inch(es)
INRMP	Integrated Natural Resource Management Plans
IUCN	International Union for Conservation of Nature and Natural Resources
IWC	International Whaling Commission
kg	Kilogram
$kg/m^2/yr$	kilogram(s) Per Square Meter(s) Per Year
kHz	Kilohertz
km	Kilometer(s)
km/hr	Kilometer(s) Per Hour
km^2	Square kilometers
kph	Kilometers Per Hour
lbs	Pounds
LC	Location Classes
LCU	Landing Craft Utillity
LOAPEX	Long-range Ocean Acoustic Propagation Experiment
LTR	Laser Training Range(s)
m	Meter(s)
m/km	Meter(s) Descent Per Kilometer

LIST OF ACRONYMS AND ABBREVIATIONS
(Continued)

m/sec	Meters Per Second
m^2	Square Meter(s)
m^3	Cubic Meter(s)
m^3/yr	Cubic Meter(s)
MBTA	Migratory Bird Treaty Act
mg	Milligram(s)
Mg/m^2/yr	Milligram(s) Per Square Meter(s) Per Year
MHI	Main Hawaiian Islands
mi	Mile(s)
mi^2	Square Mile(s)
min	Minute(s)
MLCD	Marine Life Conservation Districts
MLLW	Mean Lower Low Water
mm	Millimeter(s)
mm/d	Millimeter(s) Per Day
MMA	Marine Managed Area
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
MMU	Minimum Mapping Unit
MOU	Memorandum of Understanding
MPA	Marine Protected Area
MPPRCA	Marine Plastic Pollution Research and Control Act
MPRSA	Marine Protection, Research, and Sanctuaries Act
MRA	Marine Resources Assessment
msec	Millisecond(s)
MSFCMA	Magnuson-Stevens Fishery Conservation and Management Act
mt	Metric Ton(s)
MUS	Management Unit Species
N/A	Not Available
NARP	National Artificial Reef Plan
NASA	National Aeronautics and Space Administration
Navy	United States Navy
NCCOS	National Centers for Coastal Ocean Science
NEC	North Equatorial Current
NEPA	National Environmental Policy Act
NFEA	National Fishery Enhancement Act
NGDC	National Geophysical Data Center
NHP	National Historical Parks
NHRC	North Hawaiian Ridge Current
NM	Nautical Mile(s)
NM^2	Square Nautical Miles
NMFS	National Marine Fisheries Service
NMML	National Marine Mammal Laboratory
NMS	National Marine Sanctuaries
NMSA	National Marine Sanctuaries Act
NMSP	National Marine Sanctuaries Program
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NP	National Parks
NPAL	North Pacific Acoustic Laboratory
NPCW	North Pacific Central Water
NPIW	North Pacific Intermediate Water
NPS	National Park Service

LIST OF ACRONYMS AND ABBREVIATIONS
(Continued)

NPSG	North Pacific Subtropical Gyre
NRFCC	National Recreational Fisheries Coordination Council
NWHI	Northwestern Hawaiian Islands
NWHICRER	Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve
NWR	National Wildlife Refuge
NWRS	National Wildlife Refuge System
OCS	Outer Continental Shelf
ONR	Office of Naval Research
OPA	Oil Pollution Act
OPAREA	Operating Area
PBR	Potential Biological Removal
PCMUS	Precious Corals Management Unit Species
PDF	Portable Document Format
PDO	Pacific Decadal Oscillation
PDW	Pacific Deep Water
PHCRT	Potentially Harvested Coral Reef Taxa
PI	Principal Investigator
PIFSC	Pacific Islands Fisheries Science Center
PIR	Pacific Islands Region
PMRF	Pacific Missile Range Facility
PMUS	Pelagic Management Unit Species
POM	Particulate Organic Matter
POP	Platforms of Opportunity Program
ppt	Parts Per Thousand
PRIA	Pacific Remote Island Areas
psu	Practical Salinity Unit(s)
RFRCP	Recreational Fishery Resources Conservation Plan
RIMPAC	Rim of the Pacific
S.D.	Standard Deviation
SCUBA	Self Contained Underwater Breathing Apparatus
sec	Second(s)
SFA	Sustainable Fisheries Act
SLP	Sea Level Pressure
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SWFSC	Southwest Fisheries Science Center
SWR	Southwest Region
SWTR	Shallow Water Training Range
TIN	Triangular Irregular Network
TTS	Temporary Threshold Shifts
TZCF	Transition Zone Chlorophyll Front
U.N.	United Nations
U.S.	United States
U.S.C.	United States Code
USACE	U.S. Army Corps of Engineers
USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USMC	United Sates Marine Corp
USVI	United States Virgin Islands
VLA	Vertical Line Array(s)
WIDECAST	Wider Caribbean Sea Turtle Conservation Network
WPRFMC	Western Pacific Regional Fishery Management Council

LIST OF ACRONYMS AND ABBREVIATIONS
(Continued)

WWII	World War II
XML	Extensible Markup Language
yd	Yard(s)
yr	Year(s)
ZTA	Zevenbergen and Thorn Algorithm

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1.0 INTRODUCTION

The COMPACFLT contracted this MRA to initiate collection of data and information concerning the protected and commercial marine resources found in the Hawaiian Islands OPAREA. For the purposes of this MRA, the Hawaiian Islands OPAREA and surrounding region may also be referred to as the "study area" or "study region."

1.1 PURPOSE AND NEED

The goal of this MRA is to provide a compilation of the most recent data and information on the occurrence of marine resources in the Hawaiian Islands OPAREA. This MRA report includes a discussion of the physical environment, habitats (coastal and oceanic), and protected species found in the OPAREA and surrounding region. Also addressed in this assessment are EFHs, commercial and recreational fisheries, and other areas of interest (e.g., MMAs and SCUBA diving sites) that occur around the Hawaiian Islands. The identification of data gaps and the prioritization of recommendations for future research in the OPAREA are additional components of this report.

The DoN is responsible for organizing, training, and equipping naval forces for combat. The mission of the Hawaiian Islands OPAREA is to support Navy and U.S. Marine Corps (USMC) tactical training by providing air, surface, and subsurface space for operations such as gunnery, rocket and missile firing, ordnance delivery and recovery, sonar/radar testing, vessel and submarine transit, and undersea warfare exercises (DoN 2000). Section 4.1.1 of Department of Defense (DoD) Instruction 4715.3, "Environmental Conservation Program" states that "All DoD conservation programs shall work to guarantee continued access to our land, air, and water resources for realistic military training and testing while ensuring that natural and cultural resources are sustained in a healthy condition for scientific research, education, and other compatible uses by future generations." The information assembled in this MRA will serve as a baseline from which the Navy may evaluate its operations and their potential impacts on the marine environment while balancing the requirement to provide trained and ready forces with the obligations of sound resource stewardship. This assessment will contribute to the U.S. Pacific Fleet's (Fleet) integrated long-range planning process and represents an important component in the Fleet's ongoing compliance with U.S. federal mandates that aim to protect and manage resources in the marine environment. All species and habitats potentially affected by the Navy's maritime exercises and protected by U.S. federal resource laws or EOs are considered in this assessment.

A search and review of relevant literature and data was conducted to provide information on important features of the marine environment, the occurrence patterns of protected species, the distribution of EFHs, and other Navy concerns in the Hawaiian Islands OPAREA and vicinity. To describe the physical environment and habitats of the OPAREA, physiographic, bathymetric, geologic, hydrographic, and oceanographic data for the study region were compiled and the locations of coral, hardbottom, seagrass, estuarine, mangrove, intertidal, deep sea, and artificial habitats were identified. Comprehensive sighting, stranding, incidental fisheries bycatch, satellite tracking, and haulout data for marine mammals and sea turtles were collected and analyzed to qualitatively predict the areas of occurrence for these protected species in the OPAREA. Marine mammal and sea turtle areas of occurrence have been identified, mapped, and described along with the likely causative factors (behavioral, climatic, or oceanographic). Federally protected seabird species are also addressed in this assessment. Occurrence maps produced for these species were developed from available sighting and habitat data as well as known distributional information (e.g., foraging/breeding ranges). Biological characteristics, such as habitat preferences, behaviors, and life history patterns, were researched for all federally protected species potentially occurring around the Hawaiian Islands. Also reviewed were commercial and recreational fishing activities, EFHs, U.S. maritime boundaries, commercially navigable waterways, MMAs, SCUBA diving sites, the NPAL sound source, and whale watching and swim with wild dolphin tours.

1.2 Location of the Hawaiian Islands OPAREA

The Hawaiian Islands OPAREA is located in the central North Pacific Ocean and surrounds the eight main Hawaiian Islands (MHI) as well as Kaula and Nihoa (**Figure 1-1**). The MHI include (from southeast to northwest): Hawaiʻi (the Big Island), Maui, Kahoʻolawe, Lānaʻi, Molokaʻi, Oʻahu, Kauaʻi, and Niʻihau. Kaula Island, also known as Kaula Rock, is a small, uninhabited island located 35 kilometers (km) southwest of Niʻihau. Nihoa Island lies near the western boundary of the OPAREA and is the easternmost of the Northwestern Hawaiian Islands (NWHI). Collectively, the MHI and NWHI comprise what is known as the "Hawaiian Islands chain" or the "Hawaiian archipelago." This 21,500-km long island chain is the most geographically isolated in the world (Maragos 2000). The closest lands to this archipelago are the islands of Johnston Atoll, an unincorporated U.S. territory situated over 800 km to the southwest.

The Hawaiian Islands are the summits of gigantic volcanic mountains that were formed by countless eruptions of fluid lava over several millions of years. Some of these islands tower more than 9,000 meters (m) above the ocean floor. These volcanic peaks, which have risen above the ocean surface, represent only a tiny visible part of an immense submarine ridge that is composed of more than 80 large volcanoes. At present, all of the Hawaiian Islands are dormant except for Hawaiʻi. Bordering the Hawaiian Islands is an extensive system of coral reefs, submerged banks, and seamounts. The coral reefs of the Hawaiian Islands are some of the healthiest and most undisturbed coral reefs remaining on Earth (Ziegler 2002).

Approximately 99 percent (%) of the emergent land in the Hawaiian archipelago is located in the MHI; consequently, this is where the majority of the human population is concentrated. The NWHI, nearly all of which are uninhabited by humans, are comprised primarily of submerged islands, shoals, and atolls. These islands are considered the geologically older region of the archipelago. The reefs and atolls of the NWHI represent the "footprints" of former high volcanic islands. All of the NWHI belong to the State of Hawaiʻi except for Midway Atoll, an unincorporated U.S. territory. Aside from Kure Atoll (a state preserve) all of the NWHI are administered as federally protected national wildlife refuges (NWR). Several areas in the NWHI are also designated as critical habitat for the endangered Hawaiian monk seal (Loope 1998).

Covering 745,154 square kilometers (km^2) of ocean area, the Hawaiian Islands OPAREA includes seven nearshore components as well as a sizable offshore component. The offshore (oceanic) ecosystem is considered to be rather homogenous in terms of habitat, while the nearshore (coastal) regions are more complex. Although the insular shelf around the Hawaiian Islands is narrow, the nearshore regions of the archipelago support a great diversity of marine mammal, sea turtle, fish, and coral species (Mundy and Everson 1998). The nearshore component of the OPAREA consists of six coastal areas around the MHI: (1) Kiholo Bay (Hawaiʻi), (2) the western shore of Molokaʻi, (3) Pearl Harbor (Oʻahu), (4) waters surrounding Marine Corps Base Hawaiʻi and Marine Corps Training Area Bellows (Oʻahu), (5) waters off Kahe Point (Oʻahu), and (6) a nearshore area ranging from Pacific Missile Range Facility (PMRF) Barking Sands to Port Allen Military Reservation (Kauaʻi). The OPAREA also encompasses all coastal waters surrounding Kaula. The offshore component of the Hawaiian Islands OPAREA is extensive, stretching beyond the limits of the U.S. Exclusive Economic Zone (EEZ) in three locations. The boundaries of the Hawaiian Islands OPAREA roughly lie along the following parallels: 154°W (eastern boundary), 17°N (southern boundary), and 162°W (western boundary). The northern boundary of the OPAREA runs along 25°N except where the KUKU OPAREA juts out to approximately 26°N.

Major port cities adjacent to the Hawaiian Islands OPAREA include Honolulu on Oʻahu, Kahului on Maui, and Hilo and Kawaihae on Hawaiʻi (AAPA 2005). Important military installations in proximity to the OPAREA include Pearl Harbor Naval Complex on Oʻahu (**Figure 1-2**) and PMRF Barking Sands on Kauaʻi (**Figure 1-3**). Fleet Area Control and Surveillance Facility (FACSFAC) Pearl Harbor and PMRF Barking Sands maintain surveillance and coordinate the scheduling of the Hawaiian Islands OPAREA to ensure maximum availability and utilization. FACSFAC Pearl Harbor regulates the use of UNIFORM and ECHO OPAREAs, "hot areas" KAPU/Quickdraw and WELA, restricted area R3107, and warning areas W-187, W-189, W-190, W-191, W-192, W-193, W-194, and W-196. PMRF Barking Sands oversees operations conducted in KUKU OPAREA, restricted area R3101, and warning areas W-186 and W-188 (DoN 2000).

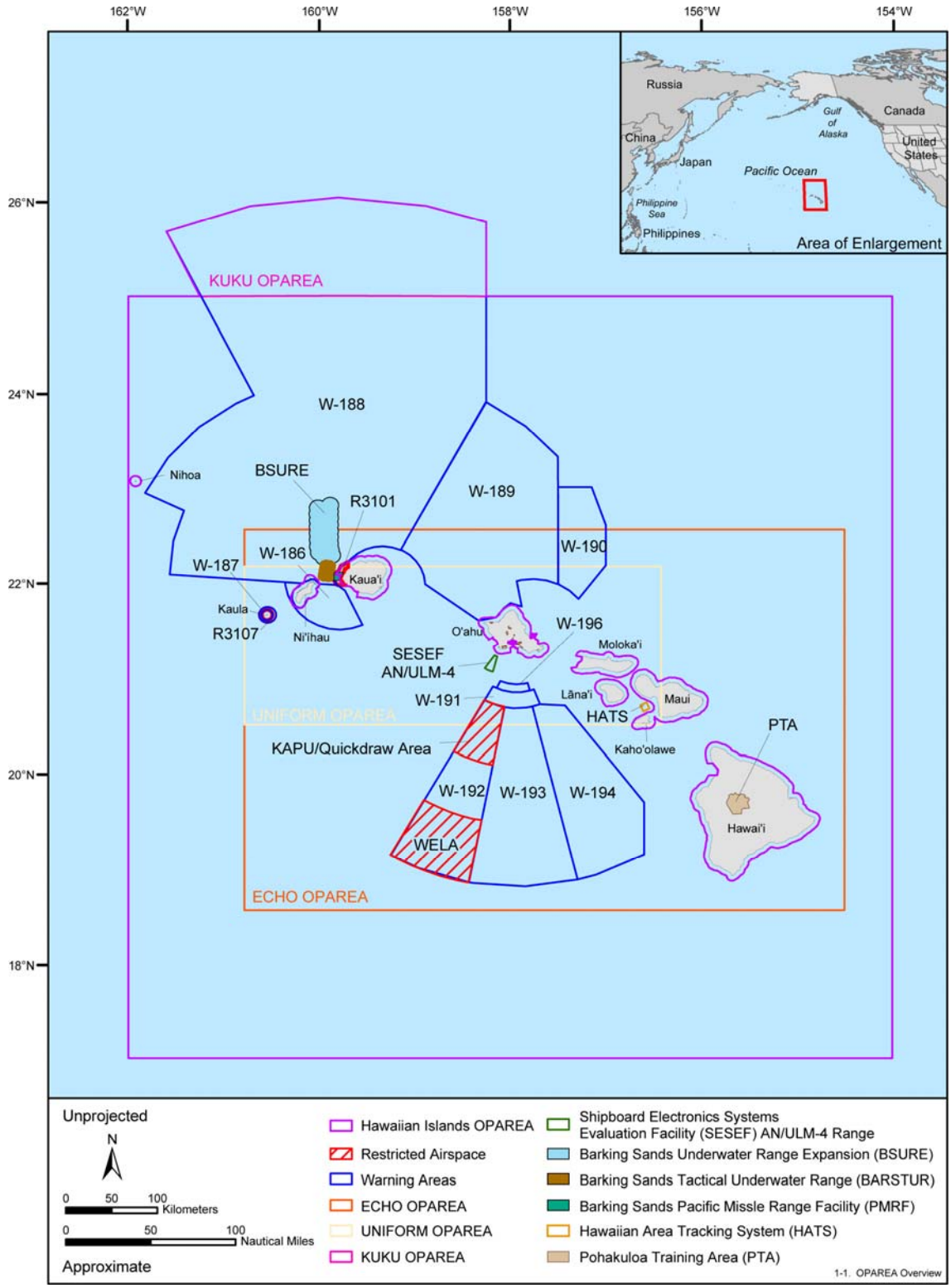

Figure 1-1. The Hawaiian Islands OPAREA is located in the central North Pacific Ocean and surrounds the eight main Hawaiian Islands (MHI) (Hawai‘i, Maui, Kaho‘olawe, Lāna‘i, Moloka‘i, O‘ahu, Kaua‘i, and Ni‘ihau) as well as Kaula and Nihoa. The OPAREA runs up to the Hawaiian shoreline off northwestern Hawai‘i, western Moloka‘i, southwestern Kaua‘i, at three locations around O‘ahu, and around the entire island of Kaula. Source data: SRS Technologies, Inc. (2003).

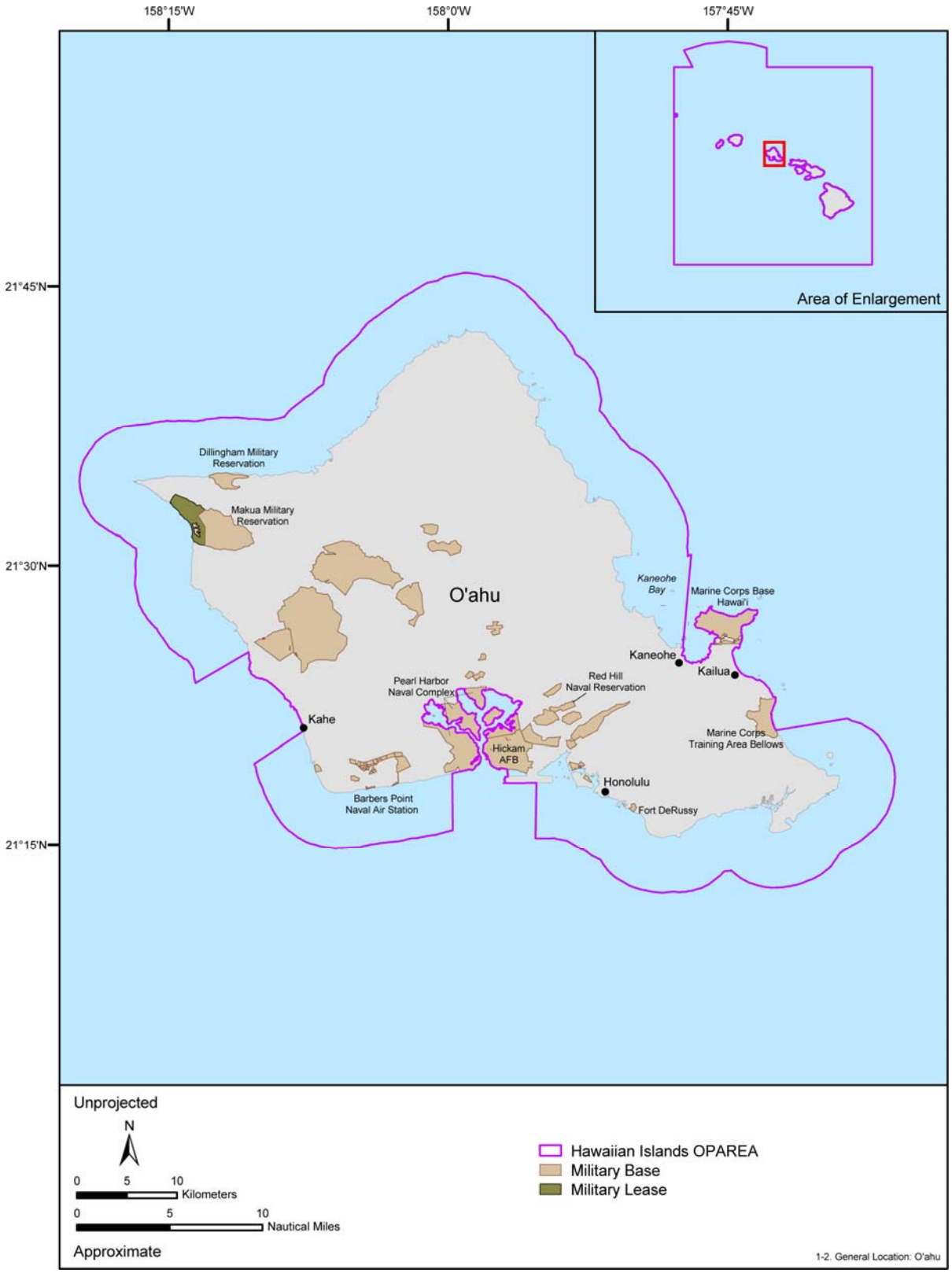

Figure 1-2. A zoom-in view of O‘ahu and the major cities and nearshore military installations located on the island. Source data: SRS Technologies, Inc. (2003).

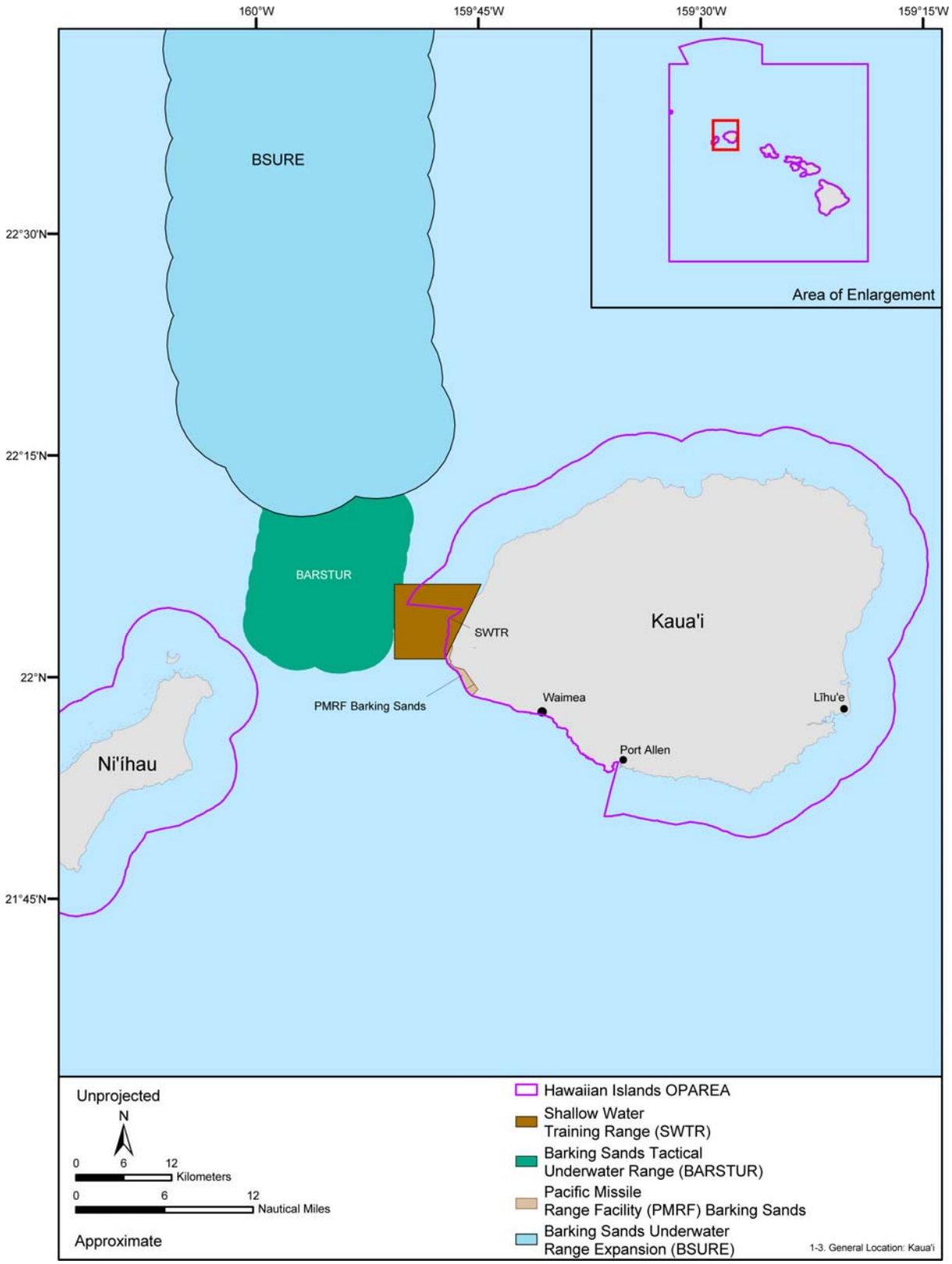

Figure 1-3. A zoom-in view of Kaua‘i and the major cities and nearshore military installations located on the island. Source data: SRS Technologies, Inc. (2003).

Pearl Harbor Naval Complex provides services similar to those of a large port city. It is one of the Navy's busiest installations in the Pacific region, completing approximately 65,000 boat runs and transporting 2.4 million passengers and 200,000 vehicles each year. Tour boats manned by Navy personnel transport more than 2 million visitors to the *U.S.S. Arizona* Memorial each year. Pearl Harbor Naval Complex also houses approximately 3,000 permanent party and transient personnel (DoN n.d.). PMRF Barking Sands is the largest instrumented, multi-dimensional testing and training range in the world. It consists of multiple land, air, and sea facilities throughout the State of Hawai‘i (DoN 2001a). Besides the DoD, this facility supports the U.S. Department of Energy, National Aeronautics and Space Administration (NASA), Defense Special Weapons Agency, and Ballistic Missile Defense Organization. The NPAL sound source, an underwater cable located along the northwest coast of Kaua‘i, originates from PMRF Barking Sands (ONR 2001). The Navy’s Shallow Water Training Range (SWTR) is also located adjacent to the PMRF.

The *Integrated Natural Resources Management Plan: Pacific Missile Range Facility Hawaii* (DoN 2001a) and the *Pearl Harbor Naval Complex Integrated Natural Resources Management Plan* (DoN 2001b) provide an abundance of information on the coastal environments and Naval activities found at the above installations. The *Ehime Maru Environmental Assessment* (DoN 2001c), the *Rim of the Pacific (RIMPAC) Programmatic Environmental Assessment* (DoN 2002a), and the *Environmental Assessment for the Hawaiian Islands Shallow Water Training Range* (DoN 2002b) also provide detailed environmental information for Naval training areas and installations located throughout the Hawaiian Islands chain.

A prominent Naval training area in the Hawaiian Islands used to be located on the island of Kaho‘olawe, the smallest of the MHI. Located about 10 km southwest of Maui, Kaho‘olawe served as a critically important Naval gunfire, aerial bombardment, and defense training area for the U.S. and its allies during World War II (WWII), Korea, Vietnam, and the Cold War. In 1993, defense training on the island ended and the Navy embarked on the most extensive unexploded ordnance cleanup project in history to clear specific areas of the island for controlled public use (e.g., camping, historical and cultural preservation, wildlife conservation). A detailed history of the island and an inventory of its terrestrial and marine flora and fauna can be found in the *Environmental Impact Statement: Military Use of Kahoolawe Training Area, Hawaiian Archipelago* (DoN 1979). Currently, Kaula is the only island within the OPAREA and vicinity that is under complete control of the Navy. This island is utilized primarily as a target range/impact area (DoN 2001c).

1.3 APPLICABLE LEGISLATION

The primary environmental laws that govern Navy activities in the marine environment include the National Environmental Policy Act, the Marine Mammal Protection Act, the Endangered Species Act, and the Magnuson-Stevens Fishery Conservation and Management Act. In addition to these federal acts, there are several other federal mandates and executive orders that deal with resource conservation and management in ocean waters under U.S. jurisdiction. Following are lists of the many laws and regulations (both federal and state) that the Navy must consider when conducting maritime operations.

1.3.1 Federal Resource Laws

- The **National Environmental Policy Act** (NEPA) of 1969 (42 U.S. Code [U.S.C.] §§ 4321 et seq.) established national policies and goals for the protection of the environment. The NEPA aims to encourage harmony between people and the environment, to promote efforts to prevent or eliminate damage to the environment and the biosphere, and to enrich the understanding of ecological systems and natural resources important to the country. Thus, environmental factors must be given appropriate consideration in all decisions made by federal agencies.

  The NEPA is divided into two sections: Title I outlines a basic national charter for protection of the environment, while Title II establishes the Council on Environmental Quality (CEQ), which monitors the progress made towards achieving the goals set forth in Section 101 of the NEPA. Other duties of the CEQ include advising the President on environmental issues and providing guidance to other federal agencies on compliance with the NEPA.

Section 102(2) of the NEPA contains "action-forcing" provisions that ensure that federal agencies act according to the letter and the spirit of the law. These procedural requirements direct all federal agencies to give appropriate consideration to the environmental effects of their decision-making and to prepare detailed environmental statements on recommendations or reports on proposals for legislation and other major federal actions significantly affecting the quality of the environment.

Future studies and/or actions requiring federal compliance which may utilize the data contained in this MRA should be prepared in accordance with Section 102(2)(c) of the NEPA, the CEQ regulations on implementing NEPA procedures (40 Code of Federal Regulations [CFR] 1500-1508), and the DoN regulations on implementing NEPA procedures (32 CFR 775).

- The **Marine Mammal Protection Act** (MMPA) of 1972 (16 U.S.C. §§ 1361 et seq.) established a moratorium on the "taking" of marine mammals in waters or on lands under U.S. jurisdiction. Marine mammals include cetaceans (whales, dolphins, and porpoises), pinnipeds (seals and sea lions), sirenians (manatees and dugongs), sea otters, walruses, and polar bears. The MMPA defines taking as "harassing, hunting, capturing, killing, or attempting to harass, hunt, capture, or kill any marine mammal" (16 U.S.C. §§ 1362[13]). It also prohibits the importation into the U.S. of any marine mammal or parts or products thereof, unless it is for the purpose of scientific research or public display, as permitted by the Secretary of the Interior or the Secretary of Commerce. In the 1994 amendments to the MMPA, two levels of "harassment" were defined. Harassment is defined as any act of pursuit, torment, or annoyance that has the potential to injure a marine mammal or marine mammal stock in the wild (Level A), or any act that has the potential to disturb a marine mammal or marine mammal stock in the wild by disrupting behavioral patterns, including, but not limited to migration, breathing, nursing, breeding, feeding, or sheltering (Level B). In 2003, the National Defense Authorization Act for Fiscal Year 2004 altered the MMPA's definition of Level A and B harassment in regards to military readiness and scientific research activities conducted by or on behalf of the federal government. Under these changes, Level A harassment was redefined as any act that injures or has the significant potential to injure a marine mammal or marine mammal stock in the wild. Level B harassment was redefined as any act that disturbs or is likely to disturb a marine mammal or marine mammal stock in the wild by causing disruption of natural behavioral patterns, including, but not limited to, migration, surfacing, nursing, breeding, feeding, or sheltering, to a point where such behavioral patterns are abandoned or significantly altered.

  Section 101(a)(5)(A) of the MMPA directs the Secretary of Commerce, upon request, to authorize the unintentional taking of small numbers of marine mammals incidental to activities (other than commercial fishing) when, after notice and opportunity for public comment, the Secretary: (1) determines that total takes during a five year (or less) period have a negligible impact on the affected species or stock, and (2) prescribes necessary regulations that detail methods of taking and monitoring and requirements for reporting. The MMPA provides that the moratorium on takes may be waived when the affected species or population stock is at its optimum sustainable population and will not be disadvantaged by the authorized takes (i.e., be reduced below its maximum net productivity level). Section 101(a)(5)(A) also specifies that the Secretary has the right to deny permission to take marine mammals if, after notice and opportunity for public comment, the Secretary finds: (1) that applicable regulations regarding taking, monitoring, and reporting are not being followed, or (2) that takes are, or may be, having more than a negligible impact on the affected species or stock.

- The **Marine Protection, Research, and Sanctuaries Act** (MPRSA) (33 U.S.C. §§ 1401 et seq.), often referred to as the "Ocean Dumping Act," was also enacted in 1972, two days after passage of the MMPA. The MPRSA regulates the dumping of toxic materials beyond U.S. territorial waters and provides guidelines for the designation and regulation of marine sanctuaries. MPRSA Titles I and II prohibit persons or vessels subject to U.S. jurisdiction from transporting any material out of the U.S. for the purpose of dumping it into ocean waters without a permit. The term "dumping," however, does not include the intentional placement of devices in ocean waters or on the sea bottom when the placement occurs pursuant to an authorized federal or state program.

- The **Coastal Zone Management Act** (CZMA) of 1972 (16 U.S.C. §§ 1451 et seq.) established a voluntary national program through which U.S. states and territories can develop and implement coastal zone management plans (USFWS 2003a). The National Oceanic and Atmospheric Administration (NOAA), under the Secretary of Commerce, administers this act. States and territories use coastal zone management plans "to manage and balance competing uses of and impacts to any coastal use or resource" (NOAA 2000). A coastal zone management plan must be given federal approval before the state or territory can implement the plan (USFWS 2003a). The plan must include, among other things, defined boundaries of the coastal zone, identified uses of the area that the state/territory will regulate, a list of mechanisms that will be employed to control the regulated uses, and guidelines for prioritizing the regulated uses. Currently, there are 34 U.S. states and territories with federally approved coastal zone management plans. These states and territories manage over 153,500 km (99.9%) of U.S. shoreline along the Atlantic, Pacific, and Arctic Oceans as well as the Great Lakes (NOAA 2003a). The Hawai'i Coastal Zone Management Program received federal approval from the NOAA in 1978 (NOAA 2003b).

  The CZMA also instituted a federal consistency requirement, which provides federal agencies with restrictions concerning their behavior in relation to state and territory managed coastal zones. Federal agency actions that affect any land or water use or natural resource of the coastal zone (e.g., military operations, offshore oil and gas development, dredging projects, and developments on federal lands or in protected areas) must be "consistent to the maximum extent practicable" with the enforceable policies of a state or territory's coastal management program (Coastal Zone Act Reauthorization Amendments of 1990). The federal consistency requirement was enacted as a mechanism to address coastal effects, to ensure adequate federal consideration of state and territory coastal management programs, and to avoid conflicts between states/territories and federal agencies by fostering early consultation and coordination (NOAA 2000). Within each state or territory coastal zone management plan is a list of the federal agency activities for which consistency determinations must be prepared. Under certain circumstances, the President is authorized to exempt specific activities from the federal consistency requirement if they determine that the activities are in the paramount interest of the U.S. The state of Hawai'i's lead coastal management agency, the Office of Planning, has regulatory authority over all federal activities, permits, licenses, and funding approvals for projects that affect the coastal zone resources of the Hawaiian Islands (NOAA 2003b).

- The **Endangered Species Act** (ESA) of 1973 (16 U.S.C. §§ 1531 et seq.) established protection over and conservation of threatened and endangered species and the ecosystems upon which they depend. An "endangered" species is a species that is in danger of extinction throughout all or a significant portion of its range, while a "threatened" species is one that is likely to become endangered within the foreseeable future throughout all or in a significant portion of its range. All federal agencies are required to implement protection programs for threatened and endangered species and to use their authority to further the purposes of the ESA. The National Marine Fisheries Service (NMFS), also known as the NOAA Fisheries Service, and the U.S. Fish and Wildlife Service (USFWS) jointly administer the ESA and are also responsible for the listing (i.e., the labeling of a species as either threatened or endangered) of all "candidate" species. A "candidate" species is one that is the subject of either a petition to list or status review, and for which the NMFS or USFWS has determined that listing may be or is warranted (NMFS 2004). The NMFS is further charged with the listing of all "species of concern" that fall under its jurisdiction. A "species of concern" is one about which the NMFS has some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the ESA (NMFS 2004).

  A species may be a candidate for listing as a threatened or endangered species due to any of the following five factors: (1) current/imminent destruction, modification, or curtailment of its habitat or range; (2) overuse of the species for commercial, recreational, scientific, or educational purposes; (3) high levels of disease or predation; (4) inadequacy of existing regulatory mechanisms; or (5) other natural or human-induced factors affecting its continued existence.

  The major responsibilities of the NMFS and USFWS under the ESA include: (1) the identification of threatened and endangered species; (2) the identification of critical habitats for these species; (3) the

implementation of research programs and recovery plans for these species; and (4) the consultation with other federal agencies concerning measures to avoid, minimize, or mitigate the impacts of their activities on these species (Section 7 of the ESA). Further duties of the NMFS and USFWS include regulating "takes" of listed species on public or private land (Section 9) and granting incidental take permits to agencies that may unintentionally "take" listed species during their activities (Section 10a).

The ESA allows the designation of geographic areas as critical habitat for threatened or endangered species. The physical and biological features essential to the conservation of a threatened or endangered species are included in the habitat designation. Designation of critical habitat affects only federal agency actions and federally funded or permitted activities.

There are 28 marine mammal (26 cetacean and two pinniped), five sea turtle, and several seabird, species with known or potential occurrence in the Hawaiian Islands. Seven marine mammal, five sea turtle, and three seabird species are listed as either threatened or endangered under the ESA (**Table 1-1**). An additional six seabird species with known or potential occurrence in the OPAREA are listed as "birds of conservation concern" (BCC), which include candidate, proposed, and recently delisted bird species that are in highest need of conservation (USFWS 2002). Consultation between the USFWS and the Navy resulted in the decision that nine seabird species of particular concern would be addressed in this MRA. For the marine mammals, the NMFS has jurisdiction over all cetaceans and pinnipeds. For the sea turtles, the NMFS has jurisdiction over them while they are in the water, and the USFWS has jurisdiction over them while they are on land (including eggs, hatchlings that are on the beach, and nesting females). The USFWS has jurisdiction over the protected seabirds.

- The **Fishery Conservation and Management Act** (FCMA) of 1976 (16 U.S.C. §§ 1801 et seq.), later renamed the **Magnuson-Stevens Fishery Conservation and Management Act** (MSFCMA), established a 200 nautical mile (NM) fishery conservation zone in U.S. waters and a network of regional Fishery Management Councils (FMC). The FMCs are comprised of federal and state officials, including the USFWS, which oversee fishing activities within the fishery management zone. The act also establishes national standards (e.g., optimum yield, scientific information, allocations, efficiency, and costs/benefits) for fishery conservation and management. In 1977, the multifaceted regional management system began allocating harvesting rights, with priority given to domestic enterprises. Since a substantial portion of fishery resources in offshore waters was allocated for foreign harvest, these foreign allocations were eventually reduced as domestic fish harvesting and processing industries expanded under the domestic preference authorized by the MSFCMA. At that time, exclusive federal management authority over U.S. domestic fisheries resources was vested in the NMFS.

  The authority to place observers on commercial fishing and processing vessels operating in specific geographic areas is also provided by the MSFCMA. The data collected by the National Observer Program, which is overseen by the NMFS, is often the best means to get current data on the status of many fisheries. Without observers and observer programs, there would not be sufficient fisheries data for effective management. Observer programs also satisfy requirements of the ESA and MMPA by documenting incidental fisheries bycatch of federally protected species, such as marine mammals and sea turtles.

- In 1977, Congress addressed the heightened concern over water pollution by amending the **Federal Water Pollution Control Act** (FWPCA) of 1948 (33 U.S.C. §§ 1251 et seq.). The 1977 amendments, known as the **Clean Water Act** (CWA), extensively amended the FWPCA. For a synopsis of FWPCA initiatives prior to 1977, consult USFWS (2003b), which documents the history of the FWPCA since its origin.

  The CWA took the first step towards establishing a comprehensive solution to the country's serious water pollution problems (EPA 2003). Through standards, technical tools, and financial assistance, the CWA works towards the accomplishment of two goals: (1) to make U.S. waters fishable and swimmable and (2) to eliminate contaminant discharge into such waters. Under the authority of the

Table 1-1. ESA designated species and USFWS designated birds of conservation concern with known or potential occurrence in the Hawaiian Islands OPAREA and surrounding region.

Taxon Group	Scientific Name	Status
Marine Mammals		
North Pacific right whale	*Eubalaena japonica*	Endangered
Humpback whale	*Megaptera novaeangliae*	Endangered
Sei whale	*Balaenoptera borealis*	Endangered
Fin whale	*Balaenoptera physalus*	Endangered
Blue whale	*Balaenoptera musculus*	Endangered
Sperm whale	*Physeter macrocephalus*	Endangered
Hawaiian monk seal	*Monachus schlauinslandi*	Endangered
Sea Turtles		
Green turtle	*Chelonia mydas*	Threatened[1]
Hawksbill turtle	*Eretmochelys imbricata*	Endangered
Loggerhead turtle	*Caretta caretta*	Threatened
Olive ridley turtle	*Lepidochelys olivacea*	Threatened
Leatherback turtle	*Dermochelys coriacea*	Endangered
Seabirds		
Short-tailed albatross	*Phoebastria albatrus*	Endangered
Black-footed albatross	*Phoebastria nigripes*	BCC[2]
Laysan albatross	*Phoebastria immutabilis*	BCC
Hawaiian petrel	*Pterodroma sandwichensis*	Endangered
Christmas shearwater	*Puffinus nativitatis*	BCC
Newell's shearwater	*Puffinus auricularis newelli*	Threatened
Band-rumped storm petrel	*Oceanodroma castro*	Candidate ESA/BCC
Tristram's storm petrel	*Oceanodroma tristrami*	BCC
Blue-gray noddy	*Procelsterna cerulea*	BCC

[1] Although the species as a whole is listed as threatened, the Mexican Pacific nesting stock of the green turtle is listed as endangered. It is possible, although not likely, that some of the green turtles residing in the Hawaiian Islands OPAREA come from the Mexican Pacific nesting population and are therefore endangered (NMFS and USFWS 1998a, 1998b).

[2] BCC = Birds of Conservation Concern, as listed in USFWS (2002).

Environmental Protection Agency (EPA), the CWA sets water quality standards for all pollutants, requires a permit for the discharge of pollutants from a point source, and funds sewage treatment plant construction (EPA 2003). Section 401 of the CWA requires that all applicants for a federal permit or license for activities that may result in a discharge to a water body obtain State Water Quality Certification that the proposed activity will comply with state water quality standards. Section 403 sets out permit guidelines specific to the discharge of contaminants into the territorial sea, the contiguous zone, and waters further offshore, while Section 404 establishes permit guidelines for the discharge of dredged or fill material into U.S. navigable waters at specified disposal sites. The U.S. Army Corps of Engineers (USACE), through issuance of CWA Section 401 and 404 permits, is the regulatory agency that approves all discharges of dredge or fill material into U.S. waters, especially water bodies with high resource value such as wetlands, riparian areas, and headwaters (USFWS 2003b).

In addition to regulating pollution in offshore waters, the CWA, under the amendment known as the **Water Quality Act** of 1987, also requires state and federal agencies to devise programs and management plans that aim to maintain the biological and chemical integrity of estuarine waters. In estuaries of national significance, the NOAA is permitted to conduct water quality research in order to evaluate state and federal management efforts. Sensitive estuarine habitats, such as seagrass beds and wetlands, are protected from pollution under this act.

- In 1984, Congress passed the **National Fishery Enhancement Act** (NFEA) (33 U.S.C. §§ 2101 et seq.) in recognition of the social and economic value of artificial reefs in enhancing fishery resources. Under this act, the Secretary of Commerce and the USACE are charged with the responsibility for encouraging and regulating artificial reefs in the navigable waters of the U.S. (NOAA 2003b). One of the primary directives of the NFEA was the preparation of a long-term National Artificial Reef Plan (NARP) (33 U.S.C. §§ 2103). Section 202 of the act recognizes the harmful effects of overfishing on fishery resources and proposes that properly designed, constructed, and located artificial reefs could enhance the habitat and diversity of these fishery resources. The NARP, which underwent revision in 2002, was implemented in November 1985 to provide guidance and/or criteria on various aspects of artificial reef use, including types of construction materials and planning, siting, designing, permitting, installing, maintaining, and managing artificial reefs (NMFS 2002a). One of the most significant recommendations in the NARP encouraged the development of state-specific artificial reef plans and programs. At present, the Hawai‘i Department of Land and Natural Resources (HDLNR) has two programs in place to oversee the development of artificial reefs around the Hawaiian Islands: the Commercial Fisheries and Resource Enhancement Program and the Aquatic Recreation Program (HDLNR n.d.).

- Like the CWA, the **Marine Plastic Pollution Research and Control Act** (MPPRCA) of 1987 (33 U.S.C. §§ 1901 et seq.) also regulates the discharge of contaminants into the ocean. Under this federal statute, the discharge of any plastic materials (including synthetic ropes, fishing nets, plastic bags, and biodegradable plastics) into the ocean is prohibited. The discharge of other materials, such as floating dunnage, food waste, paper, rags, glass, metal, and crockery, is also regulated by this act. Ships are permitted to discharge these types of refuse into the water, but they may only do so when beyond a set distance from shore, as prescribed by the MPPRCA. An additional component of this act requires that all ocean-going, U.S. flag vessels greater than 12.2 m in length, as well as all manned, fixed, or floating platforms subject to U.S. jurisdiction, keep records of garbage discharges and disposals (NOAA 2004).

- Passage of the **Oil Pollution Act** (OPA) of 1990 (33 U.S.C. §§ 2701 et seq.) further increased the protection of our nation’s oceans. In addition to amending the CWA, this act also details new policies relating to oil spill prevention and cleanup methods. Any party that is responsible for a vessel, offshore facility, or deepwater port that could potentially cause an oil spill must maintain proof of financial responsibility for potential damage and removal costs. The act details which parties are liable in a variety of oil spill circumstances and what damage and removal costs must be paid. The President has the authority to use the Oil Spill Liability Trust Fund to cover these costs when necessary. Any cost for which the fund is used must be in accordance with the National Contingency Plan, which is an oil and hazardous substance pollution prevention plan established by the CWA (USFWS 2003c). Federal, state, Indian tribe, and foreign trustees must assess the natural resource damages that occur from oil spills in their trusteeships and develop plans to restore the damaged natural resources. The act also establishes the Interagency Coordinating Committee on Oil Pollution Research, whose purpose is to research and develop plans for natural resource restoration and oil spill prevention.

- During the reauthorization of the MPRSA in 1992, Title III of the MPRSA was designated the **National Marine Sanctuaries Act** (NMSA) (16 U.S.C. §§ 1431 et. seq.). Title III authorizes the Secretary of Commerce to designate and manage areas of the marine environment with nationally significant aesthetic, ecological, historical, or recreational value as national marine sanctuaries (NMS). The primary objective of this law is to protect marine resources, such as coral reefs, sunken historical vessels, or unique habitats while facilitating all compatible public and private uses of these resources.

NMS, similar to underwater parks, are managed according to management plans, prepared by the NOAA on a site-by-site basis. The NOAA is the agency responsible for administering the NMS Program.

- In 1996, the MSFCMA was reauthorized and amended by the **Sustainable Fisheries Act** (SFA). The SFA provides a new habitat conservation tool in the form of the EFH mandate. The EFH mandate requires that the regional FMCs, through federal Fishery Management Plans (FMP), describe and identify EFH for each federally managed species, minimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitats. Congress defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity" (16 U.S.C. §§ 1802[10]). The term "fish" is defined in the SFA as "finfish, mollusks, crustaceans, and all other forms of marine animals and plant life other than marine mammals and birds." The regulations for implementing EFH clarify that "waters" include all aquatic areas and their biological, chemical, and physical properties, while "substrate" includes the associated biological communities that make these areas suitable fish habitats (50 CFR 600.10). Habitats used at any time during a species' life cycle (i.e., during at least one of its life stages) must be accounted for when describing and identifying EFH (NMFS 2002b).

  Authority to implement the SFA is given to the Secretary of Commerce through the NMFS. The SFA requires that the EFH be identified and described for each federally managed species. The identification must include descriptive information on the geographic range of the EFH for all life stages, along with maps of the EFH for life stages over appropriate time and space scales. Habitat requirements must also be identified, described, and mapped for all life stages of each species. The NMFS and regional FMCs determine the species distributions by life stage and characterize associated habitats, including habitat areas of particular concern (HAPC). The SFA requires federal agencies to consult with the NMFS on activities that may adversely affect EFH. For actions that affect a threatened or endangered species, its critical habitat, and its EFH, federal agencies must initiate ESA and EFH consultations.

  In 2002, the EFH Final Rule was authorized, which simplified EFH regulations (NMFS 2002b). Significant changes delineated in the EFH Final Rule are: (1) clearer standards for identifying and describing EFH, including the inclusion of the geographic boundaries and a map of the EFH, as well as guidance for the FMCs to distinguish EFH from other habitats; (2) more guidance for the FMCs on evaluating the impact of fishing activities on EFH and clearer standards for deciding when FMCs should act to minimize the adverse impacts; and (3) clarification and reinforcement of the EFH consultation procedures (NMFS 2002b). The process by which federal agencies can integrate MSFCMA EFH consultations with ESA Section 7 consultations is described in NMFS (2002b).

- Congress passed the **Rivers and Harbors Appropriation Act** of 1899 (33 U.S.C. §§ 401 et seq.) to restrict the building of structures over or in U.S. navigable waterways. Under Section 9, no bridge, dam, dike, or causeway may be constructed without Congress' approval. Structures contained within a state that have been approved by the state legislature may be built with the approval of the Secretary of Transportation or the Chief of Engineers and the Secretary of the Army. Section 10 prohibits the building of wharfs, piers, and jetties over or in navigable waterways without the approval of Congress. The Chief of Engineers and the Secretary of the Army must approve both structures and excavation in navigable waters.

- The federal government furthered its estuary protection efforts by passing the **Estuary Restoration Act** of 2000 (33 U.S.C. §§ 2901 et seq.). This act establishes the Estuary Habitat Restoration Council, a federal interagency council that must develop a national estuary habitat restoration strategy. Private entities propose projects to the council that must meet certain criteria and fulfill the council's strategy. The council chooses projects to recommend to the USACE. Projects recommended to the USACE are selected for implementation based on another set of criteria. The federal government pays up to 65% of the project costs, excluding operation and maintenance costs. The ultimate goal of the act is to restore 405,000 hectares (ha) of estuary habitat by 2010.

- The **Migratory Bird Treaty Act** (MBTA) of 1918 (16 U.S.C. §§ 703 et seq.) prohibits the taking, transporting, and harming of migratory birds and their parts, eggs, nests, and young unless permitted by federal regulations. This act implements provisions from the 1916 convention between the U.S. and Great Britain that addressed the protection of migratory birds. Provisions from later conventions with Mexico, Japan, and the Soviet Union are also implemented as amendments to the MBTA. The USFWS has the authority to enforce the act's provisions, which includes determining periodically when the taking of migratory birds may occur. State governments may pass laws that increase migratory bird protection as long as open seasons do not extend beyond those set at the national level.

  In 2000, Congress furthered the protection of migratory birds by passing the **Neotropical Migratory Bird Conservation Act** (16 USC §§ 6101 et seq.). The act sets aside funds used to finance projects that assist in the conservation of North American migratory birds in the U.S., Latin America, and the Caribbean. Project proposals are submitted to the Secretary of the Interior, who uses a set of criteria to determine which projects will receive federal funding. Not more than 25% of the project's funds can come from the federal government. At least 75% of the funds allocated for this act, which is $5 million a year until 2005, must be used on projects outside the U.S.

1.3.2 Executive Orders

- **EO 12114 on Environmental Effects Abroad of Major Federal Actions** (44 Federal Register [FR] 1957) was passed in 1979 to further environmental objectives consistent with U.S. foreign and national security policies by extending the principles of the NEPA to the international stage. Under EO 12114, federal agencies that engage in major actions that significantly affect a non-U.S. environment must prepare an environmental assessment of the action's effects on that environment. This is similar to an environmental impact statement (EIS) or environmental assessment (EA) developed under the NEPA. Certain actions, such as intelligence activities, disaster and emergency relief actions, and actions that occur in the course of an armed conflict, are exempt from this order. Such exemptions do not apply to major federal actions that significantly affect an environment that is not within any nation's jurisdiction, unless permitted by law. The purpose of the order is to force federal agencies to consider the effects their actions have on international environments (U.S. Office of the President 1979).

- **EO 12962 on Recreational Fisheries** (60 FR 30769) was enacted in 1995 to ensure that federal agencies strive to improve the "quantity, function, sustainable productivity, and distribution of U.S. aquatic resources" so that recreational fishing opportunities nationwide can increase. The overarching goal of this order is to promote the conservation, restoration, and enhancement of aquatic systems and fish populations by increasing fishing access, education and outreach, and multi-agency partnerships (U.S. Office of the President 1995). The National Recreational Fisheries Coordination Council (NRFCC), co-chaired by the Secretaries of the Interior and Commerce, is charged with overseeing federal actions and programs that are mandated by this order. The specific duties of the NRFCC include: (1) ensuring that the social and economic values of healthy aquatic systems, which support recreational fisheries, are fully considered by federal agencies; (2) reducing duplicative and cost-inefficient efforts among federal agencies; and (3) disseminating the latest information and technologies to assist in the conservation and management of recreational fisheries. In June 1996, the NRFCC developed a comprehensive Recreational Fishery Resources Conservation Plan (RFRCP) specifying what member agencies would do to achieve the order's goals (NMFS 1999). In addition to defining federal agency actions, the plan also ensures agency accountability and provides a comprehensive mechanism to evaluate achievements. A major outcome of the RFRCP has been the increased utilization of artificial reefs to better manage recreational fishing stocks in U.S. waters (USFWS 2003d).

- **EO 13089 on Coral Reef Protection** (63 FR 32701) was issued in 1998 "to preserve and protect the biodiversity, health, heritage, and social and economic value of U.S. coral reef ecosystems and the marine environment." The EO directs all federal agencies to protect coral reef ecosystems to the extent feasible and instructs particular agencies to develop coordinated science-based plans to

restore damaged reefs as well as mitigate current and future impacts on reefs, both in the U.S. and around the globe. This order also establishes the interagency U.S. Coral Reef Task Force, co-chaired by the Secretary of the Interior and the Secretary of Commerce through the Administrator of the NOAA (U.S. Office of the President 1998).

- **EO 13158 on Marine Protected Areas** (MPA) (65 FR 34909) of 2000 is a furtherance of EO 13089. It created the framework for a national system of MPAs. MPAs are defined in EO 13158 as "any area of the marine environment that has been reserved by federal, state, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein." This EO strengthened governmental interagency cooperation in protecting the marine environment. It also calls for strengthening management of these existing areas, creating new ones, and preventing harm to marine ecosystems by federally approved, conducted, or funded activities (U.S. Office of the President 2000a). Currently, the NOAA is redefining the criteria used to designate MPAs and has recently reclassified all existing MPAs as "marine managed areas." A more in-depth discussion on the NOAA's process of redefining MPAs is included in Chapter 5.

- **EOs 13178 and 13196 on the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve** (65 FR 76903 and 66 FR 7395) were promulgated in 2000 and 2001, respectively, to ensure the comprehensive, strong, and lasting protection of the coral reef ecosystem and related marine resources and species of the NWHI. The Reserve stretches across approximately 2,200 km of insular habitat in the central North Pacific Ocean, from Nihoa Island in the east to Kure Atoll in the west. Areas included within the Reserve are submerged lands and waters of the NWHI beyond the state of Hawai'i's jurisdiction out to 50 NM from the approximate center geographical positions of the ten largest islands, atolls, and shoals in the NWHI. The following activities are highly restricted within the confines of the Reserve: commercial and recreational fishing; vessel anchoring; oil, gas, and mineral development; drilling; dredging; construction; ocean dumping; and harvesting of living and non-living resources. To further protect the resources of the Reserve, these EOs also designated several areas in the NWHI as Reserve Preservation Areas (U.S. Office of the President 2000b, 2001a). Additional information on the Reserve is presented in the MMAs section of Chapter 5.

- **EO 13186 on the Responsibilities of Federal Agencies to Protect Migratory Birds** (66 FR 3853) was enacted in 2001 to support the efforts of the MBTA and other acts. The order directs executive departments and agencies that detrimentally affect migratory birds to increase their protection of these birds, especially those that were identified by the USFWS as BCC. Each department or agency must develop and implement a Memorandum of Understanding (MOU) through the USFWS. The MOU must incorporate a variety of efforts set out in the EO that promote the conservation of migratory bird populations. These efforts include restoring migratory bird habitats and preventing pollution in environments that affect migratory birds. The departments and agencies have two years to implement their MOUs, but the order encourages them to implement the order's policies immediately. Such practices can be implemented through activities already established or incorporated into new plans. The order also formed the interagency Council for the Conservation of Migratory Birds, which administers the order (U.S. Office of the President 2001b).

1.4 METHODOLOGY

1.4.1 Literature and Data Search

Prior to the production of this report, a thorough and systematic search for relevant scientific literature and data was conducted. Information, data, and literature that were deemed vital to the production of this MRA were identified, obtained, reviewed, and then catalogued. Of the available scientific literature (both published and unpublished), the following types of documents were utilized in the assessment: journals, periodicals, bulletins, monographs of scientific and professional societies, theses, dissertations, project reports, conference proceedings, endangered species recovery plans, stock assessment reports, EAs, EISs, FMPs, Navy integrated natural resource management plans (INRMP), and other technical reports published by government agencies, private businesses, or consulting firms. A multitude of individuals,

agencies, and databases were consulted during the search for data and information on the occurrence of marine resources in the Hawaiian Islands OPAREA (all of which are mentioned below).

To investigate the physical environment and habitats of the OPAREA; to summarize the occurrence patterns of protected species; to determine the locations of EFH; to describe the region's recreational and commercial fisheries; and to ascertain the distribution of maritime boundaries, shipping lanes, MMAs, and other concerns, information was collected from the following sources:

- Academic and educational/research institutions (Blue Ocean Institute, Cascadia Research Collective [CRC], Cetos Research Organization, Hawai'i Association for Marine Education and Research Inc., Hawai'i Marine Mammal Consortium, Hawai'i Sea Grant, Hawai'i Wildlife Fund, Kula Nai'a Wild Dolphin Research Foundation, Los Angeles County Museum of Natural History, Marine Mammal Research Consultants Ltd., Marine Conservation Biology Institute, Markrich Research, Pacific Whale Foundation, Reef Environmental Education Foundation, Sea Turtle Association of Japan, SRS Technologies Inc., University of California at San Diego [Scripps Institute of Oceanography], University of Hawai'i [Kewalo Basin Marine Mammal Laboratory, Hawai'i Institute of Marine Biology], Whale and Dolphin Conservation Society, Wider Caribbean Sea Turtle Conservation Network [WIDECAST]);

- The Internet, including various databases and related websites (NOAA, NMFS, USFWS, U.S. Geological Survey [USGS], Hawaiian Islands Humpback Whale National Marine Sanctuary [HIHWNMS], Elsevier, Allen Press, Blackwell-Science, FishBase, ReefBase, Food and Agriculture Organization [FAO], FR, seaturtle.org, University of Florida Online Sea Turtle Bibliography, and the National Sea Grant Library);

- Federal agencies (DoD; DoN; Department of State [DoS]; Department of Transportation [DoT]; Marine Mammal Commission; Minerals Management Service [MMS]; NASA; National Park Service [NPS]; NMFS: Alaska Fisheries Science Center [AFSC] - National Marine Mammal Laboratory [NMML], Office of Protected Resources, Office of Habitat Protection, Pacific Islands Fisheries Science Center [PIFSC], PIR, SWFSC, Southwest Region [SWR], Western Pacific Regional Fishery Management Council [WPRFMC]; NOAA: HIHWNMS, National Centers for Coastal Ocean Science [NCCOS], National Geophysical Data Center [NGDC], National MPA Center, National Ocean Service [NOS], National Weather Service; USFWS: Pacific Remote Islands National Wildlife Refuge Complex; U.S. Coast Guard [USCG]; USGS); and

- State/regional agencies (HDLNR, Hawai'i Division of Aquatic Resources [HDAR], Hawai'i Office of Planning, O'ahu Civil Defense Agency).

1.4.2 Spatial Data Representation—Geographic Information System

The geographical representation of marine resource occurrences in the Hawaiian Islands OPAREA and vicinity was a major constituent of this MRA report. The marine resources data and information accumulated for this project were accessed from a wide variety of sources, were in disparate formats, covered a broad range of time periods, and represented differing levels of accuracy as well as quality assurance. The spatial or geographical component that was common to all datasets allowed the widely dissimilar data to be visualized in a meaningful manner. Without this common data characteristic, graphical display of such disparate data would have been difficult, if not impossible, to achieve.

A GIS was used to store, manipulate, analyze, and display the spatial data and information accumulated for the Hawaiian Islands OPAREA. For this project, Environmental Systems Research Institute, Inc.'s (ESRI) ArcView® version 8.3 GIS software was used to create the majority of the map figures and metadata. ArcView® was chosen for this project due to its widespread use, ease of operation, and its ability to create multiple views and layouts within the same project file.

The geographic locations of important marine resources in the Hawaiian Islands OPAREA and vicinity were derived from four types of sources (in order of reliability): source data, scanned source maps,

source information, and information adapted from published maps. The "source data," containing geographic coordinates or GIS shapefiles, were scrutinized to ascertain their data quality. If the data were in coordinate form, they were then converted to decimal degrees if necessary and text fields were renamed or added for ease of manipulation. Once standardized, the source data were imported into the GIS software. Some of the data were only available as graphical representations or "source maps." These data were scanned, imported into ArcView®, and geo-referenced, after which significant information was digitized into a shapefile format. Materials acquired as Adobe® portable document format (PDF) files were also treated as scanned source maps (i.e., they were geo-referenced and pertinent information was digitized), since they were already in a digital form. A third type of source, "source information," encompasses information that was neither taken from a scanned map nor was available in coordinate form. For example, maps displaying non-coordinate data, information given via personal communication, or information extracted from a literature description are referenced as source information. In certain cases, source maps and/or information had to be interpreted to be usable in the GIS environment. Maps displaying geographic information that was interpreted or altered from the original source map/information are noted in the figure caption as being "adapted from" with a corresponding source name.

The source type and associated references for all marine resource data presented in the map figures are listed in each figure's caption. The full reference citations for map source data or information may be found in the Literature Cited section of each MRA chapter. The two primary types of spatial information used in the Hawaiian Islands OPAREA MRA were coordinate data and scanned maps. These two source types are associated with differing levels of data reliability or confidence (**Appendix A-1** contains a further explanation of data confidence). Numerical or authentic data are associated with the highest level of reliability while data obtained by scanning source maps is less reliable.

Source data were not always in a standard format, there was often no standard naming convention for species names, and some datasets included missing or unlabeled data fields. To mitigate these difficulties, many steps were taken to standardize and ensure the quality of the numerical data, especially for the marine mammal and sea turtle data. Therefore, prior to using the data, a master database was created in Microsoft® Access where the data format was standardized so that the data could be merged and later used in the GIS. To accomplish this, data was manipulated so that records were matched with a set of standard field names. In some cases, the latitude and longitude had to be converted to decimal degrees with accuracy to the fourth decimal place. Species' common names were added to the database to replace the multiple species codes that accompanied the original data. The codes or names used to identify species were not always consistent from one dataset to the next. Compiling a comprehensive list of species names increased the chances of plotting all sightings for a given species on the map figures. To maintain integrity of the original data, all fields and records were kept without alteration. When necessary, fields were created to store supplemental information or data that was altered from the original source. No original data fields were deleted and all added fields are signified by the "GMI_" prefix (GMI: Geo-Marine, Inc.). For example, the field that was added to the main dataset to indicate the origin (source) of the data is indicated by the field name "GMI_source."

GIS data are displayed as layers for which scale, extent, and display characteristics can be specified. Multiple themes are represented on an individual map figure. Throughout the project, data imported into ArcView® had to be maintained in the most universal, least transformed manner in order to avoid conflict between theme coordinate systems and projections. In the GIS, the most flexible spatial data format is the unprojected geographic coordinate system, which uses decimal degree latitude and longitude coordinates (**Appendix A-2** contains more information on map projections). The decimal degree format is the only coordinate system format that allows unlimited, temporary, custom projection and re-projection in ArcView® and is therefore the least restrictive spatial data format. The printed maps and electronic GIS map data for this MRA report are unprojected and are therefore not as spatially precise (in terms of distance, area, and shape) as a projected map. Consequently, the maps should not be used for measurement or analysis and an appropriate projection should be selected when using the GIS data.

Once the marine resource data were imported and stored in the GIS, maps were created representing multiple layers of either individual or combined data. The maps in this MRA report are presented in kilometers and nautical miles. The majority of maps in this report are presented in either of two forms: a

display that includes two seasonal maps per page and a display that includes one full-page map. Maps of each display type are often presented at the same approximate scale. Seasons throughout the report are defined as fall/winter (October through February) and spring/summer (March through September). These divisions are based on general oceanographic conditions in the study region, with high salinity/lower temperature waters occurring from October through February (fall/winter) and low salinity/higher temperature waters occurring from March through September (spring/summer) (Murphy et al. 1960).

The ability to display and analyze multiple data themes or layers simultaneously is one of the advantages to using a GIS rather than other graphic software. Customizations were made to the software in ESRI's ArcObjects™ proprietary language to automate the more repetitive map-making tasks as well as the processing and analysis of large volumes of data.

1.4.2.1 Maps of the Physical Environment and Habitats

Bathymetry—The bathymetry data used in this MRA represent two levels of sampling resolution. Data from the NOAA's National Geophysical Data Center (NOAA 2002) were sampled at 3-arcsecond resolution and extracted at 15-arcsecond resolution to obtain a smaller and more usable file size. Bathymetric data from Sandwell et al. (2004) were sampled and extracted at 2 minute (min) resolution. Highly detailed vector bathymetry or depth contours (isobaths) were prepared with contour intervals of 10 m for depths shallower than 100 m while depths deeper than 100 m were contoured at 100 m intervals. Selected isobaths from the resulting two-dimensional (2D) contours are shown on the bathymetry figures and on various maps throughout the MRA report.

To illustrate the three-dimensional (3D) bathymetry of the Hawaiian Islands OPAREA, triangular irregular networks (TINs), which interpolate intermediate data values between surveyed data points, were created using the available bathymetry data and processing those data in the ArcGIS® 3D Analyst extension. The 2 min bathymetric sounding data sampled from Sandwell et al. (2004) were used to create the TIN, which depicts the 3D bathymetry of the Hawaiian Islands OPAREA and vicinity (**Figure 2-2**). The TINs were viewed in the ArcGIS® 8.3 ArcScene™ extension to model the 3D display. ArcScene® allows the 3D display to be manipulated (i.e., rotated, tilted, zoomed, classified, and overlaid with data). The most authentic display was exported directly from an ArcScene® view as a graphic file (.tif), which was then imported into ArcView® for the final map layout.

The true or natural shelf break for the Hawaiian Islands OPAREA was derived using the detailed vector bathymetry contours that were adapted from the NOAA (2002) and Sandwell et al. (2004) raster datasets. The bathymetric contours were transformed into a 0.004 decimal degree grid of water depths. This grid was created using the Zevenbergen and Thorn (1987) algorithm (ZTA), which is a complex series of equations used to model elevation data. The ZTA analysis is based on a rectangular grid of evenly spaced depths that covers the OPAREA. An analytical unit composed of 3 grid cells by 3 grid cells was repetitively analyzed throughout the rectangular depth grid to derive a digital depth model. ArcView 3.3® was then employed to evaluate the gridded digital depth-model against the quartic formula (the ultimate of the ZTA equations). The resulting grid of depth gradient values was visualized as 50 continental shelf break classes (50 was an arbitrary value and represented neither too large nor too small a set of depth classes). The true continental shelf break was identified from within the 50 classes of grid cell values. The shelf-break class representing the grid cell value of 100 was determined to be the location of the true continental shelf break. The value of 100 best matched the gradient change associated with the continental shelf break as defined by Kennett (1982) where the depth changes from the gradient of 1:1000 on the continental shelf to 1:30 on the continental slope. The grid cells for the associated depth model were reclassified into two values: 1 (original depth values ≤100 m) and 0 (original depth values >100 m) to isolate the continental shelf break. The grid model was converted into polygons, which were then converted to line topology, removing all extraneous lines. The isolated shelf break line was then splined to smooth the 90° angles characteristic of grid cells. The model of the continental shelf break was then evaluated in conjunction with the detailed isobaths to determine positional accuracy. The resulting line feature represents the model of the "true" continental shelf break and is not representative of one depth but varies in depth.

In the case of Nihoa Island, available bathymetric data was too crude to allow for the modeling of a shelf break. Rather, bathymetric maps obtained from individual cruises performing bathymetric analysis of the islands were used to provide a best estimate of the shelf break location (NOAA 2005).

Satellite Data—Seasonal averages of SST were compiled from weekly averaged Advanced Very High-resolution Radiometer (AVHRR) satellite data, which contain multi-channel SST pixel data (NASA 2000). Seasons were defined with the same monthly derivations used throughout the MRA report (fall/winter: October through March, spring/summer: April through September). Data for the OPAREA were collected from 1981 to 2001; these data were extracted from the global dataset and the pixel values were converted to SST using MATLAB® with the following function:

$$\text{SST } (°\text{C}) = 0.15 * \text{DN} - 2.1$$

where DN is the pixel value.

Day and night SST values were averaged and the data were parsed into seasons. The seasonal data were then converted to a grid with cell sizes of 0.12 km by 1.09 km and interpolated to produce a smoother image. In the GIS environment, the range of SST values for the OPAREA were associated with a color spectrum grading from red to blue that represents warmer and cooler surface water temperatures (degrees Celsius [°C]), respectively.

Seasonal averages of chlorophyll *a* (chl *a*) concentrations were compiled from monthly averaged Coastal Zone Color Scanner (CZCS) satellite data to provide a proxy for primary productivity in the OPAREA (NASA 1998). Pixel data for the OPAREA extent from 1978 to 1986 were extracted and converted to chl *a* values using MATLAB® and the provided function:

$$\text{chl } a \text{ (mg/m}^3\text{)} = 10^{(\text{DN} * 0.012) - 1.4}$$

where DN is the pixel value.

The chlorophyll data were parsed into seasons, converted to grid cell sizes of 0.12 km by 1.09 km, and interpolated. The seasonal range of chl *a* concentrations (in milligrams [mg] per cubic meters [m^3]) is visualized on the MRA map figures as a color spectrum with chl *a* concentrations increasing from red to blue.

Habitat Data—Multiple sources of data and information were used in the creation of maps for the coastal and oceanic habitats located in the Hawaiian Islands OPAREA and vicinity. The maps displaying estuarine, seagrass, mangrove, coral reef, hardbottom, deep sea, and artificial habitats (**Figures 2-13** through **2-23**) are all examples of multiple data sources used in the creation of a single map. These maps were created using scanned images, coordinate data, GIS shapefiles, and other information available in the scientific literature and technical reports.

1.4.2.2 Biological Resource Maps—Species of Concern

Marine mammal and sea turtle occurrence records were accumulated from every available source; however, it was impossible to obtain every data source in existence for the Hawaiian Islands OPAREA. An overview of existing marine mammal and sea turtle data sources is found in **Appendix A-3**. Available data displayed on the marine mammal and sea turtle occurrence maps included in this MRA are listed in **Table A-1**. These data include occurrence records from aerial and shipboard (sighting) surveys, stranding events, incidental fisheries bycatch events, and other sources (e.g., opportunistic sighting programs and species occurrence databases). Sighting, stranding, and bycatch records available from the scientific literature or through personal communications with regional experts or volunteers were also used in this MRA. The combined source data mentioned above were vital to the determination of areas of occurrence for marine mammals and sea turtles potentially occurring in the Hawaiian Islands OPAREA. Of greatest utility were sightings collected during aerial and shipboard surveys of the OPAREA and near vicinity.

Several assumptions were made regarding the marine mammal and sea turtle data collected for this MRA. First, it was assumed that the species identifications given in each dataset were correct. This assumption was necessary since the reliability of species identifications from one dataset to the next was not always known. Marine mammals and sea turtles are often difficult to distinguish to species when they are young (i.e., small size classes), during poor sighting conditions, and when those who observe them do not have a high level of identification experience. Correct species identification is highly dependent on the skill level of the observer. Sighting data presented in this MRA range from those collected by experienced professionals during dedicated surveys (e.g., NMFS surveys) to those collected opportunistically and/or by less experienced observers. For the sake of consistency, reliability of species identification was not considered in the plotting of any marine mammal or sea turtle records.

Although it was assumed that the species identifications provided in each dataset were correct, it could not always be assumed that the locations of the occurrence records, when provided, were also correct. Problems were often encountered when original geographic coordinates were plotted and animals were shown to occur in unexpected locations or in areas far from the dedicated survey coverage. Occurrence records that were obviously erroneous were omitted if they could not be corrected through consultation with the data provider. It should be noted that several of the marine mammal and sea turtle datasets lacked geographic coordinates entirely. As a result, determination of the locations where the records occurred required educated predictions based upon physical descriptions of the locales.

In conjunction with hired subcontractors, marine mammal and sea turtle areas of occurrence within the Hawaiian Islands OPAREA and vicinity were drawn based upon known habitat preferences, distribution patterns, and the available sighting, stranding, bycatch, and haulout data. Four types of occurrence information may be displayed on each marine mammal or sea turtle species map: areas of **primary occurrence** (areas and habitats where a species is primarily found), areas of **secondary occurrence** (areas and habitats where a species may be found, especially during anomalous environmental conditions [e.g., El Niño events] or seasonal migrations), areas of **rare occurrence** (areas and habitats where a species is not expected to be found with any regularity), and areas labeled **no survey effort** (areas and habitats that have not been adequately surveyed). An underlying premise used during the map creation process was that a conservative approach to delineating the areas of occurrence for marine mammals and sea turtles was necessary since all five sea turtle species and several of the marine mammal species are listed as either threatened or endangered under the ESA.

As a supplement to the seasonal occurrence maps and species-specific discussions, maps were also created to depict known movement patterns, critical habitats, and haulout areas for certain marine mammals and sea turtles that occur within the OPAREA and vicinity. Section 3.1 of this MRA includes a migration map for the humpback whale, which is a summary of the vast amount of data and information that have been collected on long distance movement patterns of humpback whales in the North Pacific Ocean. Section 3.1 also includes a map of critical habitats that have been designated by the NMFS for the Hawaiian monk seal.

Section 3.2 of this MRA includes two supplemental maps. The first depicts areas of known sea turtle nesting and basking activity within the MHI, Nihoa, and Kaula. Sea turtle haulout locations were depicted using GIS shapefiles available from an Environmental Sensitivity Index (ESI) atlas for the Hawaiian Islands (NOS 2001) and other information presented in an environmental report for the Hawaiian Islands Shallow Water Training Range (DoN 2002b). The second map in this section displays the transoceanic migration of a loggerhead turtle from Baja California, Mexico to Japan. During its journey, the loggerhead traveled through the northernmost portion of the Hawaiian Islands OPAREA. This satellite-tracking map was created from coordinate data that were accessible from the published literature. Satellite-tag coordinates with location classes (LC) of 2 (accurate to within 350 m) and 3 (accurate to within 150 m) were plotted on this map. According to Reid (1997), these data are at the most acceptable levels of accuracy for plotting.

Section 3.3 contains maps that display important habitat and occurrence data on the nine seabirds of particular concern addressed in this MRA. These maps are a synthesis of all available sighting data (both survey-based and opportunistic) as well as information on distribution patterns, movements, and

migrations. Foraging and breeding ranges were mapped for several of the species that had sufficient information available. Dr. Robin Baird (CRC) provided a number of protected seabird sighting records that were recorded opportunistically during cetacean surveys around the MHI for inclusion in this MRA.

1.4.2.3 Biological Resource Maps—Fish and Fisheries

Maps displaying the EFH for all life stages of the bottomfish, pelagic, crustacean, precious corals, and coral reef ecosystem management units found within the Hawaiian Islands OPAREA and vicinity were created from official FMP habitat descriptions and maps produced by the WPRFMC. None of the EFH data were available in a usable electronic format. As a result, the locations of EFH were determined by developing polygons encompassing the bathymetric ranges identified for each species or life stage.

EFH designations can include the entire water column or a subsection of the water column (e.g., benthic, surface, or from 50 m to 250 m). The subsection of the water column where EFH is designated has been included in parentheses after the lifestage category. If there are no parentheses after the lifestage, then EFH is designated for the entire water column.

1.4.2.4 Maps of Additional Considerations

Information regarding the locations of U.S. maritime boundaries, commercially navigable waterways, MMAs, SCUBA diving sites, sound sources, and whale watching and swim with wild dolphin tours in the Hawaiian Islands OPAREA was gathered from a wide array of sources. Maps displaying the major commercial shipping lanes and MMAs around the MHI and Nihoa were created from data available at U.S. federal and state agency websites. On the MMA map, federal sites that are currently listed in the MMA Inventory were displayed along with state level sites identified as MMAs by the Hawai‘i Office of Planning. SCUBA diving sites in the Hawaiian Islands OPAREA and vicinity were depicted using geographic data, maps, and information that were available from dive books and the Hawai‘i ESI Atlas. The location of the NPAL sound source was created from available geographic coordinates, while the locations of whale watching and swim with wild dolphin tours were acquired from information available from the scientific literature, relevant websites, and personal communications with tour operators.

1.4.2.5 Metadata

The creation of metadata (or information about the GIS data) documentation files was a large component of the GIS work completed for this assessment. Every GIS file used in the creation of the map figures within this MRA has a metadata file associated with it. When possible, metadata were obtained along with GIS data used in this MRA; those data are included in the metadata documentation. Often documentation information, especially on the accuracy or reliability of the associated data, was not available.

Metadata for geographical data should include the data source, creation date, format, projection, scale, resolution, accuracy, and reliability with regard to some standard. Metadata also consists of properties and process documentation. Properties are derived from the data source, while documentation is entered manually. ESRI ArcCatalog® creates metadata in extensible markup language (XML) format, so the same metadata can be viewed in many different ways using different styles. Metadata created to accompany this MRA report are provided in both XML and hypertext markup language (HTML) formats, so that the metadata can be viewed in many types of viewers and are accessible within the GIS environment by other users.

1.4.3 Limitations of Marine Survey Sighting Data

When attempting to use sighting data from aerial and shipboard surveys as a major indicator of a species' occurrence, it is necessary to first recognize the inherent biases associated with each survey type. One of the main drawbacks of surveys in the marine environment is that aerial and shipboard surveys count only the number of animals at the water's surface, where species such as marine mammals and sea turtles spend relatively little time. Sea turtles often spend over 90% of their time underwater (e.g., Byles 1988; Renaud and Carpenter 1994; Mansfield and Musick 2003). As a result, it has been postulated that marine

surveys undersample (underestimate) the total number of sea turtles in a given area by as much as an order of magnitude (Shoop and Kenney 1992). While scientists have devised mathematical formulas to account for animals not seen at the surface, the diving behavior of one animal may be different from that of other members of the same species. Even though marine mammals and sea turtles are obligated to come to the surface to breathe, many individuals will not surface within an observer's field of view. This is of particular concern when attempting to sight species that dive for extended periods of time; do not possess a dorsal fin; and are known to exhibit cryptic behavior, such as beaked whales, *Kogia* spp., and sperm whales (e.g., Würsig et al. 1998; Barlow 1999). Beaked whales are often solitary individuals, which makes their sightability much different from a species that regularly occurs in large groups, such as dolphins in the genus *Stenella* (e.g., Scott and Gilbert 1982).

Sighting conditions also affect the sightability of marine mammals and sea turtles. Sighting frequencies vary due to the amount of sun glare on the water's surface, the sea state, weather, and the water clarity. Both sea state and glare have statistically significant effects on sighting frequency (e.g., Scott and Gilbert 1982; Thompson 1984). When water clarity is poor, animals are difficult to sight below the water's surface, and only those animals at the water's surface that are extremely close to the observer are usually identifiable.

Problems also arise when attempting to select an optimal and efficient survey method for sampling marine mammals and sea turtles. Since most sighting surveys target multiple species, the sampling designs, although likely cost- and labor-efficient, cannot be considered optimal for each species (Scott and Gilbert 1982). The altitude at which marine mammal aerial surveys are flown is much higher than is desirable to sight sea turtles (which are typically much smaller than cetaceans). Shipboard surveys designed for sighting marine mammals are adequate for detecting large sea turtles but usually not the smaller-sized turtles. Their size, diving behavior, and startle responses to vessels make smaller sea turtles difficult to sight or visually observe from a ship. The youngest age-classes of sea turtles, which often inhabit waters far from land, are extremely difficult to spot. There have been no shipboard surveys in the Atlantic or Pacific Oceans designed to specifically address information needs relative to sea turtles. Other difficulties with marine surveys include weather, time, and logistical constraints. For example, the operating cost for a research vessel is approximately $10,000 per day (Forney 2002).

In addition, data derived from marine surveys do not provide adequate information for scientists to accurately describe the seasonal occurrence of marine mammals and sea turtles in extremely large areas, such as the North Pacific Ocean. The occurrence of marine mammals and sea turtles in an area often changes on a seasonal basis in response to changes in water temperature, the movement and availability of prey, or an individual's life history requirements, such as reproduction. Therefore, the number of sightings on a specific date over a specific trackline may not be representative of the number of individuals occurring in the entire area over the course of an entire season. As a result, sighting frequency is often a direct result of the level of survey effort expended in a given area.

There are also a number of biases and data limitations inherent in conducting small-boat based surveys. If the primary goal of a small-boat based survey varies between each field effort, it can lead to considerable spatial and temporal heterogeneity in survey coverage over the duration of the study. Baird et al. (2005) noted that there were both inter-annual and seasonal biases in survey effort during small-boat based surveys for odontocetes around the MHI from 2000 through 2005. Survey effort was also geographically biased by region and depth. The likelihood of documenting species occurrences depends to a large degree on the water depths surveyed, which, during these surveys, varied among islands and among years. Additionally, a strong small sample size bias existed for areas that weren't as intensely surveyed. Identification of biases and limitations in small-boat based survey data can help to minimize potential misinterpretation of the sighting data collected (Baird et al. 2005).

1.4.4 Limitations of Stranding Data

How closely the distribution of marine mammal and sea turtle stranding records mirrors the actual occurrence of a species in a given region is often not known. Sick animals may strand well beyond their normal range and carcasses may travel long distances before being noticed by observers. Stranding

frequency in a given area is as much a function of nearshore and offshore current regimes and coastal zone patrol efforts as it is a function of the stranded species' actual pattern of occurrence in that area. Since coastal species will strand more frequently than oceanic species, due to their proximity to shore, stranding frequencies should not be used when attempting to compare the occurrence of a coastal versus an oceanic stock in a certain area. Comparisons cannot be made between species of differing sizes and social structures, as strandings of large-bodied species and groups of individuals are much more likely to be reported than strandings of small-bodied species or single individuals. An additional problem with the use of stranding data involves the inability of reporters to identify carcasses as a certain species. For example, only the most experienced marine mammal scientists are able to differentiate between the several species of beaked whales in the genus *Mesoplodon*.

1.5 REPORT ORGANIZATION

This report consists of eight major chapters and four associated appendices. Chapter 1—Introduction provides background information on this project, an explanation of its purpose and need, a review of relevant environmental legislation, and a description of the methodology used in the assessment. Chapter 2—Physical Environment and Habitats describes the physical environment of the study area, including the marine geology (physiography, bathymetry, and bottom sediments), physical oceanography (circulation and currents), hydrography (surface temperature and salinity), biological oceanography (plankton), and habitat complexity. It also discusses the distribution of inshore habitats (e.g., wetlands, lagoons, and fish ponds), seagrasses, mangroves, coral reefs, and hardbottom and artificial habitats in the OPAREA and vicinity. Chapter 3—Species of Concern covers all protected species found in Hawaiian Islands OPAREA: marine mammals, sea turtles, and nine species of birds. For these species, detailed narratives of their morphology, status, habitat preferences, distribution (including migratory patterns), behavior, life history, and acoustics and hearing (if known) have been provided. Chapter 4—Fish and Fisheries investigates fish, EFH, and fishing activities (commercial and recreational) that occur within the OPAREA. Chapter 5—Additional Considerations provides information on U.S. maritime boundaries, navigable waterways and commercial shipping lanes, MMAs, SCUBA diving sites, sound sources, and whale watching and swim with wild dolphin tours. Chapter 6—Recommendations suggests future avenues of research that may fill the data gaps identified in this project and prioritizes research needs from a cost-benefit approach. Chapters 7 and 8 are the List of Preparers and Glossary, respectively. Appendix A includes supplementary materials referred to in Chapter 1 (including the marine mammal and sea turtle data sources) while Appendices B and C contain density and occurrence map figures that are described or referenced in the marine mammal and sea turtle sections (3.1 and 3.2, respectively) of Chapter 3. Appendix D includes maps for all fish species that have designated EFH (for at least one life stage) within the OPAREA.

This report is written in a format and reference style similar to that found in *The Chicago Manual of Style*, 14th Edition. Cited literature appears at the end of each chapter except in Chapter 3, Species of Concern, where the cited literature appears at the end of each section.

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2.0 PHYSICAL ENVIRONMENT OF THE HAWAIIAN ISLANDS OPAREA

2.1 INTRODUCTION

The Hawaiian archipelago is a chain of 132 islands, islets, and reefs spanning 2,450 km in the Pacific Ocean (18°54'N, 154°40'W to 28°15'N, 178°20'W); the archipelago formed during the last few million years via the gradual accretion of volcanic lava flows (Balazs 1980; Miller 1994). The islands are the emergent areas of the mostly submerged Hawaiian Ridge and are located in the center of the subtropical gyre of the north Pacific Ocean (Qiu et al. 1997); the eight main inhabited islands (Hawaiʻi, Maui, Kahoʻolawe, Lānaʻi, Molokaʻi, Oʻahu, Kauaʻi, and Niʻihau) comprise over 99% of the total land mass (16,600 km^2) (Balazs 1980).

The Hawaiian Islands are geologically diverse with features ranging from submarine canyons to snow-capped peaks in excess of 3,650 m (Shepard and Dill 1966; EPA 1998). The diversity of environments and the extreme isolation of the Hawaiian Islands have resulted in an amazing variety of species, many of which are endemic to the islands (EPA 1998).

2.2 CLIMATE/WEATHER

The Hawaiian Islands are located along the northern edge of the tropics; however, the climate of the region can be best described as subtropical (Miller 1994). Small changes in solar energy and the persistent northeast trade winds (**Figure 2-1**) play a major role in moderating the climate of the Hawaiian Islands; this results in seasonal temperatures that vary only slightly throughout the year (Miller 1994; Flament et al. 1996). Atmospheric temperatures range from 22 to 32°C in the summer and 22 to 26°C in the winter; the average temperature has increased 2.4°C over the last century (EPA 1998). Cooler temperatures tend to occur on the more western islands of Kauaʻi and Niʻihau (DoN 2001a, b); lower temperatures generally occur during periods of weaker trade winds that are accompanied by heavy dew (DoN 2001b).

Cool ocean currents and warm, moist, northeast trade winds result in abundant rainfall and relatively humid conditions (60 to 80%) (Miller 1994; DoN 2001c; OCDA 2003). High humidity tends to occur during periods of high rainfall in mid-summer or on cold nights during mid-winter (DoN 2001b); rain falls when warm, moisture-laden air is forced up and over mountain peaks on the islands causing condensation (orographic rainfall). Seventy-five percent of the rain falls from October to April (EPA 1998; Hafner and Xie 2003; Roe 2005); however, mean precipitation has decreased 20% over the last century (EPA 1998). Due to wind patterns, the northeastern (windward) sides of the islands receive the most rain (Miller 1994); on Mount Waiʻaleʻale, Kauaʻi, rainfall has exceeded 12,700 millimeters (mm) per year (yr) and rainfall has exceeded 610 mm in less than 4 hours (hr) (Miller 1994; DoN 2001a). On average, six heavy rain events occur per year; a rainfall rate exceeding 250 mm per day (d) is not uncommon (Kodama and Barnes 1997). As the trade winds descend the western (leeward) side of the islands they become warm and dry making them the driest regions of the Hawaiian Islands (Miller 1994). In some locales (e.g., Kauaʻi), annual rainfall on the western coasts is 2 to 4% that of the windward side; evaporation often exceeds rainfall in these dry regions (Miller 1994; Flament et al. 1996; DoN 2001a, b). One leeward location in which rainfall does occur in relative abundance is the Kona coast of Hawaiʻi. High rains can occur here due to converging cyclonic and anticyclonic eddies off the coastline (Miller 1994). The massive size of the islands can also cast "rain shadows" onto islands located downwind. The islands of Kahoʻolawae, Lānaʻi, and Niʻihau are shielded from warm, moist trade winds by the larger islands resulting in drought and erosion problems (Miller 1994; DoN 2001a).

2.2.1 Seasons

Rainfall in the Hawaiian Islands can be divided into two distinct seasons: dry and rainy (Farmers' Almanac 2004; NASS 2004). The dry season (May through October) receives less than 20% of the annual rainfall (Farmers' Almanac 2004). Approximately 50% of the normal annual rains occur within a three-month period (December through February) and 80% of the annual rainfall occurs during the rainy season (November through April) (DoN 2001b; Farmers' Almanac 2004; NASS 2004).

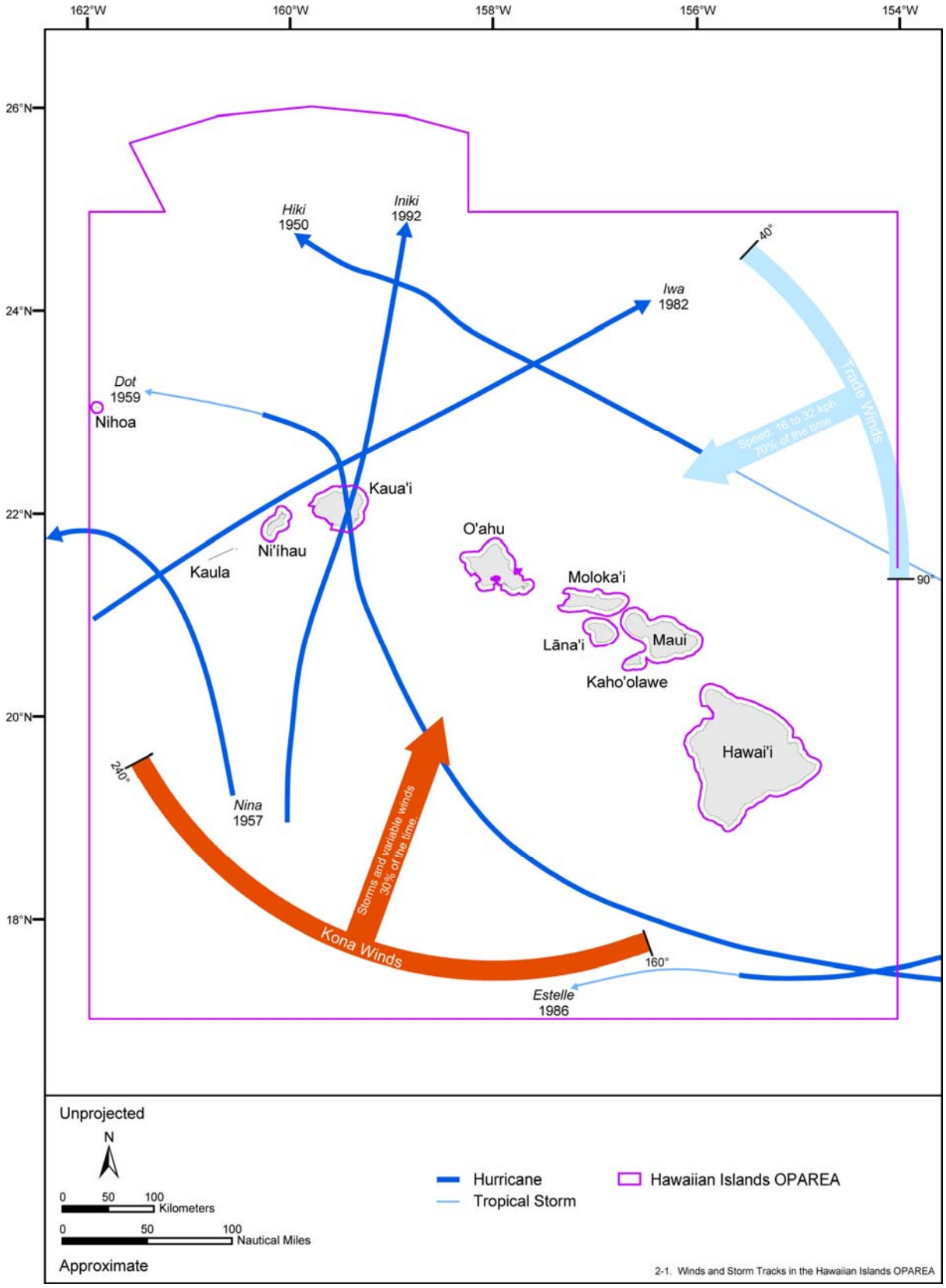


Figure 2-1. Wind forcings and major tropical cyclones affecting the Hawaiian Islands OPAREA and vicinity. Map adapted from: Fletcher et al. (2002) and OCDA (2003).

Oceanographically, high salinity and low temperature waters from the north occur during the fall and winter months (October through February) and low salinity and high temperature waters from the southeast occur during the spring and summer months (March through September) (Murphy et al. 1960).

2.2.2 Winds

Winds in the Hawaiian Islands OPAREA and vicinity originate from three main sources: trade winds, Kona winds, and hurricanes or tropical storms (OCDA 2003; **Figure 2-1**).

2.2.2.1 Trade Winds

Northeast trade winds are dominant during the majority of the year (70 to 80%) and play a major role in defining the region's climate (Kodama and Businger 1998; DoN 2001b; OCDA 2003). These persistent winds blow from a northeast to east-northeast direction; they range in velocity from 16 to 32 kilometers per hour (kph) (Miller 1994; DoN 2001b; OCDA 2003). Occasionally, trade winds of 65 to 95 kph occur for several days at a time when a sub-tropical high-pressure cell in the central North Pacific Ocean intensifies. For example, during the 1993/1994 and the 1994/1995 winter seasons, strong and gusty trade winds of 65 to 80 kph lasted several days and inflicted damage to roof tops, tree limbs, and telephone equipment (OCDA 2003). As a result, the east-facing (windward) coastlines are most impacted by the trade winds; wind speeds decrease on the leeside of the islands (Miller 1994). The strong trade winds also funnel through the major channels between the islands: Kaua‘i, Kaiwi, Pailolo, Kalohi, and ‘Alenuihāhā Channels. Mountains on either side of the channel constrict these winds; they pass through at speeds of 9 to 37 kph faster than the speeds over the open ocean (Patzert 1969; Miller 1994).

Topographically, the high altitude of the mountains in the Hawaiian archipelago (600 km long) obstructs winds and produces weak winds on the leeside of the islands (Chavanne et al. 2002). In addition, a series of atmospheric eddies are formed on the leeside of the island due to the wind shear of the trade winds passing the island chain. These eddies are cyclonic on the northern side and anticyclonic on the southern side of the islands (Chavanne et al. 2002). Atmospheric eddies are a permanent feature off of Hawai‘i during trade wind conditions; they may occur off of other islands as well but are less intense for the lower and smaller islands.

2.2.2.2 Kona Winds

Kona, from the Polynesian word for leeward, is a Hawaiian term for the rain-bearing winds that blow over the islands from the southwest or south-southwest. They flow in the opposite direction of the trade winds and bring strong storm events to the islands (Simpson 1952; Miller 1994; OCDA 2003; **Figure 2-1**). Kona winds blow 15 to 30% of the time causing the western, or typically leeward, coasts of the islands to become windward (Chavanne et al. 2002). Kona winds occur when a low-pressure system occurs within 800 km to the northwest of the islands and has an unusually low central pressure (below 1000 millibars) (OCDA 2003). During summer months, winds are light and variable when trade wind circulation diminishes; during winter months when winter storm systems move across Hawaiian waters, they occur as strong southerly winds (OCDA 2003). Damaging Kona winds have reached constant velocities of 80 kph for several days.

Kona storms generally form between 15° to 35°N and 175°E to 140°W and move westward (Kodama and Businger 1998). Kona storms are persistent; they can remain in the Hawaiian Islands for up to two weeks. During this time, considerable damage can be inflicted on boats caught in the open ocean or anchored in southwest exposed anchorages; widespread flooding is not uncommon (Ramage 1962; OCDA 2003). Coastal erosion can result from the extended periods of heavy rain, strong surf, and high winds. It is not uncommon for trees to be uprooted, branches downed, and roofs blown off houses. When reinforced by the mountainous topography, the velocity of downslope winds can increase and be destructive to low lying areas; the Kane‘ohe-Kahalu‘u area at the base of the Ko‘olau Mountains (O‘ahu) has experienced extensive damage due to strong Kona winds (OCDA 2003).

2.2.2.3 Tropical Cyclones

Damaging winds on the Hawaiian Islands are also associated with passing tropical cyclones in the form of tropical depressions, tropical storms, or hurricanes (**Figure 2-1**). A Tropical depression is an organized system of clouds and thunderstorms with defined circulation patterns and maximum sustained winds of 61 kph or less. A tropical storm is an organized system of strong thunderstorms with a defined circulation and maximum sustained winds of 63 to 118 kph. A hurricane is an intense tropical weather system with well-defined circulation patterns and maximum sustained winds of 118 kph or higher; they can span hundreds of miles (OCDA 2003). Only storms exceeding tropical depression strength are named and storms originating in the central North Pacific (an area bounded by the equator and 140° to 180°W) are given Hawaiian names (Schroeder 1993).

Hurricanes (referred to as typhoons west of 180°) are one of the most dramatic, damaging, and potentially deadly events that occur within the Hawaiian Islands (OCDA 2003). Historically, most tropical cyclones have passed by the Hawaiian Islands to the south and west (**Figure 2-1**). Because these storms have a cyclonic rotation (counterclockwise) in the Northern Hemisphere, the east-facing (windward) coastlines of the Hawaiian Islands receive the brunt of strong onshore winds; as the storms pass to the west the south and west coastlines experience onshore winds (OCDA 2003). However, the highest wind speeds may occur on the island side opposite the storm approach. Localized “microbursts” and downdrafts descend over cliffs (palis) and accelerate downslope to reach wind speeds in excess of 320 kph (Fletcher et al. 2002; OCDA 2003). For example, as Hurricane Iwa (1982) passed to the west of O‘ahu, the highest recorded winds were microbursts at the base of the Pali in Kane‘ohe, O‘ahu. In addition, more than 26 microbursts were observed on Kaua‘i during Hurricane Iwa (OCDA 2003; CPHC 2005a).

The Central Pacific Hurricane Center (CPHC) has compiled a comprehensive survey of the documented tropical cyclones between 1832 and 1979. Using written accounts, 19 storms were recorded in the Hawaiian Islands during the period of 1832 to 1949 and seventeen storms recorded from 1950 through 1959. Early satellite data became available in 1960 and recorded 34 tropical cyclones in the decade of the 1960s. The following decade (1970 through 1979) produced 34 tropical storms in the central Pacific and during the 1980s the number of tropical storms increased to 53. From 1970 to 1992, 105 tropical cyclones have been recorded in the central Pacific at an average of 4.5 storms per year (Schroeder 1993). Not all of these storms pass through the Hawaiian Islands OPAREA, and actual hurricane strikes on the Hawaiian Islands are relatively rare (Schroeder 1993). More commonly, hurricanes passing close to the islands generate large swell, large waves, high winds, beach erosion, and marine overwash causing varying degrees of damage (e.g., the Wai‘anae Coast of O‘ahu as Hurricane Iniki passed to the west of O‘ahu and hitting Kaua‘i) (Fletcher et al. 2002). The impact of a storm to the coastal zone is determined by the storm’s wind strength, maximum wind radius, timing, and the proximity to the coast (OCDA 2003).

Hurricane Iniki (1992) remains the most powerful and destructive hurricane to hit Hawai‘i in recorded history (**Table 2-1**). Iniki formed on September 5, approximately 2,575 km southwest of Baja California (12°N, 135°W); this is farther west and south than the initial position of most mid-season hurricanes (CPHC 2005b). Iniki approached the islands from the south, 480 km south of Hawai‘i. It turned northward and hit Kaua‘i on 11 September 1992. Sustained wind speeds reached 224 kph and gusts reached speeds of 280 kph (Dreyer et al. 2005).

El Niño plays an important role in the formation of hurricanes across the Pacific Ocean (Fletcher et al. 2002). The primary source of central Pacific hurricanes are cyclonic atmospheric disturbances that form in the eastern Pacific and move to the west; these are steered by winds in the surrounding environment (Schroeder 1993). During the onset of an El Niño, changes in the equatorial wind patterns of the central Pacific region create a zone of high-shear between the subtropical winds flowing to the east and west-flowing winds along the equator; cyclonic disturbances can develop into hurricanes in these shear zones (Fletcher et al. 2002). Under normal climatic conditions, waters of the central Pacific Ocean retain enough heat to permit the formation of hurricanes but lack the necessary atmospheric disturbances for hurricane

Table 2-1. Significant hurricanes of the Hawaiian Islands in the 20th century (OCDA 2003).

Name	Date	Damage (in Dollars)	Deaths
Mokapu Cyclone	August 19, 1938	Unknown	Unknown
Hiki	August 15, 1950	Unknown	Unknown
Nina	December 2, 1957	$900,000	4
Dot	August 6, 1959	$28,000,000	0
Iwa	November 23, 1982	$394,000,000	1
Iniki	September 11, 1992	$1,800,000,000	4

formation. However, during the onset of El Niño (see below), tropical storms gradually form farther eastward as the shear zone between eastward and westward blowing winds migrate from the western Pacific into the central Pacific region (Fletcher et al. 2002).

2.2.2.4 Additional Wind Patterns

To the north of the islands wind patterns are dominated by the westerlies following the north Pacific anticyclone. The westerlies shift to the north during the summer months when the trade winds intensify, reaching as far north as 35°N; however, during cooler winter months the westerlies extend as far south as 28°N and may affect wind patterns of the Hawaiian Islands (Flament et al. 1996).

2.2.3 El Niño/Southern Oscillation

El Niño (the little boy or Christ Child in Spanish) was originally defined by fisherman from the western coast of South America with the onset of unusually warm waters occurring near Christmas. El Niño/Southern Oscillation (ENSO) is the result of interannual changes in sea level pressures (SLP) between the eastern and western hemispheres of the tropical Pacific (Conlan and Service 2000); these events can initiate large shifts in the global climate, atmospheric circulation, and oceanographic processes (Jacobs et al. 1994). ENSO conditions typically last 6 to 18 months although they can persist for longer periods of time (Barber and Chavez 1983; Lynn et al. 1998; Durazo et al. 2001; Schwing et al. 2002); they are the main signs of global change over time scales of months to years (Philander 1983). During normal, non El Niño conditions, trade winds blow west across the tropical Pacific and cause warm water to pile up in the west Pacific (~0.5 m sea surface height difference between Indonesia and Ecuador) (Conlan and Service 2000; NOAA 2005a, b). The equatorward flow of the eastern boundary Peru Current along the South America coastline and the California Current along the North America coastline along with the easterly trade winds create a net offshore transport of cool surface water (the Ekman layer) (Pickard and Emery 1982; NOAA 2005b). This transport can be visualized as a large “cold tongue” extending westward across the Equatorial Pacific. The surface water advected westward is replaced by cold nutrient-rich water; this newly upwelled water enhances primary productivity and the abundance of higher trophic level animals (e.g., fish and marine mammals). Under these normal conditions, rainfall is low in the eastern Pacific and is high over the warm waters of the western Pacific.

El Niño conditions occur when unusually high atmospheric pressure develops over the western tropical Pacific and Indian Oceans and low SLPs develop in the southeastern Pacific (Trenberth 1997; Conlan and Service 2000). During El Niño conditions, the trade winds weaken in the central and west Pacific; thus, the normal east to west surface water transport and upwelling along South America decreases; coastal upwelling continues but the newly upwelled waters are low in nutrients resulting in decreased production (Chavez et al. 2002). This causes the SST to increase across the mid to eastern Pacific (Donguy et al. 1982). In the western equatorial Pacific, SST decreases (Kubota 1987) and rainfall patterns shift eastward across the Pacific resulting in increased (sometimes extreme) rainfall across the southern U.S. and Peru and drought conditions in the western Pacific (Conlan and Service 2000).

Historically, strong El Niño events have been documented in 1940, 1958, 1983, 1992, and 1997 to 1998 (Hayward 2000; Leet et al. 2001).

La Niña is the opposite phase of El Niño in the Southern Oscillation cycle (NOAA 2005a). La Niña is characterized by strong trade winds that push the warm surface waters back across to the western Pacific (Schwing et al. 2000). Under these conditions, and due to increased upwelling along the eastern Pacific coastline, the thermocline in the western Pacific deepens and the thermocline in the eastern Pacific becomes shallower; this shift results in abnormally cold SST along the equatorial Pacific. Often with La Niña, the climatic effects are the opposite of those encountered during an El Niño warming event (e.g., higher SST in the western equatorial Pacific, high production along Pacific upwelling coasts, and heavy rainfall in Australia and Indonesia) (NOAA 2005a).

During an El Niño event, the Hawaiian Islands experience a decrease in annual rainfall (Fletcher et al. 2002). The ten driest years on record for the Hawaiian Islands are all associated with El Niño years (**Table 2-2**). Rainfall is decreased because of a southerly shift in the atmospheric circulation system of the north Pacific, more specifically a southern shift of the Hadley Cell. The Hadley Cell is a large continuous belt of moisture-laden air that rises from the warm equatorial waters at about 8°N and moves to the north across the subtropics. The air cools and loses the ability to retain moisture and produces abundant rainfall (Kodama and Businger 1998; Fletcher et al. 2002). Eventually the air descends back to the surface as a column of dry, cool air and creates a pressure system known as the Pacific High (Fletcher et al. 2002). Under normal conditions the Hawaiian Islands experience a wet climate, while to the north and northeast, the Pacific High creates a dry climate. However, during El Niño the surface waters at the equator become significantly warmer and the rising motion of the Hadley Cell shifts to the south. This brings the Pacific High south as well, and the Hawaiian Islands experience a decrease in rainfall (Fletcher et al. 2002). However, future alterations in precipitation levels for the Hawaiian Islands are uncertain because they depend upon unpredictable changing El Niño conditions (EPA 1998).

Table 2-2. Driest years on record for the Hawaiian Islands OPAREA and vicinity and the associated El Niño event (Fletcher et al. 2002).

Rank	Year	El Niño Event
1	1897	1896-1897
2	1926	1925-1926
3	1919	1918-1919
4	1953	1953
5	1912	1911-1912
6	1941	1941
7	1903	1902-1903
8	1905	1905
9	1977	1976-1977
10	1925	1925-1926

2.2.4 Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) is a long-term climatic pattern capable of altering the SST, surface winds, and SLP (Mantua 2002; Mantua and Hare 2002). The PDO is often described as a long-lived El Niño-like pattern of Pacific climate variability and experiences both warm and cool phases (Mantua 2002; Mantua and Hare 2002). However, the PDO possesses three characteristics that distinguish it from ENSO

events and El Niño. First, PDO events can persist for 20 to 30 years, contrasting with the relatively short duration of ENSOs (up to 18 months). Second, climatic effects of the PDO are more prominent in ecosystems outside the tropics. Third, the mechanisms controlling the PDO are unknown, while those forces creating ENSO variability have been well resolved (Mantua and Hare 2002). During warm phases of the PDO, the western tropical Pacific experiences periods of increased SLP while the opposite are true during cold periods of the PDO. In Hawaiʻi, precipitation appears to be the factor most strongly connected to PDO, with drier conditions prevailing during cooler phases of the PDO; SST is also increased during warm phases of the PDO. However the overall impact of the PDO on surface meteorology near Hawaiʻi is relatively small (Brix et al. 2004).

2.3 MARINE GEOLOGY

The Hawaiian OPAREA and vicinity is a region that has experienced dynamic geological change. Important processes determining the marine geology of the region include volcanism, isostatic adjustment, and sedimentation (Moberly and McCoy 1966).

2.3.1 Geologic Setting

The Hawaiian Islands are located at the southeastern end of a chain of shield volcanoes spanning 21,500 km from the island of Hawaiʻi to Midway and Kure Atolls (30°N, 179°W) that began forming from 70 to 130 million years ago (Bridges 1997; Itano and Holland 2000; Rutherford and Kaye 2004). Many of these volcanoes formed islands, originally fed by the underlying “hot spot”, have continued to erode, subside, and are again located beneath sea level. A number of old volcanoes comprising the Hawaiian Ridge never reached sea level; these submerged volcanoes formed large seamounts spanning the Pacific (Rutherford and Kaye 2004). The Hawaiian Islands are the youngest volcanoes to emerge from the sea from the gradual accretion of basaltic lava flows following countless eruptions (Miller 1994; Rutherford and Kaye 2004).

The Hawaiian Islands existence is attributed to a "hot spot" in the Earth’s mantle that may have changed location only slightly over the past 70 million years (Tarduno and Cottrell 1997; Tarduno et al. 2003; Steinberger et al. 2004; Koppers and Staudigel 2005). This hot spot is located beneath southeastern Hawaiʻi and the seamount Loʻihi. It is one of three known active hot spots located in the Pacific Ocean (Clague and Dalrymple 1973; Karl et al. 1989). However, the volcanoes did not continue to erupt because the Pacific Plate was continually moving northwestward across the hot spot at a rate of 7 to 15 centimeters (cm) per yr (Leslie et al. 2002; Rutherford and Kaye 2004). Eventually each volcano is torn away from the hot spot and carried northwestward. Nihoa, located to the northwest of the MHI, is the precipitous remnant of a volcanic peak (Clapp et al. 1977); the island is estimated to be 7.2 million years old. It is the emergent portion of a large basaltic shelf and is considered the best example of a nearly undisturbed coastal ecosystem in the entire Hawaiian archipelago (NOAA 2001). Of the eight main Hawaiian Islands, Kauaʻi is the oldest (Miller 1994). Oʻahu emerged from the sea approximately 10 million years ago when the top of Waiʻanae Volcano broke the surface of the Pacific Ocean. Koʻolau Volcano appeared a few million years later and eventually the two volcanoes fused to form a single island (DoN 2001b). Hawaiʻi is still mountain building and Loʻihi Seamount (off the coast of Hawaiʻi) marks the probable location of the next island to break the sea surface (Miller 1994; Rutherford and Kay 2004).

During the last million years changes in sea level, as glaciers formed and melted, have resulted in extremely differing appearances of the Hawaiian Islands. At its extremes, the sea was 76 m higher and 91 m lower than at present (DoN 2001b). During a period of low sea level in the recent geologic past, the islands of Maui, Lānaʻi, Molokaʻi, and Kahoʻolawe were connected into a single island known as Maui Nui (MacDonald 1983; Miller 1994). 3,500 to 4,000 years ago mean sea level was 1.6 m above current sea level. During one of the last sea level rises, 80,000 years ago, the sea stood 7.6 m higher than present for several centuries (Fletcher and Jones 1996; DoN 2001b). These higher sea levels have resulted in the formation of a carbonate terrace surrounding the edges of the Hawaiian Islands (DoN 2001b).

2.3.2 Physiography and Bathymetry

The seafloor of the Pacific Ocean is scattered with large seamounts and broad swells resulting in an overall pattern of benthic roughness (**Figures 2-2** and **2-3**). The Hawaiian archipelago has developed on one of these broad swells (800 km wide) with the islands rising abruptly from the archipelagic apron of the adjacent seafloor (Dietz et al. 1954; Moberly and McCoy 1966; Miller 1994). In general, the Hawaiian Ridge forms a continuous barrier, exerting a dramatic influence over oceanic current patterns along the seafloor in the Hawaiian Islands (Qiu et al. 1997; Itano and Holland 2000); this barrier becomes extremely porous 500 m above the seafloor. Only around the islands does the ridge extend high enough above the seafloor to break the sea surface (Roden 1991; Qiu et al. 1997).

In general, the bathymetric features of the Hawaiian Islands can be described as having a steep, narrow continental margin and a seafloor comprised of depressed island moats, seamounts, submarine canyons, and submerged banks. Each of these regions is described in further detail in the sections that follow.

2.3.2.1 Continental Margins

The boundary, or transition, between a continent and the ocean basin is referred to as the continental margin (Kennett 1982). In general, two types of continental margins are found on the globe: passive and active. Passive continental margins are usually found in the Atlantic Ocean and consist of three major physiographical regions that transition from one to another with depth: the continental shelf, the continental slope, and the continental rise. Passive margins are not correlated with the boundaries of continental plates but rather strictly distinguish the transition from continent to ocean (Kennett 1982). Passive margins can also be considered stable, as they are not associated with seismic or volcanic activity.

Active margins border the Pacific Ocean and are characterized by the rapid transition from a shelf to a slope to a deep trench (Kennett 1982). Unlike passive margins, active continental margins mark the boundary between two crustal plates. Due to the collision of the crustal plates, active margins are associated with deep oceanic trenches, the formation of seamounts, seismic activity, and volcanism.

The Hawaiian Islands, however, are located in the middle of the Pacific plate where no collision, subduction, or tectonic spreading occurs. Rather, the islands are a series of seamounts that possess no true continental shelf (**Figures 2-3** and **2-4**). The underwater coastal shelf system of the OPAREA is very narrow with the 37 m isobath only a few km from shore (Balazs 1980). The insular shelf of the region is located around the islands to a depth of approximately 100 to 300 m (Mathewson 1970; E2I EPRI 2004; Sandwell et al. 2004); with few exceptions, the topography of the islands, from 400 m depth seaward, is steep and drops almost immediately to the abyssal plain at 4,800 m (Miller 1994). This steep drop is not considered to be a true continental slope.

2.3.2.2 Isostatic Equilibrium

Isostasy is a geologic term referring to a state of gravitational equilibrium between the lithosphere (the Earth's crust) and the asthenosphere (the upper mantle) such that the tectonic plates "float" at an elevation dependant upon thickness and density. It is invoked to explain how different topographic heights can exist at the Earth's surface. When a certain area of lithosphere reaches the state of isostasy, it is said to be in isostatic equilibrium. The seafloor near the Hawaiian Islands is adjusting to the mass of the island volcanoes on the oceanic crust (Moberly and McCoy 1966). In contrast to the island aprons bordering the Marquesas, Samoan, Society, Marshall, and Line Islands where the slope from the island base to the abyssal plain is a smooth curve downward, the crust underlying the Hawaiian Islands has subsided 2 to 6 km under the large shield volcanoes, and the adjacent sea floor has been downwarped accordingly (4,000 to 5,600 m) forming the Hawaiian Deep or Moat (Dietz et al. 1954; Miller 1994; Moberly and McCoy 1966; Bridges 1997; Leslie et al. 2002; **Figure 2-4**). The Hawaiian Deep is nearly featureless except in the area of the seamount cluster northeast of O'ahu and to the east where the deep intersects the Molokai Fracture Zone. The Hawaiian Deep is filled with debris shed from the islands during large

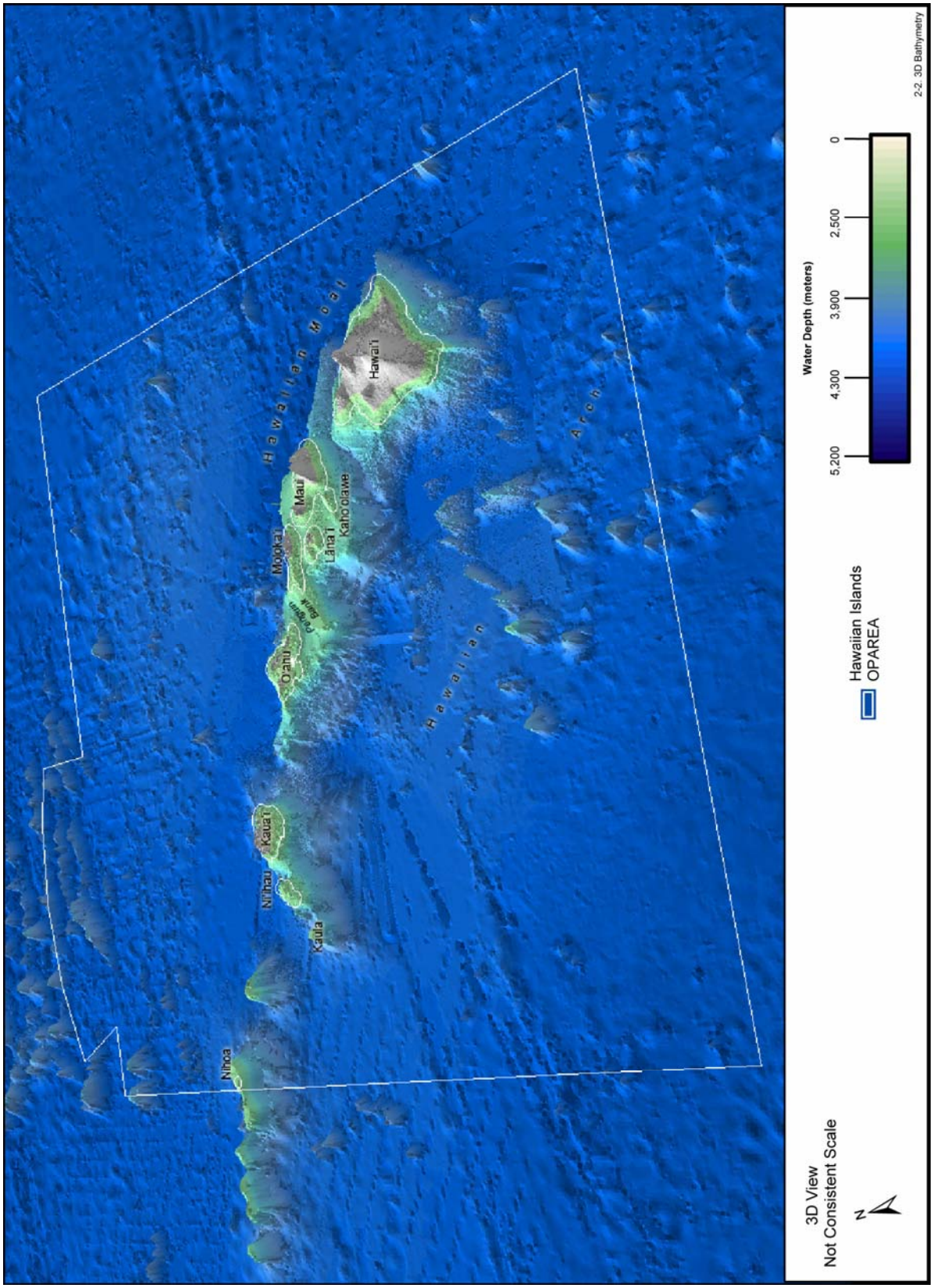


Figure 2-2. Three-dimensional bathymetry of the Hawaiian Islands OPAREA and vicinity. Source data: NOAA (2002) and Sandwell et al. (2004).

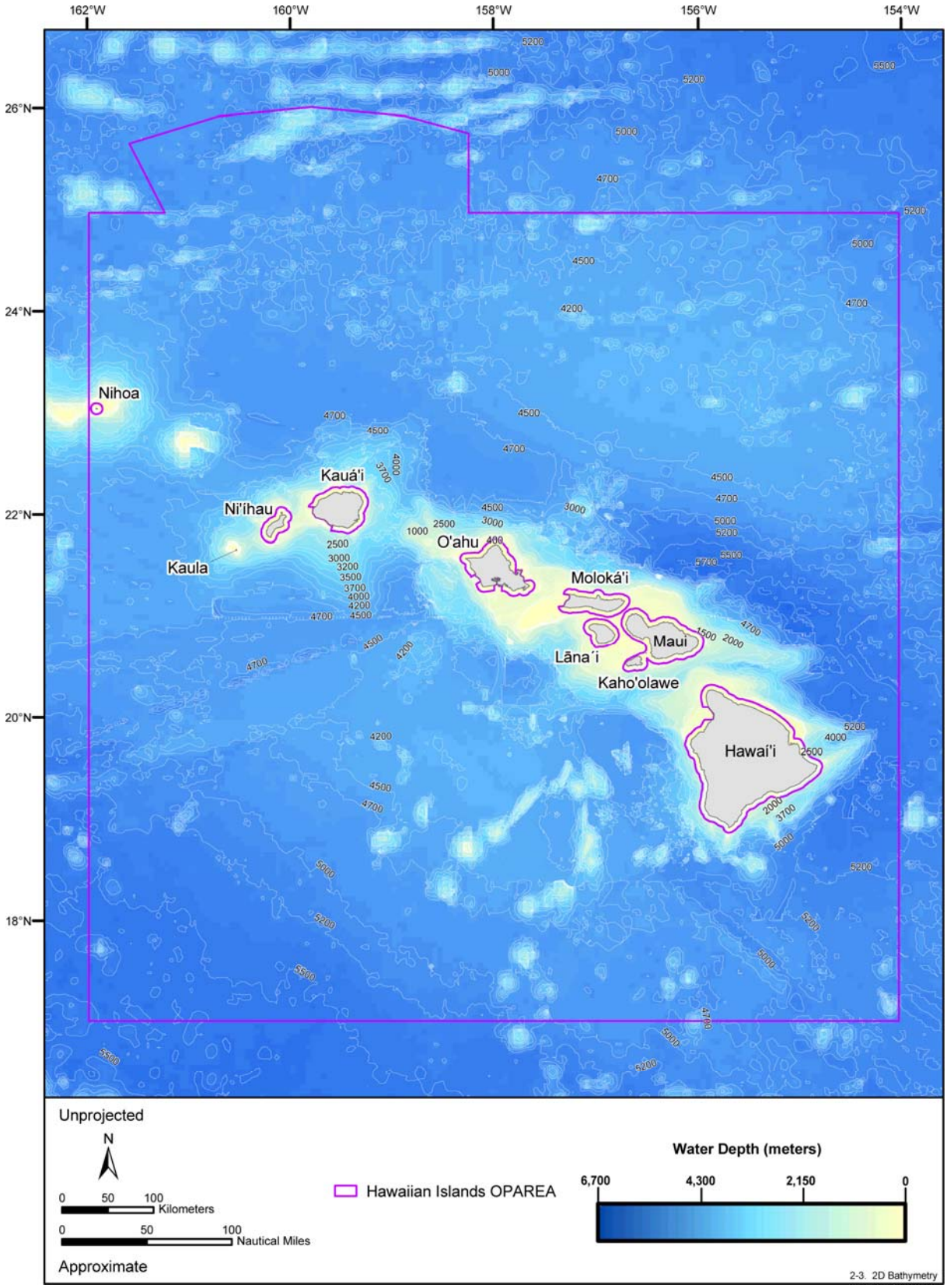


Figure 2-3. Two-dimensional bathymetry of the Hawaiian Islands OPAREA and vicinity. Source data: NOAA (2002) and Sandwell et al. (2004).

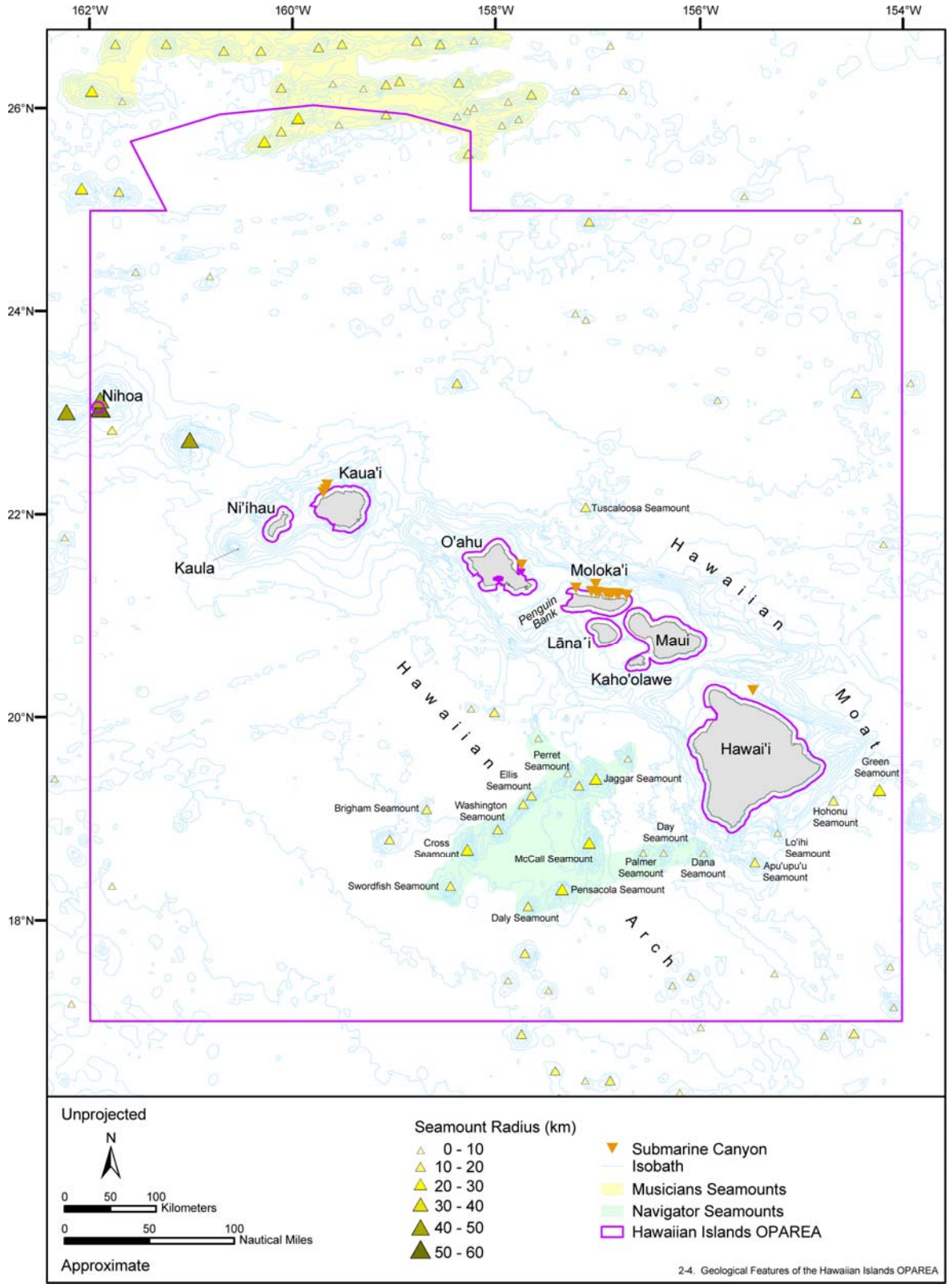


Figure 2-4. Major geological features of the Hawaiian Islands OPAREA. Source data: Bridges (1997), Itano and Holland (2000), NOAA (2002), and Sandwell et al. (2004). Map adapted from: Shepard and Dill (1966), Mathewson (1970), Moore (1987), Eakins et al. (2003), and Moore and Clague (2004).

submarine landslides (Moberly and McCoy 1966; Bridges 1997). Southeast of Hawai‘i the Frontal Hawaiian Moat is the most recent expression of the Deep. The Hawaiian Deep is surrounded by a rise in the seafloor, the Hawaiian Arch, located 150 to 370 km from the base of the islands and is an upwarp of the oceanic crust and mantle formed as the weight of the islands pushes crustal material outward and upward creating a seafloor that lies approximately 1 km above the adjacent regions (Hamilton 1957; Moberly and McCoy 1966; Miller 1994). The Frontal Hawaiian Moat and Arch are short-lived features that will eventually be covered by the expanding Hawaiian Ridge as the Pacific Plate migrates across the Hawaiian hot spot (Leslie et al. 2002); seaward of the Hawaiian Deep and Arch lie hundred of seamounts, the majority of which are yet to be sampled (Bridges 1997).

2.3.2.3 Seamounts

Seamounts are undersea mountains that rise steeply from the ocean floor to an altitude greater than 1,000 m above the surrounding soft sediments of the ocean basin (Thurman 1997). Generally, seamounts tend to be conical in shape and volcanic in origin. Massive landslides from near islands can also form seamounts (e.g., Papa‘u Seamount) (Fornari et al. 1979a; Rogers 1994; **Figure 2-4**). The seamount topography is a striking difference to the surrounding flat, sediment covered abyssal plain, and the effects seamounts can impart on local ocean circulation are complex and poorly understood (Rogers 1994). However there have been correlations of seamounts to increased levels of phytoplankton, primary production, and pelagic and demersal fish (Zaika and Kovalev 1984; Fedorov and Chistikov 1985; Greze and Kovalev 1985; Parin et al. 1985; Rogers 1994). Seamounts can modify flow patterns of the large ocean currents, although in most cases flow effects are more local (Boehlert and Genin 1987). Effects include the formation of eddies, trapping of waves and the amplification, distortion or reflection of internal waves (Rogers 1994). An upwelling of cold, deep water can appear as a dome over the seamount (Johnston and Santillo 2004). Under certain conditions a clockwise eddy, known as a Taylor column can become localized above a seamount forming a closed circulation system (Darnitsky 1980; Boehlert and Genin 1987; Rogers 1994; Johnston and Santillo 2004).

To date, 390 seamounts with a diameter of over 1 km have been identified within the Hawaiian EEZ (**Figure 2-4**). The diameters of these seamounts range from 1 km to over 57 km with the majority possessing diameters of less than 15 km; the abundance of seamounts increases with decreasing size (Bridges 1997). On average, in the Hawaiian Islands OPAREA and vicinity seamounts (all sizes) have an average abundance of 309 per 10^6 km^2. For seamounts with a diameter greater than 1 km, this number decreases to 182 per 10^6 km^2, an order of magnitude fewer than other areas surveyed in the Pacific (Bridges 1997). In general, the seamounts of the Hawaiian Islands OPAREA and vicinity can be subdivided into four distinct classes: cones, pancakes, heaps, and stars. Cones are circular shaped seamounts, pancakes are flat-topped with step-like sides, heaps are generally irregular in shape, and stars are large seamounts with prominent radiating spines. Secondary features common of seamounts in the region include summit craters, summit mounds, coalesced boundaries, landslides, and grabens (depressions of rock lying between two faults) (Bridges 1997).

Two major groupings of seamounts are located within the Hawaiian Islands OPAREA: the Navigator Seamounts and the Musicians Seamounts (**Figure 2-4**). The Navigator Seamounts are located south of the islands between 18° to 20°N and 156° to 160°W (Itano and Holland 2000). Within the Navigator Seamounts, Cross Seamount rises to within 330 m of the surface and is the site of a productive tuna fishery. Although several other seamounts of the Navigator group surround Cross Seamount, none rise to depths shallower than 600 m (Itano and Holland 2000).

Several hundred km northwest of the MHI are the deeper Musicians Seamounts (25° to 29°N and 158° to 163°W), a group of elongated volcanic ridges and single seamounts that formed 5 to 15 million years ago (Freedman and Parsons 1986; Kopp et al. 2003). They are separated into a northern and a southern volcanic province by the Murray fracture zone (20 to 30°N); only the southern province is located within the OPAREA. Ridges in the southern province exceed 400 km in length and extend in an east-west orientation (Kopp et al. 2003).

2.3.2.4 Submarine Canyons

Submarine canyons have been identified along the coastlines of Hawaiʻi, Molokaʻi, Oʻahu, and Kauaʻi (Shepard and Dill 1966; Moore 1987; Moore and Clague 2004; **Figure 2-4**). These canyons have steep walls, winding valleys, narrow "V-shaped" cross-sections, steps, and considerable irregularity along the sea floor, often following the terrestrial canyons cut by rivers (Shepard and Dill 1966; Kennett 1982; Thurman 1997). The turbidity currents associated with active submarine canyons serve as major conduits for sediment transport to the deep sea; they erode canyon walls and transport loose sediments to the continental slope where they are ultimately deposited in a sediment cone or fan, however the submarine canyons of the Hawaiian Islands OPAREA are not believed to be actively transporting sediment downslope (Kennett 1982; Moore and Clague 2004).

Three submarine canyons have been identified off the windward coast of Kohala Volcano, Hawaiʻi. These canyons begin less than 1 km from the shore and can be traced downslope only to the limit of available bathymetry, 440 m (Moore 1987). The walls of these canyons are shallow, only 40 to 80 m deep, and are less deeply incised than corresponding terrestrial canyons which have walls 600 m high.

Twelve submarine canyons have been mapped off of the northern coast of Molokaʻi (Shepard and Dill 1966; Mathewson 1970). Most of these canyons lie directly offshore of terrestrial canyons and start less than 2 km from the shoreline. Pelekunu Canyon is a seaward extension of the land canyon of the same name, and the submarine canyon starts less than 1.6 km from shore. Waikolo Canyon, just east of the Kalaupapa Peninsula also appears to be connected to a large terrestrial gorge on the island (Shepard and Dill 1966). East of Pelekunu Bay, correlations between terrestrial and submarine canyons are not as clear. All canyons off of Molokaʻi have a typical V-shape and extend outward from the shore in a straight line, particularly Naʻiwa Canyon, the westernmost canyon (Shepard and Dill 1966). These canyons also have low wall heights (on average less than 240 m) and descend to depth along an even gradient (100 m descent per km [m/km]) (Shepard and Dill 1996).

Canyons located off of the northeast coast of Oʻahu (at least 14) start 3 to 4 km offshore and extend downward to depths over 2,000 m (Shepard and Dill 1966; Moore 1987). These canyons are small slope canyons and do not resemble those seen off of Molokaʻi (Shepard and Dill 1966). The upper regions of these canyons have been filled extensively by sediments and a sediment fan exists near the base of the Hawaiian Deep (Andrews and Bainbridge 1972; Moore 1987).

Canyons off the coast of Kauaʻi start approximately 3.5 km offshore of the northeast coast and can be traced to depths exceeding 2,200 m (Shepard and Dill 1966; Moore 1987). These canyons are steep-walled; walls of Honopu Canyon are over 750 m in height with an axial depth of 1,500 m (Moore 1987). Some of the canyons follow a straight path to depth (e.g., Hanakapiaʻi Canyon), while others are more twisting as they descend (Shepard and Dill 1966). The canyons are narrow, like those of Molokaʻi. The canyons are steep near the coastline (250 m/km), shallow (120 m/km) at approximately 900 m, but again become steep at greater depths (Shepard and Dill 1966).

2.3.3 Submerged Banks

Submerged banks are raised offshore plateaus that are similar to nearshore shelves except they lack a bordering land area (Emery 1960). The islands of Maui, Lānaʻi, Kahoʻolawe, and Molokaʻi form the largest oceanic bank complex in the MHI (Miller 1994). This region forms a semi-enclosed shallow protected area composed of unusually steep slopes in some areas and expansive flat-bottom in other areas (Miller 1994; DoN 2002). Depths in the region range from 30 to 80 m (Mercado and Frazer 1999).

To the west of West Molokaʻi Volcano, a broad shoal (Penguin Bank) appears to be formed from a separate volcano that completed its shield-building stage approximately 2.2 million years ago and has subsided below sea level; Penguin Bank has an average depth of 60 m with a range of 50 to 200 m (Miller 1994). The bank is covered with a coral deposit of unknown thickness (USGS 2003).

2.3.4 Bottom Substrate

The island of Hawai‘i, still undergoing active volcanic accretion, has a bottom substrate more reflective of this volcanic activity. The east coast of Hawai‘i is the principle locus of volcanic activity, and thus the bottom is dominated by fresh lava pillows and cylinders and lacks pelagic sediments and benthic faunas (Fornari et al. 1979b). The nearshore region of the southeast coast is comprised of volcanic sands and rubble. The west coast sediments are composed of carbonate sands and varying amounts of volcanic material while the northwest coast lacks volcanic forms and has a number of carbonate terraces; however, the presence of steady trade winds make sampling of the north shore difficult (Fornari et al. 1979b). The ‘Alenuihāhā Channel, located between Hawai‘i and Maui is flat and sediment covered from 900 to 950 m depth; below 950 m, the slope drops to the seafloor (1,940 m) and is comprised primarily of basalt talus with occasional reef outcrops intermixed with sediment occurring on the northern side of the channel (Chave and Jones 1991).

Coastal regions of the other islands in the Hawaiian Islands OPAREA all have similar substrate compositions at depths of 300 to 1,600 m and are dominated by silty sands and clay with an increase in rocky outcrops and coral rubble at shallow depths (Miller 1994; **Figure 2-5**). Bays and harbors are dominated by soft sediments often composed of carbonate grains derived from coralline algae, coral, mollusk fragments, foraminiferans, and tests of bryozoans and echinoderms (Calhoun et al. 2002). In some locations (e.g., Hanale‘i Bay, Kaua‘i) sediments are completely devoid of coral rubble (DeFelice and Parrish 2001).

- Pearl Harbor—Softbottom sediments (a layer of terrigenous mud and/or calcareous sand) comprise over 90% of the bottom (**Figure 2-5**). Along the harbor shoreline, the layer of soft sediments is thin and overlays a limestone platform of fossil reef origin (DoN 2001b). The remaining 10% is hardbottom, formed from pier pilings, submerged materials, dredged channel walls, and exposed limestone platform (DoN 2001b). The limestone platform terminates in either a dredged vertical face or slopes to the channel floor. On the channel floor, the layer of mud and sand is generally thicker than on the limestone platform. Closer to the mouth of the harbor, the channel floor has an increased percentage of calcareous sands and decreased terrigenous mud.

Sediments overlying submerged banks in the region, including Pengiun Bank, are dominated by sand with occasional outcrops of course sediments, limestone talus, limestone holes, and limestone platforms (Miller 1994). At the base of the islands the Hawaiian Deep is not entirely filled with volcanic rocks; sediments are composed of a mixture of authigenic silicates and organic carbonates. Much of the sediment in this region has slumped down submarine slopes or has been transported through submarine canyons. At this depth carbonate shells dissolve leaving the remaining sediment with a decreased carbonate component (Moberly and McCoy 1966).

The abyssal regions of the Hawaiian Islands OPAREA are covered with a layer of fine-grained marine clays littered with manganese nodules (Stephens et al. 1997; Mason et al. 1997; Rona 2002; Lambshead et al. 2003). The golf- to tennis ball-sized nodules lie on and in sediment on vast expanses of the abyssal plains that cover some 80% of the ocean basin at typical water depths of about 5 km. The portion of the nodules that protrudes above the surface of the seafloor sediment is precipitated from metals dissolved in seawater (Rona 2002).

2.3.5 Seismic Activity

2.3.5.1 Volcanism

A unique type of volcanism formed the Hawaiian-Emperor islands; the majority of volcanoes in the Pacific Ocean occur at boundaries between colliding or spreading plates. For example, at a subduction zone one plate dips underneath an adjacent plate and plunges into the mantle. Volcanoes form on the overriding plate from the melted remains of the subducting plate (Cooke 2002). At spreading centers, plates move apart and pull melted material up from the asthenosphere, a layer of soft but solid, mobile rock comprising

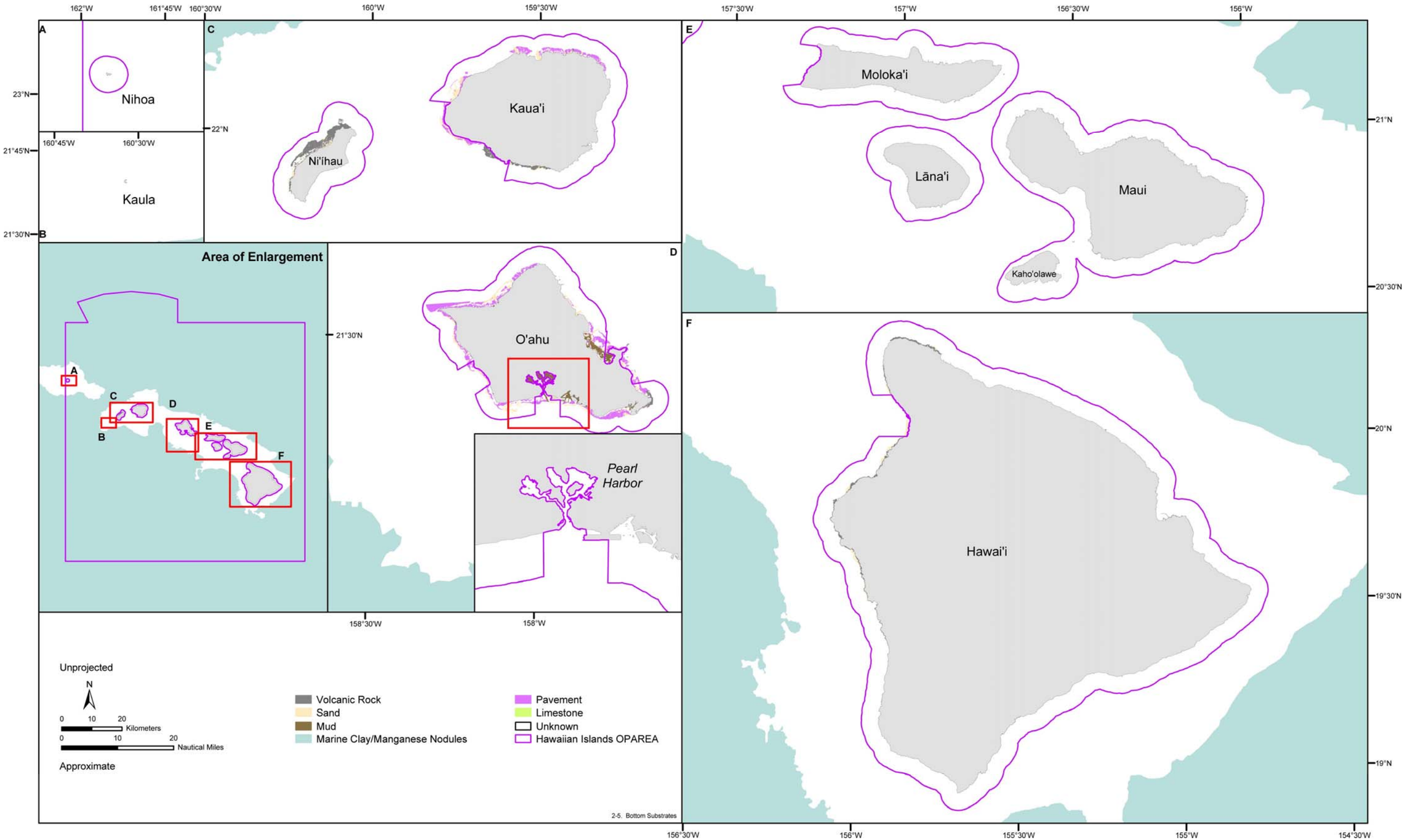


Figure 2-5. Distribution of bottom substrates in the Hawaiian Islands OPAREA. Source data: Bridges (1997), DoN (2001b), NOAA (2002), NOAA (2003), and Sandwell et al. (2004). Map adapted from: Rona (2002).

the lower part of the upper mantle (Cooke 2002). These tectonic processes account for the majority of volcanoes in the Pacific. The Hawaiian Islands are in the middle of the Pacific Plate, far away from any plate boundary, and have formed via a different process. In certain locations on the Earth, hot material from the deep mantle of the asthenosphere rises up in plumes, melting the lithosphere, a layer of solid, brittle rock making up the outer 100 km of the Earth, into magma. Magma builds up in chambers until a vent forms at the surface, tapping the magma reservoir to produce one or more volcanoes (Cooke 2002). Beneath Hawaiʻi is one of these hot spots where hot plumes rise up from the asthenosphere. Although the hot spot remains stationary, a spreading center pushes the overlying Pacific Plate northwest at a rate of 7 to 15 cm/yr (Leslie et al. 2002; Rutherford and Kaye 2004). Volcanoes are born over the hot spot, but they eventually move away from the supply of magma and become inactive. Eventually, a new vent forms as an outlet for the magma, creating a new volcano over the hot spot and driving the cycle of island chain volcanism.

Hawaiian volcanoes typically evolve in four stages 1) early alkalic, when volcanoes originate on the deep sea floor; 2) shield, during which 95% percent of a volcano's volume is formed; 3) post-shield alkalic, when small-volume eruptions build scattered cones thinly capping the lavas from the shield-stage; and 4) rejuvenated, during which lavas of distinct chemistry erupt following a lengthy period of erosion and volcanic calm (Eakins et al. 2003). Mantle-derived magma rises through a vertical conduit and is temporarily stored in a shallow summit reservoir from which magma may erupt within the summit region or be injected laterally into local rift zones. Rift zones commonly extend deep underwater, producing submarine eruptions of bulbous pillow lava (Eakins et al. 2003).

Once a volcano has grown above sea level, subaerial eruptions produce lava flows of jagged, clinkery `a`ā (stony, rough lava) or smooth, ropy pahoehoe (smooth, unbroken lava). If the flow of lava reaches the ocean, the lava is rapidly quenched by seawater and shatters, producing a steep blanket of unstable volcanic sediment that mantles the upper submarine slopes. Above sea level, the volcanoes develop the classic shield profile of gentle lava-flow slopes, whereas below sea level slopes are substantially steeper. While the volcanoes grow rapidly during the shield stage, they may also collapse catastrophically, generating giant landslides and tsunami, or fail more gradually, forming slumps (bodies of rock that incrementally move downslope over extended time periods) (Leslie et al. 2002; Eakins et al. 2003).

The youngest volcano in the Hawaiian-Emperor chain, and the probable site of an emerging island, is the underwater Loʻihi Seamount (**Figure 2-4**), found 28 km south of the Big Island, 980 m below sea level and represents the leading edge of the Hawaiian hot spot (Karl et al. 1989; Caplan-Auerbach and Duennebier 2001; Cooke 2002; Leslie et al. 2002). The largest and most southeastern island of the chain, Hawaiʻi, consists of five volcanoes: Kohala, Mauna Kea, Hualālai, Kilauea, and Mauna Loa. Three of these volcanoes, Kilauea, Mauna Loa, and Hualālai, have erupted in the past 200 years and are therefore considered active. Maui is the result of the fusion of two shield volcanoes connected by an isthmus of lava from the West Maui Mountains to Haleakalā (DoN 2002). Haleakalā, also known as East Maui volcano, is located on the eastern side Maui and last erupted 400 to 500 years ago (DoN 2001a; Rutherford and Kaye 2004). Molokini, a well known dive location located 4 km from Maui and 5.6 km from Kahoʻolawe, is the final remnant of a small, coral covered volcano. Lānaʻi is an island resultant from a single shield volcano that emerged from the sea (DoN 2002). Molokai is composed of three different extinct volcanoes: Kamakou (East Molokaʻi), Maunaloa (West Molokaʻi), and Puu Uao (the Kalaupapa peninsula), which last erupted 230,000 years ago (Rutherford and Kaye 2004).

2.3.5.2 Earthquakes

The seismic hazard and earthquake occurrence rates in Hawaiʻi are locally as high as that near the most hazardous faults elsewhere in the U.S. The area of the seismically most active regions, active volcano flanks, is comparable to the San Francisco Bay area or the Los Angeles basin in California (Klein et al. 2001).

Unlike many other regions where seismic activity accompanies movement along tectonic boundaries, volcanism is the source of energy for approximately 95% of the earthquakes on Hawaiʻi, (Okubo 1998; Fletcher et al. 2002). However, the central region, the area encompassing Maui and Oʻahu, is seismically

and volcanically much less active, and the seismicity is generally related to tectonic activity on the seafloor near the Hawaiian Islands, although the potential for volcanic-related seismicity on Maui's Haleakala Volcano is considered significant (Klein et al. 2001; Fletcher et al. 2002). The Molokaʻi Fracture Zone (**Figure 2-6**) is an extension of a transform fault from the East Pacific Rise that reaches from Molokaʻi to the Gulf of California, and is suspected to contribute to central region seismicity (Fletcher et al. 2002). In the OPAREA and vicinity the Molokaʻi Fracture Zone is characterized by a series of east to west trending ridges and troughs (Smith and Menard 1963); two known earthquakes (1871 and 1938) have occurred along the fracture (Fletcher et al. 2002). The northwestern, or Kauaʻi-Niʻihau region, has experienced tremors from earthquakes originating farther south but no known seismic activity has originated among these northern islands. The earthquake risk for the northwestern islands has been evaluated as minimal.

The island of Hawaiʻi experiences thousands of earthquakes each year (Watson 1997). Although most are too small to be noticed, several earthquakes are felt in the state annually, and minor damage resulting from a stronger shock is not an infrequent occurrence (Fletcher et al. 2002). The majority of seismicity on Hawaiʻi is related to the movement of magma within Kilauea or Mauna Loa. A few earthquakes are related to movements along fault zones located at the base of the volcanoes or deeper within the crust due to the gravitational adjustment of the volcanic edifice. Historically, southern Hawaiʻi has experienced a number of large-magnitude earthquakes, such as the Great Kaʻū Earthquake in 1868 (M = 7.8) and the Kalapana Earthquake in 1975 (M = 7.2), the largest earthquake to have been recorded instrumentally on the island of Hawaiʻi. (Hansen et al. 2004; Nettles and Ekström 2004). These two earthquakes were the most destructive recorded in Hawaiian history (Fletcher et al. 2002); the Kapalana earthquake, felt as far away as Oʻahu, generated a tsunami that inundated the Kaʻū and Puna coastlines of Hawaiʻi.

Seismicity has also long been detected in the region near Loʻihi Seamount, but this seismic activity has only been attributed to the volcano since the early 1960s (Caplan-Auerbach and Duennebier 2001). Since that time, between 2 and 10 Loʻihi earthquakes have been detected each month near the summit of the volcano by the seismic network of the Hawaiʻi Volcano Observatory (HVO) 0 to 10 km beneath the seafloor (De Carlo et al. 1983; Caplan-Auerbach and Dunnebier 2001). This background seismic activity is punctuated by periodic "earthquake swarms" in which tens to hundreds of earthquakes occur on the volcano within a few days. Since 1959, when Loʻihi earthquakes were first located by the HVO network, nine earthquake swarms have been detected; a poorly located swarm in 1952 may have been associated with Loʻihi (Klein 1982). The earthquake swarm of July/August 1996 was the largest ever recorded on Loʻihi Seamount (Caplan-Auerbach and Dunnebier 2001).

2.3.5.3 Landslides

Volcanic activity and gentle erosion are not the only forces to shape the Hawaiian Islands. Landslide debris has been mapped off of all the islands; enormous quantities of volcanic and island have traveled great distances, indicating that the slides were truly catastrophic (Paduan 2004). Landslides along the Hawaiian archipelago may occur throughout the life of an individual volcano but the largest landslides tend to occur during the shield-building stage (Leslie et al. 2002). Waiʻanae Volcano comprises the western half of Oʻahu Island; multiple collapses and deformation events during and after the shield stage created the Waiʻanae slump complex along the southwest flank of Oʻahu. This slump complex is the largest in Hawaiʻi, covering an area of approximately 5,500 km^2 (Coombs et al. 2004).

The Nuuanu and Wailau landslides ripped the volcanoes forming eastern Oʻahu and northern Molokaʻi, respectively, in half and deposited blocks offshore large enough to be considered seamounts (Paduan 2004). Tsunami generated during these slides would have been devastating to the entire Pacific Basin; the Wailau landslide, which occurred approximately 1.5 million years ago, has greatly altered the slope on the northern submarine flank of Molokaʻi, carving out submarine canyons (Clague and Moore 2002).

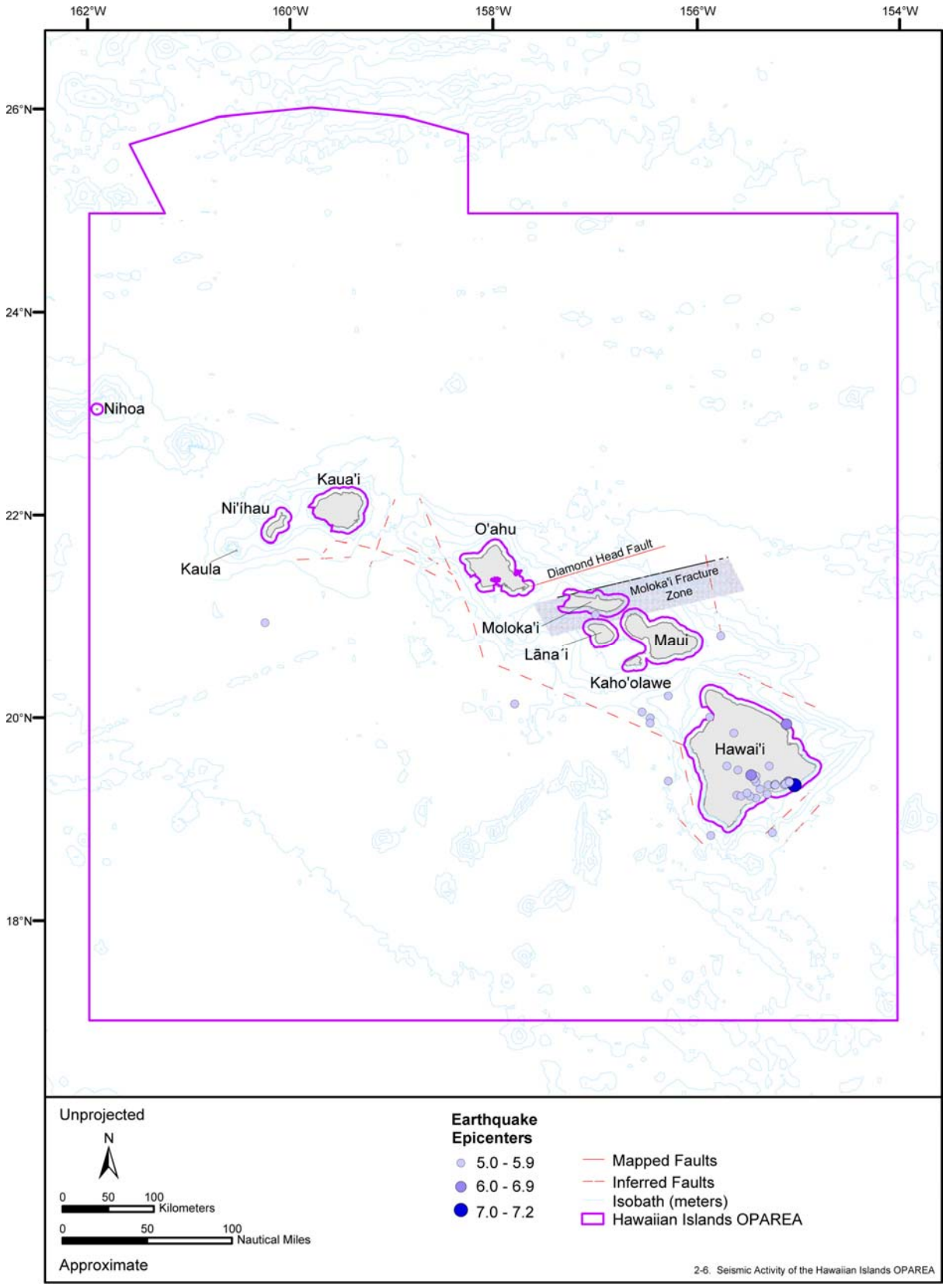


Figure 2-6. Location of seismic faults and earthquakes (Magnitude >5.0, 1973 through 2004) in the Hawaiian Islands OPAREA. Source data: USGS (2004). Map adapted from Fletcher et al. (2003).

2.3.5.4 Tsunami

A tsunami is a series of great waves most commonly caused by violent movements of the sea floor. It is characterized by high speed (up to 950 kph), long wavelengths (up to 193 km), long periods between successive crests (varying from 5 min to a few hours [generally 10 to 60 min]), and low wave amplitude in the open ocean (less than 0.3 m) (Curtis 1998; Fletcher et al. 2002; OCDA 2003). Seafloor movements that generate tsunami may include faulting, landslides, or submarine volcanic eruptions. Submarine faulting, often consisting of the vertical movement of a block of oceanic crust, creates seismic tremors and earthquakes. The resulting tsunami, then, is the result of the submarine faulting, not the earthquake generated. Landslides originating either under the sea or above sea level and sliding into the ocean may also generate a tsunami. On 9 July 1958, a massive rockslide at the head of Lituya Bay, a fjord in Alaska, produced a tsunami that surged more than 518 m up an adjacent hillside (Fletcher et al. 2002). Tsunami are also initiated by explosions or sudden seafloor movements related to submarine volcanism. For example, the violent explosion of the island volcano Krakatoa in 1883 produced tsunami waves 40 m high on the shores of Sumatra and Java, killing over 36,000 people. The high degree of volcanism and seismic instability in and around the Pacific Ocean has led to a long history of tsunami occurrences.

Tsunami waves are imperceptible in the open ocean. In deep water, a large tsunami wave may measure less than 0.3 m high, but may span 50 to 100 km (Curtis 1998). The speed at which the tsunami travels will decrease as water depth decreases. For example, since the speed of an approaching tsunami is dependent upon water depth, as depth shallows, the wavelength between crests is shortened and the energy is crowded into less area, increasing the height of the wave (Curtis 1998; OCDA 2003). A tsunami may increase in height from 1 m in the open ocean to more than 20 m during runup (the maximum vertical height of the wave in relation to sea level) (OCDA 2003).

The Hawaiian Islands OPAREA is located in one of the most geologically active regions on Earth; the region is under the continuous threat of tsunami inundation (Fletcher et al. 2002). It is thought that large tsunamis were generated from time to time during the early history of the Hawaiian Islands when massive portions of the young islands slid into the sea resulting in wave runups as high as 400 m on the island of Hawai‘i (Fletcher et al. 2002; McMurtry et al. 2004). More recently, the Hawaiian Islands have experienced 175 tsunamis from 1813 through 1988, or one tsunami per year, including several large Pacific-wide tsunamis during the 20th century (Walker 2005). The largest of these were the result of earthquakes with magnitudes of 9.6 (Chile, 1960), 9.2 (Alaska, 1964), 9.0 (Kamchatka, 1952), 8.7 (Aleutians, 1965), and 8.6 (Aleutians, 1957). For comparison, the magnitude of the Indonesian earthquake west of Sumatra producing the Asian tsunami was reported to measure 9.0 (Walker 2005). On average, the Hawaiian Islands experience a damaging tsunami occurrence every seven years, but between 1945 and 1975, seven large tsunamis impacted the Hawaiian Islands, or one every 3.3 years (OCDA 2003). Experiences with ocean-wide tsunamis in the Hawaiian Islands is limited to source areas from the circum-Pacific arc extending from Japan through Alaska and from the west coast of South America, as other regions of the Pacific have not generated significant tsunami events in the region (Walker 2005).

Despite complex differences in the geography and orientation of the many coastlines, several locations along the Hawaiian Islands have historically been subject to severe tsunami impacts, including Hilo Bay, Hawai‘i; Kahului Bay, Maui; and Kakiaka Bay, O‘ahu (Fletcher et al. 2002). Queen’s Beach on the southeastern shore of O‘ahu has also been repeatedly inundated by tsunami (1946, 1952, 1957, and 1960) and is of interest as photographic evidence of the effects of tsunami waves dates to the Aleutian tsunami of 1946. Wave runup during these tsunamis ranged from 3 and 11 m (Keating et al. 2004); however, eyewitnesses reported inundations exceeding 20 m in Kealakipapa Valley (Makapu‘u Lookout) (Keating et al. 2004). Unlike storm waves, tsunami waves may be very large in embayments, actually experiencing amplification in long funnel-shaped bays. In addition, offshore ridges may act as collecting lenses and further intensify a tsunami (OCDA 2003). Conversely, fringing and barrier reefs appear to have a mitigating influence on tsunamis by dispersing the wave energy. For example, within Kaneohe Bay, O‘ahu, which is protected by a barrier reef, the 1946 tsunami reached only 0.6 m in height, while at neighboring Mokapu Head the wave crest exceeded 6 m (Fletcher et al. 2002).

2.4 HYDROGRAPHY

Hydrography refers to the scientific study of the measurement and description of the physical features of the oceans. The following sections describe the temperature of water at the ocean surface, and the distribution of the salinity in the Hawaiian Islands OPAREA and vicinity in detail.

2.4.1 Sea Surface Temperature

In the Hawaiian Islands OPAREA and vicinity, SST has a strong gradient from the north to the south, and a small annual cycle (Flament et al. 1998; **Figure 2-7**). Mean annual temperatures in the region typically range from 24° to 28°C (Itano and Holland 2000). Lowest temperatures occur early in the year (January to March) and can dip as low as 21°C, while temperatures are at a maximum during the months of June through October reaching as high as 29°C (Miller 1994; Flament et al. 1998). Inter-island variations tend to follow the island chain with warmer temperatures occurring to the west at a given latitude (Flament et al. 1998). SST does not undergo substantial changes during El Niño and La Niña events, as temperatures do not tend to deviate from long-term means (DoD 2002).

2.4.2 Salinity

The surface salinity of the Hawaiian Islands OPAREA and vicinity reflect a balance between precipitation and evaporation in the region. The average salinity reaches a maximum of 35.2 practical salinity units (psu) at 26°N and decreases southward to 34.3 psu at 10°N as precipitation strength is increased in the vicinity of the Inter-tropical Convergence Zone (approximately 5°N in the Pacific Ocean) (Flament et al. 1998; Thurman 1997). On the leeside of the Hawaiian archipelago, and in the wake of the islands, salinities increase as more saline waters are mixed from depth (Heywood et al. 1990).

At depth, the salinity distribution reflects the sinking of water from the north. Higher salinity waters (35.2 psu) are located at 150 m depth and are traceable to high salinity surface waters north of Hawai‘i. As depth approaches 500 m, the salinity decreases to 34.1 psu and is representative of the low surface salinity waters located further to the northwest of the Hawaiian Islands. Below 500 m, the salinity gradually increases with waters overlying the abyssal plain possessing salinities of 34.7 psu (Flament et al. 1998).

2.5 PHYSICAL OCEANOGRAPHY

2.5.1 Water Masses, Currents, and Circulation

2.5.1.1 North Pacific Subtropical Gyre

The North Pacific Subtropical Gyre (NPSG), the planet’s largest circulation pattern, encompasses 2 X 10^7 km^2 of ocean and is bounded by the North Pacific Current to the north, the North Equatorial Current (NEC) to the south, the California Current to the east, and the Kuroshio Current to the west (**Figure 2-8**). The NPSG is a very old ecosystem in which the present boundaries have existed since the Pliocene (10^7 years ago) (McGowan and Walker 1985) and is considered a climax community in which the climate affects the seascape, community structure, and community dynamics of the Pacific (Karl 1999). The center of the gyre is located at approximately 20°N and tilts poleward; the Hawaiian Islands OPAREA is positioned within the NPSG to the south of the stagnation region separating the NEC from the North Pacific Current (31 to 33°N) and north of the doldrums (11 to 12°N) (Roden 1974; Karl and Lukas 1996; Itano and Holland 2000; **Figure 2-8**).

Despite being the largest contiguous ecosystem on the planet, the NPSG is remote, poorly sampled, and not well understood (Karl and Lukas 1996; Karl 1999); it is considered to be analogous to a terrestrial desert, comprised of warm (>24°C) nutrient depleted surface waters containing low standing stocks of living organisms and a persistent deep-water chlorophyll maximum (Karl et al. 1995; Karl 1999). The water column can be divided vertically into two distinct regions: a light-saturated nutrient-limited zone at

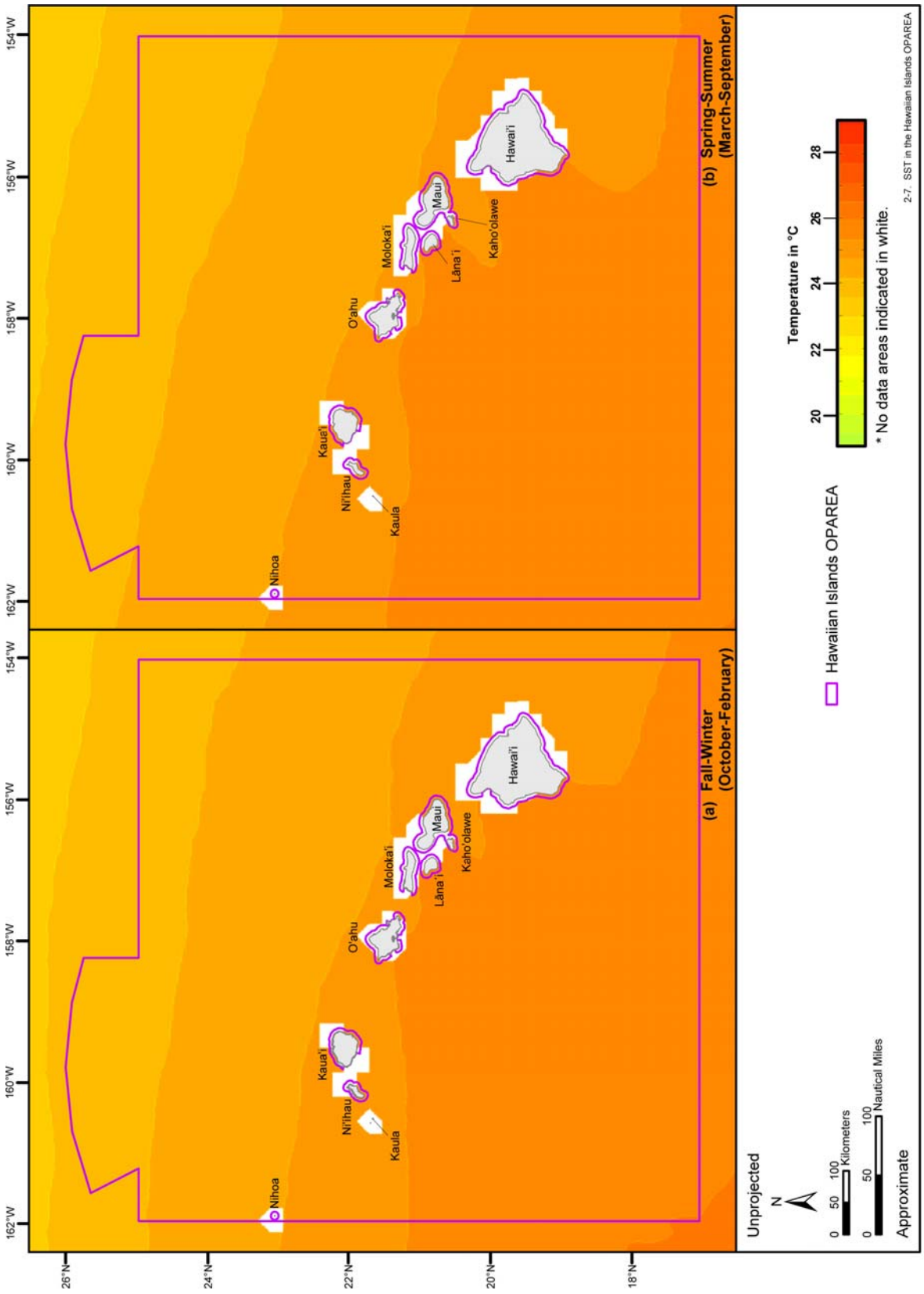


Figure 2-7. Sea surface temperature of the Hawaiian Islands OPAREA and vicinity during the a) fall/winter oceanographic season (October through February) and the b) spring/summer oceanographic season (March through September). Source data: NASA

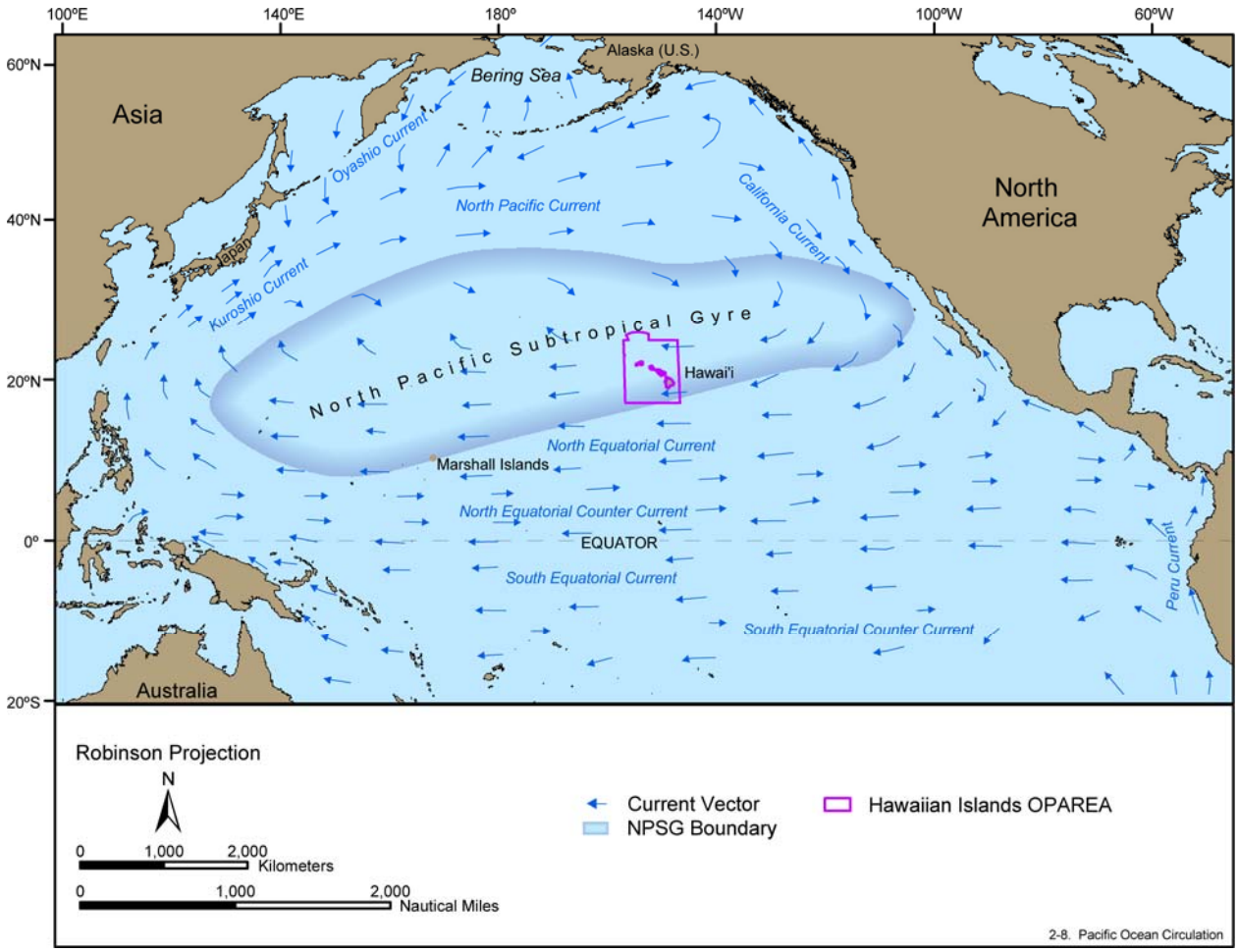


Figure 2-8. Surface circulation of the Pacific Ocean and outline of the North Pacific Subtropical Gyre (NPSG). Source information: Karl (1999). Map adapted from Pickard and Emery (1982).

the surface (0 to 70 m) and a light-limited nutrient-rich zone at depth. Surface circulation in the gyre is wind driven and the overall anti-cyclonic rotation of the NPSG restricts the exchange of water and nutrients with adjacent current systems (Karl and Lukas 1996; Karl 1999).

The NPSG is thought to be a semi-enclosed, stable, and relatively homogenous habitat undergoing weak seasonal changes (Karl and Lukas 1996); however, increasing evidence suggests that the NPSG exhibits substantial physical, chemical, and biological variability with time and space (Karl 1999). For example, regions of the NPSG show extensive mesoscale variability via the formation of discrete eddies, near-inertial motions, and internal tides (Venrick 1990). In addition, during winter months, tropical cyclones pass through the NPSG deepening the mixed layer and injecting nutrient rich water into the surface waters fueling ephemeral phytoplankton blooms (Karl 1999). Over longer time scales, the NPSG is affected by El Niño conditions. During an El Niño event, shifts occur in the circulation patterns creating weaker flow, enhanced primary production, and intense water column stratification (Karl et al. 1995). These conditions enable community shifts in the phytoplankton towards nitrogen fixing cyanobacteria (e.g., *Trichodesmium* spp.) and shift the region from a nitrogen-limited to a phosphorus-limited ecosystem (Karl et al. 1995).

2.5.1.2 Surface Currents

In the Hawaiian Islands OPAREA and vicinity, mean coastal currents are to the west at variable speeds, usually averaging less than 20 cm per second (sec) (Miller 1994; Flament et al. 1996; **Figure 2-9**). Circulation in the OPAREA and vicinity is driven by a number of forces including the tides, West Wind Drift, circulation of the Pacific Gyre, and local wind and eddy systems; circulation around the islands is dominated by eddies (Miller 1994). The high topography of the islands drastically affects both the atmospheric and oceanic flows in the region (Chavanne et al. 2002).

North Equatorial Current—The Hawaiian Islands OPAREA and vicinity are heavily influenced by the NEC which is driven by the trade winds and flows westward eventually turning to the north to form the Kuroshio current off of Japan (Pickard and Emery 1982; Jokiel and Cox 2003; **Figures 2-8** and **2-9**). East of the Hawaiian Islands, the NEC flows due west bifurcating near the island of Hawai‘i (Itano and Holland 2000). The southern portion of the NEC continues to the west to the south of the islands reaching an average velocity of 17 cm/sec at 13°N; speed decreases as the NEC approaches the islands (Flament et al. 1998; Itano and Holland 2000). The northern component of the NEC flows to the northwest, following the Hawaiian Ridge as the North Hawaiian Ridge Current (NHRC) (Qiu et al. 1997; Itano and Holland 2000). The NHRC flows along the islands with a width of 100 km at an average speed of 10 to 25 m/sec, veering westward at the northern tip of the Hawaiian Islands (Qiu et al. 1997). As the westward flowing current passes by the islands, shear force generates mesoscale eddies on the leeside of the archipelago (Wyrtiki 1982; Lukas and Santiago-Mandujano 2001; Lumpkin and Flament 2001; Seki et al. 2002).

Hawaiian Lee Counter Current—West of the Hawaiian Islands, the narrow Hawaiian Lee Counter Current (HLCC), extends from 175 to 158°W between two elongated circulations resulting from wind driven surface currents flowing between the islands and the islands blocking the flow of the NEC (Qiu et al. 1997; Itano and Holland 2000; Qiu and Durland 2002; Liu et al. 2003; Yu et al. 2003; **Figure 2-9**). Westward extent of the current is limited by eddy activity (Yu et al. 2003); a clockwise circulation centered at 19°N merges to the south with the southern branch of the NEC while a counterclockwise rotation located at 20.5°N confines the HLCC between 19 and 20°N (Flament et al. 1996; Chavanne et al. 2002; **Figure 2-9**). The HLCC flows to the east at an average speed of 15 cm/sec (Qiu and Durland 2002) and strength is strongest from summer through winter, with the weakest flow occurring in the spring (Kobashi and Kawamura 2002).

2.5.1.2.1 Pearl Harbor

Pearl Harbor, located on the southern-central side of O‘ahu is a large estuarine environment comprised of three larger lochs (East, Middle, and West) and one smaller loch (Southeast) that are separated from the open ocean by a narrow channel (Daniel 2004). Throughout Pearl Harbor a freshwater surface layer (<1.5 m) moves seaward regardless of tidal condition; this surface water flow is largely driven by the trade winds (DoN 2001b). Underlying the southward flowing surface layer a deeper layer (>1.5 m) is present; this deep layer is influenced by tidal flows and reverses direction with the ebbing and flooding tide (DoN 2001b). Pearl Harbor is isolated from oceanic circulation and water exchange in the harbor is slow; mean residence time of bottom water is approximately 6 days while surface waters remain in the harbor only 1 to 3 days (Grovhoug 1992).

Circulation in Mamala Bay, O‘ahu to the south of Pearl Harbor is complex, with substantial changes in flow occurring over short times and distances (Laws et al. 1999; Petrenko et al. 2000); however, flow is forced by the NEC to the west at all depths (Laws et al. 1999). The westward flow of the water column, combined with the large outflow of freshwater from Pearl Harbor, results in less saline water building up on the western edge of the harbor (Laws et al. 1999).

2.5.1.2.2 Eddy formation

Current flow perturbations can lead to the formation of eddies in the wake of an obstacle and have been observed on the leeside of numerous oceanic islands (e.g., Arístegui et al. 1997; Signorini et al. 1999;

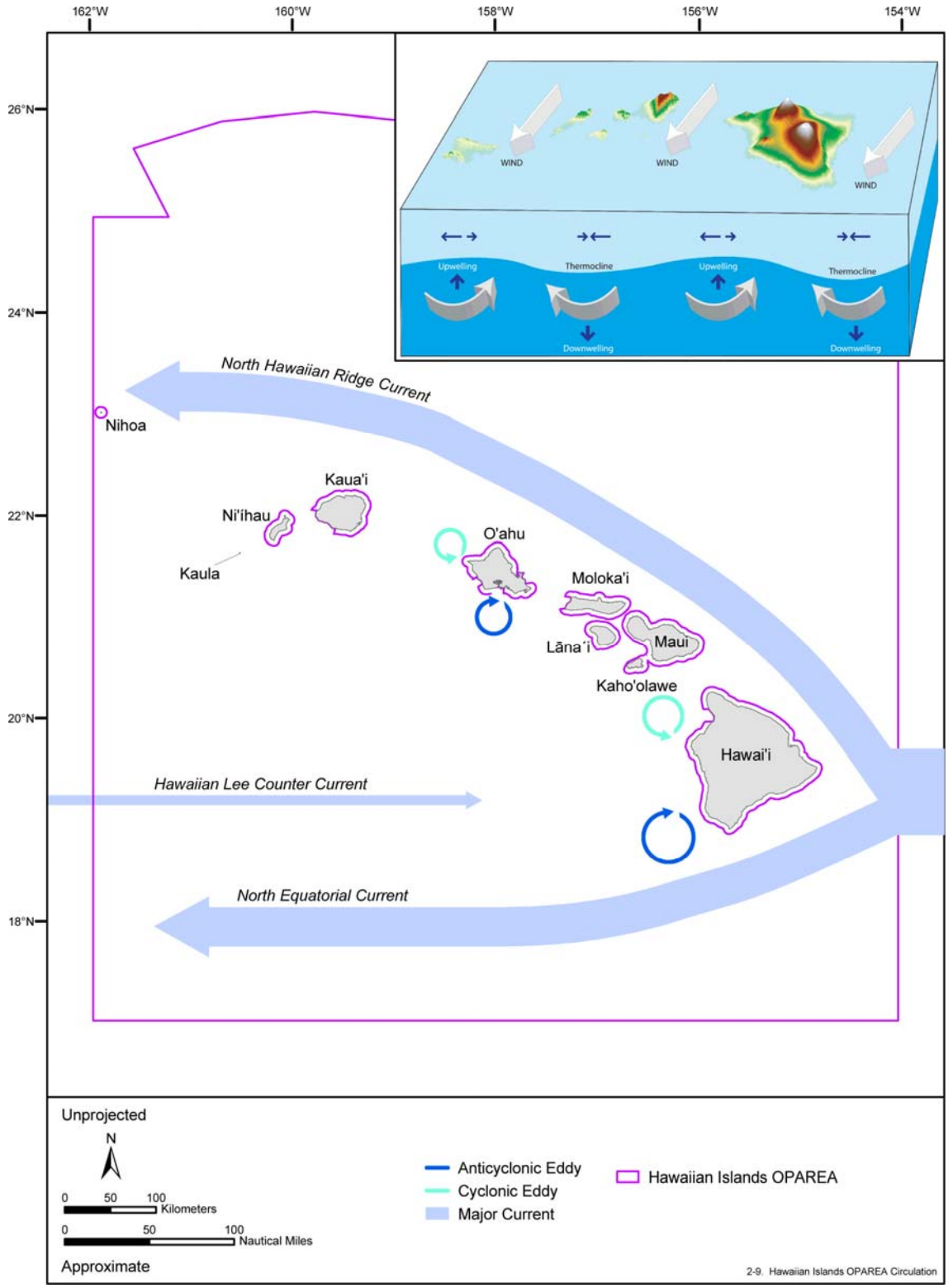


Figure 2-9. Regional surface circulation of the Hawaiian Islands OPAREA and vicinity including (a) major currents and (b) mechanisms underlying eddy formation on the leeward side of the islands. Source information: Falkowski et al. (1991), Itano and Holland (2000), Lukas and Santiago-Mandujano (2001), Seki et al. (2002), Liu et al. (2003). Map adapted from: Flament et al. (1996), Chavanne et al. (2002).

Martinez and Maamaatuaiahutapu 2004); circulation around the Hawaiian Islands are dominated by these formed eddies (Miller 1994; Arístegui et al. 1997). Energetic eddies in the Hawaiian Islands OPAREA are formed on the leeside of the islands as a result of wind stress circulation patterns (Falkowski et al. 1991; Lumpkin and Flament 2001); the eddies are shallow (upper 150 m of the water column), have diameters of 5.7 to 150 km (100 to 17,700 km^2), and have surface currents in excess of 100 cm/sec (Patzert 1969; Falkowski et al. 1991; Miller 1994; Seki et al. 2002). Eddies formed on the leeside of the islands are short-lived, lasting for 6 to 12 weeks (Falkowski et al. 1991; Seki et al. 2002); they are located close to shore (within 40 km of the shoreline) and occur throughout most of the year (Patzert 1969; Miller 1994). Eddies formed north of the midpoint of an island have a predominantly cyclonic rotation while those located off of the southern end of the islands are anticyclonic in nature. Cyclonic eddies result in either a doming of surface waters or an upwelling of nutrient-rich waters from depth; although formed off of all islands, eddies are observed predominantly off of Hawai‘i and O‘ahu and in the ‘Alenuihāhā Channel (Falkowski et al. 1991; Lukas and Santiago-Mandujano 2001; Seki et al. 2002).

2.5.1.2.3 Island wakes

As currents flow past an island or group of islands, the current eddies and slows, creating an oceanographic “wake” on the lee side of the island. Such wakes have been recognized along various islands and islands groups of the Pacific (e.g., Johnston Atoll and the Marquesas Islands) and Atlantic (e.g., Scilly Isles) and are usually limited to regions in close proximity to the islands (Barkley 1972; Simpson et al. 1982; Signorini et al. 1999; Miller and Phillips 2002). The Hawaiian Islands, however, possess an extensive wake on the leeside of the archipelago, stretching 8,000 km from Hawai‘i to Asia (JAMSTEC 2001; Miller and Phillips 2002; Hafner and Xie 2003); the Hawaiian wake is formed as the trade winds impinge on the Hawaiian Islands, creating a series of individual wakes behind each island. These individual wakes dissipate rapidly and are replaced by a broad eastward-flowing wake 300 km downwind. This wake advects warm water from the west and forms a warm-water tongue (approximately 1°C warmer than surrounding waters) that points towards the islands (JAMSTEC 2001; Miller and Phillips 2002). In addition, an atmospheric shadow forms in which the northeasterly trade winds are weaker forming a trail of clouds over the warm-water tongue (JAMSTEC 2001).

2.5.1.3 Tides

Tides are the most predictable oceanic motions; the gravitational pull of the moon (and to a lesser extent of the sun) creates "bulges" of water on opposite sides of the earth (Flament et al. 1998; Thurman 1997). Each region of the earth passes through these bulges twice a day, resulting in semi-diurnal (half daily) components to the tidal cycle. Furthermore, the moon and the sun do not generally lie over the equator; this displacement creates one tidal bulge larger than the other, thus leading to a diurnal (daily) component to the tides.

Alterations in the tidal range result from the relative position of the moon and the sun; when the moon is in new and full phases, the moon and the sun act together to produce larger "spring" tides. When the moon is in its first or last quarter, smaller than average "neap" tides occur. The cycle of spring to neap tides and back is half of the 29 day lunar cycle and is known as the fortnightly cycle (Flament et al. 1996; Flament et al. 1998). The combination of diurnal, semi-diurnal and fortnightly cycles dominates the variability in sea level throughout the Hawaiian Islands.

Tides in the Hawaiian Islands OPAREA and vicinity are relatively small, as the Hawaiian Islands are located within a few hundred kilometers of an amphidromic point (i.e., a point on the Earth around which the tides rotate). Seven such points exist in the Pacific Ocean, while four are found in each of the Atlantic and Indian Oceans. At an amphidromic point, there is essentially no tidal range, and tidal amplitudes increase with distance from these points (Thurman 1997). The Maui coast (measured at Kahana) has a mean daily tidal range of roughly 0.6 m, with minimum and maximum daily tidal ranges of 0.4 m and 1.0 m, respectively (USGS 2003). In general, the typical tidal range in the Hawaiian Islands is less than 1 m (Norcross et al. 2002). Local bathymetry of the shoreline also affects the range and phase of the tides as the tides wrap around the islands. The diurnal tide reaches the coastline of Hawai‘i first, bringing cool clear water onto the reef flat, and then sweeps across Maui, O‘ahu, and finally Kaua‘i (Flament et al.

1996; Flament et al. 1998; Storlazzi et al. 2004; **Table 2-3**). In addition, single islands are greatly affected by local bathymetry; high tide at Haleiwa on the north shore of O‘ahu occurs over an hour before high tide at Honolulu Harbor (Flament et al. 1998).

Table 2-3. Tidal Ranges and phase of the semi-diurnal and diurnal component at several coastal sea level stations in the Hawaiian Islands. * = Times are given relative to Honolulu Harbor, O‘ahu. Adapted from Flament (1996).

Location (Harbor)	Semi-diurnal Tidal Range (cm)	Semi-diurnal Tidal Phase*	Diurnal Tidal Range (cm)	Diurnal Tidal Phase*
Hilo, Hawai‘i	43.6	-1 hr 2 min	34.8	+0 hr 18 min
Kawaihae, Hawai‘i	39.4	-0 hr 11 min	32.6	-0 hr 34 min
Honolulu, O‘ahu	33.0	0	31.4	0
Kaneohe, O‘ahu	31.0	-1 hr 28 min	37.0	+1 hr 19 min
Kahului, Maui	33.0	-1 hr 40 min	35.4	+0 hr 15 min
Nawiliwili, Kaua‘i	29.8	-0 hr 28 min	31.6	+0 hr 6 min
Port Allen, Kaua‘i	29.8	-0 hr 36 min	31.8	-0 hr 31 min

2.5.1.4 Waves

High waves are common along the shorelines of the Hawaiian Islands, making the region perhaps the most popular destination for big-wave surfing in the world (OCDA 2003). Annually, waves that reach the shores of the Hawaiian Islands originate from four primary sources; north Pacific swell, northeast trade wind swell, south swell, and Kona storm swell (Fletcher et al. 2002; Rooney et al. 2003; **Figure 2-10**); hurricanes and tropical storms are also important sources of waves that impact coasts of the OPAREA on an interannual basis. The North Pacific Swell delivers the highest waves during the year with heights of 1.5 to 6.1 m and moderate to long wave periods (10 to 20 sec) due to the high intensity and proximity of subpolar and mid-latitude storms in the north Pacific (Fletcher et al. 2002; Norcross et al. 2002; Rooney et al. 2003). North Pacific swells occur throughout the year, but are most common between October and May and have the greatest impact on the north-facing coasts of the islands. The north shore of O‘ahu, famous for its large surf, directly faces the swells with the faces of some breaking waves over 15 m in height (OCDA 2003). Northeast trade wind waves range from <1 to 3.7 m in height, occur approximately 70% of the year (April to November), and can reach slightly greater heights during intense trade wind events that occur for 1 to 2 weeks each year. Trade wind waves have short wave periods (5 to 9 sec) and are only moderately energetic when they reach the shoreline (Fletcher et al. 2002; Norcross et al. 2002). Waves from South Pacific swells travel large distances and have especially long wave periods (12 to 22 sec) with moderate wave heights (0.3 to 3 m). Increased wave periods are associated with South Pacific waves; however, these swells translate into energetic waves when they arrive at Hawai‘i’s shores, especially along south-facing coastlines. South Pacific waves are most common between the months of April and October, but do occur throughout the year. Waves generated from Kona storms are steep, with moderate heights (3 to 6 m) and short to moderate periods (6 to 10 sec); Kona storm waves have the greatest impact on south- and west-facing coasts (Fletcher et al. 2002; Rooney et al. 2003). Waves from hurricanes and tropical storms (June to November) can reach extreme heights (4.6 to 10.7 m) and tend to occur on east-, south-, and west-facing coastlines; however, occasionally north-facing shores are impacted (Fletcher et al. 2002; OCDA 2003).

Offshore, the seas are generally rough, with significant wave heights of 1 to 4 m, but these waves vary seasonally corresponding to the strength of the trade winds (Flament et al. 1998). In the channels located between the islands, winds are funneled and the seas are intensified. The leeside of the islands are

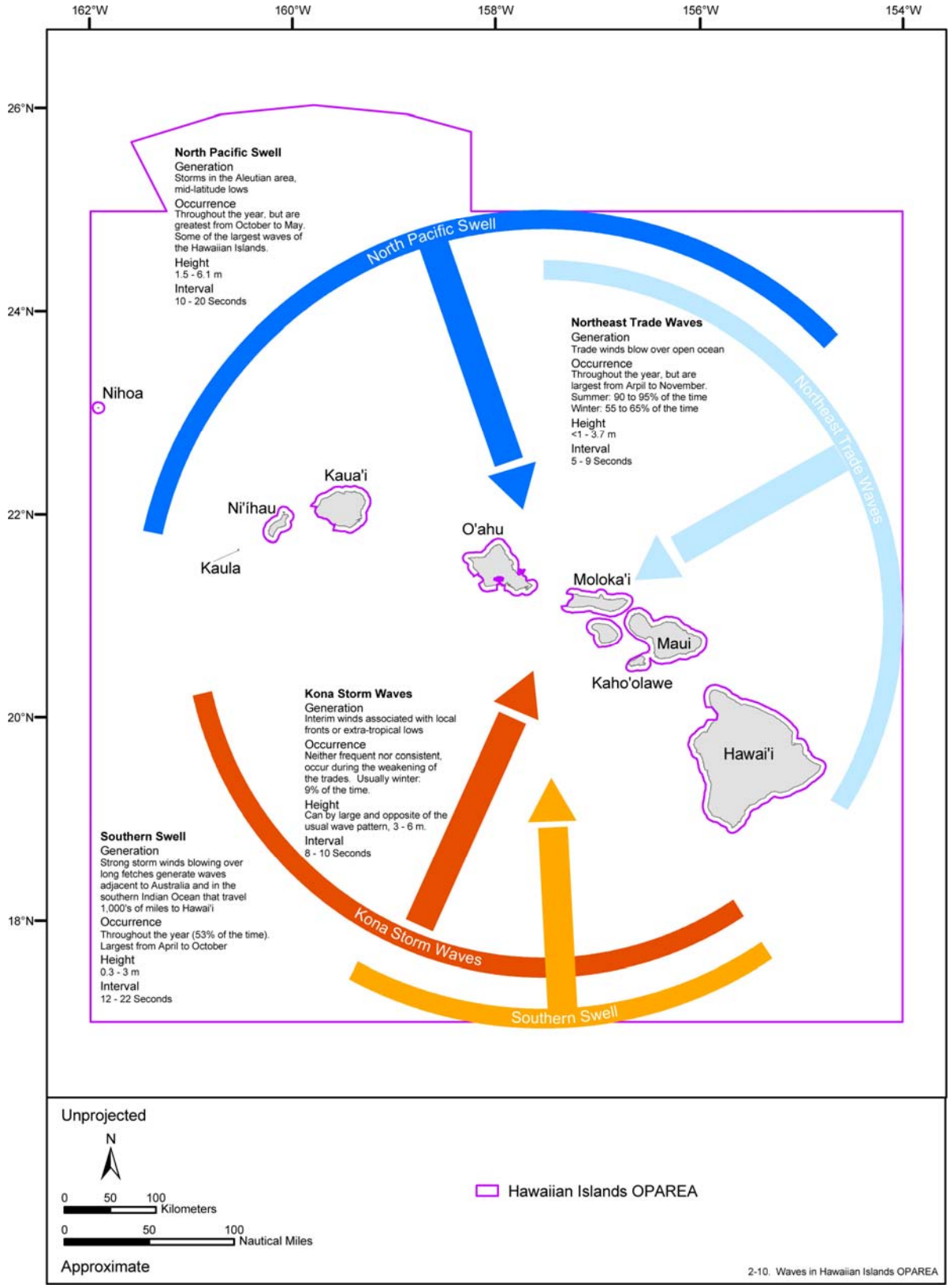


Figure 2-10. Major wave patterns and their corresponding physical properties that impinge on the Hawaiian Islands. Source information: Norcross et al. (2002), Rooney et al. (2003). Map adapted from: Fletcher et al. (2002).

generally sheltered from the winds resulting in calmer seas; however, during winter months, winds can shift to the northwest or southwest creating unusual sea conditions (Flament et al. 1996).

2.5.1.5 Thermocline

Near the surface, the islands of the Hawaiian Islands OPAREA interact directly with the wind-driven subtropical gyre creating a well-mixed surface layer with uniform properties (Flament et al. 1998; Qiu et al. 1997). The depth of this turbulent area varies from 120 m in the winter to less than 30 m in the summer; stratification of the water column is weakest in the winter and strongest in the summer (Miller 1994; Flament et al. 1996). Below the mixed layer, there is a sharp decrease in temperature (from 25°C at the surface to 5°C at 700 m), with the main thermocline occurring at a depth of 300 to 400 m around the Hawaiian Ridge (Flament et al. 1996; Karl and Lukas 1996; Qiu et al. 1997). Below the thermocline, temperatures decrease more gradually, achieving a temperature of 1.5°C at the ocean floor (Flament et al. 1996; Flament et al. 1998).

2.5.1.6 Deepwater Currents/Water Masses

At depth in the Hawaiian Islands OPAREA and vicinity, the water column is composed of three main water masses: North Pacific Central Water (NPCW), North Pacific Intermediate Water (NPIW), and Pacific Deep Water (PDW). Together, these water masses extend from a depth of 100 m to the ocean floor; below a depth of 2,000 m the Hawaiian Ridge forms a nearly continuous mid-Pacific barrier and exerts a dramatic influence over oceanic current patterns in the region (Miller 1994; Itano and Holland 2000).

North Pacific Central Water—NPCW, also known as North Pacific Tropical Water, is the shallowest of the deep-water masses, extending from 100 to 300 m depth. It is characterized as a subsurface salinity maximum (34.2 to 35.2 psu) that flows within the NEC (Miller 1994; Suga et al. 2000). This water originates from the zone of highest sea surface salinity (Tropic of Cancer, 20 to 30°N) centered on the international dateline and spreads along isopycnal geostrophic flow patterns (Suga et al. 2000). The high salinity and temperature (10° to 18°C) combine to make this water mass the least dense of subsurface water masses of the region (Miller 1994).

North Pacific Intermediate Water—NPIW is located beneath the NPCW at a depth ranging from 300 to 1,500 m and is recognized as the salinity minimum in the water column (Talley 1993). The water in this region is formed in the northwestern Pacific subtropical gyre off of northern Japan between the Kuroshio extension and Oyashio front and is composed of colder (5° to 10°C), less saline (34.2 to 34.5 psu) waters than the NPCW (Talley 1993; Miller 1994; Talley 1997; Yasuda 1997).

Pacific Deep Water—PDW is a mixture of North Atlantic Deep Water and Antarctic Bottom Water (Thurman 1997); it is the deepest of the water masses occurring in the Hawaiian Islands OPAREA and vicinity, extending from 1,500 m depth to the ocean floor. Temperatures range from 1.1° to 2°C with a salinity of 346 to 34.7 psu (Miller 1994). PDW flows northward from the Antarctic, and then westward to the south of the Hawaiian Islands (0.5 cm/sec), eventually reaching the western equatorial Pacific (Thurman 1997; Siedler et al. 2004).

2.5.1.7 Upwelling

Upwelling is a wind driven, dynamic process that brings nutrient-rich deep water to the surface through the interaction of currents, density, or bathymetry (Mann and Lazier 1991). In wind driven upwelling, surface waters are transported perpendicular to the direction of the wind. Deep, cold water moves vertically into the euphotic zone to replace the displaced nutrient-poor surface water causing appreciable increases in the concentration of phytoplankton (Johnston and Santillo 2004).

Regions of enhanced chl *a* levels surrounding the islands are not completely understood but are likely a product of the island mass interacting with currents. Currents passing by the islands or through channels in island chains have been observed to create turbulent conditions, bringing more nutrient rich waters to

the surface in the Hawaiian Islands (Doty and Oguri 1956; Gilmartin and Revelante 1974; Seki et al. 2002), the Scilly Isles of the Celtic Sea (Simpson et al. 1982), the Marquesas Islands (Signorini et al. 1999; Martinez and Maamaatuaiahutapu 2004), the Galapagos Islands (Feldman et al. 1984), and Johnston's Atoll (Barkley 1972). In addition, the formation of cyclonic eddies off the islands in the OPAREA results in Ekman pumping and the upwelling of nutrient-rich waters to the surface, stimulating primary production in local surface waters (Karl and Lukas 1996; Vaillancourt et al. 2003).

2.6 BIOLOGICAL OCEANOGRAPHY

2.6.1 Primary Production

Primary production is a rate at which the biomass of organisms changes and is defined as the amount of carbon fixed by organisms in a fixed volume of water through the synthesis of organic matter using energy derived from solar radiation or chemical reactions (Thurman 1997). The major process through which primary production occurs is photosynthesis. The intensity and quality of light, the availability of nutrients, and seawater temperature all influence primary productivity as generated through photosynthesis (Valiela 1995). However, with the knowledge that chemosynthesis, another form of primary production, occurs among hydrothermal vent and whale fall communities (such as those occurring in the Hawaiian Islands OPAREA), and it will also be discussed in this section.

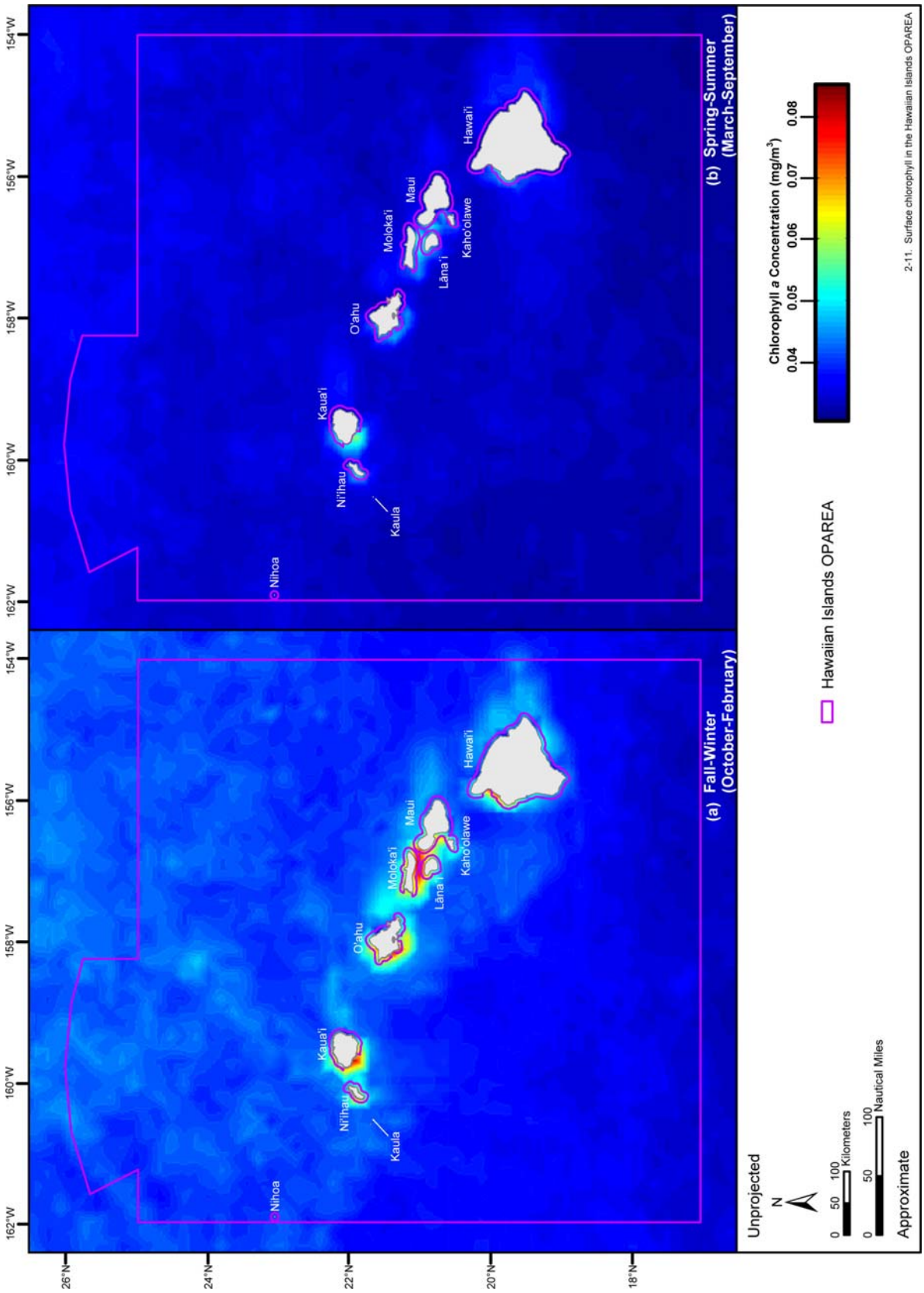
2.6.1.1 Photosynthesis

Photosynthesis is a chemical reaction that converts solar energy from the sun into chemical energy stored within organic molecules by combining water, carbon dioxide, and light energy to form sugar and oxygen. In the oceanic system, the majority of photosynthesis is carried out by phytoplankton utilizing a suite of light harvesting compounds to convert solar energy into chemical energy, the most common being chl *a* (Thurman 1997). Rates of photosynthetic production can vary from between less than 0.1 gram (g) of carbon (C) per square meter (m^2) per day (d) in oligotrophic regions, such as the western equatorial Pacific, to more than 10 $gC/m^2/d$ in highly productive areas (Thurman 1997). Primary production in the Hawaiian Islands OPAREA and vicinity has been estimated at 0.5 $gC/m^2/d$, and is representative of an oligotrophic gyre (Bienfang and Szyper 1981; Ondrusek et al. 2001; **Figure 2-11**).

2.6.1.1.1 Phytoplankton

Approximately half of all primary production is supported by oceanic phytoplankton located within subtropical gyres (Falkowski 1994; Karl 1999); however, standing stocks of phytoplankton biomass (concentrations of chl *a*) in the Hawaiian Islands OPAREA are low, with the majority of the chl *a* located beneath the surface (Bienfang and Szyper 1981; NASA 1998; Karl 1999; Ondrusek et al. 2001). Phytoplankton communities in the region are dominated by small nanoplankton and picoplankton that contribute substantially to the overall productivity (Karl 1999; Higgins and Mackey 2000). Based on the abundance of class-specific photosynthetic pigments and direct electron microscopic observations of water samples collected from Hawaiian waters, the majority of the phytoplankton community is composed of small organisms (Bienfang and Szyper 1981); *Prochlorococcus*-like microorganisms constitute approximately 50% of total chl *a* while another prokaryote, *Synechococcus*, and two picoeukaryotic algal groups, prymnesiophytes and pelagophytes, accounted for the majority of the remainder of the standing stock of phototrophic cells (Andersen et al. 1996). Cells larger than 8 microns (µm) (for example, diatoms and dinoflagellates) were rare; nevertheless, under certain conditions these larger species of *Eukarya* can be abundant in the NPSG, especially when nutrient-rich water is injected into the surface waters from below (e.g., summer) (Scharek et al. 1999; Ondrusek et al. 2001).

Phytoplankton biomass tends to accumulate in the wakes of islands due to an increase of turbulent mixing and the advection of iron-rich waters to the area (Feldman et al. 1984; Dandonneau and Charpy 1985; Heywood et al. 1990; Signorini et al. 1999). As currents pass by the islands, cyclonic eddies are formed off the northern coastlines of the islands, displacing the nutricline, creating biologically enhanced patches, and stimulating primary production by as much as 20% (Falkowski et al. 1991; Seki et al. 2002; Vaillancourt et al. 2003).



2-11. Surface chlorophyll in the Hawaiian Islands OPAREA

Figure 2-11. Seasonal distribution of chlorophyll throughout the Hawaiian Islands OPAREA and vicinity during the a) fall/winter (October through February) and the b) spring/summer (March through September). Source data: NASA (1998).

El Niño results in an increase in primary production due to a community shift towards nitrogen-fixing cyanobacteria such as *Trichodesmium* spp., shifting the region from primarily nitrogen-limited to a phosphorus-limited habitat (Karl et al. 1995). Over decadal scales, the region off of Hawai'i has experienced a doubling of local chl *a* concentrations and primary production during the past three decades (Venrick 1997; Karl et al. 2001). This increase in chl *a* has been accompanied by a shift in phytoplankton community structure to one dominated by prokaryotes (e.g., *Prochlorococcus* sp.) (Karl et al. 2001).

2.6.1.2 Chemosynthesis

Another potentially significant source of biological productivity does not occur in the light of the surface, but rather at great depths within the ocean. In some locations, including the Hawaiian Islands OPAREA, hydrothermal springs and whale falls can support vast benthic communities (Karl et al. 1989; Moyer et al. 1998). It has been estimated that at any given time there may be in excess of 500,000 sulfide-rich whale skeletons on the deep-sea floor (Smith and Baco 2003). Many organisms live in association with bacteria capable of deriving energy from hydrogen sulfide that is dissolved in the hydrothermal vent fluid or supplied by the decaying whale carcasses of whales (Thurman 1997). Since these bacteria are dependant upon the release of chemical energy, the mechanism responsible for this production is called chemosynthesis. Little is known regarding the significance of bacterial productivity on the ocean floor on a global scale. Hydrothermal indicators, vents, and whale falls and their associated communities are described in further detail in subsequent sections.

2.6.2 Secondary Production

Secondary production refers to the production (change in biomass) of organisms that consume primary producers (i.e., the production of bacteria and animals through heterotrophic processes) (Scavia 1988; Strayer 1988; Karl 1999). Detailed descriptions of protected species including marine mammals and sea turtles, as well as species such as corals and seagrasses are found in later sections of this chapter or later chapters of this MRA. In this section, marine zooplankton are discussed.

2.6.2.1 Zooplankton

Because very small phytoplankton are dominant in the tropical and subtropical oligotrophic oceans, including the Hawaiian Islands OPAREA and vicinity, animals in the mesozooplankton size range (0.2 to 20 mm) cannot compete effectively with small protists as major consumers of primary production (Sieburth et al. 1978; Landry et al. 2001). However, the flow of materials through the mesozooplankton is disproportionately important in supporting higher tropic levels and pelagic fisheries; net samples of mesozooplankton have been collected offshore of the Hawaiian Islands routinely since 1994 (Landry et al. 2001). Zooplankton communities in the region exhibit remarkable diversity and consistency relative to other ecosystems (McGowan and Williams 1973; McGowan and Hayward 1978; McGowan and Walker 1979, 1985); copepods dominate the mesozooplankton in the region accounting for 77 to 80% of the community due largely to the abundance in smaller size fractions (Landry et al. 2001). McGowan and Walker (1979) have provided the most detailed analysis of copepod taxonomic diversity in the region (67 species and 12 multi-species groups). The larger size fractions (>2 mm) are dominated by chaetognaths (38 to 40%) and other crustaceans (34 to 47%) (Landry et al. 2001).

Seasonal variability of zooplankton in the region is not well understood, as some researchers have commented upon an overall lack of a seasonal signal (Hayward et al. 1983; Hayward and McGowan 1985) while others have reported a peak in mesozooplankton abundance and biomass during the summer months corresponding to an increase in nitrogen-fixing organisms (Rodriguez and Mullin 1986; Landry et al. 2001; Sheridan and Landry 2004). Mesozooplankton in the region has also increased at a rate of 45 to 60 milligrams per square meters per year ($mg/m^2/yr$) since 1994, consistent with the observed decadal-scale increase in phytoplankton chl *a* (Landry et al. 2001; Sheridan and Landry 2004). Increased nitrogen fixation could provide the new nutrients to support the increased productivity and enhanced zooplankton standing stocks (Landry et al. 2001; Sheridan and Landry 2004).

Climate forcings from El Niño events may have influenced general ecosystem productivity and zooplankton biomass in the Hawaiian Islands OPAREA and vicinity. However, it is difficult to evaluate the effect of climate cycles in the region (Sheridan and Landry 2004). The central position of mesozooplankton in the local food web makes them potentially vulnerable to ecological perturbations of both higher trophic levels and those passed up the food chain via climatic influences regulating nutrient fluxes; mesozooplankton are an important piece in resolving the long-term shifts in community composition and structure (Landry et al. 2001; Sheridan and Landry 2004).

2.7 HABITAT

Marine ecosystems in Hawaiian waters are diverse and extensive; they extend offshore to a depth of 5,000 m and inland to include coastal marine anchialine ponds (Maragos 1998). The Hawaiian Islands have three distinct types of volcanic islands: young (the largest), mature, and drowned (atolls and seamounts). The distribution of marine ecosystems is determined by island age, reef growth, wave exposure, depth (which affects light and temperature), and latitude. This dynamic geology yields a diverse array of habitats; most harbor large communities of macroflora, corals, invertebrates, and pelagic life. Anchialine ponds and tidepools occur on rocky shorelines; small beaches occur around bays and coves (Maragos 1998). Mature volcanic islands have undergone extensive weathering and erosion and typically have eroded slopes, broad, gently sloping coastal plains, numerous streams and estuaries, sandy beaches, fringing reefs, and, occasionally, barrier reefs. Lagoons provide protected environments for the development of unique coral “patch” and “pinnacle” reefs (Maragos 1998). Rocky beaches are also present, especially along the north and south coasts that experience heavy wave exposure; seagrasses, mangroves (introduced flora), and coral reef flats are common in the nearshore waters of protected shorelines. Eventually the Hawaiian Islands will subside and in some cases an atoll will form from surrounding corals that grow fast enough to compensate for the rate of sinking. An atoll reef, the coastal perimeter of a drowned volcanic island, encloses protected waters to form a lagoon that is connected to the open ocean by passes cut through the reef. Sometimes benches are present and reef flats are very common. Guyots (sunken atolls that become flat-topped seamounts) and other seamounts provide important habitat for fisheries and precious corals (Maragos 1998). As these ancient islands moved to the northwest, the spores of marine plants and larvae of corals, fishes, and other marine animals drifted to colonize the younger islands. This process fostered the evolution of marine species in the region over millions of years. The Hawaiian Islands has the highest reported endemism among marine ecosystems from any tropical archipelago in the Pacific and perhaps in the world (Maragos 1998).

2.7.1 Marine and Estuarine Wetlands

Wetlands can be subdivided into five major systems: marine, estuarine, riverine, lacustrine (lake), and palustrine (freshwater marsh) (Cowardin et al. 1979). Of these five major categories, only the marine and estuarine systems are relevant to the Hawaiian Islands OPAREA. These areas are subject to tidal influence, characterized by strong salinity gradients, and include tidal salt marshes, mudflats, salt flats, mangroves, seagrass beds, and coastal lagoons (MMS 2001). For all marine and estuarine wetlands, salinity varies with season, time, precipitation, location, and water depth. The USFWS defines wetlands as having one or more of three attributes: 1) the area supports predominantly hydrophytes, at least periodically; 2) the substrate is predominantly undrained hydric soil; and 3) the substrate is nonsoil and is saturated with water or submerged by shallow water at some time during the growing season of each year (Cowardin et al. 1979).

Wetlands form the transition zone between terrestrial and marine systems; because of this, they help to prevent shoreline erosion, reduce flood damage, and improve water quality (Carlisle et al. 2002). For example, pollutants from terrestrial runoff are filtered through wetlands where 1) particulates settle to the substrate; 2) excessive nutrients (i.e., the nitrogen and phosphorous found in fertilizers) are taken-up by vegetation and microorganisms (Bertness 1999); 3) contaminants are bound and broken down; 4) excess carbon from the burning of fossil fuels is absorbed; and 5) nitrogen and sulfur are re-cycled (Mendelssohn 1979). In addition, estuarine and marine wetlands are among the most productive natural systems on earth, capable of producing more food per acre than the richest farmland (RAE/ERF 1999). They support essential habitat for 80% of the world’s fish and shellfish species and provide feeding, nesting, shelter,

high tide refuge, spawning grounds, nursery habitat, and other benefits for thousands of commercially and recreationally important fish, birds, mammals, and invertebrates. Per unit surface area, wetlands are more diverse than any other marine habitat (Bertness 1999).

The tidal range in the Hawaiian Islands is less than 1 m (Maragos 1998) creating a narrow nearshore environment in most areas. However, due to the variability within the habitats, biodiversity is high throughout the nearshore zone (Thurman 1997). Three types of marine and estuarine wetlands occur in the MHI: a large embayment at Pearl Harbor, Oʻahu; stream mouths on all major islands; and locations of coastal groundwater discharge such as those surrounding Hawaiʻi (Maragos 1998). Wetlands are generally confined to portions of the higher islands with floodplains or coastal plains (Meier et al. 1993). The floors of embayments and stream-mouth estuaries are sediment covered; groundwater estuaries are sometimes rocky. Over 450 significant wetlands have been identified throughout the islands (Meier et al. 1993). Marine and estuarine wetland environments located within the Hawaiian Islands OPAREA and vicinity include fishpond and harbor, lagoon, seagrass, mangrove, mudflat, and rocky and sandy intertidal habitats (**Figure 2-12**). Within the Hawaiian Islands OPAREA, there are two areas of important marine and estuarine wetlands, mangrove, and mudflat habitats: Mamala Bay and Pearl Harbor on the south coast of Oʻahu and Kāneʻohe Bay on the northern coast of Oʻahu. Further discussion of these habitats can be found within this chapter.

Prior to human intervention in the Hawaiian Islands, marine and estuarine wetlands had few species of vascular plants. Seagrasses, *Ruppia maritima* and *Halophilia hawaiiana*, could be found subtidally and herbaceous plants such as *Susuvium portulacastrum*, *Heliotropium curassacvicum*, and *Lycium sandwicense* occurred in the upper intertidal zone; the bulk of the intertidal zone was primarily inhabited by algal and fungi flora. These historic marine and estuarine wetlands have since been heavily modified (Allen 1998). Presently, common animals that occur in the Hawaiian Islands marine and estuarine wetland habitats include crabs, shrimps, mollusks, mullets (*Mugil*), endemic flagtails, *āhelehole* (*Kuhlia sandwichensis*), anchovies, small jacks, barracudas, and eels (Maragos 1998). Some juvenile jacks, *Caranx ignobilis* and *Caranax melampygus* (which supported a fishery value of $14,400 in 1998), occupy estuarine wetlands opportunistically before moving to nearshore marine wetlands (Smith and Parrish 2002). Five endemic and endangered species of waterbirds including the Hawaiian Stilt or *āeʻo* (*Himantopus mexicanus knudseni*), Hawaiian duck or *koloa* (*Anas wyvilliana*), Laysan duck (*Anas laysanensis*), Hawaiian Gallinule (*Gallinula chloropus sandvicensis*), and Hawaiian Coot (*Fulica americana alai*) rely heavily on marine and estuarine wetlands for foraging, nesting, and resting (Maragos 1998, 2000).

In the Hawaiian Islands, wetland loss has occurred via many different means. Many low-lying coastal marshes were walled and modified to create ponds called loʻi for taro cultivation (Meier et al. 1993). During the previous century, sugar cane and pineapple agriculture caused many coastal ponds and marshes to be buried or drained. Coastal wetlands were filled for ranching and livestock that in turn increased soil erosion (Meier et al. 1993). In addition, rice farming, harbor and port construction, housing and civil works projects, and stream diversion has resulted in a major loss or modification of wetland habitat (Meier et al. 1993).

In the State of Hawaiʻi, wetlands are managed by one federal, several state, and two county agencies. The USFWS is responsible for National Wildlife Refuges (NWR) while the Department of Land and Natural Resources is responsible for state refuges including wetlands and Natural Area Reserves (Meier et al. 1993). For additional information regarding marine and coastal protected areas in the Hawaiian Islands OPAREA refer to Chapter 5 in this document.

- Mamala Bay—Mamala Bay is a coastal indentation extending a distance of approximately 30 km along the southern shoreline of Oʻahu in the Hawaiian Islands, from Diamond Head in the east to Barbers Point in the west (Laws et al. 1999). Maintenance of high water quality is a particularly sensitive issue in an area such as Mamala Bay, with currently receives wastewater in the form of primary treated sewage from a population of roughly 750,000 persons (Laws et al. 1999). Mamala Bay and its tributaries receive 100 to 300 x 10^6 cubic meters per year (m^3/yr) of land

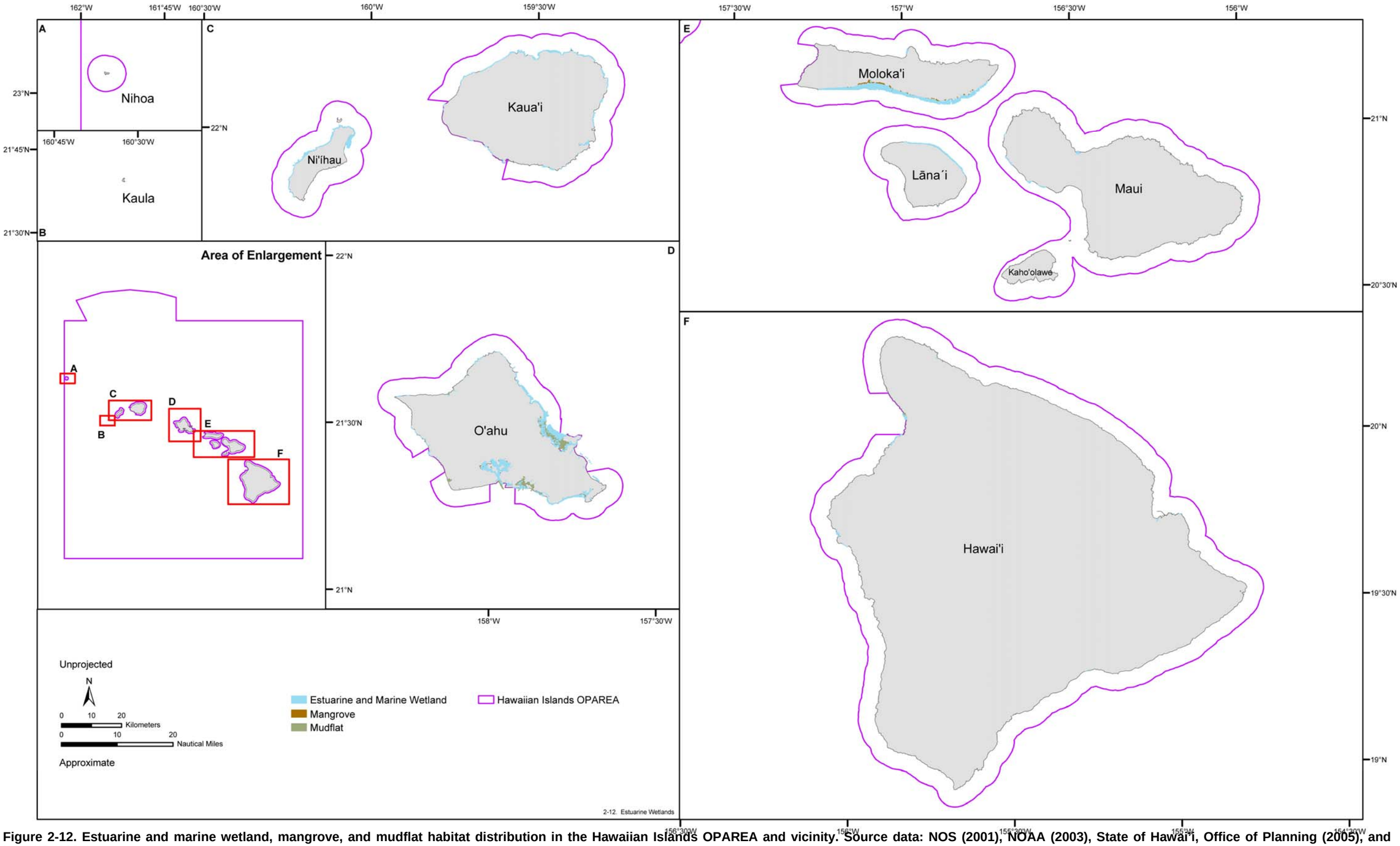


Figure 2-12. Estuarine and marine wetland, mangrove, and mudflat habitat distribution in the Hawaiian Islands OPAREA and vicinity. Source data: NOS (2001), NOAA (2003), State of Hawai'i, Office of Planning (2005), and USFWS (2005).

runoff/groundwater seepage and 150 x 10^6 m^3/yr of treated sewage effluent (Laws et al. 1999). However, water quality in the bay is good because nonpoint source discharge enters either estuaries or harbors which function as buffer zones. Also, the principal point source discharges are located in deep water and the coastal current system has a strong exchange with the offshore ocean (Laws et al. 1999).

- Kāneʻohe Bay—Kāneʻohe Bay is located on windward Oʻahu; ten major named stream systems empty into the bay encompassing a watershed approximately 10,300 hectare (ha) in size (Englund et al. 2003). The Kāneʻohe Bay ecosystem consists of the watershed, the bay itself, the protecting barrier reef, and the nearshore oceanic environment. The three major physiographic marine zones of Kāneʻohe Bay are the inshore, inner bay, and outer bay. The inshore zone consists of the intertidal zone along the shoreline and the fringing reef. The inner bay zone consists of the lagoon and patch reefs; the lagoon is generally divided into southeast, central, and northwest sectors. The outer bay consists primarily of the barrier reef complex and the two channels bisecting the reef. The offshore portion comprises 34% of the total Bay area. It consists almost entirely of an extensive shallow coral and sand reef 0.3 to 1.2 m in depth. In the central section, live coral, small-sized coral rubble, coarse coral sand, and volcanic rock are found (Englund et al. 2003).

  Kāneʻohe Bay offers a diverse array of habitats for marine organisms, ranging from inter-tidal to deep-sea within only a few kilometers. Although natural shoreline areas consisting of beaches, stream mouth deltas, and promontories are still found along Kāneʻohe Bay, much of the bay's shoreline has been heavily modified. Agriculture, urbanization, and streambed channels have increased freshwater runoff rates causing sedimentation and pollution; the introduction of mangroves has also modified the shoreline environment.

  Benthic habitats in Kāneʻohe Bay are found in upper, middle, and lower intertidal zones along the coast. Shorelines have small sandy beaches, rocky shores, mud flats, and mangrove swamps, and many of these areas are affected by estuarine conditions (Englund et al. 2003). In the subtidal regions of the bay, organisms live on live coral reefs as well as in dead coral and coral rubble areas. Sandy and muddy areas of the lagoon floor along with hardbottom areas of limestone and lithified sand dunes in the bay also provide habitats with organisms living both in as well as on top of the bottom substrates. Sand dwellers (e.g., acorn worms, auger shells, box crabs, alpheid shrimp, the lampshell, and clams) frequently burrow into the substrate (Englund et al. 2003). *Halophila* or turtle grass is also found growing in sandy areas, especially on parts of the sand bar. The commercially valuable black-lipped pearl oyster (*Pinctada margaritifera*), once abundant in Kāneʻohe Bay, is now protected from harvest (Englund et al. 2003). *Lingula reevii*, a brachiopod endemic to the Hawaiian Islands, is literally a living fossil remaining essentially unmodified for 350 to 400 million years (Emig 1987). *Eucheuma spinosum* or tambalang, a red alga, and *Opheodesoma spectabilis*, a giant non-burrowing sea cucumber, are found almost exclusively in Kāneʻohe Bay (Englund et al. 2003).

  The interrelated influences of tides, circulation, bathymetry, wave action, and water quality produce an infinitely varied set of vertically and horizontally arranged habitats. Vertical and horizontal distribution of marine organisms reflects corresponding changes in the environment. Pelagic organisms in Kāneʻohe Bay include large fish such as ulua and papio, aku, hammerhead sharks, halfbeak and needlenose fish, Hawaiian green sea turtles, and occasionally Pacific bottlenose dolphins. Kāneʻohe Bay is also a pupping ground for the scalloped hammerhead shark, *Sphyrna zygaena* or mano kihikihi (Clarke 1971).

  Offshore and oceanic waters outside of Kāneʻohe Bay support large schools of aku and mahi mahi; occasionally humpback whales are seen during winter months. The first specimen of a previously unknown shark, "Megamouth", was also captured offshore of Kāneʻohe Bay at a depth of approximately 150 m (Englund et al. 2003).

2.7.1.1 Fishponds and Harbors

Fishponds are ancient structures that still exist along many of the island shorelines (**Figure 2-13**). These structures were typically built in embayments, on reef flats, or over submarine springs. Fishponds allow fish to become trapped while at the same time tidal flows replenish nutrients through gates in fishpond walls (Maragos 1998). Fishponds are significant natural resources that provide nurseries for fish stocks nd foraging areas for endangered waterbirds. Fishponds are currently being overgrown by invasive mangroves; their root systems are gradually destroying the walls of the ancient structures (DoN 2001c). Similar to fishponds, harbors are generally constructed in areas sheltered from strong waves. Harbors attract fish, sediment-adapted biota, and rocky intertidal organisms (Maragos 1998). Plants commonly found in fishpond and harbor habitats include rock-dwelling algae and *limu* (seaweeds); animals commonly found in fishpond and harbor habitats include mullet, *moi*, anchovies, crabs, shrimps, clams, and oysters (Maragos 1998). Within the Hawaiian Islands OPAREA there are numerous fishponds located in Mamala Bay and Pearl Harbor on the southern coast of Oʻahu, five on the northern coast of Oʻahu in and around Kāneʻohe Bay, and three on the southwestern coast of Kauaʻi (**Figure 2-13**).

- Pearl Harbor—Pearl Harbor is a type C estuary, with an area of 20.1 km^2 and a mean tidal range of 0.37 m (Laws et al. 1999). There are a total of 187.7 ha of wetlands in the Pearl Harbor area (DoN 2001b). The wetlands provide a variety of vital functions in the natural environment, including endangered waterbird habitat, juvenile fish habitat, natural treatment/purification of upland runoff, wetland agriculture, and important cultural and aesthetic value (DoN 2001b). Pearl Harbor encompasses approximately 2,024 ha of permanently submerged soft sea floor habitat (e.g., mud and sand) that acts as a sink or repository for chemicals entering the harbor (DoN 2001b). As an estuary, Pearl Harbor has received pollutant inputs from many sources over the years, including industrial, urban, and agricultural activities in surrounding lands, thermal, and sewage discharges. Most of the pollutants are sequestered in the bottom sediments, which are also the natural habitat for many types of marine life. Among the many fishponds in the Hawaiian Islands, there are four significant Hawaiian fishponds located within the Pearl Harbor region: Loko Laulaunui, Loko Paʻaiau, Loko Okiʻokiolepe, and Loko Pamoku (DoN 2001b). However, due to existing contamination of harbor sediments, fish consumption is not appropriate in these fishponds.

  Wetland areas adjacent to Pearl Harbor include mudflats, shallow ponds, small streams, pickleweed beds, kiawe forests, cattails, and watercress; these wetlands provide habitat for waterbirds including the endangered Black-necked Stilt, Hawaiian Coot, Common Moorhen, and Hawaiian Duck. Wetlands along the coastline also provide a nursery for a number of fish species that utilize the brackish water areas during their life cycle (DoN 2001b). Before the rapid expansion of mangrove, pickleweed was the most abundant vegetation type in the Pearl Harbor area. Pickleweed forms a thick mat that may be 1 m high in places. Pickleweed prefers the same physiographic areas as mangroves; however, the taller mangroves rapidly shade it out. Currently, there are only a few remnant patches of pickleweed around Pearl Harbor (DoN 2001b). A Kiawe (*Prosopis pallida*) forest habitat is located within the floor of the Makalapa Crater and on fossilized coral outcrop areas of NAVMAG Peal Harbor West Loch Branch and lower Waipio Peninsula. The Kiawe trees generally form a closed-canopy forest that currently covers 16.4 ha in Pearl Harbor (DoN 2001b). Because of the high sediment loads in Pearl Harbor, benthic communities have historically been more diverse on vertical surfaces than on horizontal surfaces where sediment accumulation results in smothering. Within the softbottom zones, most species are infaunal. There are a few stony coral communities reported within Pearl Harbor however they are sparse and very widely dispersed and generally small (DoN 2001b). In 1996, Coles et al. (1997) conducted an extensive survey of the ecosystems of Pearl Harbor; they found 434 species or higher taxa within the 15 stations sampled.

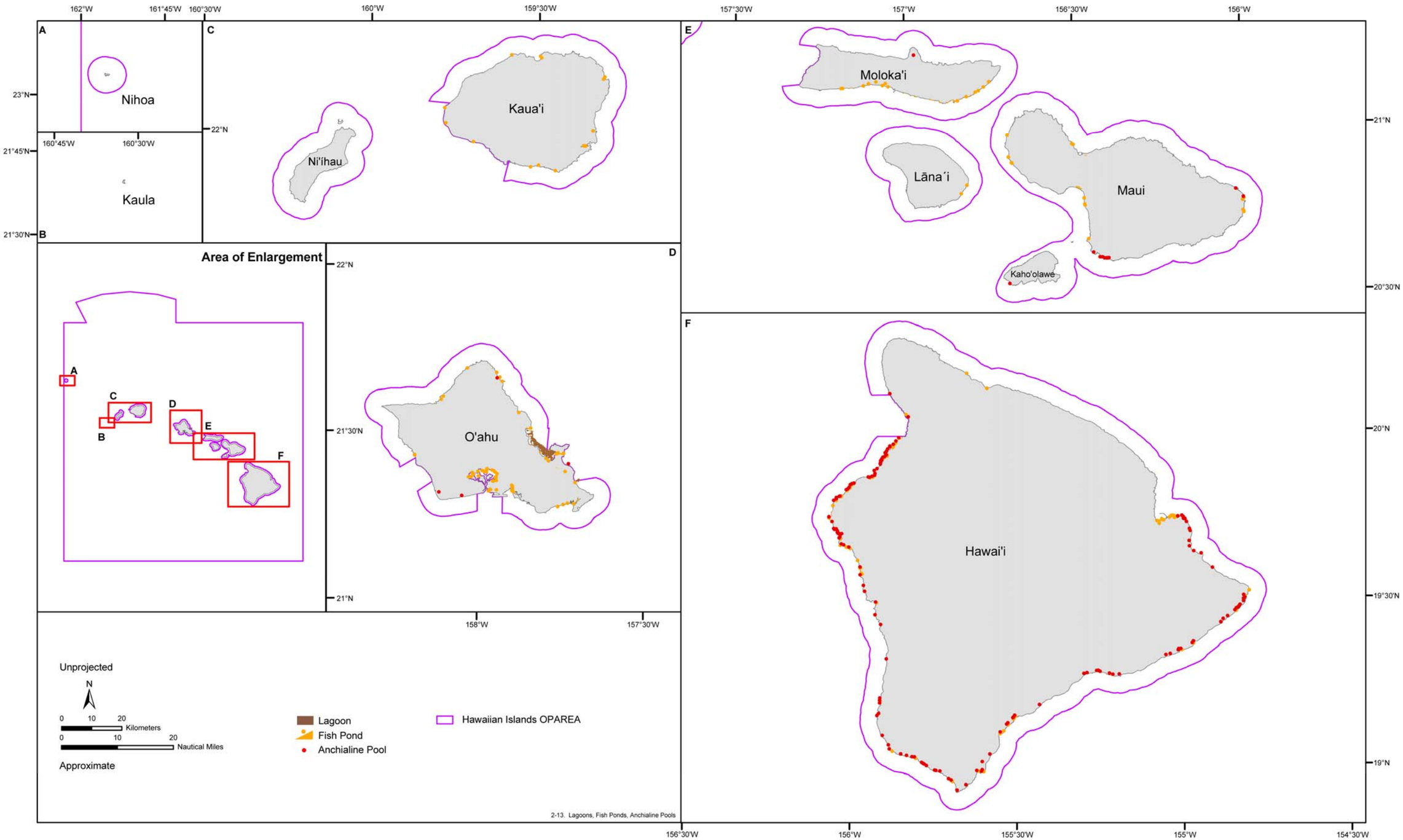


Figure 2-13. Fishpond, lagoon, and anchialine pool habitat distribution in the Hawaiian Islands OPAREA and vicinity. Source Data: NOS (2001), NOAA (2003), and State of Hawai'i, Office of Planning (2005).

2.7.1.2 Lagoons

A lagoon is a body of comparatively shallow salt water separated from the open sea by a shallow or exposed sandbank, coral reef, or similar feature. Lagoons are often formed when such sandbanks or reefs are built up parallel to the coastline and partially cuts off the nearshore water from the open ocean (Nybakken 1997).

In the Hawaiian Islands, lagoon and ocean waters are exchanged by passages cut through the reefs. In the Hawaiian Islands OPAREA, the most significant lagoon is located in Kāneʻohe Bay, Oʻahu (**Figure 2-13**); in this lagoon, pinnacle and patch reefs occur in the center of the lagoon and fringing reefs line the shoreline (Maragos 1998). The floor of the lagoon is mostly sandy and flat or undulatory; coral rubble, coral mounds (patch reefs), seagrass, and algae are also found. Coral mounds tend to be more abundant in the outer reaches of lagoons and are widely scattered or absent in the inner lagoons (PBEC 1985; NCCOS/NOAA 2005). The biota is the same as colonized hardbottom and deep soft sandy bottom habitats. Threatened green sea turtles and endangered hawksbill turtles feed on the barrier reefs and in lagoons (Maragos 1998).

2.7.1.3 Seagrass

Seagrasses are submerged aquatic vegetation that form extensive underwater meadows (or beds). They are a group of approximately 60 species and are found in shallow-water depths and various temperatures and salinity ranges throughout many parts of the world (Phillips and Meñez 1988). Most seagrasses have flattened leaves that help them adjust to light restrictions and slow rates of gas diffusion in the water column (Thayer et al. 1984). Their extensive rhizome (root) system forms dense and tough belowground mats that function in anchorage and the absorption of nutrients. The leaves are capable of transporting oxygen to the rhizomes, allowing seagrasses to grow in anoxic sediments (Thayer et al. 1984).

Seagrass beds are among the most productive habitats in the ocean. This production comes from the leaves, epiphytic organisms, underground biomass, and associated flora and fauna (50 to 95%) (Brouns and Heijs 1986). The macrophytic and microphytic algae that form a dense layer on the bottom of seagrass beds can account for 10 to 20% of the above ground production (Zimmerman 2003) and the phytoplankton residing above and between the seagrass contribute considerably to oxygen production (Brouns and Heijs 1986). Seagrass beds provide a substantial element in the sustainability of coastlines, fisheries, benthic invertebrates (e.g., shrimp, lobster), marine mammals (e.g., manatees, dugongs), reptiles (e.g., green sea turtles), and waterfowl. They sustain ecosystem productivity with internal nutrient cycles by trapping detrital material and sustaining detrital-feeding pathways (Phillips and Meñez 1988; Nybakken 1997). In addition, seagrass beds slow currents and waves to prevent coastline erosion by stabilizing sediments and promoting sedimentation. They also improve water quality by filtering sediments and sediment borne pollutants, excess nutrients, and dissolved and particulate pollutants from terrestrial run-off. Thus, they play an important role in nutrient regeneration and recycling, water quality, primary production, and carbon sequestration. As perennial structures, seagrasses are one of the few marine ecosystems capable of storing carbon for relatively long periods. This carbon can be bound into sediments or transported to the deep ocean and play an important role in long-term carbon sequestration (Phillips and Meñez 1988). However, primary production is probably the most essential function of the seagrass ecosystem.

Seagrass ecosystems promote biodiversity by providing a variety of unique niches and have been found to parallel that of adjacent high diversity ecosystems (e.g., coral reefs, mangroves, salt marshes, and bivalve reefs) (Green and Short 2003). Seagrasses can grow up to 10 millimeters per day (mm/d) (Phillips and Meñez 1988); this high rate of growth sustains the feeding pathways of many herbivores and detrital-feeders.

Short et al. (2000) and Green and Short (2003) have determined that, worldwide, between the mid 1980s and the mid 1990s, 1,200,000 ha of seagrass habitat have been lost. Coastal modifications that cause shading, resuspension of sediment (via dredging, recreational watercraft, ferries, tankers, freighters), deposition of upland soils, and oil spills may reduce the transmission of light to and/or bury seagrasses.

Within the Hawaiian Islands, seagrass beds are not abundant; they are found subtidally on shallow, sandy bottoms near coasts protected by reefs and embayments (Maragos 2000). Seagrasses colonize carbonate or terrigenous sands and muds. One known endemic seagrass species occurs in the Hawaiian Islands, *Halophilia hawaiiana* (Maragos 2000). In addition, *Halophila decipiens* is possibly an indigenous species as well. There is currently no indication that *H. decipiens* was introduced to the Hawaiian Islands. On the other hand, there is not enough evidence to speculate as to how *H. decipiens* may have come to the Hawaiian Islands, but given its broad, scattered distributions, it has probably been in the Islands at a low level and has been overlooked rather than introduced. *H. decipiens* is currently found scattered throughout the Hawaiian Islands and usually occurs in deeper water, separate from and not in direct competition with *H. hawaiiana* (Russell et al. 2003). Common animals found inhabiting seagrass beds of the Hawaiian Islands include sea cucumbers (*Holothuria*), sand-dwelling gastropods, clams, crabs, shrimps, flagtails (*Kuhlia*), mullets (*Mugil*), and rudderfish (*Kyphosus*) (Maragos 1998).

Geographic distributions of seagrasses are based upon individual species tolerances to hydrological and atmospheric conditions (i.e., water temperature, salinity, irradiance, depth, substrate, and exposure) (Phillips and Meñez 1988). In the Hawaiian Islands, seagrasses are found off the inner reef flats of south Molokaʻi, ʻAnini (Kauaʻi), and a few other locations but are generally not widespread (Maragos 2000; **Figure 2-14**). In addition, seagrasses are found on the south and north coasts of Oʻahu near Mamala Bay and Kāneʻohe Bay, respectively. However, the distribution of seagrass beds in the Hawaiian Islands is poorly known due to the difficulty of delineating seagrass habitats.

2.7.1.4 Mangrove

Mangroves are small tropical trees with salt-tolerant roots that grow in wetlands at the edge of the ocean. They often form mangrove forests that are essential habitat for many fishes and animals. Mangroves are the tropical equivalent of salt marshes; they line the shores of coastal embayments and the banks of rivers to the upper tidal limits (Myers 1999). They have large roots that spread laterally and the extensive root systems can consolidate sediments, eventually transforming surrounding mudflats into dry land (Myers 1999). Mangrove forests provide nutrient rich waters that make them among the richest nursery grounds for marine life (Scott 1993; Myers 1999).

In most parts of the tropics, mangroves are highly regarded for the ecosystem they provide; however, in the Hawaiian Islands, they are invasive and have adverse ecological and economic impacts. Mangrove colonization in the Hawaiian Islands has resulted in a reduction in habitat quality for endangered waterbirds (e.g., the Hawaiian stilt, *Himantopus mexicanus knudseni*), colonization of endemic habitats (e.g., anchialine pools), overgrowth of native Hawaiian archaeological sites, and drainage and aesthetic problems (Allen 1998). Mangrove colonization has some positive aspects including the local use of *B. gymnorrhiza* flowers for making leis, development of mangrove ecosystem habitat, sediment retention, and organic matter export (Allen 1998). Also, mangroves appear to have a positive influence on water quality in the Hawaiian Islands and may contribute to improving the quality of offshore waters (Allen 1998). In general, the turbidity of waters adjacent to mangrove habitat was lower than in areas lacking mangrove habitat. On Molokaʻi, turbidity was lower on coral reefs adjacent to mangroves than on reefs far from mangrove habitat (Allen 1998). In addition, mangroves may serve as a sink for high nitrate and phosphate levels. In the Heʻeia stream, nitrate and phosphate levels were significantly reduced in the upper reaches of the mangrove habitat (Allen 1998).

In the Hawaiian Islands, mangroves are not found naturally; they were intentionally introduced in the early 1900s. In 1902, *Rhizophora mangle* was introduced to south Molokaʻi and Kāneʻohe Bay, Oʻahu primarily for the purpose of stabilizing coastal mud flats (Allen 1998). This species is now well established in the MHIs and has spread to mud flats and estuarine waters around most of the Islands and to some rocky coastal areas around Hawaiʻi Island (Maragos 1998). Subsequently, at least five additional species of mangroves or associated species were introduced to the Hawaiian Islands and at least two of these species have established self-maintaining populations (*Bruguiera gymnorrhiza* and *Conocarpus erectus*) (Allen 1998).

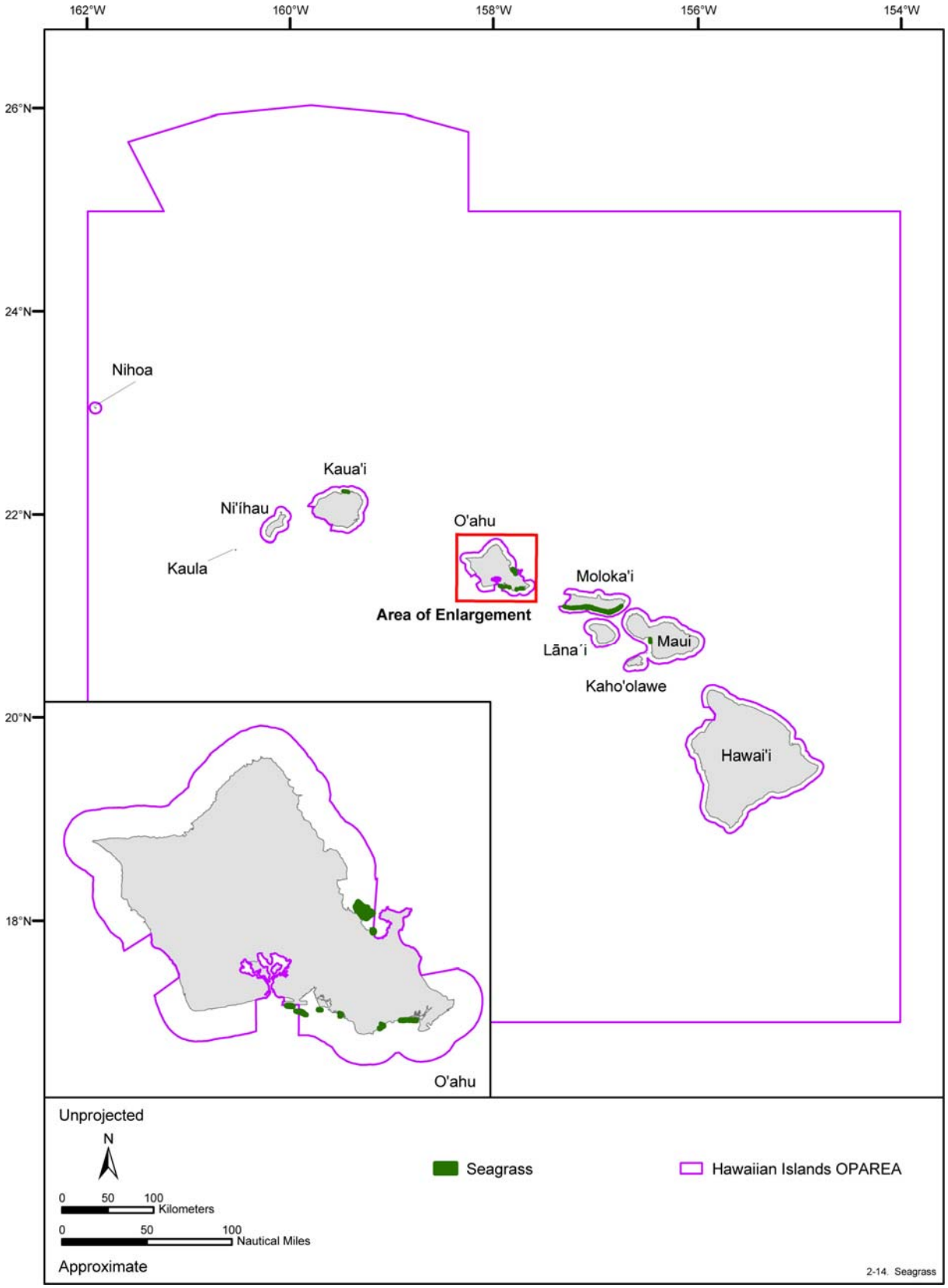


Figure 2-14. Seagrass distribution in the Hawaiian Islands OPAREA and vicinity. Source data: NOS (2001).

Mangroves have colonized nearly all of the MHI. Specifically, in the Hawaiian Islands OPAREA, *B. gymnorrhiza* and *R. mangle* are found on Oʻahu in the Heʻeia marsh on the Northeastern coast and in the Pearl Harbor estuary on the southern coast; *R. mangle* is also found on the western coast of Hawaiʻi in Kihalo Bay (Allen 1998). Unfortunately, there has not been an extensive survey of mangrove-colonized areas in the MHI and there is no comprehensive datasource to depict the occurrence of these affected areas. However, **Figure 2-12** depicts a few of the mangrove-colonized areas in the MHI.

In some areas, mangroves have also become established in anchialine pools, most notably on the west coast of Hawaiʻi (Allen 1998). Once mangroves reach anchialine pools they rapidly colonize all suitable shoreline habitat, completely filling in the shallower anchialine pools (Allen 1998). Common animals that utilize mangrove habitat include the mangrove or Samoan crab (*Scylla serrata*), other crabs, oysters, and clams. Also, the native black-crowned night heron, cattle egret, and the endangered Hawaiian stilt nest and feed among the mangroves (Maragos 1998).

2.7.1.5 Mudflat

Mudflats are relatively flat, muddy regions found in intertidal areas that are submerged by the rise of the tide; they are able to support plant life and are found in sheltered bays and estuaries. Mudflats are critical habitats for many endangered waterbirds inhabiting the Hawaiian Islands. Recently the Navy created 2 ha of critical mudflat habitats for endangered water birds on the shores of Pearl Harbor within the Honouliuli Unit of the Pearl Harbor NWR (Hommon and Stovell 2000). This refuge, which is owned by the Navy, was created as a mitigation measure to replace mudflat habitat lost when Honolulu's "reef runway" was built; the refuge is managed by the Fish and Wildlife Service (Hommon and Stovell 2000). The mudflats were created in West Loch of Pearl Harbor and are home to a number of Hawaiian waterbirds, including four endangered species and a variety of migratory waterbirds. The endangered waterbirds include the koloa or Hawaiian duck (*Anas wyvilliana*), the aeʻo or Hawaiian stilt (*Himantopus mexicanus knudseni*), the `alae-keʻokeʻo or Hawaiian coot (*Fulica americana alai*), and the `alae`ula or Hawaiian moorhen (*Gallinula chloropus sandvicensis*) (Hommon and Stovell 2000). Common plants that occur in Hawaiian mudflat habitat include pickleweed (*Batis □aritime*), *Panicum purpurascens* and *Schoenoplectus* spp., and some green algae (*Ulva*, *Enteromorpha*) (Maragos 1998). In the Hawaiian Islands OPAREA, mudflat habitat is located along the southern and northern coasts of Oʻahu in Mamala Bay, Pearl Harbor and in Kāneʻohe Bay, respectively (**Figure 2-12**).

2.7.2 Rocky Intertidal

The rocky intertidal habitat is present on all shorelines of the Hawaiian archipelago where sand is absent due to constant wave action, currents, steep submarine slopes, and a lack of offshore sand reservoirs (**Figure 2-15**). Biological assemblages common to rocky intertidal habitats are defined by extreme physical factors including exposure to air and potential desiccation, strong wave and surf exposure, rocky substrate, competition for living space, and the need to find food and shelter while avoiding predators. Cracks, crevices, and overhangs create microhabitats for organisms to hide from predators, minimize wave shock, and avoid desiccation. These characteristics create a strong pattern of vertical zonation in which the distribution of an organism is determined by its physiological tolerance to desiccation and competitive and predatory interactions with other species (MMS 2001). Four zones of life occur in a rocky coast habitat: the upper intertidal, mid-intertidal, lower intertidal, and subtidal (Maragos 1998); in the Hawaiian Islands the tidal range is only about 1 m, making this vertical zonation range small.

The substrates of Hawaiian rocky intertidal habitats are mostly consolidated basalts with some consolidated limestones (cemented beach rock or raised coral reefs). Common plants found in rocky intertidal habitats include sea lettuce (*Ulva*), Sargasso or *kala* (*Sargassum*), coralline red algae (*Hydrolithon*), red fleshy algae (*Melanamansia*, *Pterocladiella*, *Jania*), brown algae (*Padina*, *Turbinaria*, *Dictyota*), and fleshy green algae (*Neomeris*, *Halimeda*, and *Caulerpa*). Common animals found in rocky intertidal habitats include keyhole limpet or *ʻopihi* (*Cellana*), periwinkles, littorine snails (*Littorina*, *Nerita*), rock crabs or *ʻaʻama* (*Metapograpsus*), gastropods (*Drupa*, *Morula*, *Cypraea*, *Strombus*), and rock urchin (*Colobocentrotus atratus*). Adjacent to rocky shoreline, offshore waters are possible feeding areas for the

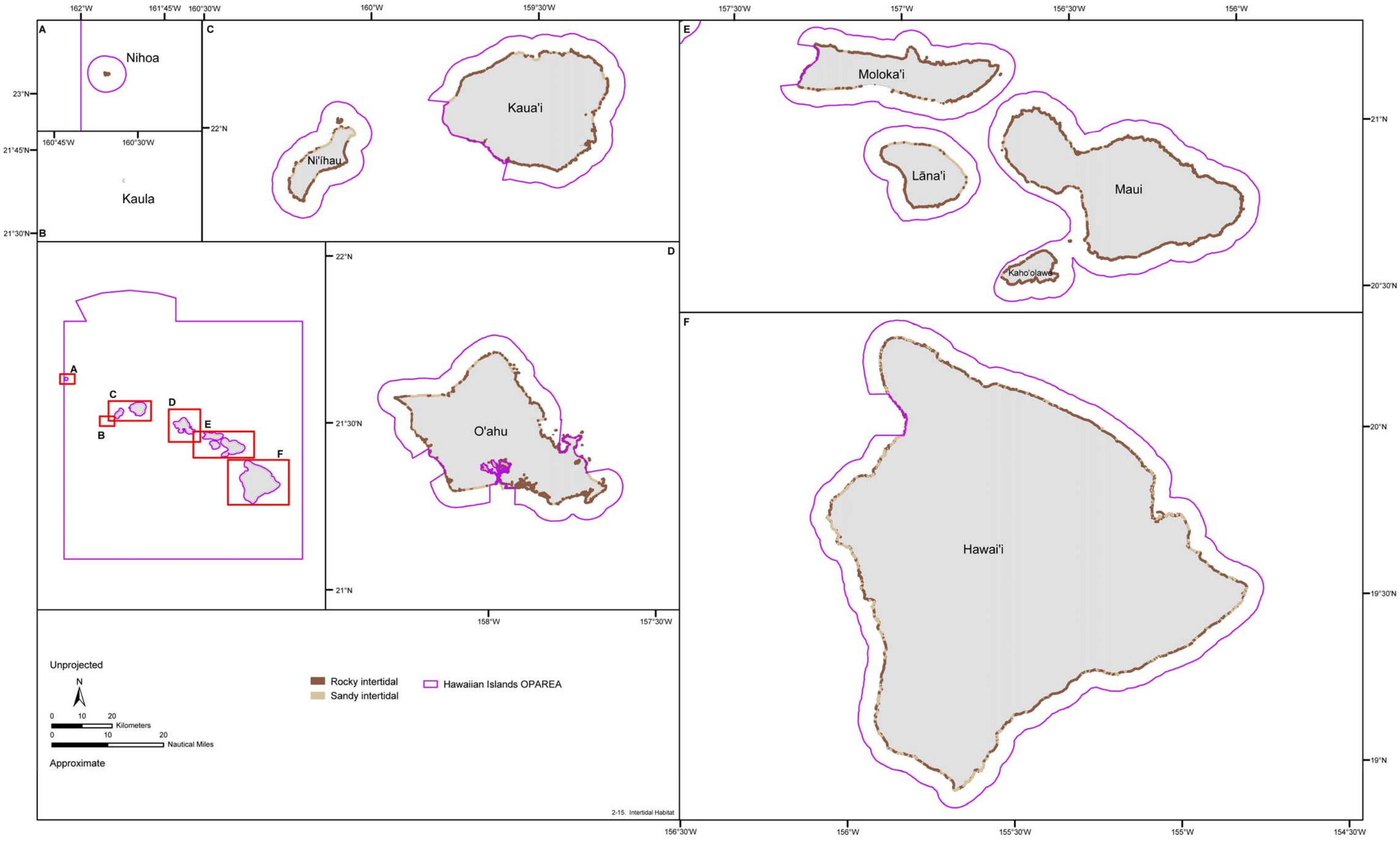


Figure 2-15. Rocky and sandy intertidal habitat distribution in the Hawaiian Islands OPAREA and vicinity. Source Data: NOS (2001) and NOAA (2003).

threatened green turtle (Maragos 1998). Other than rocky shoreline, the Hawaiian Islands have two distinct rocky intertidal habitats, tide pools and anchialine pools.

2.7.2.1 Tide Pools

As the tide recedes, depressions between rocks can retain water. These areas form pools known as tide pools. Tide pools are flooded during rising tides and are continuous with the open ocean at the surface. In he Hawaiian Islands, tide pools are formed by lava rock depressions that have subsided to sea level and where wave action breaks down the surface barriers, exposing the pool to the open ocean (Maragos 1998). A variety of reef animals and plants occupy tide pools such as crabs, small fish, snails, and many types of algae (Maragos 1998). Organisms that reside in a tide pool may be subjected to desiccation and drastic salinity and temperature changes; they are therefore uniquely adapted to survive under the harsh conditions of this habitat.

2.7.2.2 Anchialine Pools

Anchialine pools are land-locked, marine or brackish pools of water located along coasts and connected to the sea via underground caves, tunnels, or fissures (Frankel 2004). These pools are found along rocky coasts up to several hundred meters inland. Depending on the distance from the sea and the extent of groundwater input, pools range in salinity and water quality (dissolved nutrients). The porous rock walls allow them to maintain subsurface connections with the sea. Anchialine pools are often found along the basaltic coasts of younger volcanic islands (e.g., Maui and Hawai‘i) and where coral reefs have been uplifted (e.g., O‘ahu) (Maragos 2000). Anchialine pools in basalt rock are generally located where the lava rock is porous and creates broad shallow shelves near the coast. Limestone anchialine pools are found in karstic formations that consist of fossilized coral reefs now positioned above sea level; these formations have undergone extensive weathering and dissolution (Meier et al. 1993). Lava rock depressions that have subsided to sea level become flooded with seawater during tidal flow and anchialine pools are created; eventually these anchialine pools form tide pools (Maragos 1998).

Hundreds of anchialine ponds are found throughout the Hawaiian archipelago (**Figure 2-13**). Anchialine habitats are best known for their unique community assemblages, particularly invertebrate species such as the red-colored shrimp or opae-ula (Meier et al. 1993). Also, distinctive microorganism assemblages are present in the unique anchialine habitats. The microbial diversity of these habitats is important to assess because the majority of the ponds have been drastically impacted by human development. Anchialine pools have been filled for residential or resort development, including a large pond complex at the Waikola Resort at Anaeho‘omalu, Hawai‘i (Meier et al. 1993).

The Kaloko-Honokohau Park on the western coast of Hawai‘i contains 10% of Hawai‘i’s anchialine ponds (Frankel 2004). The pools have a large algal component and highly specialized and vulnerable fauna; this unique biota is continually reduced by mangrove invasion (Allen 1998). Marine algae and cyanobacteria are commonly found in anchialine pools; widgeon grass (*Ruppia maritima*), rushes (*Juncus*), or pickleweed (*Batis maritima*) may become established where sediments accumulate along edges. Common animals include shrimp (*Metabetaeus lohena* and *Halocaridina rubra*), eels (*Gymnothorax*), mullets (*Mugil*), and other crustaceans and mollusks (Maragos 1998).

2.7.3 Sandy Intertidal

Sandy beaches provide important habitat for sand-dwelling crustaceans, mollusks, and fish; they also supply resting and nesting sites for seabirds, sea turtles, and the Hawaiian monk seal. Beaches are the most abundant along the lagoon reaches of atoll islets and along the coasts of several of the MHI, especially the west and south sides of Kaua‘i, O‘ahu, Moloka‘i, Maui, Lāna‘i, and Hawai‘i (Maragos 2000; **Figure 2-15**). Four types of beaches have been recognized. White sand beaches are the most common; they are formed from the breakdown of coralline algae and corals to make white carbonate sand. Black sand beaches are derived from recent lava flows when molten lava flows into the sea and tiny tephra particles are formed; these beaches are common off Hawai‘i and Maui. Pink sand beaches are derived from the breakdown of iron-rich coastal cinder cones; one is located off east Maui. Green sand beaches

consist of olivine crystals that have eroded from lava rock; they are found off south Hawai‘i and off northeast and southeast O‘ahu (at Mokapu Peninsula and Hanauma Bay) (Maragos 1998, 2000). Beach sand tends to be coarser off wave-exposed and windy reaches of islands and finer within lagoons, embayments, mangroves, harbors and fishponds (Maragos 2000); wave action and biological and chemical erosion determine the composition and longevity of beaches (Maragos 1998).

Sandy beaches provide extensive benthic habitat; the invertebrate communities of these habitats provide important inputs to reef systems at higher trophic levels including reef-associated fish populations (DeFelice and Parrish 2001). In tropical shallow waters, the carbonate sediments of coral reefs generally cover more area than hard substrates. Carbonate sediments support diverse invertebrate assemblages; the specific assemblage structure is based upon the mean grain size and wave exposure of the site (DeFelice and Parrish 2001). In general, the number of individuals and diversity increases with increased mean grain size and decreased wave exposure (DeFelice and Parrish 2001).

Common plants that inhabit sandy beach intertidal habitat include the beach morning glory (*Ipomoea*), beach heliotrope (*Tourneforita*), milo (*Thespesia*), and hau (*Hibiscus*) (Maragos 1998). Common animals utilizing and inhabiting sandy beach intertidal habitat include ghost crabs (*Ocypode*), mitre and auger shells (*Terebra*), clams, and seabirds (Maragos 1998). On Hawai‘i, two capitellids (*Diopatra dexiognatha* and *Pygospio muscularis*) are key species in the beach intertidal habitat that provide sediment stabilization for the invertebrate community structure during normal as well as severe episodic disturbances (Dreyer et al. 2005).

2.7.4 Subtidal Colonized Hardbottom

Rocky substrate can provide support to extensive communities of marine plants and animals that require attachment for survival. Subtidal rocky substrates provide habitat for a diverse ecosystem of fish and invertebrates including seaweeds, sponges, octopus, feather stars, and the commercially valuable spiny lobster and abalone (Chess and Hobson 1997). Live bottoms, as defined by the Bureau of Land Management, are areas “containing biological assemblages consisting of such sessile invertebrates as sea fans, sea whips, hydroids, anemones, ascidians, sponges, bryozoans, and hard corals living upon and attached to naturally occurring hard or rocky formations with rough, broken, or smooth topography; and whose lithotope favors accumulation of turtles, pelagic and demersal fish.”

In the Hawaiian Islands, shallow benthic communities are found in depths of up to 50 m or more, on basalts, and on consolidated limestones (reef carbonates, beach rock). The distribution of benthic communities is determined by light penetration, temperature, wave action, availability of substrate, and movement and accumulation of sediments. Macroalgal beds dominate the shallow inner reaches of fringing reef flats and stony coral communities dominate the outer flats and upper reef slopes (Maragos 2000). Common communities include brown algae (*Sargassum*, *Turbinaria*, *Dictyota*, *Padina*, and *Dictyopteris*), green algae (*Halimeda*, *Dictyosphaeria*, *Cladophora*, *Caulerpa*, and *Ulva*), and red algae (*Pterocladiella*, *Melanamansia*, *Asparagopsis*, and *Laurencia*) (Maragos 1998). Crustose coralline algae are prevalent in wave-exposed littoral and sublittoral habitats and are strong reef builders (Maragos 2000). *Porolithon* spp. are the most common coralline algal communities and *Cyphastrea*, *Fungia*, *Psammocora*, *Porites*, *Pocillopora*, *Montipora*, *Pavona*, and *Leptastrea* are also common among coral communities (Maragos 1998).

Invertebrate communities commonly associate with the macrofauna. Of the many sessile and motile invertebrates associated with colonized hardbottom habitat in the Hawaiian Islands, the spiny and slipper lobsters are of particular interest (DoN 2001c). Spiny lobsters (family Palinuridae) and slipper lobsters (family Scyllaridae) are found throughout the Indo-Pacific Region. The Hawaiian spiny lobster (*Panulirus marginatus*) is endemic to the Hawaiian Islands and is typically found on rocky substrate in well-protected areas, in crevices, and under rocks and is the primary species of interest in the NWHI fishery (DoN 2001c). The reported depth preference of the Hawaiian spiny lobster is from 3 to 200 m but it is generally more abundant in 90 m or less (DoN 2001c). Common reef and shore animals associated with subtidal colonized hardbottom habitat include parrotfishes, wrasses, damselfishes, surgeonfishes and other reef

fishes, jacks, sea urchins, and sea cucumbers. In addition, the endangered Hawaiian monk seal feeds in the deeper colonized hardbottom offshore communities (Maragos 1998).

In the Hawaiian Islands OPAREA, colonized hardbottom, macroalgae, invertebrates, deep-slope terraces, and islets are found on every island (**Figure 2-16**). The marine benthic invertebrate assemblages are xtremely diverse and include representatives of nearly all phyla. Subtidal colonized hardbottom habitats in the Hawaiian Islands include coral reefs and communities, deep-slope terrace, and islets.

2.7.4.1 Coral Reefs and Communities

While this section includes a general discussion of coral reefs and communities of the Hawaiian archipelago, a focused discussion is provided for coral reefs and communities in the nearshore area of the Hawaiian Islands OPAREA, including coastal segments of the islands of Oʻahu, Molokaʻi, Kauaʻi, and Hawaiʻi (**Figures 2-17a** and **2-17b**). Information on coral reefs for the island of Nihoa, the only island of the NWHI encircled by the Hawaiian Islands OPAREA, is also provided. This report uses high resolution benthic habitat maps (1 m per pixel resolution) of the southern coastline of Molokaʻi produced by Cochran-Marquez (2005), benthic habitat maps of the MHIs (1 acre [ac] minimum mapping unit [MMU]) produced by NCCOS/NOAA (2003), and a benthic habitat map of Nihoa Island (4 m per pixel resolution) produced by NCCOS/NOAA (2004). Therefore most of the benthic habitat delineations used in this report depict broad habitats and lack in accuracy. Future benthic habitat mapping of the MHI would benefit from higher resolution techniques and site-specific input on reef structure and coral coverage from local experts. The site specific information on coral cover provided in this report is based on peer-reviewed publications and reports. In areas where coral cover was not reported in the literature we approximated coral cover using NCCOS/NOAA (2005).

Depicted reef habitats based on NCCOS/NOAA (2003) data are linear reefs, aggregated coral, spur and groove reefs, patch reefs, coral heads, scattered coral/rock in unconsolidated sediments, colonized pavement, and colonized volcanic rocks and boulders. Linear reefs are defined as “coral formations that are oriented parallel to shore or the shelf edge” (NOAA 2003). As a category of reefs, linear reefs include fore reefs, fringing reefs, and shelf edge reefs. Aggregated corals are reef habitats that are primarily composed of reef-building corals and have high topographic complexity. Spur and groove reefs typically occur in the fore reef environment and have alternating coral ridges (spurs) and sand channels (grooves) oriented perpendicular to the shore. Patch reefs are coral formations that are isolated by sand or seagrass from other reef habitats and that do not have a structural organization related to the shoreline or insular shelf edge. Scattered coral/rock in unconsolidated sediments (sand or seagrass) are smaller than individual patch reefs. Colonized pavement is low relief carbonate rock colonized by plentiful macroalgae, hard corals, zoanthids, and other sessile invertebrates. These organisms also constitute the live substrate of colonzied volcanic rocks and boulders (NOAA 2003).

2.7.4.1.1 Regional distribution, composition, and condition

<u>Regional Distribution</u>—Coral reefs of the Hawaiian archipelago are found on the MHI, NWHI, and islets that fringe the MHI (Maragos 2000). The geographic extremities of coral occurrence in the Hawaiian archipelago are the island of Hawaiʻi on the southeastern end of the archipelago and Kure Atoll at the northwestern end of the archipelago (Maragos 2000). While coral reefs occur throughout the Hawaiian archipelago, the rate of coral accretion (calcium carbonate production) gradually decreases from 15 kilograms per square meters per year ($kg/m^2/yr$) at Hawaiʻi to 0.3 $kg/m^2/yr$ at Kure Atoll. Reef accretion decreases with increasing latitude due to changes in incident light and SST; there is a 10° latitude difference between the island of Hawaiʻi and Kure Atoll (Grigg 1981).

The Hawaiian Islands have 17,520 km^2 of coral reef area, representing 84% of the coral reef area in the U.S. (3,504 km^2 in the MHI and 14,016 km^2 in the NWHI) (Maragos 2000). The NWHI contain approximately 80% of the coral reef habitat in the Hawaiian archipelago (Maragos et al. 2004). The MHI are for the most part high volcanic islands that include “non-structural reef communities,” fringing reefs, and two barrier reefs (Kāneʻohe Bay and Moanalua Bay, Oʻahu) (Grigg 1997a, 1997b; Friedlander et al. 2004). Reefs of the NWHI consist of atolls, islands, and banks (Grigg 1997a). Kure Atoll is known as the

Darwin Point, a threshold of atoll formation or extinction. The accretion of calcium carbonate at Kure Atoll due to coral growth is in balance with the loss of calcium carbonate due to bioerosion and subsidence (Grigg 1981). Drowned guyots and seamounts are found northwest of Kure Atoll. Due to the motion of the Pacific Plate, the Hawaiian Islands have been transported in a north to northwest direction away from their original location of formation over the hot spot at a rate of about 10 centimeters per year (cm/yr) (Grigg 1988, 1997b). The youngest island in the archipelago is Hawaiʻi, where the youngest fringing reefs and barrier reefs are found; the youngest fringing reefs on the western coast of Hawaiʻi are from 100 to 1,000 years old. The barrier reefs in the Hawaiian archipelago take approximately 2.5 million years to form while atolls take 10 million years to form (Grigg 1988, 1997b).

Wave action is the main natural control on coral reef structure along the coastline of the Hawaiian Islands (Grigg 1997a; Jokiel et al. 2001, 2004). Corals in wave-exposed areas die as fast as they can be replaced (Grigg 1997a). The breaking, scouring, and abrading action caused by waves on corals yields high mortality. Hence, no coral accretion takes place in wave-exposed areas. Other natural factors that influence the formation of coral reefs along the Hawaiian Islands include sedimentation, turbidity, incident light, and dissolved nutrients (Grigg 1997a). The greatest reef accretion occurs in areas sheltered from wave action such as embayments and on the leeward side of islands (Grigg 1997a; Jokiel et al. 2001, 2004). Coral reefs are particularly well developed on the western coast (Kona coast) of Hawaiʻi and on the south coast of Molokaʻi (Maragos 2000; Jokiel et al. 2001, 2004). Despite the fact that wave action limits the accretion of reef building corals, reefs are also found along the south and northeast coastlines of Oʻahu, the north coastline of Kauaʻi, and the northeast coastline of Lānaʻi (Maragos 2000). Stony corals, or reef-building corals, are primarily located on the seaward edge of fringing reefs and the fore reef slope (Maragos 2000); in the absence of stony corals crustose coralline algae colonize coastlines that are exposed to wave action (Maragos 2000).

Regional Composition—There are 59 known species of stony corals occupying the reefs of the Hawaiian archipelago (Maragos et al. 2004). Compared to the coral reefs of the Indo-Pacific, which can contain up to 500 species of stony corals, the reefs of Hawaiʻi have a low diversity (Grigg 1997a). Over 25% of the animals found on the reefs of Hawaiʻi are endemic (Clark and Gulko 1999); in the NWHI, at least 30% of the stony corals are endemic (Maragos et al. 2004). Overall, 29% of coral species found on Hawaiian reefs are endemic to the MHI and the NWHI (Maragos et al. 2004).

The paucity of reef corals is due in part to the geographic isolation of Hawaiʻi from larval sources (Grigg 1988). Prevailing surface water transport is from east to west, driven by the northeast trade winds. There are no coral reef ecosystems to the east of the Hawaiian archipelago capable of acting as a source of coral larvae. The non-endemic coral species originated in the western Pacific and were transported to the Hawaiian Islands as larvae by the Kuroshio Current and Subtropical Counter-Current (Grigg 1988, 1997b). The distant source of coral larvae has created a region of low species diversity and relatively high endemism (Maragos et al. 2004). Coral reefs of Hawaiʻi are also populated by 700 species of fish, 400 species of algae, 1,000 mollusk species, and 1,326 species of invertebrates (excluding stony corals) (Grigg 1997a).

Regional Condition—Humans have significantly impacted reefs of the MHI starting in the late 1700s (Maragos 2000). Historically, factors that have contributed to accelerated soil erosion and the discharge of sediments onto reefs from runoff include land clearing, construction of roads, development of sugar cane and pineapple plantations, logging, livestock ranches, and overgrazing by a growing population of game animals and livestock (Maragos 2000). Overgrazing by goats and deer accentuates soil erosion and sedimentation onto reefs on the southeast coast of Molokaʻi and the north coast of Kauaʻi (Maragos 2000).

More recently, human impacts have affected the reefs of Hawaiʻi including coastal development, urbanization, coastal pollution, increased sedimentation, excessive nearshore fishing, resort development, overuse of nearshore reefs (including reef walking and snorkeling), ship groundings, anchor damage, and invasive species (Maragos 2000; Jokiel et al. 2001, 2004; Friedlander et al. 2004). Up to 75% of the human population lives on Oʻahu and 45% of the population of Oʻahu lives in Honolulu

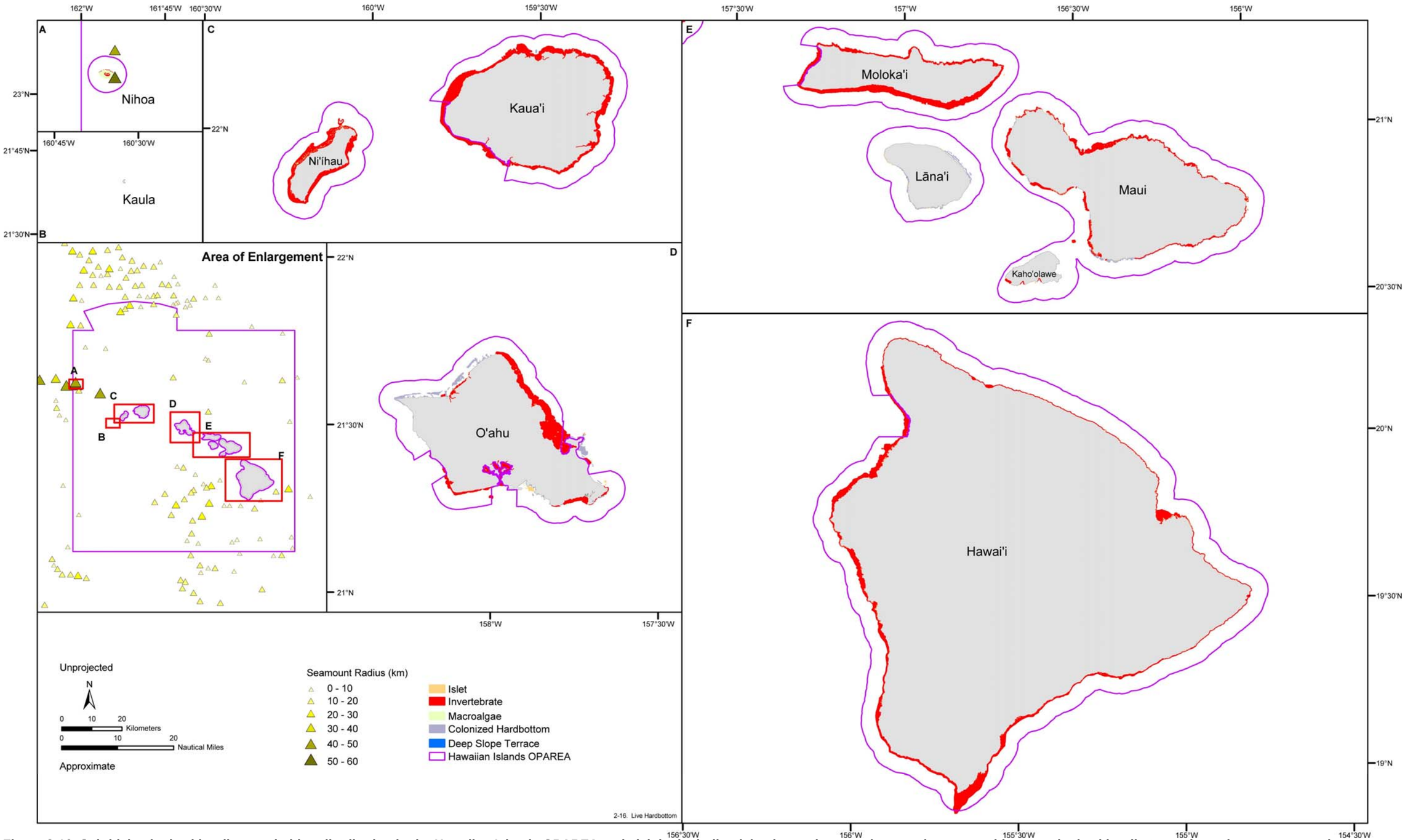


Figure 2-16. Subtidal colonized hardbottom habitat distribution in the Hawaiian Islands OPAREA and vicinity including islet, invertebrate and macroalgae assemblages, colonized hardbottom, deep slope terrace, and seamount habitat. Source Data: Bridges (1997), Itano and Holland (2000), NOS (2001), NOAA (2003), and State of Hawaii, Office of Planning (2005). Map adapted from: Eakins et al. (2003).

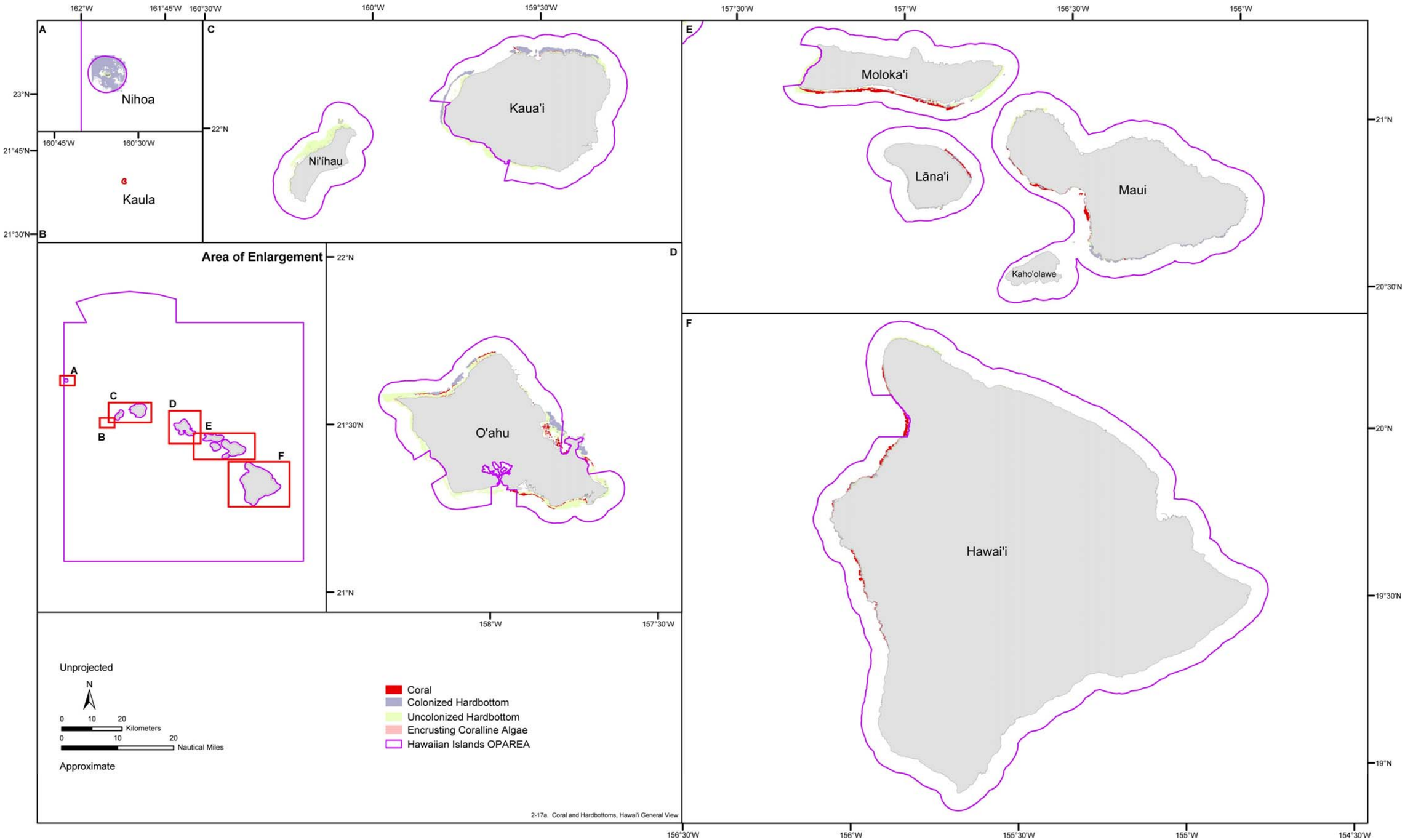


Figure 2-17a. Nearshore hardbottom habitats of the Main Hawaiian Islands and Nihoa. Depicted coral cover ranges from 10 to 100% on the south coast of Moloka'i, is greater than 10% on Nihoa, but is undefined for the remaining locations of the Hawaiian archipelago. Encrusting coralline algae cover ranges from 10 to 100% for all locations. Source data: NOS (2001); NCCOS/NOAA (2003, 2004); Cochran-Marquez (2005).

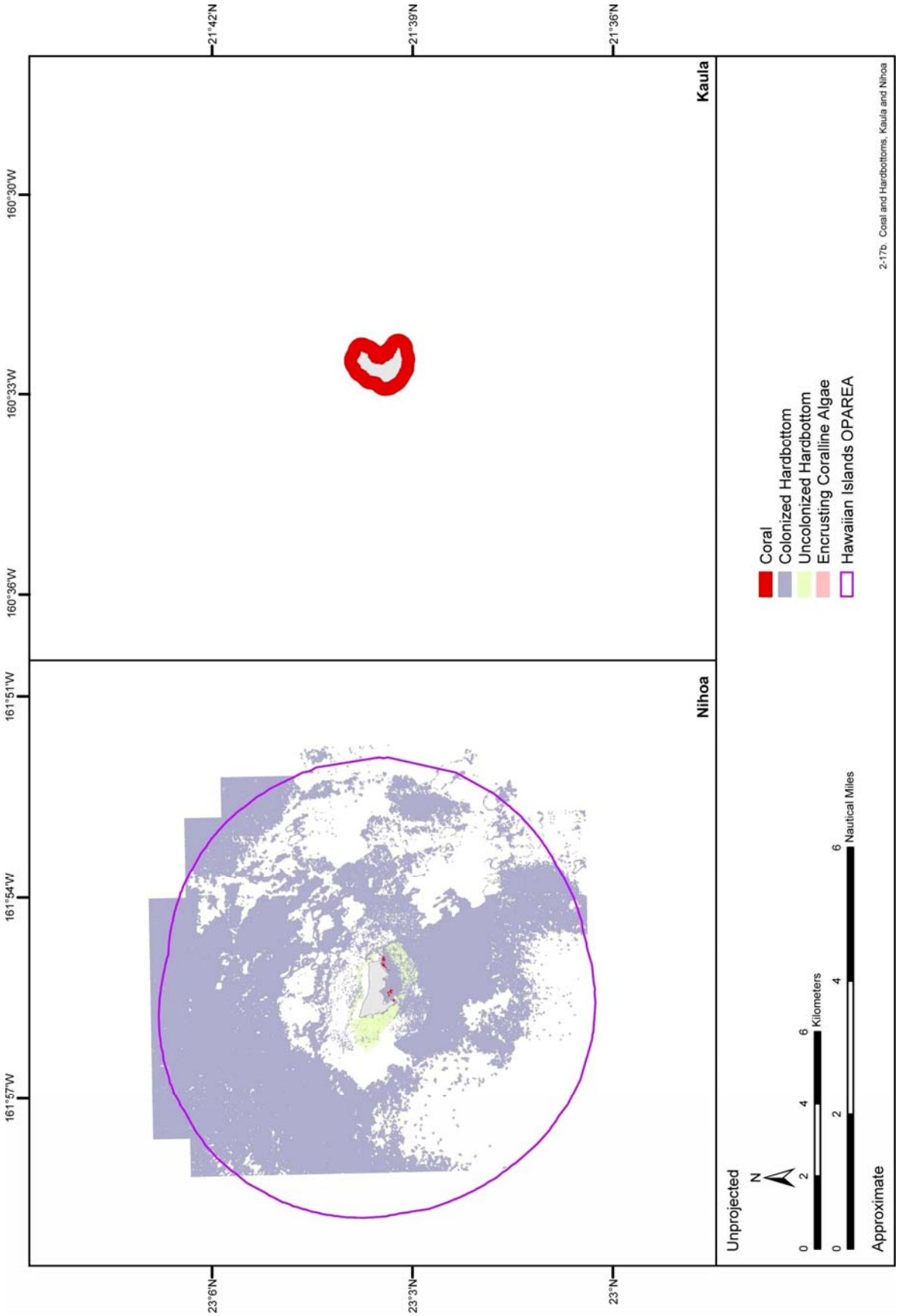


Figure 2-17b. Nearshore hardbottom habitats of Nihoa and Kaula. Depicted coral cover is greater than 10% on Nihoa. Encrusting coralline algae cover ranges from 10% to 100%. Source data: NOS (2001) and NCCOS/NOAA (2003, 2004).

(Maragos 2000; Friedlander et al. 2004); 10% of the population lives on Maui (Friedlander et al. 2004). Molokaʻi is not as populated as Maui but does have excessive sediment-laden runoff impacting reefs on the south shore of the island.

In 2004, coral reefs of the MHI were considered to be in fair to good condition but were certainly degraded (Friedlander et al. 2004; Jokiel et al. 2004; Pandolfi et al. 2005). In the MHI, coral reefs have been mainly impacted by population growth and the degradation of watersheds (Jokiel et al. 2004). Overfishing on the reefs of Hawaiʻi is a major concern (Pandolfi et al. 2003, 2005); the loss of herbivores allows algae to outcompete corals (Pandolfi et al. 2003). In contrast, the coral reefs of the NWHI are in good condition (Friedlander et al. 2004; Pandolfi et al. 2005); bleaching and marine debris are the primary sources of impacts on corals in the NWHI (Friedlander et al. 2004). While human disturbances can be managed on a local scale, global climate change is an ongoing threat (Hughes et al. 2003).

Climate change can affect coral reefs in three principal ways: (1) increased atmospheric carbon dioxide alters ocean chemistry, weakening coral skeletons and diminishing skeletal accretion at high latitude eefs (Kleypas et al. 1999); (2) increased frequency of hurricanes and tropical storms, reducing the recovery time between storms; and (3) increased magnitude of bleaching episodes and disease epidemics (Hughes et al. 2003). The coral reefs of the Hawaiian Islands are potentially susceptible to all three consequences of climate change. Therefore, coral reefs of the MHI, more so than those of the NWHI, are at risk of further degradation caused by climate change and accelerated degradation if existing human disturbances are continued or intensified (Friedlander et al. 2004; Pandolfi et al. 2005).

Coral cover increased between 2000 and 2003 on the reefs of Hawaiʻi and Kauaʻi (Friedlander et al. 2004; Jokiel et al. 2004). Sedimentation on the reefs of Kahoʻolawe ceased to be a problem when grazing animals were removed and the island was revegetated (Maragos 2000; Friedlander et al. 2004). In 2002, hard coral cover ranged from 2.3 to 84% in 59 sites on the MHI (Jokiel et al. 2004). Six coral species made up 20.3% of the total cover: *Porites lobata* (6.1%), *Porites compressa* (4.5%), *Montipora capitata* (3.9%), *M. patula* (2.7%), *Pocillopora meandrina* (2.4%), and *M. flabellata* (0.7%). Areas of the coastline on older islands (including Kauaʻi and Oʻahu) that are exposed to the west and northwest moving swells had lower coral cover and lower species richness and diversity (Friedlander et al. 2004). Over 25% of the stations surveyed incurred a significant decrease in coral cover from 2000 to 2003 (Friedlander et al. 2004). Coral cover of the majority of the reefs Jokiel et al. (2004) assessed in 2002 in the MHI was contained between 10% and 50%. Of the six islands Jokiel et al. (2004) surveyed (Kauaʻi, Oʻahu, Molokaʻi, Kahoʻolawe, Maui, and Hawaiʻi), Oʻahu had the highest proportion (41.7%) of reefs with cover lower than 10%. Molokaʻi and Kahoʻolawe had the highest proportion (50%) of reefs with coral cover exceeding 50% (Jokiel et al. 2004).

Unlike other reefs of the world, Hawaiian reefs have, until recently, been spared from coral disease epidemics (Friedlander et al. 2004). The potential causes of coral tissue necrosis on Hawaiian reefs include elevated dissolved nutrient levels in the water column, mechanical abrasion of the coral tissue, and pulses of excessive sedimentation (Hunter 1999). In three sites of the MHI, Hanauma Bay (Oʻahu), Honolua (Maui), and Puako (Hawaiʻi), colonies of *Porites lobata* bore tumors and necrotic tissue (Hunter 1999). In addition to coral tissue necrosis, band diseases also occur on corals of Hawaiʻi. The diseased portions of the coral colonies are initially colonized by turf algae (Hunter 1999).

2.7.4.1.2 Coral communities and reefs of Nihoa

The island of Nihoa is located at the southeastern end of the NWHI. There is a small area of shallow reef habitat around this island exposed to strong wave action and currents (Maragos and Gulko 2002; Maragos et al. 2004). Because of the high energy environment surrounding the island, reef development is limited to encrusting forms and to substrates found in water depths greater than 10 m. On the north side of Nihoa, corals are only found in water deeper than 20 m (Maragos and Gulko 2002). The soft coral, *Sinularia abrupta,* occurs on the windward side in areas shallower than 10 m (NOAA 2001). Most of the shallow reefs on the insular shelf of Nihoa are located on the south side of the island (NCCOS/NOAA 2004; **Figure 2-17b**).

There are 17 species of stony corals recorded at Nihoa; an encrusting form of *Porites lobata* is the most common species (Maragos and Gulko 2002) and *Pocillopora*, *Porites*, and *Montipora* are the most common genera (Maragos et al. 2004). Impacts incurred by the coral reefs of Nihoa are potentially limited to derelict fishing gear (including nets) and coral bleaching (Friedlander et al. 2004).

2.7.4.1.3 Coral communities and reefs of Kaua‘i

Receiving over 11.4 m of rainfall per year, upland watersheds on Kaua‘i deliver large quantities of sediments to the coastal area and restrict the development of fringing reefs, particularly in shallow areas and embayments (Grigg 1997a). The exposure to the northeast trade winds creates a condition in which the northeast side of the island receives the majority of the rainfall. Yet, Kaua‘i reefs are best developed along the north and northeast coasts where prevalent wave exposure and currents disperse the sediment-laden runoff before it can impact nearshore reefs. Reefs of Kaua‘i are best developed between 15 and 25 m of water depth where little exposure to sedimentation occurs (Grigg 1997a; **Figure 2-18**). In 2002, coral cover ranged from 3.6% to 26% on the northern shore of Kaua‘i (Jokiel et al. 2004). Coral cover at two sites on the southern shore ranged from 5.7% to 11.4% (Jokiel et al. 2004).

A fringing reef lies parallel to most of the northern shoreline of Kaua‘i from Haena Point to Papaa Bay except between Kalihiwai Bay and Kilauea Bay and at Moloaa Bay (**Figure 2-18**). The fringing reef is primarily composed of linear reef and in a few places coralline algae. Seaward of the reef crest, the fore reef and reef slope consist mostly of colonized pavement and linear reef. The colonized pavement on the north shore typically extends 700 m seaward from the reef crest. From Moloaa Bay to Papaa Bay, there is uncolonized pavement seaward of the reef crest. The backreef area on the northern shore contains areas of scattered corals and rock on unconsolidated sediments.

The southern shore from Nahumaalo Point to Port Allen is bordered by a narrow fringing reef. There are six short, narrow stretches of the fore reef slope where the reef consists of colonized volcanic rocks and boulders. These reefs measure approximately 180 to 1,000 km in length and 70 m in width. The longest of these fore reefs is located between Lawai Bay and Makaokahai Point.

West of Puolo Point, a fringing reef hugs the coastline to Poo Point. Seaward of the fringing reef the fore reef slope is colonized volcanic rock and boulders. The remainder of the insular shelf seaward of the fringing reef is comprised of uncolonized volcanic rocks and boulders. The colonized volcanic rock and boulders do not occur further than 400 m northeast of Kaumakani Point. From Kaumakani Point to Poo Point, the seafloor of the nearshore area is primarily covered with uncolonized volcanic rock and boulders with no coral reefs. Beyond Poo Point and up to Mana Point, the nearshore environment does not contain coral reefs and the insular shelf is uncolonized pavement. Off Kokole Point a stretch of sand (1.4 km long) interrupts the uncolonized pavement.

Located 48 NM southwest of Kaua‘i is Kaula Island (21°39'N, 160°33'W) which sits on Kaula Bank. Coral communities surround the crescent-shaped Kaula Island (NOS 2001; Gulko et al. 2002; **Figure 2-17b**). The entire bank upon which Kaula Island is found is designated as a coral reef ecosystem habitat area of particular concern (HAPC) (WPRFMC 2004). There are potentially 18 km^2 of reef communities within 3 NM of the island, and potentially 10 km^2 of reef communities within the Federal waters that surround the island (Gulko et al. 2002). The island is uninhabited but its nearshore habitats are visited by recreational fishermen and SCUBA divers (Gulko et al. 2002). Nearshore coral communities are potentially impacted by fishing gear, anchoring, and ship groundings (Gulko et al. 2002; Lahela-Adventures.com 2003; RedSea Ocean Adventures 2005).

<u>Nearshore Hawaiian Islands OPAREA, Port Allen to Nohili Point/Barking Sands</u>—North of Mana Point, a narrow fringing reef follows the coastline up to Nohili Point and Barking Sands. Seaward of the fringing reef, broad uncolonized pavement (540 m wide) and colonized pavement (700 m wide) stretch along the coastline. North of Nohili Point, the uncolonized pavement ends and the colonized pavement continues along a northward heading; it turns gradually to the east to join the coastline north of Keawanui.

2.7.4.1.4 Coral communities and reefs of Oʻahu

Coral reefs on the island of Oʻahu include linear reefs, spur-and-groove reefs, patch reefs, aggregated coral heads, and colonized pavement (NOAA 2003); reefs occupy most of the northern, eastern, and southern sides of the island (**Figure 2-19**). The Hawaiian Islands OPAREA includes three nearshore areas of Oʻahu: the Nanakuli Area on the southwestern side, the Pearl Harbor region on the south side, and Kāneʻohe Bay, Kailua Bay, and Waimanalo Bay area on the eastern side of the island.

Considerable reef development occurs in embayments and sheltered areas on Oʻahu including Kāneʻohe Bay and Hanauma Bay (**Figure 2-19**). Sediment-laden runoff and polluted runoff have impacted reefs of Oʻahu, and specifically Pearl Harbor and Kāneʻohe Bay (Banner 1974; Smith 1977; Maragos et al. 1985; Grigg 1997a).

The NCCOS/NOAA (2003) benthic habitat maps show no coral reefs along the western side of Oʻahu from the U.S. Naval Reservation to the Makua Valley Military Reservation. Furthermore, no reefs are shown along the southeastern end of the island (Kaloko to Wailea Point) (NOAA 2003; **Figure 2-19**). Fringing reefs are well developed on the southern side of Oʻahu from the Wailupe Peninsula to Kawaihoa Point and Hanauma Bay while west of Kawaihoa Point, fringing reefs as well as spur-and-groove reefs are well developed (NOAA 2003).

Other spur-and-groove reefs are found along the northern shoreline (from Dillingham Airfield to Kahuku Point), in Kailua Bay and along the southern coastline (Wailupe Peninsula to Honolulu International Airport). North of Waimea Bay on the north coast, limited coral communities have developed in two locations known as Shark's Cove and The Tables (CRAMP 1998a). The most common corals at these ites are *Porites lobata* and *Pocillopora meandrina*. In addition, the encrusting corals *Leptastrea purpurea*, *Pavona varians*, and *Montiora flabellata* are known to occur. Coral reef development has been limited in this area due to exposure to the North Pacific swell (CRAMP 1998a).

In Kāneʻohe Bay patch reefs are the most common reef type; however, aggregated coral heads are also found. Colonized pavement is present along most of the northern and eastern coastline; patch reefs and colonized pavement are also found between Halona Point and Kaloko (NOAA 2003; **Figure 2-19**).

Nearshore Hawaiian Islands OPAREA, Nanakuli Area—Even though NCCOS/NOAA (2003) indicates that no coral reefs occur from Kahe Point to Maili Beach Park, corals are located in the Kahe area and have been monitored for anthropogenic impacts since the 1970s (Coles 1998; Jokiel et al. 2004; **Figure 2-19, inset map A**). The outfall was moved to an offshore location to prevent further impacts on nearshore corals (Coles 1998). From 1983 to 1997, high coral cover developed in the immediate vicinity of the new outfall. Up until 1997, the coral species with the highest cover at Kahe Point were *Porites lobata* and *Pocillopora meandrina*. Coral cover has fluctuated at this site due to natural disturbances (e.g., Hurricane Iniki in 1992) and recovery processes (Coles 1998). In 2002, coral cover a Kahe Point was 15.1% (Jokiel et al. 1998).

Nearshore Hawaiian Islands OPAREA, Pearl Harbor Area—A fairly large spur-and-groove reef is found adjacent to the runway of the Honolulu International Airport and on the insular shelf beyond the fore reef (NOAA 2003; **Figure 2-19, inset map B**). The reef is oriented east-west and is approximately 2.8 km long and 540 m wide (NOAA 2003; **Figure 2-19**). This reef extends further eastward from the airport area toward Waikiki Beach covering an approximate distance of 8.7 km.

According to NCCOS/NOAA (2003), no coral reefs occur to the west of the airport runway, along the shoreline of the Fort Kamehameha Military Reservation, the Hickam AFB, the U.S. Naval Reservation, or within Pearl Harbor (**Figure 2-19**). Contrary to the NCCOS/NOAA (2003) data, moderately developed spur and groove reefs do occur on either side of the Pearl Harbor entrance channel, including Tripod Reef and Ahua Reef (Smith personal communication). Tripod Reef is a spur-and-groove system where average coral cover is approximately 40% and live coral cover on Ahua Reef is 40% but in some parts of the reef, coral cover reaches 80% (Smith personal communication).

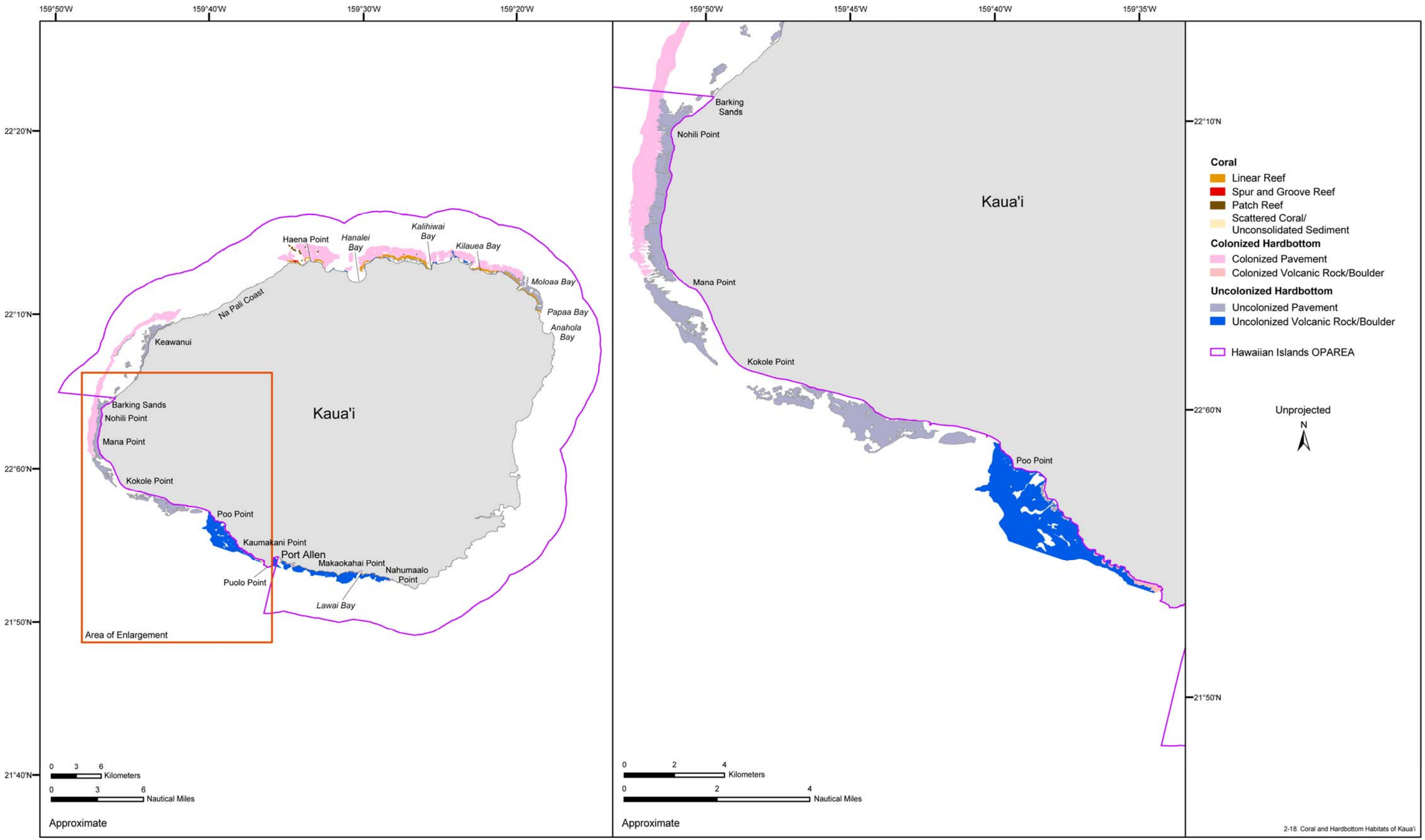


Figure 2-18. Nearshore hardbottom habitats of the Hawaiian Islands OPAREA, Kaua'i. The percent cover of coral depicted is unknown. Source data: NCCOS/NOAA (2003, 2004).

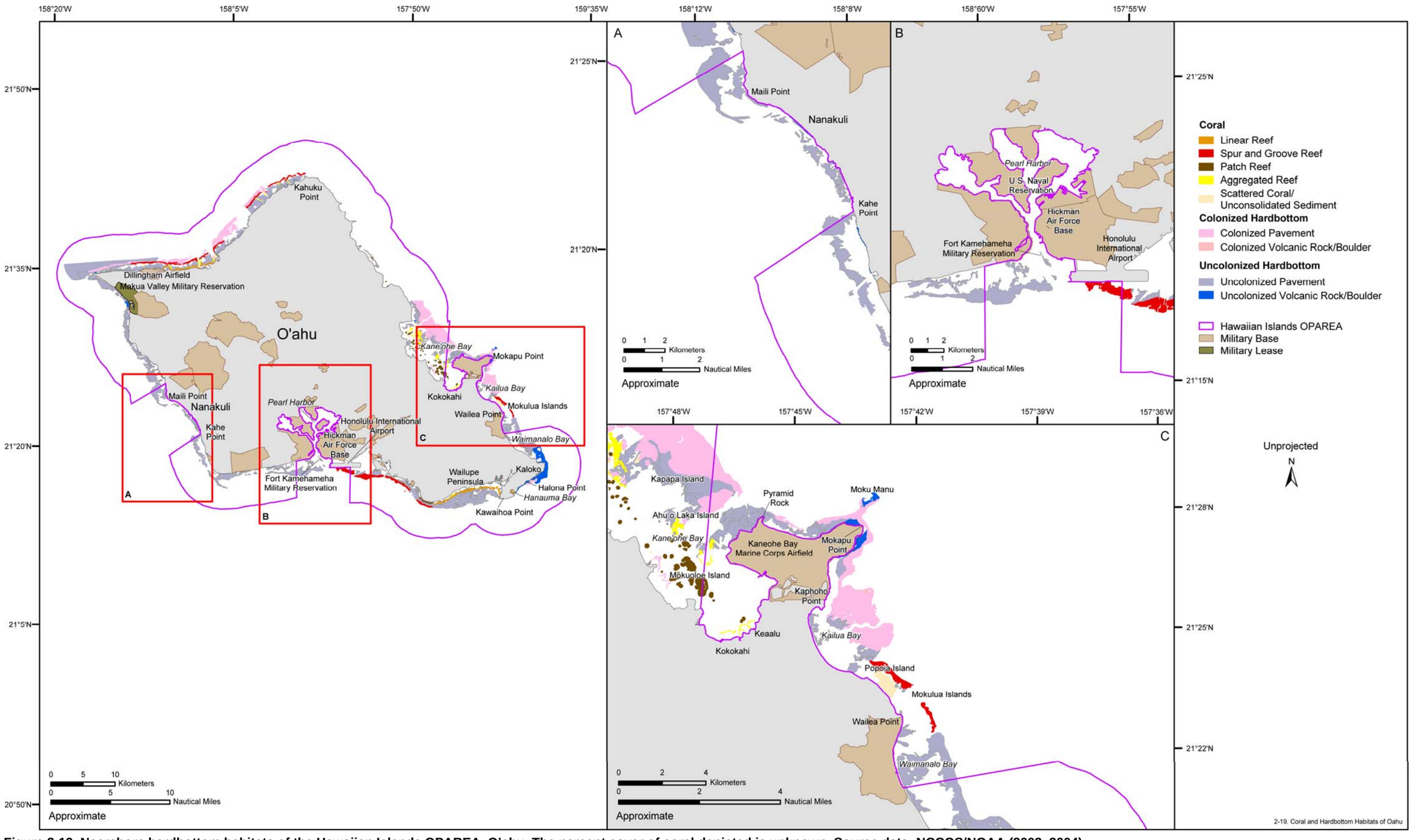


Figure 2-19. Nearshore hardbottom habitats of the Hawaiian Islands OPAREA, O'ahu. The percent cover of coral depicted is unknown. Source data: NCCOS/NOAA (2003, 2004).

Five species of stony corals occur within Pearl Harbor: *Pocillopora damicornis*, *P. meandrina*, *Porites compressa*, *Leptastrea purpurea*, and *Montipora patula* (Coles 1999). In 1996, the most common coral in Pearl Harbor was *L. purpurea,* and corals were most abundant at the entrance of the West Loch Channel. Corals may have begun to settle in Pearl Harbor starting in 1993 following the improved water quality conditions and in particular significantly decreased sedimentation (Coles 1999). Stony corals are found on the reef flat bordering the Pearl Harbor shoreline and in particular along the eastern side of the entrance channel from the Fort Kamehameha Sewage Treatment Plant to Hickam Harbor (DoN 2001b).

Nearshore Hawaiian Islands OPAREA, Kāneʻohe Bay to Waimanalo Bay—In Kāneʻohe Bay a narrow reef crest is located approximately 1 km offshore that consists of uncolonized pavement. Seaward of the reef crest a fore reef and slope are covered by colonized pavement (NOAA 2003). The colonized pavement is approximately 7 km long and 2 km wide running more or less parallel to the shoreline in a northwest to southeast direction. Aggregated coral heads are located on the backreef and isolated patch reefs occur on the reef flat shoreward of the backreef. The patch reefs range in size from 70 m in diameter to an area of 900 m by 600 m (NOAA 2003; **Figure 2-19, inset map C**). Three of the patch reefs encircle Kapapa Island, Ahu o Laka Island, and Mokuoloe Island. The largest patch reef encircles Mokuoloe Island. At the southern end of Kāneʻohe Bay off of Kokokahi and Keaalu, there are three narrow reefs (each approximately 40 m wide) made of aggregated coral heads. The lengths of these reefs range from 350 to 700 m (NOAA 2003; **Figure 2-19**). The backreef zone to the northeast of the Kaneʻohe Marine Corps Airfield contains three reefs made of aggregated coral heads located approximately 700 to 1,000 m from the shore and the reef farthest north measures approximately 100 m by 500 m. The other two reefs are relatively narrow (less than 30 to 100 m wide and up to 1,400 m long) (NOAA 2003; **Figure 2-19**).

Sediment-laden runoff and sewage discharged into the southeastern area of the Kāneʻohe Bay from 1939 to 1978 caused the luxuriant coral communities in the southeastern and central areas of Kāneʻohe Bay to become severely degraded (Banner 1974). Coral reefs of the northwestern area of the bay were less affected because of better circulation (Maragos et al. 1985). In 1977 and 1978, the two sewage outfalls in the southeastern part of the bay were diverted to the oceanside of the Mokapu Peninsula, which reduced nutrient concentrations in the bay (Marszalek 1987). This in turn generated unfavorable conditions for the growth of phytoplankton, the green alga *Dictyosphaeria cavernosa,* and particulate and detritus feeders, which led to recovery of the corals (Maragos et al. 1985; Marszalek 1987). The recovery of the coral reefs in Kāneʻohe Bay is occasionally inhibited by exposure to freshwater, sediments, and nutrients following heavy rainfall (Grigg 1997a; Jokiel 1998).

In 1998, the most common coral species within the Kāneʻohe Bay was *Porites compressa*, a species that is not wave resistant and thus occurs in protected embayments (Jokiel 1998). Other common coral species of the Kāneʻohe Bay are *Montipora verrucosa*, *Pocillopora damicornis*, *Cyphastrea ocellina*, *Pavona varians*, and *Fungia scutaria*. The most common coral species on the seaward side of the barrier reef of Kāneʻohe Bay are *Porites lobata* and *Pocillopora meandrina*. Both species are resistant to high energy environments; mean coral cover on the barrier reef ranges from 5 to 10% (Jokiel 1998). In 2002, the overall range of coral cover at six sites of Kāneʻohe Bay (two sites at Kaʻalaea, two sites at Heʻeia, and two sites at Moku o Loʻe) was 2.5% to 67.5% (Jokiel et al. 2004).

Outside of Kāneʻohe Bay and along the Mokapu Peninsula colonized pavement covers a 30 to 700 m wide strip of the nearshore insular shelf from Pyramid Rock to Moku Manu and around Mokapu Point into Kailua Bay and Kaphoho Point (NOAA 2003; **Figure 2-19**). At Kaphoho Point the colonized pavement changes from a relatively narrow strip to a fairly large area (2 km wide and 3 km long) and is interrupted by a meandering sand channel running east to west (NOAA 2003).

Starting in the area of Popoia Island, the colonized pavement ends and gives way to a reef system that runs parallel to the shore and ends before the Mokulua Islands (NOAA 2003; **Figure 2-19**). The reef crest is made of encrusting coralline algae that is located 570 m from the shoreline and is approximately 100 m wide and 1.6 km long. Seaward of the reef crest is a relatively large spur-and-groove reef (140 to 350 m wide and 2,100 m long). Landward of this reef crest is a backreef area made of unconsolidated sediments. The area is 540 m wide and 1,250 m long and supports scattered corals and rocks (NOAA 2003).

Further south, past the Mokulua Islands and into the Waimanalo Bay area, coral reefs are limited to a spur-and-groove reef located on the fore reef slope about 1 km east of Wailea Point; this reef is up to 200 m wide and 1.1 km long (NOAA 2003).

2.7.4.1.5 Coral communities and reefs of Molokaʻi

There are well-developed reefs along the southern coastline of Molokaʻi, few reefs on the eastern side of the island, and no reefs on the western shoreline (NOAA 2003; Cochran-Marquez 2005; **Figure 2-20**).

The southern coast of Molokaʻi contains the largest and longest fringing reef in the Hawaiian Islands (Grigg 1997a). The reefs of southwestern Molokaʻi are exposed to heavy sedimentation resulting from natural runoff and erosion caused by overgrazing by introduced ungulates (Grigg 1997a). The reefs off Kamiloloa are also in an area impacted by high sedimentation and there is low coral cover on both the reef flat and the fore reef, possibly caused by high sedimentation (CRAMP 1998b). Coral cover is low on the fore reef down to a depth of 12 m. Coral species found on the reef flat include *Montipora capitata*, *Porites compressa*, *Pocillopora damicornis*, and *Psammocora stellata* (CRAMP 1998b). In 2002, coral cover at two sites at Kamiloloa ranged from 2.3% to 2.7% (Jokiel et al. 2004).

The eastern side of Molokaʻi from Halawa Bay to Pukoo harbors corals in only five small areas (NOAA 2003; **Figure 2-20**). Three of the areas are backreef regions with scattered corals on unconsolidated sediments. The largest of the three areas is about 350 m long and 70 m wide. The other two areas are small (70 m diameter) patch reefs (NOAA 2003).

East of Kamalo, located near the southeastern end of the island, the reef flat is very wide and punctuated by blue holes (submerged karst dissolution features) (CRAMP 1998c). There is a high cover of *Porites compressa* on the eastern vertical faces of the blue holes. The reef crest and fore reef are also wide and extend seaward on the insular shelf. In 1998, the fore reef supported an 80% coral cover; in the 1960s. This site had been impacted by silt produced during the dredging of the Kalae Loa Harbor. Once dredging operations ceased, the reef of Kamalo began to recover; the reefs had fully recovered by 1990 (CRAMP 1998c). In 2002, coral cover at two sites at Kamalo ranged from 55.7% to 59.3% (Jokiel et al. 2004).

West of Pukoo Fishpond, a well-developed barrier reef extends to the western tip of Molokaʻi at Laau Point (approximately 60 km) (NOAA 2003). The reef crest of the barrier reef is 35 to 145 m wide and made of uncolonized and colonized pavement and linear reef. The fore reef and fore reef slope contain aggregated coral heads, colonized pavement, and an extensive spur-and-groove reef. The width of the spur-and-groove reef is typically 250 m and the approximate width ranges from 70 to 780 m. Colonized pavement and scattered coral and rock on unconsolidated sediments are common immediately landward of the reef crest (NOAA 2003).

Nearshore Hawaiian Islands OPAREA, Laau Point to Ilio Point—This nearshore area along the western side of Molokaʻi (Laau Point to Ilio Point) consists of uncolonized volcanic rock and boulders (**Figure 2-20**).

2.7.4.1.6 Coral communities and reefs of Hawaiʻi

Overall, coral communities of Hawaiʻi are considered to be in good condition (Grigg 1997a). The accretion of coral reefs around the island Hawaiʻi is correlated to the intensity and frequency of wave disturbance (Grigg 1997a). Coral reefs are primarily found on the western (leeward) side of the island, which includes the nearshore Hawaiian Islands OPAREA between Waikui and Mahukona (**Figure 2-21**). During summer, an occasional Kona storm generates storm swells of 3 to 6 m in height that can remove accreted reefs on the leeward side.

The windward (eastern) side is exposed to the northeast trade wind swell and the large north Pacific swell; in some locations these factors limit the development of coral communities to scattered coral colonies and thin crusts consisting of coralline algae. Well developed reefs do occur, however, on the

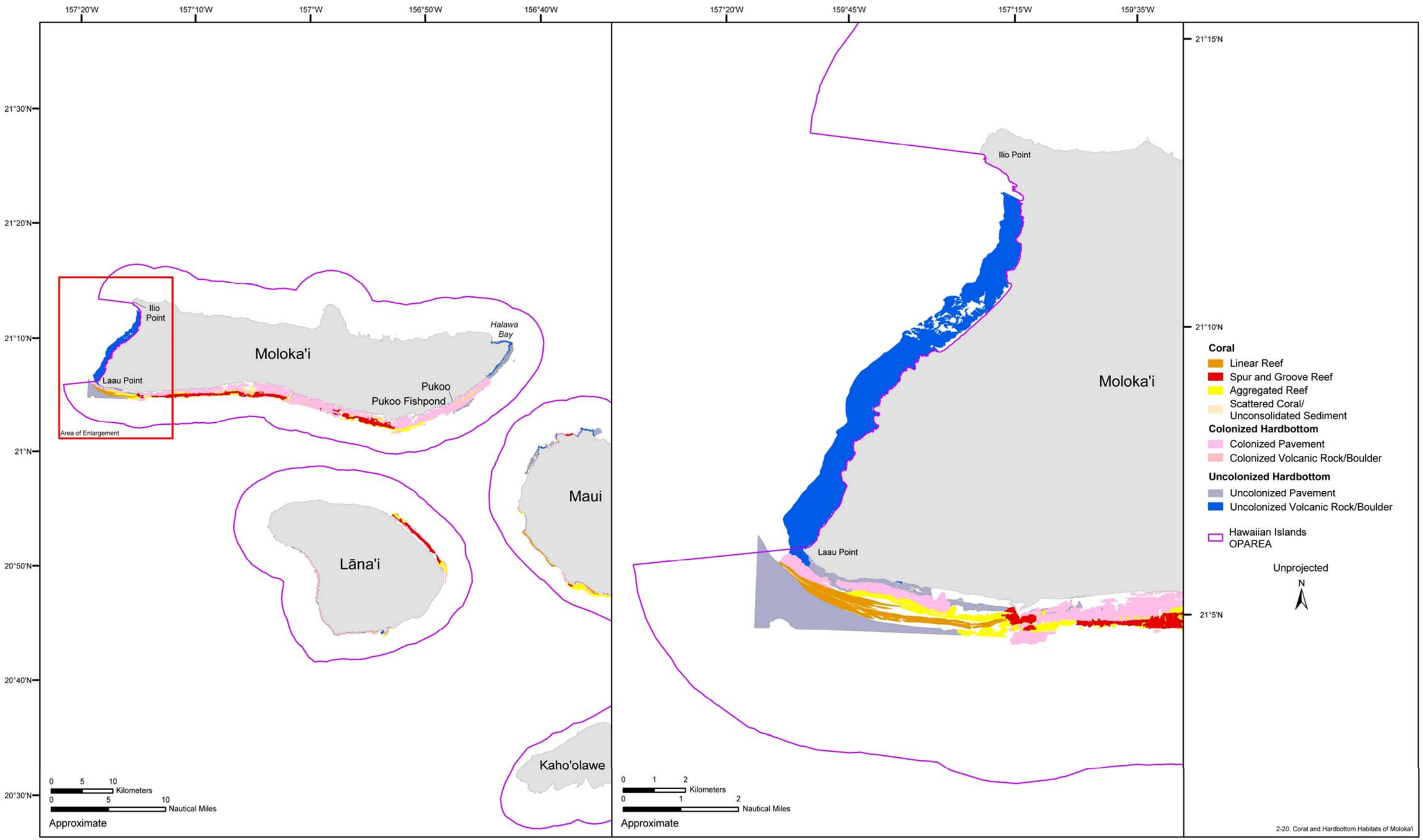


Figure 2-20. Nearshore hardbottom habitats of the Hawaiian Islands OPAREA, Moloka'i. Depicted coral cover ranges from 10 to 100% on the south coast of Moloka'i but is unknown for the remaining coastline. Source data: NCCOS/NOAA (2003, 2004); Cochran-Marquez (2005).

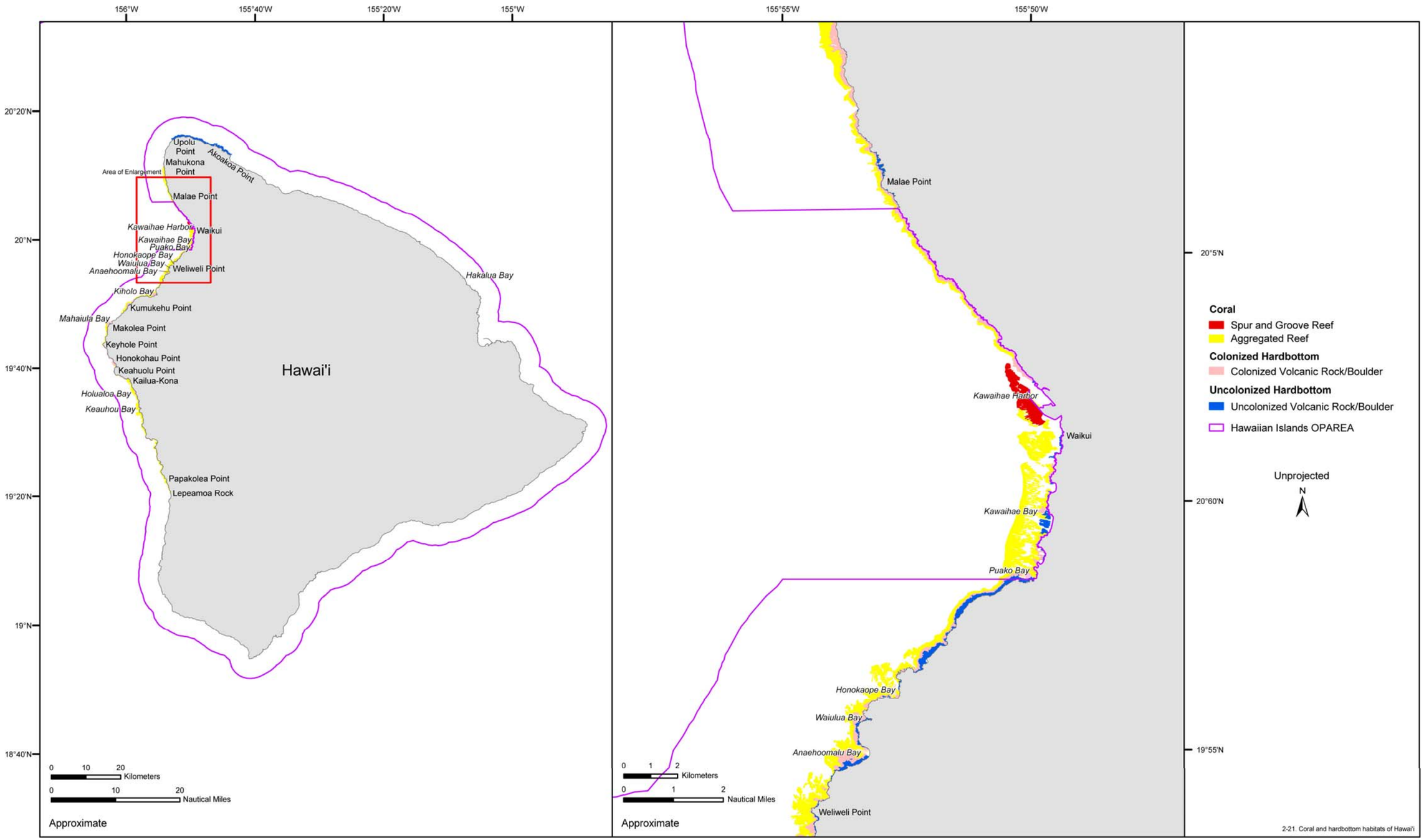


Figure 2-21. Nearshore hardbottom habitats of the Hawaiian Islands OPAREA, Hawai'i. The percent cover of coral depicted is unknown. Source data: NCCOS/NOAA (2003, 2004).

windward side of the island, for example, offshore Hilo Harbor (Smith personal communication). At this location, coral cover exeeds 70% and mainly consists of the coral genera *Montipora* and *Porites* (Smith personal communication). Coral communities of the leeward side are well developed within the 15 to 27 m depth range. The dominant coral on these reefs is *Porites compressa*. In 2002, the coral cover at four sites on the western coast of Hawai‘i (Ka‘apuna, Kawaihae, La‘aloa, Nenue Point) ranged from 12.2% to 38.6% (Jokiel et al. 2004). Coral cover at two locations on the eastern coast (Laupahoehoe, Leleiwi) ranged from 7.2% to 24.5% (Jokiel et al. 2004).

The main human-induced disturbances that impact coral reefs of Hawai‘i are overfishing and aquarium fish collecting (Grigg 1997a). These disturbances limit the reef fish biomass on all of the MHI (Grigg 1997a; Gulko et al. 2002).

A 550 m wide swath of uncolonized volcanic rocks and boulders border the northern coastline of Hawai‘i from Upolu Point to Akoakoa Point (NOAA 2003; **Figure 2-21**). There are no coral reefs on this stretch or from Akoakoa Point to Hakalua.

In contrast to the north coast of Hawai‘i, the west coast supports coral reefs. The shoreline from Papakolea Point to Makaohule Point is typically bordered by an intertidal and nearshore area consisting of uncolonized volcanic rock (**Figure 2-21**). Seaward of the uncolonized volcanic rock, the insular shelf is successively covered by colonized volcanic rock and aggregated coral heads. No benthic habitats were identified between Keahuolu Point and Honokohau, likely due to the steep topography. The width of the benthic habitats along the west coast (uncolonized volcanic rock, colonized volcanic rock, and aggregated coral heads) varies from narrow (less than 100 m) to very wide (more than 1 km). Roughly, half of the coastal area has narrow benthic habitats while the other half features relatively wide habitats, particularly the colonized volcanic rock and the aggregated coral heads.

South of the nearshore Hawaiian Islands OPAREA, several locations occur along the coastline where the aggregated coral head habitat has developed into fairly large areas. Immediately north of Kualanui Point, the aggregated coral head habitat extends 1 km seaward of the colonized volcanic substrate and is roughly 900 m wide. Keauhou Bay, located 1.8 km north of Kualanui Point, also contains an aggregated coral head habitat that is 1.7 km long and 430 to 640 m wide. Further north along the coast, Holualoa Bay and Kailua-Kona harbor aggregated coral head habitat extending more than 500 m seaward of the colonized volcanic substrate.

From Kailua-Kona to Keahole Point, aggregated coral head habitat was only a very narrow strip at Keahuolu Point. In the bay off Honokohau, aggregated coral head habitat is replaced by a fairly large area of colonized volcanic substrate. North of Keahole Point, the aggregated coral head habitat succeeds the colonized volcanic rock. Off Makolea Point, the aggregated coral head substrate is 1.2 km long and 200 to 350 m wide. In Mahaiula Bay, landward of the aggregated coral head habitat, there is a 350 to 700 m wide and 1.4 km long area of colonized volcanic rock (**Figure 2-21**).

South of the nearshore Hawaiian Islands OPAREA, there are colonized volcanic rock and/or aggregated coral head habitats at Kumukehu Point, Kiholo Bay, Weliweli Point, Anahoomalu Bay, Waiulua Bay, Honokaope Bay, and Kawaihae Bay (**Figure 2-21**). From Puako Bay to Waikui, fragments of aggregated coral head habitat are interspersed by sand within a 1 km swath from the shoreline. The most well-developed aggregated coral head habitat is located at the seaward edge.

<u>Nearshore Hawaiian Islands OPAREA, Waikui to Mahukona</u>—North of Waikui, there is a fairly large spur-and-groove reef system (2.5 km long, 180 to 540 m wide) off the Kawaihae small boat harbor (**Figure 2-21**). This is the only spur-and-groove reef that the NCCOS/NOAA (2003) benthic habitat mapping program recorded for the island of Hawai‘i. From the Kawaihae small boat harbor to Malae Point, the shoreline is flanked by a narrow intertidal area consisting of uncolonized volcanic rock (approximately 40 m wide); just seaward there is a strip of colonized volcanic rock (40 to 140 m wide) and aggregated coral heads (40 to 140 m wide). Another 4 km north of Malae Point, there is similar habitat zonation and sizes. From Malae Point to Makaohule Point the widths of colonized volcanic rock and aggregated coral head habitats range from 100 to 250 m and 180 to 360 m, respectively.

2.7.5 Deep Slope Terrace

A deep-slope terrace is an area with a near-vertical gradient from shore to the insular shelf or shelf break and is typically represented by a very narrow range of depths. The deep-slope terrace habitat is highly stratified as a result of depth zonation and provides high relief and extensive shelter for biota (fish, invertebrates, and macroflora) in the form of holes, crevices, and overhangs (Hixon and Beets 1993; Friedlander and Parrish 1998). Planktivorous fishes are very abundant along deep-slope terrace habitats where the larger diurnal species are found at deeper depths because their major prey is most accessible there. Transient species (i.e., piscivores or planktivores) are generally found at the shallower depths, presumably positioned to forage (Friedlander and Parish 1998).

Two important characteristics of deep-slope terrace habitats result in a region of abundant biota, biomass, and diversity. First, depth and high relief produce regions of habitat zonation as a function of depth. Second, rugosity (roughness or irregularity of a solid surface) provides important microhabitat niches for the resident biota and grazers (Friedlander and Parish 1998). Deep-slope terraces are located offshore of almost every island in the MHI; however, the distribution and location of these important habitats is poorly known. Off the coast of Lānaʻi, only one deep-slope terrace habitat has been identified (**Figure 2-16**).

2.7.6 Islets

In the MHI, offshore islets (small islands) are abundant; however, they are more common around the larger and older islands. Volcanic islets were initially connected to the larger, main islands before subsidence and erosion separated them; limestone islets are lithified dunes or relict reefs, both types occur in Hawaiʻi (Maragos 1998). Topographically, rocky beaches, sea cliffs, and some small white sand beaches characterize islets (Maragos 1998). They are typically located on sloping rocky submarine topography and have occasional caves covered with live coral and coralline algae. Generally, an islet is similar in composition/substrate to the adjacent island from which it was formed. For example, if an islet is located offshore from sandy beaches, sand substrates and beaches are more common (Maragos 1998).

Islet habitats support abundant biota that is comparable to the benthic communities that are found on fringing and barrier reefs (Maragos 1998). Human impact is generally minor, allowing islets to provide sheltered habitat for coral communities, important nesting beaches and rookeries for seabirds (Maragos 2000), and many of the beaches may be used for hauling out by sea turtles and monk seals (Maragos 1998).

In the MHI, approximately 30 small, coral islets have been identified. Rare endemic plant life is found on several of these islets and almost all are designated as State Offshore Island Seabird Sanctuaries. All but one of the islets (Coconut Island in Kāneʻohe Bay) are uninhabited (Maragos 2000). A few of the islets in the Hawaiian Islands OPAREA are shown on **Figure 2-16** in Pearl Harbor (Oʻahu), Mamala Bay (Oʻahu), Kāneʻohe Bay (Oʻahu), and Molokini Crater (Maui).

2.7.7 Water Column

The water column makes up the largest habitat on earth but its biology is the least known and explored (Nybakken 1997). The water column can be divided into two primary areas: neritic (waters overlying continental shelf from the subtidal zone to a depth of approximately 200 m) and pelagic (open ocean) (Nybakken 1997). Neritic waters can be described as a euphotic zone and pelagic waters consist of both a euphotic zone and an aphotic zone. Each zone is distinct in its characteristics of water movement, quantity of sunlight, temperature, pressure, availability of food, oxygen, and salinity. In the euphotic zone, sunlight reaches approximately 100 to 200 m below the water's surface and provides the energy for photosynthesis. The aphotic zone is a stable environment that is characterized by cold temperatures, extreme water pressure, very little sunlight, and less abundant biota. In the mesopelagic zone (the transition area between the light and dark zone) deep-living zooplankton and other pelagic animals capable of swimming against currents undergo diurnal vertical migration, moving upwards into the light zone at night to feed on the abundant phytoplankton and downwards during the day to avoid predation.

2.7.7.1 Neritic Ocean

The neritic zone consists of the waters that overlie the continental shelf up to depths of approximately 200 m; these waters are directly associated with coasts surrounding all of the Hawaiian Islands. Neritic waters in the Hawaiian Islands receive discharges and effluents from the land, have high oxygen concentrations, and are exposed to swells, waves, and surf (Chave and Malahoff 1998; Maragos 1998). Most pelagic animals capable of swimming against currents live near the sea surface where food is plentiful but many live or eventually migrate deeper in the water column (DoN 2001c). The endangered hawksbill turtle, Hawaiian monk seal, humpback whale, and threatened green turtle forage, rest, or otherwise use neritic waters. In addition, neritic waters support the majority of the oceanic photosynthetic plants including phytoplankton and floating algae (*Sargassum* and others) (Maragos 1998).

2.7.7.2 Pelagic Ocean

The pelagic zone encompasses open ocean waters beyond the neritic zone (Maragos 1998). Pelagic environments in the Hawaiian Islands extend from the surface to water depths of more than 6,000 m, are usually pristine, are exposed to swells, currents, and winds from all directions, have deep eddies, and experience an oxygen minimum zone at 600 m depth causing a dramatic shift in deep-sea fauna (Chave and Malahoff 1998; Maragos 1998, 2000).

Pelagic biotas live in the water column and have little or no association with the benthos. The organisms living in pelagic communities may be drifters (plankton) or swimmers (pelagic animals capable of swimming against currents). Plankton drift with the ocean currents and can be plant-like organisms (phytoplankton) or animals (zooplankton). Phytoplankton float in the photic zone and provide food for zooplankton and some other larger marine animals. Zooplankton (70% are crustaceans) live throughout the water column; they can float about freely throughout their lives or spend only the early part of their lives as plankton others settle or attach to the seafloor and become part of the benthos (DoN 2001c). In addition, there are many animals that associate and forage in the pelagic habitat including fishes, marine mammals (e.g., endangered humpback whale and monk seal), the threatened green turtle, and seabirds (e.g., endangered Newell's shearwater) (Maragos 1998).

2.7.8 Deep Benthic

The deep benthic habitat and its associated boundary layer has long been perceived as a remote and exotic environment; however, it is closely coupled with the physical and biological dynamics of the upper ocean. Significant physical, chemical, and biological interactions occur between the upper ocean and the deep benthos on time scales of days to millennia (Smith 1991). Benthic communities live within, upon, or are associated with the ocean bottom and rely on the input of food or falling detritus from the surface waters. In general, benthic biomass decreases and diversity increases with increasing distance from shore. Deep benthic fauna living on or in the benthos grow more slowly, live longer, and have smaller broods than animals living in shallow waters.

The bottom substrate of the deep-sea is typically covered with silts, clays, and fine sediments; however, there is the occasional hardbottom substrate offered by seamounts and guyots. The type of bottom substrate governs the abundance and diversity of deep-sea organisms because there are distinct differences between hardbottom and softbottom communities. Abundance and diversity are generally higher on hard, irregular substrates than on smooth, hard surfaces. However, in softbottom habitats, it has recently been shown that although abundance decreases with depth, diversity increases with depth (Gage 1996). This rich species diversity can be attributed to both biological and physical mechanisms. Biological mechanisms include competition, predation, larval recruitment, and biological structuring of the substrate; physical mechanisms include nutrients, light, waves, and currents.

In the Hawaiian Islands, very productive deep benthic microhabitats and communities extend to depths of more than 6,000 m and include rocky outcroppings (e.g., seamounts and guyots), deep-sea corals, hydrothermal vents, chemosynthetic communities, and abyssal plains (Maragos 2000). The bottom sediments covering the sea floor in much of the Hawaiian Islands are volcanic or marine in nature

(carbonate sediments from coral reefs) (Eldredge 1983). Basalt and carbonate rock substrates are common on the insular slopes; whereas, sediments (e.g., sands, gravels, and pebbles) are prevalent along the flattened surfaces of the abyssal plain. Some of the more prevalent sand-dwelling communities include cone shells (*Conus*), tritons (*Charonia*), pen shells (*Pinna*), and garden eels. This habitat supports many fish, invertebrates, and deep-sea corals including the rare, depleted precious corals (e.g., gold and pink coral, *Corallium*); however, living plants are rare or absent on the deep sea floor because of the lack of light (Maragos 1998).

Of the sponge, coral, and echinoderm species found in the Hawaiian Islands, 45% occur at depths of 15 to 400 m, 15% at 400 to 800 m, and 12% at 800 to 2000 m (Chave and Malahoff 1998). Glass sponges, crinoids, and most gorgonians occur at depths greater than 300 m; only a few gorgonians and black corals are found above 250 m (Chave and Malahoff 1998). Benthic fish and crustacean communities rapidly decrease in abundance and diversity with depth. With increasing depth, light intensity declines and eventually algae and plants are unable to survive. Benthic algae and reef-building corals also decrease in abundance and size with increasing depth. Below 100 m only a few, if any, small, stony corals are found (Chave and Malahoff 1998). Thus, there is a change in community structure with depth; at greater depths animals, including non-reef-building corals, obtain their food through suspension feeding. Suspension-feeders capture food particles from the plankton or detritus suspended in the water column. This method of food capture is efficient in the deep-sea benthic environment because it takes advantage of the swift currents that commonly flow over ridges, banks, and pinnacles on the seafloor (Chave and Malahoff 1998).

2.7.8.1 Abyssal Plain

The abyssal plain extends from bordering continental rises to mid-oceanic ridges; it is a relatively flat expanse of sea floor that is 3,000 to 5,000 m below sea level. Abyssal plains are covered with fine particles that constantly rain down from the overlying water column. These particles, fine, clay-sized sediments and the remains of marine life, drift slowly downward filling in depressions on the irregular rocky ocean floor. They have accumulated to make up the 5,000 m thick sediment bed that constitutes the largest portion of the ocean floor (O'Dor 2003). Because of this thick layer of sediment, abyssal plains are among the smoothest surfaces on the planet, with less than five feet of vertical variation for every mile. It is regarded as the true ocean floor and is characterized by extremely cold water, no light, and extremely diverse marine inhabitants (e.g., deep sea isopods, polychaetes, worms, sponges, crustaceans, and sea stars) that are adapted to near freezing temperatures and immense pressure (Wilson 1976; Beaulieu 2001a, b; O'Dor 2003; Cunha and Wilson 2003). The deep sea is one of the largest and least explored ecosystems on Earth and is a major reservoir of biodiversity and evolutionary novelty.

Extensive areas of abyssal plains exist in the Hawaiian Islands OPAREA. These areas vary in water depth, sediment type, organic content, terrestrial influence, oceanographic conditions, and contaminant inputs (Grassle 1991). As a result, the soft substrate benthic assemblages of the region are complex and diverse. In general, organism abundance decreases and diversity increases with depth.

2.7.8.2 Deep-sea Corals

Deep-sea corals live in complete darkness, in temperatures as low as 4°C, and in waters as deep as 6,000 m (CoRIS 2003). They lack the symbiotic zooxanthellae found in tropical reef-building corals. Thus, deep-sea corals do not benefit from a carbon supply provided by symbiotic algae but rather survive solely on suspension feeding. Deep-sea corals can form large communities ranging in size from patches of small solitary colonies to massive reef structures (mounds, banks, and forests) spanning an estimated total spatial coverage of about of 2,000 km^2 (Cairns 1994; Freiwald 2004). Much like shallow-water corals, deep-sea corals are fragile, slow growing, and can survive for hundreds of years (Roberts and Hirshfield 2003). Deep-sea corals can be of two basic types: 1) the hard or stony corals which are related to those found on tropical coral reefs; and 2) the soft corals which include the familiar gorgonians of tropical shallow seas, as well as a broad diversity of other fleshy or tree-like forms. Some of the stony corals are

small but they can grow to be very massive. The soft corals may be small and delicate or very large and tree-like (Watling 2003).

Deep-sea coral communities provide habitat, feeding grounds, recruitment, and nursery grounds for a range of deep-water organisms including epibenthic invertebrates (e.g., echinoderms, sponges, polychaetes, crustaceans, and mollusks), fishes, solitary precious corals (e.g., black corals), and marine mammals (e.g., monk seals) (Maragos 1998; Midson 2000; CoRIS 2003; Roberts and Hirshfield 2003; Freiwald et al. 2004). The biological diversity of deep-sea corals is high; from an economic perspective this diversity creates valuable habitat for several commercially fished species (Gass 2003). However, the full ecological importance/value of deep-sea coral habitat is still unknown.

Deep-sea coral communities are prevalent throughout the Hawaiian archipelago (**Figure 2-22**). They often form offshore reefs that surround all of the MHI at depths between 50 and 200 m (Maragos 1998). Although light penetrates to these depths, it is normally insufficient for photosynthesis. The term 'deep-sea corals' may be misleading because substrate, currents, temperature, salinity, and nutrient supply are more important factors in determining the distribution of growth rather than depth (Chave and Malahoff 1998). In the benthos of the neritic zone these offshore reefs form on a variety of substrates ranging from rocky (e.g., outcrops and steep slopes) to sandy sediment beds. In addition to corals, depth-adapted algae are common. The common coral reef-forming species include *Cycloseris*, *Leptoseris*, and *Coscinaraea* (Maragos 1998). However, most deep-sea corals are not reef-builders (Gass 2003).

In the Hawaiian Islands, gorgonians are the most common group of deep-sea corals. Of the gorgonians, primnoids are the most abundant group in the Hawaiian archipelago and are dominant off Moloka'i (Chave and Malahoff 1998). In the deep waters of the Hawaiian Islands and Johnston Atoll, deep-sea corals belonging to Milleporina and Stylasterina (the hydrocorals) and Alyconacea (soft corals) are usually found in small colonies cemented to rocks (Freiwald et al. 2004). Off Penguin Bank (Maui) at 180 m depth, small colonies of yellow dendrophyllid corals, harp primnoids, and precious corals inhabit the limestone cliffs (Chave and Malahoff 1998). Deeper than 250 m on the older lava flow and limestone formations there are some small, solitary and a few small, colonies of stony corals that dot the landscape (Chave and Malahoff 1998). **Table 2-4** lists the most abundant deep-sea corals located in the Hawaiian Islands OPAREA and vicinity. However, very little of the Hawaiian Islands seafloor has been surveyed; therefore, the distribution of Hawaiian deep-sea corals is not well known (Freiwald et al. 2004). Potential threats to deep-sea corals includes fishing (e.g., bottom trawling), oil- and gas-related activities, cable laying, seabed aggregate extraction, shipping activities, the disposal of waste in deep waters, coral exploitation, other mineral exploration, and increased atmospheric CO_2 (Gass 2003; Freiwald et al. 2004).

Precious corals are heavily exploited by the coral trade to make beads, idols, and jewelry (Midson 1999). In the Hawaiian archipelago, the distribution of three precious corals (i.e., red and pink, Hawaiian gold, and black) ranges between 200 and 600 m depth; they are found in relatively (on a large scale) aggregated areas where the bottom has been free of sediment for extended periods of time. The red (*Corallium regale*) and pink (*Corallium secundum*) corals are found at depths of 150 to 300 m; they grow at a very slow rate of only 0.64 cm/yr (Midson 1999). The Hawaiian gold coral (*Gerardia* spp.) is found off Makapu'u Point at 365 m depth, on Cross Seamount (O'ahu) at 400 m depth, and off Keahole Point (Hawai'i) at 400 m depth. In Hawai'i the larvae of gold corals settle on bamboo corals (Chave and Malahoff 1998). They grow at a rate of about 7.6 cm/yr. Black coral (*Antipathes Grandis*) form mature colonies that may take up to 50 years to grow. Black corals are found attached to ridges, benches, and hummocks where currents are strong (Midson 1999). The distribution of precious coral beds is patchy and poorly known. In 1958, the first new black coral bed to be found in centuries was discovered off Lahaina (Maui) (Freiwald et al. 2004). Fish utilize precious coral beds for shelter and Hawaiian Monk Seals feed on these resident fish. Precious corals range in age to as much as 75 years; human harvesting could alter the habitat for decades. Currently, harvest regulations are being amended to protect this endangered Hawaiian Monk Seal habitat (Midson 1999). The Makapu'u precious coral bed is an established bed that is restricted from harvest; for all the other precious coral beds in the Hawaiian Islands, both State and Federal laws strictly regulate the harvest to approximately 3% of the bed annually (Freiwald et al. 2004). Precious corals are discussed in more detail in this manuscript within the EFH Chapter 4 Section 2.4.

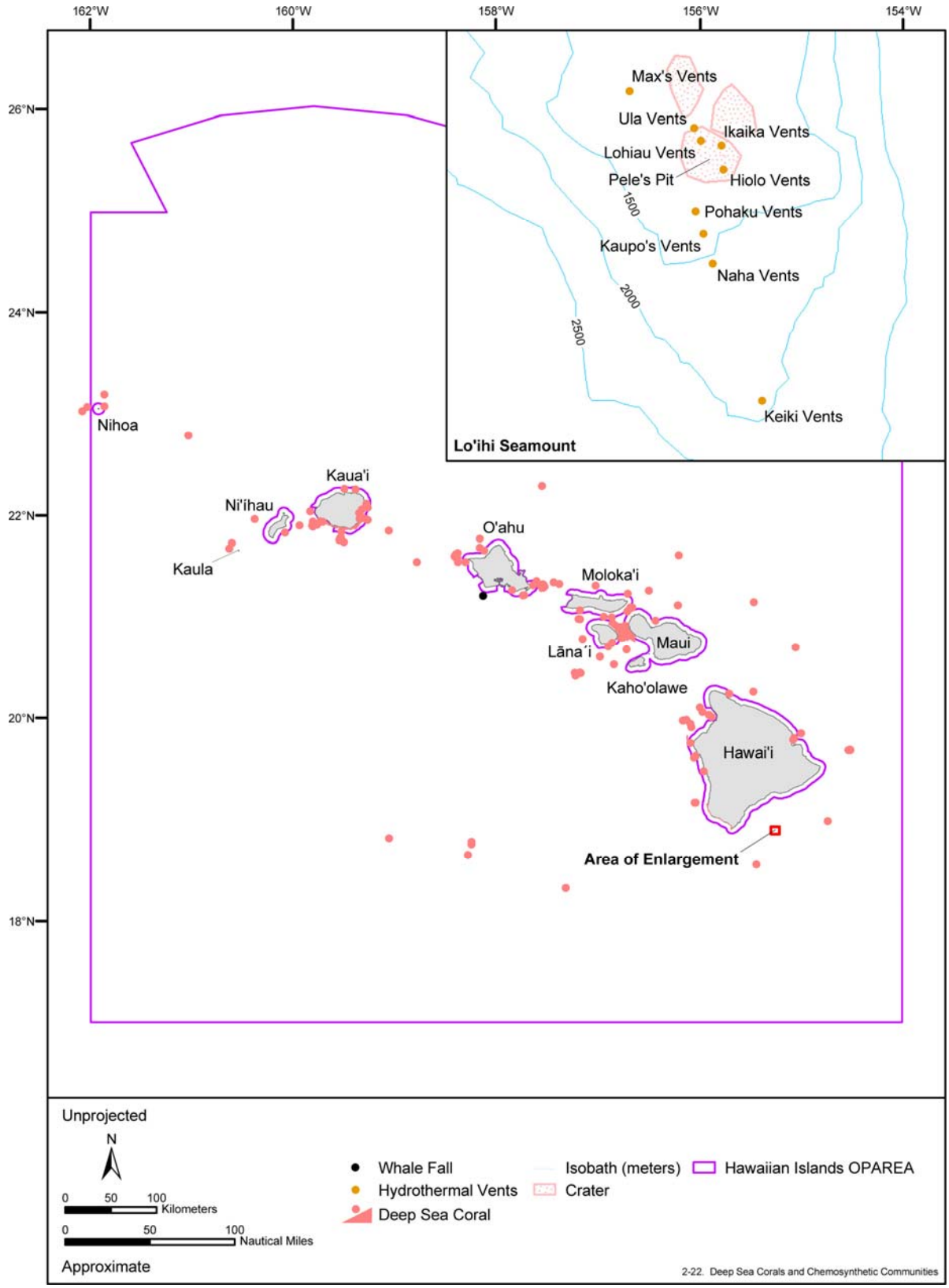


Figure 2-22. Distribution of deep-sea corals, hydrothermal vents, and the one known whale fall in the Hawaiian Islands OPAREA and vicinity. Source data: MCBI (2003) and Dahlgren et al. (2004). Map adapted from: Wheat et al. (2000).

Table 2-4. The most abundant deep-sea corals located in the Hawaiian Islands OPAREA and vicinity (adapted from Chave and Malahoff 1998). Species labeled with a "*" are the precious corals and are described in further detail in Appendix D.

Species	Depth (m)	Location (observed) in Hawaiian Islands OPAREA and vicinity
*Corallium secundum**	183-1380	Cross Seamount; Hawaiian archipelago
Paramuricid blue	180-1530	Cross Seamount; high Hawaiian Islands
Paramuricid tan	251-1500	Cross Seamount; Hawaiian archipelago
Narella spp.	327-515	Leeward Oʻahu; windward Hawaiʻi; windward Oʻahu
Eunicella spp.	332-450	Leeward Oʻahu; windward Hawaiʻi; windward Oʻahu
Lepidisis olapa Musik	318-2040	Cross Seamount; Hawaiian archipelago
Calibelemnon symmetricum	196-1650	Cross Seamount; Hawaiian archipelago; Johnston Atoll
Gerardia spp.*	343-1500	Cross Seamount; high Hawaiian Islands
Parazoanthus spp.	332-1025	Leeward Hawaiʻi; Leeward Oʻahu; Windward Hawaiʻi; Windward Oʻahu
Montipora spp.	35-158	Hawaiian archipelago; Johnston Atoll
Leptoseris spp.	54-168	High Hawaiian Islands; Johnston Atoll
Madracis kauaiensis Vaughan	122-268	High Hawaiian Islands; Johnston Atoll
Porites spp.	15-187	Hawaiian archipelago; Johnston Atoll
Cirrhipathes spiralis	107-450	Hawaiian archipelago; Johnston Atoll

2.7.8.3 Deep Rocky Substrate

In the Hawaiian Islands, rocky areas (e.g., rocky outcroppings, rubble, talus, vertical wall, and seamounts) are interspersed with soft substrate such as sand or gravel. Characteristically, on deep hard substrate, patterns of species distribution and abundance are related to substrate relief (Thompson et al. 1993). These habitats are challenging to study because they usually lie beyond the range of SCUBA and mechanical sampling is difficult. In general, most deep hardbottom organisms are suspension feeders; for example, corals, anemones, ophiuroids, and crinoids are all common in the Hawaiian Islands area. In the Hawaiian Islands, the macrophyte and macrofauna assemblages associated with seamount habitats have been extensively studied; this information is detailed below.

2.7.8.3.1 Seamounts

Seamounts are found in all oceans but are more numerous in the Pacific Ocean, with over 2,000 having been identified (Thompson et al. 1993). Seamounts occur wherever magma has risen to the sea floor and erupted. Lava or magma that has erupted and hardened then forms new seafloor. Seamount topography is a striking difference to the surrounding flat, sediment covered abyssal plain and the effects seamounts can impart on local ocean circulation are complex and poorly understood (Rogers 1994). Very little research has been conducted on seamounts; they are among the least understood habitats in the ocean-basins and are even more poorly understood than abyssal plains (Rogers 1994). Seamounts provide a unique habitat for both deep-sea and shallow water organisms due to the large ranges of depth, hard substrate, steep vertical gradients, cryptic topography, variable currents, clear oceanic waters, and geographic isolation that characterize seamount habitats (Rogers 1994). Thus, seamounts are capable of supporting a wide range of organisms (Wilson and Kaufman 1987). The most common invertebrates found on seamounts worldwide are cnidarians and the most common fishes are scorpaenids and morids (Wilson and Kaufman 1987). The abundant and diverse benthic fauna consists of a wide array of sponges (including large brilliant-yellow barrel sponges that have been known to support intrinsic communities),

coral (including large gorgonians and huge golden coral seafans), brittlestars, crinoids, clams, seastars, polychaetes, crabs, tunicates, sea urchins, sea cucumbers, and octopi (Rogers 1994).

Seamounts attract significant commercial species as a result of the aggregation of exploitable populations of benthopelagic animals. A rich and diverse benthic fauna with a high degree of endemism exists on seamounts. Levels of endemism among 850 macro- and megafaunal species could be as high as 29 to 34% (Johnston and Santillo 2004). Thus, seamounts can function ecologically as island groups or chains, leading to localized species distributions with apparent speciation. Seamount-associated fish are in general very long-lived species and are thus extremely vulnerable to overexploitation. Some seamount fish and benthos are already known to have been seriously impacted by fishing activities (Johnston and Santillo 2004).

Although there are numerous seamounts located in the Hawaiian Islands OPAREA (**Figure 2-16**), the Lo‘ihi Seamount is significant because it may become the newest volcanic island in the archipelago (Maragos 2000). Lo‘ihi also provides additional habitat because it harbors chemosynthetic communities in and around its hydrothermal vents.

2.7.9 Chemosynthetic Communities

In a normal marine ecosystem, the primary producers (e.g., phytoplankton and seagrasses) produce energy through photosynthesis (a photosynthetic ecosystem). In environments rich in methane and sulfides, chemosynthetic bacteria, sulfur-oxidizing bacteria, methane-oxidizing bacteria, and sulfide-reducing bacteria, create the energy that can be used by the organisms in the environment (a chemosynthetic ecosystem) (JAMSTEC 1998). Chemosynthetic communities are a significant source of biological productivity on the deep-sea floor where bacterial communities undergo chemosynthesis to utilize chemicals released from the seafloor to create energy. Little is known regarding the significance of bacterial productivity on the ocean floor on a global scale.

Chemosynthetic habitats are formed by a variety of geological and biological processes on continental margins. Chemosynthesis-based communities, despite their location in the deep sea, have high biomasses maintained by chemosynthetic bacterial production (Fujikura et al. 2002). Hydrothermal vent communities are found across plate formation regions and at submarine volcanoes where volcanic activity is high (Hessler and Lonsdale 1991; Hashimoto et al. 1995; Galkin 1997). Gas hydrates that seep from the sediment bed support extensive chemosynthetic communities (Fisher et al. 2000; Lanoil et al. 2001; Reed et al. 2002). In addition, chemosynthetic communities are also found around whale carcasses and grain carriers that have sunk to the deep-sea floor where the benthic fauna are sustained by the methane and sulfides produced during the decay of fat and grain (JAMSTEC 1998).

2.7.9.1 Hydrothermal Vents

Deep-sea hydrothermal vents occur in areas where new crust is being formed, at or near mid-ocean ridge systems both in fore-arc and back-arc regions (Humphris 1995). Seawater permeating through the crust and upper mantle is superheated by hot basalt and is chemically altered to form hydrothermal fluids. These less dense hydrothermal fluids rise through the network of fissures in the newly-formed seafloor (Humphris 1995; McMullin et al. 2000). The temperature of the hydrothermal fluid is characteristically 200° to 400°C in areas of focused flows and less than 200°C in areas of diffuse flow. Hydrothermal vent fluids are therefore rich in chemicals as the heated seawater reacts with the molten rock, causing metals and other minerals such as sulfur to go into solution.

Hydrothermal fluids are typically poor in oxygen content and contain toxic reduced chemicals including hydrogen sulfide and heavy metals (McMullin et al. 2000). As the hot hydrothermal fluids come in contact with the much cooler seawater overlying the vent, heavy metals precipitate out and accumulate, forming chimneys and mounds. In complete darkness, high ambient pressure, and extreme thermal and chemical conditions of the deep sea, metazoans (multicellular animals) are able to adapt and colonize these sites to form luxuriant chemosynthetic communities. Chemosynthetic bacteria use the reduced chemicals of the hydrothermal fluid (primarily hydrogen sulfide) as an energy source for carbon fixation and generate

chemosynthetic-based primary production. Metazoans consume the chemosynthetic bacteria or form symbiotic relationships and use numerous morphological, physiological, and behavioral adaptations to flourish in this extreme deep-sea environment. These chemosynthetic organisms produce communities typically characterized by a high biomass and low diversity.

Since 1979, more than 200 seafloor vent sites have been located (Wheat et al. 2000). These plumes are of fundamental importance to the composition of the oceans. These hot springs support a unique ecosystem of micro-organisms and animals that do not need sunlight to survive: some 500 new species have been found. In the Hawaiian Islands OPAREA, there was one known hydrothermal vent field, Pele's Vents, on the summit of the Lo'ihi Seamount (Hawai'i) (Chave and Malahoff 1998). Pele's Vents supports an active, deep-sea hydrothermal vent ecosystem which is surrounded by cold seawater; this provides specific and unique physical, chemical, and biological inputs that affect all of the habitats contained therein (Moyer et al. 1998). Vertical dikes filled with molten magma fill the interior of Lo'ihi. Seawater interacts with the hot dikes located there by circulating freely through the porous pillow lava and talus that cover the slopes of Lo'ihi. The seawater becomes hot, leaches minerals from the surrounding basalt, and migrates upward as a mineral-laden heated solution. The 30°C fluid exiting the vents comes into contact with the much cooler 2°C seawater, resulting in the precipitation of minerals such as iron oxide, a yellow to red powdery substance seen covering the summit (Chave and Malahoff 1998). The composition of hydrothermal discharge from Lo'ihi is similar to the composition of the discharge from other non-mid-ocean-ridge axis hydrothermal systems (i.e., rich in Fe and CO_2) (Wheat et al. 2000).

For at least 9 years prior to July 1996, hydrothermal fluids flowed from Pele's Vents on Loihi Seamount (Wheat et al. 2000). In July/August 1996, a tectonic event destroyed Pele's Vents, creating a pit crater (Pele's Pit) and several of the hydrothermal venting sites (Wheat et al. 2000; **Figure 2-22**). Thermal and mass fluxes resulting from the 1996 event impacted the regional hydrography. The currently active areas of Lo'ihi volcano have created hostile environments for marine animals by the noxious particles emitted from hydrothermal vents, sulfur-rich sediments, and unstable rocks (Wheat et al. 2000). While large bacterial mats are present at the vent sites, only a few small animals inhabit the vents, unlike the rich faunal assemblages inhabiting older hydrothermal areas of the Pacific Ocean (Wheat et al. 2000). Large metazoans inhabit the slopes of Lo'ihi away from the hydrothermal deposits, vents, and older lava flows on the volcano's flanks; cnidarians and large sessile sponges inhabit the areas several hundred meters from the vent fields (Chave and Malahoff 1998).

2.7.9.2 Methane Hydrates

Hydrates are crystalline solids comprising water molecules linked by hydrogen bonds in a tight polyhedral cage structure. Methane (or other hydrocarbon) molecules are packed closely together in the hydrate lattice. They are stable at depths below 200 m and at temperatures below 10 to 15°C (Gornitz and Fung 1994). A cubic meter of hydrate yields about 160 m^3 of methane at standard temperature and pressure and about 0.87 m^3 of water (Masutani and Coffin 2001). Methane hydrates are found in high-pressure, moderate temperature regimes in ocean sediments and low-temperature Arctic permafrost zones. Estimates of the total volume of hydrocarbon gas locked in hydrate deposits worldwide range widely from about 2.8×10^{15} to 7.6×10^{18} m^3 (Masutani and Coffin 2001). Significant hydrate deposits have been identified worldwide in undersea basins on continental margins; sediment layers in deep ocean basins also may contain large deposits of methane hydrates but these areas have not yet been thoroughly explored. Methane hydrates may exercise a profound effect on the global climate if the carbon sequestered in these solids is released into the environment by commercial exploitation of the fuel or through destabilization and outgassing induced by ocean warming (Masutani and Coffin 2001). Methane hydrates have the potential to form in the deeper areas of the Hawaiian Islands OPAREA where the water is cold and the pressure is high enough to support hydrate formation.

2.7.9.3 Whale Falls

In addition to hydrothermal vents and methane hydrates, whale carcasses on the seafloor support a high abundance of organisms commonly found near vents and other deep-sea hard substrates (Baco and Smith 2003). It has been estimated that at any given time there may be in excess of 500,000 sulfide-rich

whale skeletons on the deep-sea floor (Smith and Baco 2003). These “whale falls” promote high species diversity by providing hard substrates for settling, organic enrichment, and free sulfides on a typically organic-poor, sediment covered sea floor (Bennett et al. 1994; Butman et al. 1995; Smith and Baco 2003); these whale falls can support productive communities of chemosynthetic organisms for decades.

The biota of geological reducing habitats (e.g., vents and hydrates) can be compared with those of biogenic origin (due to large organic falls) to fully understand the biogeography and evolution of chemosynthetic communities (Smith et al. 2003). Natural whale falls and wood falls, hydrothermal vents, and wood falls provide specific habitat duration and faunal community. Each of these chemosynthetic habitats appears to foster a characteristic fauna; sulfide-rich whale falls (50 to 80 year habitat duration) harbor a highly diverse assemblage (100 to 200 species) dominated by bathymodiolin mussels, cocculiniform limpets, dorvilleid polychaetes, and in some cases vesicomyid clams (Smith et al. 2003). Wood falls harbor low-diversity assemblages of wood-boring bivalves, galatheids, and ampharetid, dorvilleid and polynoid polychaetes. At present, whale falls are known to share 11 species with hydrothermal vents and 20 species with cold seeps (Smith et al. 2003).

Whale falls are intense point sources of organic enrichment at the deep-sea floor; the decay of the whale fall passes through three successional stages. At less than 1.5 months, whale falls have largely intact carcasses with soft tissue; at this stage, predominantly hagfish, sleeper sharks, and lysianassic amphipods scavenge the whale fall (Dahlgren et al. 2004). Carcasses at the seafloor for 4 to 18 months still attract hagfish but are essentially stripped of soft tissue; at this stage the whale fall primarily supports invertebrate opportunists on bones and in organically enriched sediments. Organic-rich bones and sediments characterize the “enrichment opportunist” stage approximately 4 to 24 months after carcass arrival on the seafloor (Dahlgren et al. 2004). The bones of carcasses at the seafloor for 4.5 to >15 years are colonized by chemoautotrophic microbial mats and macrofaunal invertebrates including some taxa known from vents such as vesicomyid clams, bathymodiolin mussels, and vestimentiferan polychaetes (Baco and Smith 2003; Dahlgren et al. 2004). During all stages, whale falls harbor a number of potentially endemic species and have been shown to create ephemeral habitats. These ephemeral habitats have been hypothesized to be a significant source for broad dispersal across the deep-sea floor and effective local recruitment for new sites (Dahlgren et al. 2004).

There is one known whale fall community in the Hawaiian Islands OPAREA and vicinity located off the coast of O‘ahu (**Figure 2-22**). This community was implanted on the slope of O‘ahu at 1000 m and consists of one sperm whale and balaeanopterid bones (Dahlgren et al. 2004).

2.7.10 Artificial Habitat

Artificial habitats (shipwrecks, artificial reefs, jetties, pontoons, docks, and other man-made structures) are physical alterations to the naturally occurring marine environment. In addition to artificial structures intentionally or accidentally placed on the seafloor, fish aggregating devices (FAD) are suspended in the water column and anchored on the seafloor to attract fish (Klima and Wickham 1971; Bohnsack et al. 1991; Blue Water 2002). Artificial structures provide a substrate upon which a marine community can develop (Fager 1971). Navigational, meteorological, and oceanographic buoys suspended in the water column potentially function like artificial habitats. Epibenthic organisms will settle on artificial substrates (including algae, sponges, corals, barnacles, anemones, and hydroids) to eventually provide a biotope suitable for large motile invertebrates (e.g., starfish, lobster, crabs) and demersal and pelagic fishes (Fager 1971; Bohnsack et al. 1991). In the Hawaiian Islands OPAREA, there are a significant number of artificial habitats available for the marine communities. Shipwrecks are the most common followed by FADs and artificial reefs (**Figure 2-23**).

2.7.10.1 Artificial Reefs

An artificial reef consists of one or more submerged structures of natural or man-made origin that are purposefully deployed on the seabed to influence the physical, biological, or socioeconomic processes related to living marine resources (Seaman and Jensen 2000). Artificial reefs are defined both physically

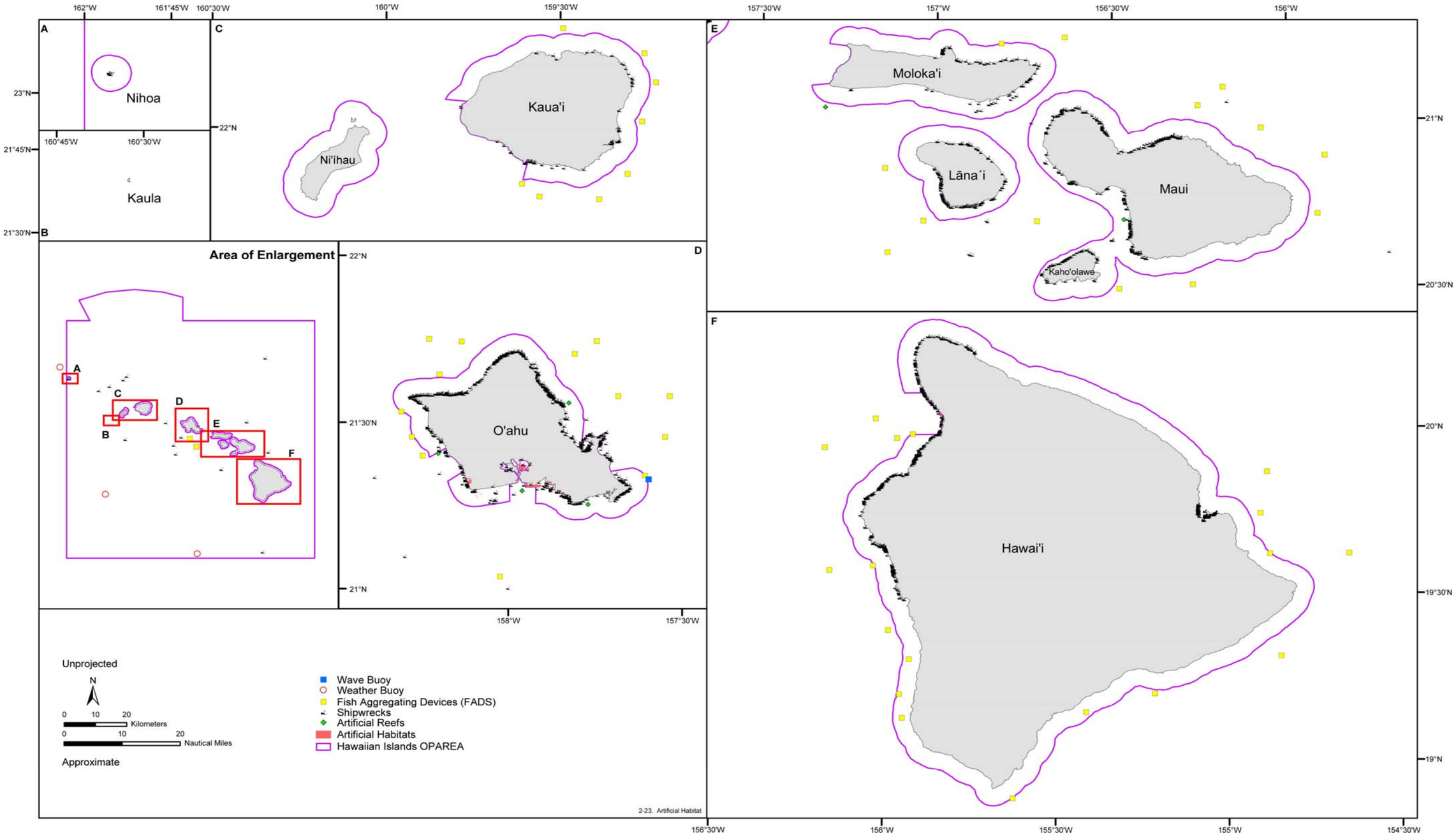


Figure 2-23. Artificial habitats (artificial reef, shipwreck, fish aggregating device (FAD), weather buoy, wave buoy, and artificial substrate) in the Hawaiian Islands OPAREA and vicinity. Source Data: NOS (2001), Veridian Corporation (2001), Hawai'i Fishing News (2004), and SHOP (2005).

by the design and arrangement of materials used in construction and functionally according to their purpose (Seaman and Jensen 2000). A large number of items are used for the creation of artificial reefs including natural objects such as wood (weighted tree trunks) and shells, quarry rock, or man-made objects like vehicles (automobile bodies, railroad cars, and military tanks), aircraft, steel-hulled vessels (Liberty ships, landing ship tanks, barges, and tug boats), home appliances, discarded construction materials (concrete culverts), scrap vehicle tires, oil/gas platforms, ash byproducts (solid municipal incineration, and coal/oil combustion), and prefabricated concrete structures (reef balls) (ARS 1997). The purpose of deploying artificial reefs in the marine environment is to: (1) enhance commercial fishery production/harvest; (2) enhance recreational activities (fishing, SCUBA diving, and tourism); (3) restore/enhance water and habitat quality; (4) provide habitat protection and aquaculture production sites; and (5) control fish mortality (Seaman and Jensen 2000).

Artificial reefs have been constructed from a variety of materials in the Hawaiian Islands including old cars, concrete pipes, tires, and concrete modules designed specifically for reefs (Fitzhardinge and Bailey-Brock 1989). The material chosen for construction could influence benthic community development. Concrete has been recommended for artificial reef construction because community development is most similar to coral; it is durable in seawater and it can be shaped to specification. Coral community development has been estimated to take at least 20 years in Hawaiian offshore environments; coral growth in the Hawaiian ecosystem is slow compared to lower latitude reefs (Fitzhardinge and Bailey-Brock 1989). Thus, it is important that artificial reefs should be durable and last for 20 years or more to allow for coral communities to develop. Transplantation of corals was also recommended to accelerate natural reef development (Fitzhardinge and Bailey-Brock 1989).

There are currently 4 artificial reefs dedicated around O‘ahu, one artificial reef located off the southwest coast of Moloka‘i, and one located off the southwest shore of Maui. The two artificial reefs located off the southern shore of O‘ahu and the one artificial reef located off of Moloka‘i are located within the Hawaiian Islands OPAREA (**Figure 2-23**).

2.7.10.2 Shipwrecks

In the Hawaiian Islands, there have been thousands of wrecks, from junked trucks to WWII submarines, most from the past two centuries (**Figure 2-23**). A WWII era Japanese submarine, scuttled by the Navy, is one of two I-400 Sensuikan Toku class subs captured in the Pacific a week after Japan surrendered in 1945. The U.S. deliberately sank both submarines. The 400 ft long hulls were the largest built prior to the nuclear ballistic missile submarines of the 1960s (Lee 2005). Also, in 2002, a Japanese midget submarine was discovered in the waters off O‘ahu that had been sunk an hour before Japan’s aerial attack on Pearl Harbor in 1941. However, the majority of current small boat groundings are the result of operator error. The Hawaiian shipping boom began in the 1800s, well after the heyday of piracy in the late 1600s to mid 1700s (Lee 2005). The Hawaiian island chain will most likely yield 19th century cargo ships, submarines, old whaling and merchant ships, fishing boats, or twentieth century recreational craft and land vehicles. Certain sunken vessels, such as the battleship USS Arizona at Pearl Harbor, are federally protected gravesites and cannot be used for recreational diving (Lee 2005). The Mahi, a scuttled Navy minesweeper off the Waianae Coast, has grown into a 58 m artificial reef that is home to corals, leaf scorpion fish, pufferfish, triggerfish, eels and magnificent eagle rays (Lee 2005). The nearby 30 m landing craft utility (LCU) ship also houses white-tipped reef sharks (Lee 2005).

Many of the shipwrecks along the shorelines of the study area have become popular dive sites (see Section 5.4 for more information on dive site locations). The groundings of ships can also create numerous hazards for navigation or the environment including the formation of large scars through seagrass beds or coral reefs, blockage of entry into ports or harbors, and the release of engine oil and fuel into the surrounding waters (NOAA 2004).

2.7.10.3 Fish Aggregating Devices

It has long been known that pelagic fishes will aggregate to floating objects like logs, nets, and other debris. However, these objects drift around and may only be occasionally encountered by lucky

fishermen. Researchers have found that anchoring a buoy or platform in the open ocean will also attract and hold pelagic fishes; although, whether the fish are attracted to the anchored FADs for the same reasons they associate with natural drifting objects is not yet known. Using acoustic transmitters, data loggers attached to some FAD moorings monitor the long-term movement patterns of tunas returning to the FADs (Sea Grant 2005). These studies have found that tunas tagged around seamounts behave very similarly to tunas tagged around FADs. It is thought that maybe the FAD serves the same function as a seamount, providing a point of reference for the tuna (Sea Grant 2005).

FADs consist of single or multiple floating devices (Samples and Hollyer 1989) connected to the ocean floor by ballast or anchors. Usually prefabricated, FADs are designed to attract fish species to them (Klima and Wickham 1971). Even though a naturally floating log attracts fish, it is not considered an FAD because humans did not intentionally place it in the ocean (Blue Water 2002). Two fundamentally different types of FADs have been employed since the 1970s: large floating FADs and small mid-water FADs. Large FADs have been deployed in water depths exceeding 1,800 m for ocean pelagic commercial and recreational fisheries. Small FADs have been used in more nearshore and coastal environments for recreational fisheries in water depths ranging from 15 to 30 m (Rountree 1990).

The State of Hawai‘i has placed FADs in the waters surrounding the MHI. These buoys attract schools of tuna and other important pelagic fishes, such as dolphinfish (mahimahi), wahoo (ono), and billfish. FADs allow fishermen to easily locate and catch these species (Sea Grant 2005). In 1980, the Division of Aquatic Resources designed, constructed and deployed 26 FADs in waters around the MHI. The FADs were located 2.4 to 25 miles offshore and in depths of 146 to 2,760 m as recommended by Hawaiian fishermen through statewide public meetings (Sea Grant 2005). In 1996, the State FAD program came under the operation of Hawai‘i Institute of Marine Biology (HIMB), SOEST, University of Hawai‘i in cooperation with the State of Hawai‘i’s Division of Aquatic Resources (HDAR) (Sea Grant 2005).

Over the last 16 years, FAD designs and deployment have been greatly improved to increase the life and effectiveness of the system. The State of Hawai‘i’s FAD Program utilizes two types of FADs: surface and subsurface (Sea Grant 2005). Surface FADs anchored using a catenary mooring method have an average life expectancy of about 3 to 4 years depending on sea and weather conditions. Subsurface FADs tend to last longer (5 to 6 years) because of decreased tugging on the mooring line and are less likely to be run over by ships. However, because they are beneath the surface, they tend to be harder for fishermen to locate (Sea Grant 2005). Currently, there are 55 surface and 4 subsurface FADs monitored and maintained statewide (**Figure 2-23**).

In the Hawaiian Islands, FADs have been shown to attract a wide variety of pelagic fish species of commercial and recreational fishing importance. The most commonly caught species include: skipjack tuna (aku), yellowfin tuna (ahi), bigeye tuna (ahi), albacore, dolphin fish (mahimahi), wahoo (ono), blue marlin (au), striped marlin (nairagi), mako sharks, silky sharks, oceanic whitetip sharks, galapagos sharks, mackerel (opelu), bonito (kawakawa) (Sea Grant 2005).

Buoys—A buoy is a floating platform used for navigational purposes or supporting scientific instruments that measure environmental conditions. Currently one wave buoy and two weather buoys capable of measuring wave energy, wave direction, and SST are active and located in the Hawaiian Islands OPAREA (**Figure 2-23**).

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3.0 SPECIES OF CONCERN

This chapter provides detailed information for marine mammals, sea turtles, and endangered, threatened, and candidate species of birds. These species are of particular interest to the Navy due to their protected status and potential to be impacted by Navy activities.

Marine mammals include cetaceans (whales, dolphins, and porpoises) and pinnipeds (seals, fur seals, and sea lions); cetaceans are the taxon group with the largest number of federally protected species in the Hawaiian Islands OPAREA. Section 3.1 of this chapter provides information on the 27 marine mammal species with potential occurrence in the Hawaiian Islands OPAREA. All marine mammals are protected by the MMPA; six cetacean and one pinniped species are additionally listed as threatened or endangered under the ESA. An overview of marine mammals, as well as a brief introduction to acoustics and hearing, which is useful in consideration of any potential anthropogenic impacts to these animals, is included. A detailed narrative has been prepared for each marine mammal species, consisting of a species' description, status, habitat preferences, distribution (including a focus on the Hawaiian Islands OPAREA), behavior and life history, and an account of its vocalizations and hearing capabilities (when available). Maps depicting the seasonal occurrence records and predicted areas of occurrence for each marine mammal species in the OPAREA are found in **Appendix B** (**Figures B-1a** through **B-25b**).

Five sea turtle species are known or have the potential to occur in the Hawaiian Islands OPAREA and all are either threatened or endangered. Section 3.2 of this chapter consists of an overview on sea turtle biology and life history and provides basic information on the hearing capabilities of these animals. Each of the sea turtle species is then described in detail by its physical description, status, habitat preferences, distribution (including a focus on the Hawaiian Islands OPAREA), and behavior and life history. Maps depicting the seasonal occurrence records and predicted areas of occurrence for each sea turtle species in the OPAREA are found in **Appendix C** (**Figures C-1a** through **C-6b**).

Nine bird species of concern may potentially occur in the Hawaiian OPAREA. Two are listed as endangered, one as threatened, and the others are listed as BCC by the USFWS. Section 3.3 of this chapter provides information about the physical description, status, habitat preferences, distribution (including a focus on the Hawaiian Islands OPAREA), and behavior and life history of these species. Maps depicting the occurrence records (if any) and predicted distributions (e.g., breeding and foraging) of each bird species in the OPAREA are embedded in this section (**Figures 3-5** through **3-13**).

The locations of literature citations in Chapter 3 differ from other MRA chapters. Literature cited in the marine mammal section is found at the end of Section 3.1, literature cited in the sea turtle section is found at the end of Section 3.2, and so forth. Map figures associated with the marine mammal and sea turtle species described in Chapter 3 are located in **Appendices B** and **C**. Map figures associated with the bird species are located within Section 3.3.

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3.1 MARINE MAMMALS

3.1.1 Introduction

More than 120 species of marine mammals occur worldwide (Rice 1998). The term “marine mammal” is purely descriptive, referring to mammals that carry out all or a substantial part of their foraging in marine, or in some cases, freshwater environments. Marine mammals as a group are comprised of various species from three orders (Cetacea, Carnivora, and Sirenia).

The vast majority of the 27 marine mammal species with confirmed or possible occurrence in the Hawaiian Islands OPAREA are cetaceans (whales and dolphins). Cetaceans are divided into two major suborders: Mysticeti and Odontoceti (baleen and toothed whales, respectively). Toothed whales use teeth to capture prey, while baleen whales use baleen plates to filter their food from the water. Beyond contrasts in feeding methods, there are also life history and social organization differences between baleen and toothed whales (Tyack 1986). Pinnipeds are divided into three families: Phocidae (the “true” or earless seals); Otariidae (sea lions and fur seals); and Odobenidae (walruses). Of the pinnipeds, only phocids are expected to occur in the study area. Relative to otariids, phocids are more streamlined and better adapted to an aquatic lifestyle. Some of the more obvious distinctions of phocids are that they lack external ears; are unable to rotate the pelvis to position the hind limbs under the body, leading to relatively poor terrestrial locomotion; use of pelvic flippers for underwater propulsion; and have small pectoral appendages (which are used for steering) (Riedman 1990). Beyond the physical differences, there are also life history differences (e.g., Riedman 1990).

3.1.1.1 Adaptations to the Marine Environment: Sound Production and Reception

Marine mammals display a number of anatomical and physiological adaptations to an aquatic environment which are discussed in detail by Pabst et al. (1999). Sensory changes from the basic mammalian scheme have also taken place in response to the different challenges an aquatic environment imposes. Sound travels faster and further in water than in air and hearing is, therefore, an important sense. Touch and sight are also well developed in whales and dolphins (Wartzok and Ketten 1999). Pinnipeds are faced with two different environments (terrestrial and aquatic), and as a result, they have compromised full underwater or full terrestrial adaptation to allow for functional vision and hearing in both media (Wartzok and Ketten 1999). The vibrissae (whiskers) of pinnipeds are extensively developed and provide the animal with information about contour and texture (Wartzok and Ketten 1999). A recent study has demonstrated that the whiskers of harbor seals are highly sensitive to water movements, and may be an important mechanism for seals hunting in the dark (or in murky waters) to detect water movements generated by fish (Dehnhardt et al. 2001; Vester et al. 2001).

Marine mammal vocalizations often extend both above and below the range of human hearing; vocalizations with frequencies lower than 18 Hertz (Hz) are labeled as infrasonic and those higher than 20 kiloHertz (kHz) as ultrasonic. Baleen whales primarily use the lower frequencies, producing tonal sounds in the frequency range of 20 to 3,000 Hz, depending on the species. Clark and Ellison (2004) suggested that baleen whales use low frequency sounds not only for long-range communication, but also as a simple form of echo ranging, using echoes to navigate and orient relative to physical features of the ocean. The toothed whales produce a wide variety of sounds, which include species-specific broadband “clicks” with peak energy between 10 and 200 kHz, individually variable “burst pulse” click trains, and constant-frequency or frequency-modulated whistles ranging from 4 to 16 kHz (Wartzok and Ketten 1999). The general consensus is that the tonal vocalizations (whistles) produced by toothed whales play an important role in maintaining contact between dispersed individuals, while clicks are used during echolocation (Wartzok and Ketten 1999). Burst pulses have also been strongly implicated in communication, with some scientists suggesting that they play an important role in agonistic encounters (McCowan and Reiss 1995), while others have proposed that they represent “emotive” signals in a broader sense, possibly representing graded communication signals (Herzing 1996). Sperm whales, however, are known to produce only clicks, which are used for both communication and echolocation (Whitehead 2003).

Sounds produced by pinnipeds include airborne and underwater vocalizations (Thomson and Richardson 1995). Calls include grunts, barks, and growls, in addition to the more conventional whistles, clicks, and pulses. The majority of pinniped sounds are in the sonic range (20 Hz to 20 kHz) (Ketten 1998; Wartzok and Ketten 1999). In general, phocids are far more vocal underwater than are otariids. Phocid calls are commonly between 100 Hz and 15 kHz, with peak spectra less than 5 kHz, but can range as high as 40 kHz (Ketten 1998; Wartzok and Ketten 1999). There is no evidence that pinnipeds echolocate (Schusterman et al. 2000).

Data on the hearing abilities of cetaceans are sparse, particularly for the larger cetaceans, such as the baleen whales. The auditory thresholds of some of the smaller odontocetes have been determined in captivity. It is generally believed that cetaceans should at least be sensitive to the frequencies of their own vocalizations. Comparisons of the anatomy of cetacean inner ears and models of the structural properties and the response to vibrations of the ear's components in different species provide an indication of likely sensitivity to various sound frequencies. The ears of small toothed whales are optimized for receiving high-frequency sound, while baleen whale inner ears are best in low to infrasonic frequencies (Ketten 1992, 1997).

In comparison with toothed whale hearing ability, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, and poorer sensitivity at the best frequency (Richardson et al. 1995). However, some pinnipeds (especially phocids) may have better sensitivity at low frequencies (<1 kHz) than do toothed whales (Richardson et al. 1995). The pinniped ear appears to have been constrained during its evolution by the necessity of functioning in two acoustically dissimilar media (air and water). The patterns of air and water hearing sensitivity appear to correspond to the patterns of life history of the pinniped species (Kastak and Schusterman 1998). Comparisons of the hearing characteristics of otariids and phocids suggest two types of pinniped ears, with phocids being better adapted for underwater hearing (Richardson et al. 1995; Kastak and Schusterman 1998; Ketten 1998; Wartzok and Ketten 1999). In phocids tested, peak sensitivities ranged between 10 and 30 kHz, with a functional high frequency limit of about 60 kHz (Richardson et al. 1995; Ketten 1998; Wartzok and Ketten 1999).

General reviews of cetacean and pinniped sound production and hearing may be found in Richardson et al. (1995), Edds-Walton (1997), Wartzok and Ketten (1999), and Au et al. (2000). For a discussion of acoustic concepts, terminology, and measurement procedures, as well as underwater sound propagation, Urick (1983) and Richardson et al. (1995) are recommended.

3.1.1.2 Marine Mammal Distribution—Habitat and Environmental Associations

Marine mammals inhabit most marine environments, from deep ocean canyons to shallow estuarine waters. They are not randomly distributed. Marine mammal distribution is affected by demographic, evolutionary, ecological, habitat-related, and anthropogenic factors (Bowen et al. 2002; Bjørge 2002; Forcada 2002; Stevick et al. 2002). Most information on marine mammal distribution has been obtained from shipboard and aerial observations, which provide a very limited perspective on their life at or near the surface, with little insight into their behavior under the water where they spend up to 90% of their time (e.g., Costa 1993).

Our knowledge of marine mammal habitats is often quite limited. Poor definition of spatiotemporal scales is the primary cause for confusion and disagreement among studies about factors that associate with marine mammal (in particular, cetacean) distribution (e.g., Jaquet 1996; Jaquet et al. 1996; Gregr and Trites 2001; Hamazaki 2002; Ferguson 2005). Marine mammals may not respond to instantaneous changes in ocean conditions, instead there might be a time lag between the change of oceanographic conditions and top-level predator responses. As noted by Ferguson (2005), time lags are particularly important when proxies such as chlorophyll data are used to indicate toothed whale habitat. It is not the primary producers themselves that the whales eat, but the squid and mesopelagic fishes several trophic levels higher up. Time lapses before energy and nutrients from the primary producers climb the food chain up to cetacean prey species. For baleen whales feeding on zooplankton, which are trophically close to primary production, this lag may be on the order of several weeks, whereas the lag might be considerably greater for sperm whales where the primary prey (cephalopods) are removed from primary

production by approximately four months (Gregr and Trites 2001). Integrated approaches are underway in some areas to examine the temporal and spatial relationship of marine mammals to the structure and variability of their habitat (e.g., Croll et al. 1998). Efforts are also underway in habitat modeling, which predicts potential habitat in unsurveyed areas based on the relationships between species' presence and the environmental parameters observed in surveyed areas (e.g., Gregr and Trites 2001; Hamazaki 2002; Ferguson 2005; Hastie et al. 2005).

Even in the best-studied marine mammal species, determining the fundamental reasons behind the linkage between habitat variables and distribution can be problematic, and often requires extensive datasets (e.g., Forney 2000; Gregr and Trites 2001; MacLeod and Zuur 2005). For example, though topography might increase primary productivity, and as a result, provide a local increased availability of prey, not every marine mammal species is necessarily concentrated in that area. Additional factors may be involved, such as habitat segregation between other species that share the same ecological niche (MacLeod and Zuur 2005). The degree of similarity in diet between two or more predators that occur in the same habitat will affect the level of competition between these predators. Competition between predators can result in the exclusion of one or more of them from a specific habitat. For example, MacLeod et al. (2003) suggested that an example of niche segregation might be that *Mesoplodon* spp. occupy a separate dietary niche from bottlenose whales (*Hyperoodon*) and Cuvier's beaked whales (*Ziphius*), though they share the same distribution. In contrast, *Hyperoodon* and *Ziphius* appear to occupy very similar dietary niches but have geographically segregated distributions, with *Hyperoodon* occupying cold-temperate to polar waters and *Ziphius* occupying warm-temperate to tropical waters.

Movements are often related to feeding or breeding activity (Stevick et al. 2002). A migration is the periodic movement of all, or significant components of an animal population from one habitat to one or more other habitats and back again. Migration is an adaptation that allows an animal to monopolize areas where favorable environmental conditions exist for feeding, breeding, and/or other phases of the animal's life history. Some baleen whale species, such as humpback whales, make extensive annual migrations to low-latitude mating and calving grounds in the winter and to high-latitude feeding grounds in the summer (Corkeron and Connor 1999). These migrations undoubtedly occur during these seasons due to the presence of highly productive waters and associated cetacean prey species at high latitudes and of warm water temperatures at low latitudes (Corkeron and Connor 1999; Stern 2002). The timing of migration is often a function of age, sex, and reproductive class. Females tend to migrate earlier than males and adults earlier than immature animals (Stevick et al. 2002; Craig et al. 2003). Not all baleen whales, however, migrate. Some individual gray, fin, Bryde's, minke, and blue whales may stay year-round in a specific area.

Cetacean movements can also reflect the distribution and abundance of prey (Gaskin 1982; Payne et al. 1986; Kenney et al. 1996; Croll et al. 1998). Cetacean movements have also been linked to indirect indicators of prey, such as temperature variations, sea-surface chl *a* concentrations, and features such as bottom depth (Fiedler 2002). Oceanographic conditions such as upwelling zones, eddies, and turbulent mixing, can create regionalized zones of enhanced productivity that are translated into zooplankton concentrations, and/or entrain prey.

Since most toothed whales do not have the fasting capabilities of the baleen whales, toothed whales probably follow seasonal shifts in preferred prey or are opportunistic feeders, taking advantage of whatever prey happens to be in the area. Small-scale hydrographic fronts may act as convergence zones. Bottlenose dolphins have demonstrated a spatial association with the area near the surface features of tidal intrusion fronts, which could be related to increased foraging efficiency resulting from the accumulation of prey in the frontal region (Mendes et al. 2002).

Long-ranging movements are quite common in pinnipeds; hooded seals (*Cystophora cristata*) and northern elephant seals are both good examples, since they make extensive movements (Le Bouef et al. 2000; Mignucci-Giannoni and Odell 2001). Pinniped movements depend on the abundance of prey, its energy content, and the seasonality of prey distribution (Forcada 2002). Additionally, the pinniped reproductive cycle mandates that individuals return to land or ice to pup (give birth), nurse, and rear their offspring and molt. Pinnipeds will also haul out for resting, thermoregulation, and to escape predators,

among other reasons. Phocids appear to migrate more than otariids, as they generally live in higher latitudes, where the environment (i.e., ice cover) is more variable (Bowen and Siniff 1999). As with migrating cetaceans, there are variations in the timing of these movements and in the patterns between age classes (Forcada 2002).

Occurrence of cetaceans outside the area with which they are usually associated may reflect fluctuations in food availability. Some studies have correlated shifts in the distribution of some baleen whale and toothed whale populations with ecological shifts in prey patterns after intense fishing efforts by commercial fisheries in the western North Atlantic (Payne et al. 1986, 1990; Kenney et al. 1996). DeMaster et al. (2001) predicted, based upon current data on human population growth and marine mammal fisheries interactions, that in the future, the most common type of competitive interaction would be ones in which a fishery has an adverse effect on one or more marine mammal populations without necessarily overfishing the target species of the fishery.

Pinniped movements, as noted earlier, are a reflection of both foraging ecology and the need to return to land for breeding and molting. Like cetaceans, pinnipeds are often associated with either transient (oceanographic features such as frontal systems) or non-transient, physical features that serve to concentrate prey. Individual seal foraging behavior is probably related to oceanographic features in the water column, such as thermal discontinuities that act to concentrate prey species (Field et al. 2001). McConnell and Fedak (1996) hypothesized that seals out in the open ocean may be influenced by mesoscale frontal systems with locally enhanced prey abundance. All pinniped species leave the water periodically to haul out on land or ice to molt, sleep, mate, pup, or avoid marine predators (Riedman 1990). Human disturbance can affect haulout behavior, including causing seals to return to the water or decreasing attendance and nursing in mother and pup seals (Schneider and Payne 1983).

In recent years there has been growing concern about the effects of climate change on marine mammal populations (MacGarvin and Simmonds 1996; IWC 1997; Evans 2002; Würsig et al. 2002; Le Boeuf and Crocker 2005). Large-scale climatic events and long-term temperature changes may affect the distribution and abundance of marine mammal species, either impacting them directly or indirectly through alterations of habitat characteristics and distribution or prey availability (Kenney et al. 1996; IWC 1997; Harwood 2001; Greene and Pershing 2004; Keiper et al. 2005; Le Boeuf and Crocker 2005). In the Pacific Ocean, climate variability has been linked to the PDO and the ENSO. The PDO is a long-term climatic pattern capable of altering SST, winds, and SLP over the Pacific Basin (Mantua 2002; Mantua and Hare 2002) and has been linked to cycles in fishery production (e.g., Hare 1996). In years when the PDO Index is positive, the central North Pacific experiences anomalously cold SSTs, while the western coast of the U.S. experiences anomalously cold temperatures. When the PDO index is negative, the opposite occurs. The PDO is weak in tropical areas, such as the Hawaiian Islands OPAREA, and thus climatic anomalies are most likely due to ENSO forcings (Mantua 2002; Mantua and Hare 2002). The ENSO is the result of interannual swings in SLPs in the tropical Pacific between the eastern and western hemispheres (Conlan and Service 2000). Typically, ENSO events last 6 to 18 months, and can initiate large shifts in the global atmospheric circulation. In the western equatorial Pacific, SST is lower than in non-El Niño years (Kubota 1987), and rainfall patterns shift eastward across the Pacific as the strength of the tradewinds weakens, resulting in increased (sometimes extreme) rainfall in the southern U.S. and Peru and drought conditions in the western Pacific (Conlan and Service 2000). An ENSO can have dramatic effects on rainfall and phytoplankton community structure; however, ENSO appears to have little, if any, effect on SST in the Hawaiian Islands OPAREA (Karl et al. 1995; DoD 2002; Fletcher et al. 2002). Long-term climate change has also been recognized in the Hawaiian Islands OPAREA and vicinity. Over the last century rainfall amounts have decreased by 20% and the average temperature in the region has increased 2.4°C (EPA 1988). Gregr and Trites (2001) noted difficulties in interpreting climate change impacts in working with habitat prediction models, including that using incorrect spatial scales might fail to detect a shift in habitat usage. For further information regarding the PDO, ENSO, and long-term climate change, refer to Chapter 2.

3.1.2 Marine Mammals of the Hawaiian Islands OPAREA

The vast majority of the 27 marine mammal species occurring in the Hawaiian Islands OPAREA are cetaceans (whales and dolphins) (**Table 3-1**). The Hawaiian monk seal is the only pinniped species with expected occurrence here. The northern elephant seal very rarely occurs in this area. At least 15 species of cetaceans are regularly documented in Hawaiian waters, yet until recently, as noted by Baird et al. (2003a) virtually all research has been focused on just two species, the humpback whale and the spinner dolphin; both occur in nearshore waters in this area. As noted by Maldini et al. (2005), there have been no systematic surveys undertaken in both nearshore and offshore waters and/or year-round across the entire Hawaiian Islands area to monitor cetacean abundance and distribution patterns.

Table 3-1. Marine mammal species of the Hawaiian Islands OPAREA. Taxonomy follows Rice (1998) for pinnipeds and sirenians and IWC (2004) for cetaceans. [Regular = A species that occurs as a regular or normal part of the fauna of the area, regardless of how abundant or common it is; Rare = A species that only occurs in the area sporadically; Extralimital = A species that does not normally occur in the area, but for which there are one or more records that are considered beyond the normal range of the species; *****includes more than one species, but nomenclature is still unsettled].

	Scientific Name	Status	Occurence[1]
Order Cetacea			
Suborder Mysticeti (baleen whales)			
Family Balaenidae (right whales)			
North Pacific right whale	*Eubalaena japonica*	Endangered	Rare
Family Balaenopteridae (rorquals)			
Humpback whale	*Megaptera novaeangliae*	Endangered	Regular
Minke whale	*Balaenoptera acutorostrata*		Rare
Sei whale	*Balaenoptera borealis*	Endangered	Rare
Fin whale	*Balaenoptera physalus*	Endangered	Rare
Blue whale	*Balaenoptera musculus*	Endangered	Rare
Bryde's whale	*Balaenoptera edeni/brydei**		Regular
Suborder Odontoceti (toothed whales)			
Family Physeteridae (sperm whale)			
Sperm whale	*Physeter macrocephalus*	Endangered	Regular
Family Kogiidae (pygmy sperm whales)			
Pygmy sperm whale	*Kogia breviceps*		Regular
Dwarf sperm whale	*Kogia sima*		Regular
Family Ziphiidae (beaked whales)			
Cuvier's beaked whale	*Ziphius cavirostris*		Regular
Blainville's beaked whale	*Mesoplodon densirostris*		Regular
Longman's beaked whale	*Indopacetus pacificus*		Regular
Family Delphinidae (dolphins)			
Rough-toothed dolphin	*Steno bredanensis*		Regular
Common bottlenose dolphin	*Tursiops truncatus*		Regular
Pantropical spotted dolphin	*Stenella attenuata*		Regular
Spinner dolphin	*Stenella longirostris*		Regular
Striped dolphin	*Stenella coeruleoalba*		Regular
Risso's dolphin	*Grampus griseus*		Regular
Melon-headed whale	*Peponocephala electra*		Regular
Fraser's dolphin	*Lagenodelphis hosei*		Rare
Pygmy killer whale	*Feresa attenuata*		Regular
False killer whale	*Pseudorca crassidens*		Regular
Killer whale	*Orcinus orca*		Regular
Short-finned pilot whale	*Globicephala macrorhynchus*		Regular
Order Carnivora			
Suborder Pinnipedia (seals, sea lions, walruses)			
Family Phocidae (true seals)			
Hawaiian monk seal	*Monachus schauinslandi*	Endangered	Regular
Northern elephant seal	*Mirounga angustirostris*		Rare

There are a number of records of common dolphins (*Delphinus* spp.) reported for the Hawaiian Islands OPAREA, mostly from the Hawai‘i Longline Observer Program and the NMFS Platforms of Opportunity Program (POP). However, many of these records, especially those from the MHI and south, are suspect. Common dolphins can be very difficult for observers to distinguish from other long-beaked, oceanic species (such as pantropical spotted, spinner, and striped dolphins). In fact, in reviewing Walsh and Kobayashi (2004), it is clear that there were problems in the identifications from the longline fishery (e.g., 9% of reports were of *Delphinus* spp., which does not agree with recent survey results), and it is likely that most or all of the *Delphinus* records reported therein are inaccurate. There are no stranding records for this species in Hawai‘i (Maldini 2003; Maldini et al. 2005), and there are no confirmed sightings (i.e., those supported by photos, video, or detailed notes from experienced observers) from near the MHI. However, short-beaked common dolphins were the most frequently-caught cetacean species in the now-defunct high-seas driftnet fisheries for flying squid and tunas in the central North Pacific Ocean (Ferrero and Walker 1995). These fisheries captured common dolphins as far south as the southern extent of the fishing area, at about 29°N (Ferrero and Walker 1995), well north of the MHI, but it is probable that the species extends south of this area as well (Jefferson personal communication). Furthermore, there is a report of a short-beaked common dolphin (*Delphinus delphis*) taken several hundred miles northeast of Hawai‘i, in a U.S. longline fishery in the central Pacific at about 35°N, 143°W (Forney 2004). However, the lack of any sightings of this species on recent extensive aerial and shipboard surveys of Hawaiian waters, extending out to the 200 mile EEZ (e.g., Mobley et al. 2000; Barlow et al. 2004), combined with the lack of strandings, strongly suggests that common dolphins are either absent or rare in waters of the Hawaiian Islands OPAREA. This is further supported by the known habitat preferences of this species, which occurs mostly in upwelling-modified waters in the eastern Pacific (Au and Perryman 1985; Ballance and Pitman 1998; Reilly 1990). Waters such as this, with strong upwelling are not known to occur in the OPAREA (Karl 1999).

The Hawaiian Islands OPAREA lies within an oceanic province with generally very low levels of primary productivity (see **Figure 2-11**). Any local hotspots in production may attract all components of the local food chain. Strong interactions between the local oceanography and topography exist in the study area. The Hawaiian Islands OPAREA and vicinity is comprised of a series of volcanic seamounts, several of which have broken the surface to form the Hawaiian Islands. Seamount topography has been previously correlated with enhanced production due to the formation of vortices capable of mixing nutrients to the surface and entraining phytoplankton in the overlying waters (reviewed by Rogers 1994). For an in depth examination of seamounts, refer to Chapter 2.

In addition, the passage of the North Equatorial Current (NEC) through the Hawaiian archipelago is capable of creating regions of enhanced turbulence. Passage of the current of the NEC can initiate the formation of eddies on the lee side of the islands (Wolanski et al. 2003); these are capable of entraining phytoplankton and creating localized regions of enhanced primary production visible as increased concentrations of chl *a* in the surface waters (see the lee side of Hawai‘i and O‘ahu, **Figure 2-11**). In addition, passage of currents through a narrow channel (as found in the Alenuehaha Channel between Hawai‘i and Maui) can create localized zones of turbulent flow capable of mixing nutrients into the surface layer to fuel primary production (Gilmartin and Revelante 1974; Simpson et al. 1982; **Figure 2-11**). This “island effect” on productivity is covered in further detail in Chapter 2.

Gannier (2002) reviewed cetacean occurrence in various locations of the tropical Pacific and provided a general assessment. Areas without a significant continental shelf domain do not shelter large densities of bottlenose dolphins. A stable component of four oceanic or semi-oceanic species is present in all areas: spinner and pantropical spotted dolphins, Risso’s dolphin, and pilot whale. Spinner and pantropical spotted dolphins are among the two most frequently sighted species in all areas. A general rule is that in many tropical areas, spinner dolphins and pantropical spotted dolphins are the most common cetacean species (Jefferson personal communication).

3.1.2.1 Marine Mammal Occurrences

The distribution of available marine mammal records is presented for spring through summer (March through September) and fall through winter (October through February) in the maps in **Appendix B**. An

occurrence record does not reflect the number of marine mammals; due to the social nature of cetaceans, multiple individuals of a species are often sighted at the same time at the same location. It should also be noted that the number of marine mammal observations in this area is a function of the level of effort to collect this information, rather than just the actual marine mammal abundance in the area.

A listing and description of data sources used to determine each species' occurrence in the Hawaiian Islands OPAREA is found in Appendix A-2, while the process used to create the map figures is described in Section 1.4.2.2. On the map figures, various types of shading and terminology designate the occurrence of marine mammals in the Hawaiian Islands OPAREA. "Area of primary occurrence" (area shaded in dark blue) is defined as the areas and habitats where the species is primarily found. "Area of secondary occurrence" (area shaded in medium blue) is the areas and habitats where the species may be found, especially during "anomalous" environmental conditions. "Area of rare occurrence" (light blue area) is the areas and habitats where the species is not expected to be found regularly. "Area of no survey effort" (hatched) is the areas and habitats for which insufficient information is available to establish occurrence due to lack of survey effort (best judgment follows then whether the area would be anticipated to be of primary or secondary occurrence). Protected species biologists with the NMFS-SWFSC ultimately devised these qualitative terms.

The oceanic waters surrounding the Hawaiian Islands do not contain a true continental shelf, and therefore no true shelf break; the region in which there is a sharp break in the slope of the island shelf (Kennett 1982; Thurman 1997). Rather, the Hawaiian Islands are composed of a series of volcanic islands that have broken the sea surface where the offshore bottom topography is steep and slopes rapidly reach the ocean basin floor (4,000 m) within tens of kilometers (see **Figures 2-2** and **2-3**).

Each marine mammal species is listed below with its description, status, habitat preference, distribution (including location and seasonal occurrence in the Hawaiian Islands OPAREA), behavior and life history, and information on its acoustics and hearing ability. Species appearance within the text begins with threatened and endangered marine mammals, while the remaining species follow the taxonomic order as presented in **Table 3-1**.

3.1.2.2 Threatened and Endangered Marine Mammals of the Hawaiian Islands OPAREA

There are seven marine mammal species that are listed as endangered under the ESA with confirmed or possible occurrence in the study area: North Pacific right whale, humpback whale, sei whale, fin whale, blue whale, sperm whale, and Hawaiian monk seal. Most of the cetacean species and the Hawaiian monk seal are expected to occur in the OPAREA.

Information Specific to the Hawaiian Islands OPAREA—Humpback and sperm whale records dominate the determination of the occurrence patterns for threatened and endangered cetaceans throughout the year. During the fall-winter period, the area of primary occurrence for threatened and endangered cetaceans is from the shoreline to seaward of the OPAREA boundary, excluding Pearl Harbor where the occurrence of this group of animals is expected to be rare (**Figures B-1a** and **B-1b**). During the spring-summer period, the area of primary occurrence is expected to be seaward of the shelf break. There is an area of secondary occurrence between the shore and the shelf break, excluding Pearl Harbor where the occurrence of this group of animals is expected to be rare (**Figures B-1a** and **B-1c**).

- North Pacific Right Whale (*Eubalaena japonica*)

  Description—Until recently, right whales in the North Atlantic and North Pacific were classified together as a single species, referred to as the "northern right whale." However, genetic data indicate that these two populations represent separate species: the North Atlantic right whale (*Eubalaena glacialis*) and the North Pacific right whale (*Eubalaena japonica*) (Rosenbaum et al. 2000).

  Right whales have a robust body shape; overall body color is black, although many individuals also have irregular white patches on their undersides (Reeves and Kenney 2003). There is no dorsal fin on the broad back. The largest recorded North Pacific right whales were an 18.3 m female and a 16.4

m male (Omura et al. 1969); North Pacific right whales are larger than their North Atlantic counterparts (Reeves and Kenney 2003). The head is nearly one-third of the total body length. The jawline is arched and the upper jaw is very narrow in dorsal view. The head is covered with irregular whitish patches called "callosities," which have whale lice attached.

Status—The North Pacific right whale is perhaps the world's most endangered large whale species (Perry et al. 1999; IWC 2001). North Pacific right whales are classified as endangered both under the ESA and the IUCN Red List (Reeves et al. 2003). There are insufficient genetic or resighting data to address whether there is support for the traditional separation into eastern and western stocks (Brownell et al. 2001); however, Clapham et al. (2004) noted that north-south migratory movements support the hypothesis of two largely discrete populations of right whales in the eastern and western North Pacific. No reliable population estimate presently exists for this species; the population in the eastern North Pacific is considered to be very small, perhaps only in the tens of animals (NMFS 2002; Clapham et al. 2004), while in the western North Pacific, the population may number at least in the low hundreds (Brownell et al. 2001; Clapham et al. 2004). There is no designated critical habitat for the North Pacific right whale (NMFS 2002).

Habitat Preferences—Feeding habitat for right whales is defined by the presence of sufficiently high densities of prey, especially calanoid copepods (Reeves and Kenney 2003). Development of those patches is essentially a function of oceanic conditions, such as SST, stratification, bottom topography, and currents, which concentrate zooplankton, and concentration is probably enhanced by the behavior of the organisms themselves (Beardsley et al. 1996; Tynan et al. 2001). The shift in Bering Sea right whale occurrences from deep waters in the mid-twentieth century to the mid-shelf region in the late 1900s was attributed to changes in the availability of optimal zooplankton patches, possibility relating to climatic forcing (variability in oceanic conditions caused by changes in atmospheric patterns) (Tynan et al. 2001). Sightings in the Bering Sea are clustered in relatively shallow water with a bottom depth of 50 to 80 m (Tynan et al. 2001). However, North Pacific right whales also have been sighted in waters with bottom depths as deep as 1,700 m (Carretta et al. 1994). The IWC (2001) noted a surprising absence of evidence for coastal calving grounds, since right whales in the North Atlantic and in the Southern Hemisphere both have calving grounds located in shallow bays, lagoons, or at least in waters over the continental shelf.

Distribution—Right whales occur in sub-polar to temperate waters. The North Pacific right whale historically occurred across the Pacific Ocean north of 35°N, with concentrations in the Gulf of Alaska, eastern Aleutian Islands, south-central Bering Sea, Sea of Okhotsk, and the Sea of Japan (Omura et al. 1969; Scarff 1986; Clapham et al. 2004). Presently, sightings are extremely rare, occurring primarily in the Okhotsk Sea and the eastern Bering Sea (Brownell et al. 2001; Shelden et al. 2005). Prior to 1996, right whale sightings were very rare in the eastern North Pacific (Scarff 1986; Brownell et al. 2001). Recent summer sightings of right whales in the eastern Bering Sea represent the first reliable consistent observations in this area since the 1960s (Tynan et al. 2001; LeDuc 2001). Right whales were probably never common along the west coast of North America (Scarff 1986; Brownell et al. 2001).

Historical whaling records provide virtually the only information on North Pacific right whale distribution. During the summer, whales were found in the Gulf of Alaska, along both coasts of the Kamchatka Peninsula, the southeastern Bering Sea, and in the Okhotsk Sea (Clapham et al. 2004; Shelden et al. 2005). The whales were most widely dispersed in fall and spring, with whales occurring in mid-ocean waters and extending from the Sea of Japan to the eastern Bering Sea. In winter, right whales were found in the Ryukyu Islands (south of Kyushu, Japan), the Bonin Islands, the Yellow Sea, and the Sea of Japan. Historical concentrations of sightings in the Bering Sea together with the recent sightings indicate that this region remains an important summer habitat for eastern North Pacific right whales (Tynan et al. 2001; Shelden et al. 2005). Scarff (1986) hypothesized that those right whales that summer in the eastern North Pacific mate, calve, and overwinter in the mid-Pacific or in the western North Pacific.

Current distribution patterns and migration routes of these whales are not known (Scarff 1986; NMFS 2002). The extent to which right whales in the eastern North Pacific engage in north-south migrations is unknown (Scarff 1986). There is very little information on the winter distribution of right whales in the eastern North Pacific. The location of calving grounds for the eastern North Pacific population is unknown (Scarff 1986; NMFS 2002; Clapham et al. 2004). There are no records of newborn or very young calves in the eastern North Pacific, which appears to reflect a true absence of coastal calving grounds, at least within historic times (Scarff 1986). Neither the west coast of North America nor the Hawaiian Islands constituted a major calving ground for right whales within the last 200 years (Scarff 1986). No coastal calving grounds for right whales have been found in the western North Pacific either (Scarff 1986). Mid-ocean whaling records of right whales in the winter suggest that right whales may have wintered and calved far offshore in the Pacific (Scarff 1986, 1991; Clapham et al. 2004). Such pelagic calving would appear to be inconsistent with the records of nearshore calving grounds in other locales for the other right whale species.

Feeding grounds for North Pacific right whales are also poorly known. Based on historical whaling records and some recent sightings, the principal feeding grounds were most likely in the Sea of Okhotsk, central and eastern Bering Sea, and Gulf of Alaska. All of these feeding areas are much further offshore than the well-studied North Atlantic habitats. The eastern Bering Sea is used for foraging (NMFS 2002). Right whales in the eastern Pacific have been observed each summer since 1996 in the eastern Bering Sea in roughly the same location (Goddard and Rugh 1998; Moore et al. 2000; Tynan et al. 2001; Shelden et al. 2005).

Right whales can make long-range movements. For example, radio-tagged North Atlantic right whales make extensive movements, traveling into waters with bottom depths as great as 4,200 m (Knowlton et al. 1992; Mate et al. 1997). One individually-identified right whale was documented to make a two-way trans-Atlantic migration from the eastern coast of the U.S. to a location in northern Norway (Jacobsen et al. 2004). Clapham et al. (2004) noted seasonal movements in their review of North Pacific right whale records: a general northward migration in spring from lower latitudes (March through May); major concentrations above 40°N in summer (May through August); sightings diminish and occur further south in fall (September through October); few animals have been recorded anywhere during the winter (November through February).

- Information Specific to the Hawaiian Islands OPAREA—There are very few recorded sightings from the Hawaiian Islands; they are from both shallow and deep waters (Herman et al. 1980; Rowntree et al. 1980; Salden and Mickelsen 1999; **Figures B-2a** and **B-2b**). The highly endangered status of this species necessitates an extremely conservative determination of its occurrence (Jefferson personal communication). Secondary occurrence is expected from the coastline to seaward of the OPAREA boundaries (**Figures B-2a** and **B-2b**). Right whales are not expected to make their way into lagoons or busy harbors; therefore, occurrence in Pearl Harbor would be rare (Jefferson personal communication). Right whale occurrence patterns are assumed to be similar throughout the year. Based on migration patterns and whaling data, the Hawaiian Islands may have been a breeding ground for North Pacific right whales in the past (Clapham et al. 2004). Therefore, occurrence patterns would likely change in this area if the population were to increase substantially.

Behavior and Life History—In the North Pacific, few individuals are observed and they are usually alone (Brownell et al. 2001). The only exception is an area of the southeastern Bering Sea where small groups of right whales (at least five, and possibly seven individuals, but no calves) have been sighted in several successive years (Tynan et al. 2001). Right whales have been observed in association with humpback whales in Hawaiian waters (Herman et al. 1980; Salden and Mickelsen 1999).

Right whales in the North Pacific probably reach sexual maturity at a body length of 14.5 to 15.5 m for males and 15 to 16 m for females, which corresponds to an age of approximately 10 years (Omura et al. 1969). Calves are born during December through March after 12 to 13 months of gestation (Best

1994). Weaning occurs at 8 to 17 months (Hamilton et al. 1995). There is usually a three year calving interval in the North Atlantic (Kraus et al. 2001).

North Pacific right whales probably feed almost exclusively on calanoid copepods (*Canalus marshallae*), a type of zooplankton. High concentrations of copepods have been recorded in zooplankton samples collected in 1997 and 1999 near right whales in the North Pacific. North Pacific right whales have also been observed feeding on an extensive coccolithophore bloom of *Emiliania huxleyi* (Tynan et al. 2001). When feeding, a right whale skims prey from the water (Pivorunas 1979). Feeding can occur throughout the water column (Watkins and Schevill 1976, 1979; Goodyear 1993; Winn et al. 1995).

Dives of 5 to 15 min or even longer have been reported (Winn et al. 1995; Mate et al. 1997; Baumgartner and Mate 2003). Baumgartner and Mate (2003) found that the average depth of a North Atlantic right whale dive was strongly correlated with both the average depth of peak copepod abundance and the average depth of the bottom mixed layer's upper surface. North Atlantic right whale feeding dives are characterized by a rapid descent from the surface to a particular depth between 80 and 175 m, remarkable fidelity to that depth for 5 to 14 min, and then rapid ascent back to the surface (Baumgartner and Mate 2003). Longer surface intervals have been observed for reproductively-active females and their calves (Baumgartner and Mate 2003).

Acoustics and Hearing—North Pacific right whale calls are classified into five categories: (1) up; (2) down-up; (3) down; (4) constant; and (5) unclassified (McDonald and Moore 2002). The 'up' call is the predominant type (McDonald and Moore 2002; Mellinger et al. 2004). Typically, the 'up' call is a signal sweeping from about 90 to 150 Hz in 0.7 sec (McDonald and Moore 2002; Wiggins et al. 2004). Right whales commonly produce calls in a series of 10 to 15 calls lasting 5 to 10 mins, followed by silence lasting an hour or more; some individuals do not call for periods of at least four hours (McDonald and Moore 2002). This calling pattern is similar to the 'moan cluster' reported for North Atlantic right whales by Matthews et al. (2001). Vocalization rates of North Atlantic right whales are also highly variable, and individuals have been known to remain silent for hours (Gillespie and Leaper 2001).

Frequencies of these vocalizations are between 50 and 500 Hz (Matthews et al. 2001; Laurinolli et al. 2003); typical sounds are in the 300 to 600 Hz range with up- and down-sweeping modulations (Vanderlaan et al. 2003). Vanderlaan et al. (2003) found that lower (<200 Hz) and higher (>900 Hz) frequency sounds are relatively rare. Source levels for pulsive calls of North Atlantic right whales are 172 to 187 dB (decibels) with a reference pressure of one micropascal at one meter (dB re 1 μPa-m) (Thomson and Richardson 1995; Parks and Tyack 2005). Other sound types produced by North Atlantic right whales have source levels ranging from 137 to 162 dB re 1 μPa-m for tonal calls and 174 to 192 dB re 1 μPa-m for broadband gunshot sounds (Parks and Tyack 2005).

Morphometric analyses of the inner ear of right whales resulted in an estimated hearing frequency range of approximately 10 Hz to 22 kHz, based on established marine mammal models (Parks et al. 2004). Research by Nowacek et al. (2004) on North Atlantic right whales suggests that received sound levels of only 133 to 148 dB re 1 μPa-m for the duration of the sound exposure are likely to disrupt feeding behavior; the authors did note, however, that a return to normal behavior within minutes of when the source is turned off would be expected.

- Humpback Whale (*Megaptera novaeangliae*)

Description—Humpback whale adults are 11 to 16 m in length and are more robust than other rorquals. The body is black or dark gray, with very long (about one-third of the body length) flippers that are usually white; however, North Pacific humpback whales have more black than in the Southern Hemisphere (Jefferson et al. 1993; Clapham and Mead 1999; Jefferson personal communication). The head is larger than in other rorquals. The flukes have a concave, serrated trailing edge; the ventral side is variably patterned in black and white. Individual humpback whales may be identified using these patterns (Katona et al. 1979).

Status—Humpback whales are classified as endangered under the ESA. There is no designated critical habitat for this species in the North Pacific. As an endangered species under the ESA, the humpback whale is designated as depleted under the MMPA and, as a result, is classified as a strategic stock (Angliss and Lodge 2004).

Recent information from photo-identification studies and genetic work suggests that there are probably three stocks or populations in the North Pacific: eastern, central, and western North Pacific stocks (Baker et al. 1998; Calambokidis et al. 2001; Angliss and Lodge 2004). Calambokidis et al. (2001) further suggested that up to six subpopulations of humpback whales in the North Pacific Ocean might be recognized. Site fidelity to feeding areas is very high, but there is at least occasional interchange among different breeding areas (Salden et al. 1999; Calambokidis et al. 2001). Most individuals that breed in the Hawaiian Islands travel to waters off Alaska to feed (Baker et al. 1986; Calambokidis et al. 2001). The Hawaiian breeding group shares some genetic inter-relatedness with the group that breeds off the coast of Mexico (Baker et al. 1998) and even off Japan (Salden et al. 1999; Darling and Mori 1993), but it is rare enough that these are still considered to be separate management stocks.

Humpback whales in Hawaiian waters are considered to be from the central North Pacific stock (Angliss and Lodge 2004). There are an estimated 4,005 individuals in this stock (Angliss and Lodge 2004). Estimates from Calambokids et al. (1997) and Baker and Herman (1987) suggest that the stock has increased in abundance in recent years.

Habitat Preferences—Although humpback whales typically travel over deep, oceanic waters during migration, their feeding and breeding habitats are mostly in shallow, coastal waters over continental shelves (Clapham and Mead 1999). Shallow banks or ledges with high sea-floor relief characterize feeding grounds (Payne et al. 1990; Hamazaki 2002). The habitat requirements of wintering humpbacks appear to be determined by the conditions necessary for calving. Breeding grounds are in tropical or subtropical waters, generally with shelter created by islands or reefs. Optimal calving conditions are warm water (24° to 28°C) and relatively shallow, low-relief ocean bottom in protected areas (behind reefs), apparently to take advantage of calm seas, to minimize the possibility of predation by sharks, or to avoid harassment by males (Smultea 1994; Craig and Herman 2000; Clapham 2000). Females with calves occur in significantly shallower waters than other groups of whales, and breeding adults use deeper, more offshore waters (Smultea 1994; Ersts and Rosenbaum 2003).

Distribution—Humpback whales are globally distributed in all major oceans and most seas. They are generally found during the summer on high-latitude feeding grounds and during the winter in the tropics and subtropics around islands, over shallow banks, and along continental coasts where calving occurs. Most humpback whale sightings are in nearshore and continental shelf waters; however, humpback whales frequently travel through deep water during migration (Clapham and Mattila 1990; Norris et al. 1999; Calambokidis et al. 2001).

North Pacific humpback whales are distributed primarily in four more-or-less distinct wintering areas: the Ryukyu and Ogasawara (Bonin) Islands (south of Japan), the Hawaiian Islands, the Revillagigedo Islands off Mexico, and along the coast of mainland Mexico (Calambokidis et al. 2001). In the central North Pacific, whales use Hawaiian waters as a major breeding ground in winter and spring (mainly December through March). Although there are no reported observations of humpback whale mating or births, behaviors linked to courtship and mating and a cetacean placenta found in Hawaiian waters provide evidence of copulation and parturition (Silvers et al. 1997). There is known to be some interchange of whales among different wintering grounds, and matches between the Hawaiian Islands and Japan, and the Hawaiian Islands and Mexico have been found (Salden et al. 1999; Calambokidis et al. 2000, 2001; **Figure 3-1**). However, it appears that the overlap is relatively small between the western North Pacific humpback whale population and the central and eastern North Pacific populations (Darling and Mori 1993; Calambokidis et al. 2001).

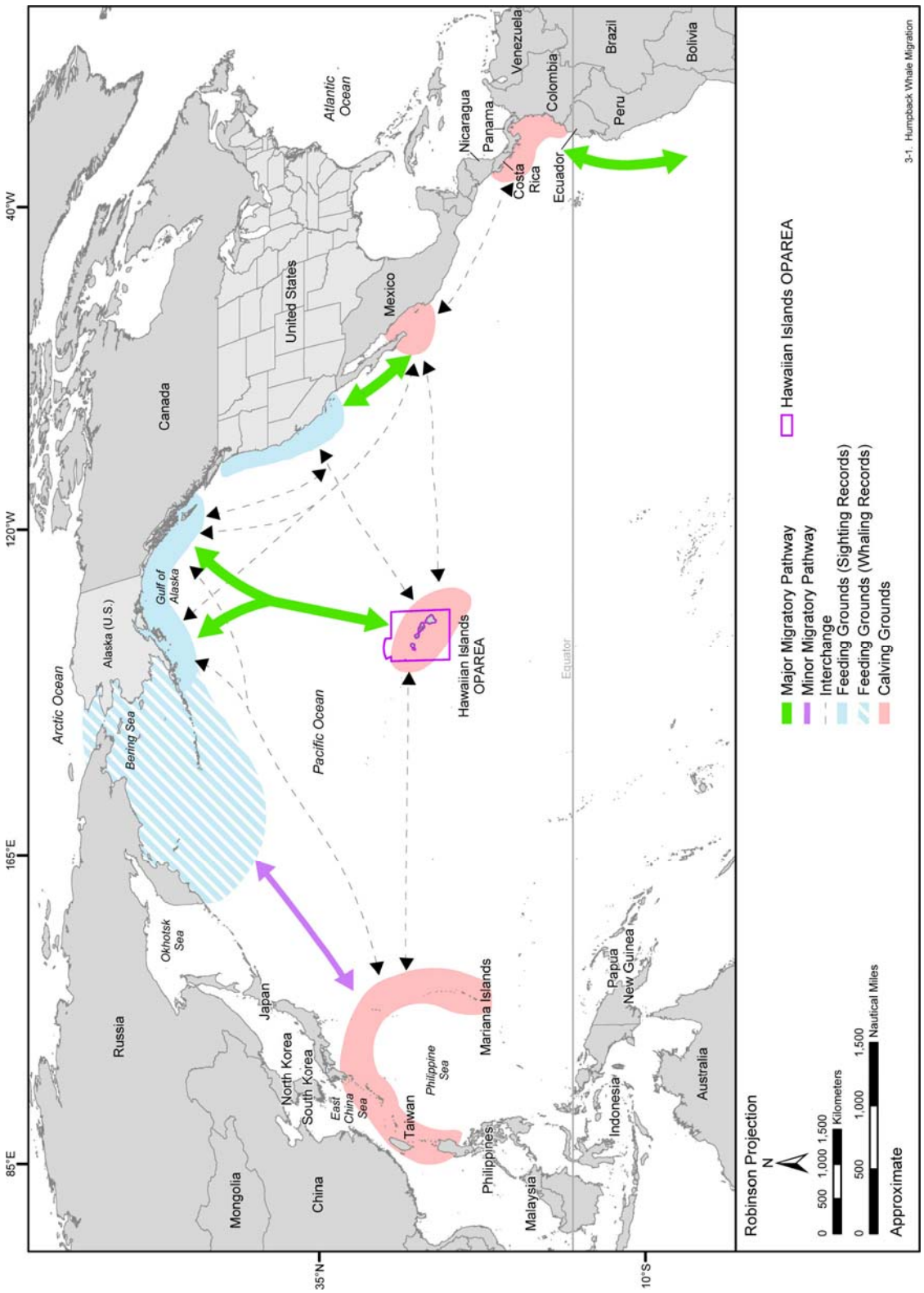

Figure 3-1. General major and minor migratory patterns of humpback whales in the North Pacific Ocean. Regions depicted with solid shading are defined by current observations of seasonal return by naturally marked individuals. Regions depicted with striped shading are defined by historical patterns of distribution during periods of commercial whaling. Source information: Baker et al. (1990) and Calambokidis et al. (2000, 2001).

Some trans-oceanic interchange also occurs between the North Pacific and South Pacific breeding populations (Medrano-Gonzalez et al. 2001). Baker et al. (1993) hypothesized that the most likely route for such interbreeding of northern and southern humpback whales is the equatorial waters of the eastern Pacific Ocean. This apparently occurs through geographic overlap of some individuals from both ocean basins off the central American coast (Acevedo and Smultea 1995). However, this is probably a relatively rare occurrence.

In addition to Japanese waters, humpbacks have been documented in recent years off Taiwan and the Philippines (Yamaguchi et al. 2002), although it is not known if whales are breeding in these latter areas or simply using them as stopover points. The waters of the Ogasawara (Bonin) Islands off Japan are considered to be one of the main wintering grounds for humpback whales of the western North Pacific population (Mori et al. 1998). Mori et al. (1998) suggested that calving might actually take place in waters with slightly higher temperatures than the waters of the Ogasawara Islands, for example, in the lower latitudes along the Ogasawara Islands rim, possibly extending from the Kazan Retto to the Northern Mariana Islands. The historical winter range in the western North Pacific included the waters around Taiwan, Hainan Island, and the Mariana and Marshall Islands (Darling and Mori 1993). Darling and Mori (1993) suggested that the recent humpback whale sightings off Saipan might indicate that the range of the population is currently expanding, or alternatively, these could just be a few wayward individuals. In addition, humpback whales have recently been observed in the Babuyan Islands off the northern Philippines, raising the question as to whether this also may have been part of their traditional wintering range (Yamaguchi et al. 2002).

During summer months, North Pacific humpback whales feed in a nearly continuous band from southern California to the Aleutian Islands, Kamchatka Peninsula, and the Bering and Chukchi seas (Calambokidis et al. 2001; **Figure 3-1**). There is much interchange of whales among different feeding grounds although some site fidelity is the rule. Whales migrate between the Mexican breeding ground and feeding grounds along the west coast of the continental U.S., using a corridor along the coast of Baja California (**Figure 3-1**). The primary feeding range of the western North Pacific humpback stock is not known. Mark recoveries from whaling operations suggest connections with summering areas in the Okhotsk and Bering seas, off Kamchatka, and the Aleutian Islands (Nishiwaki 1966; Ohsumi and Masaki 1975). There are recent photo-identification matches to the Gulf of Alaska, southeast Alaska, and the Pacific Northwest (Calambokidis et al. 2001). However, there are also indications of genetic associations of Ogasawara humpbacks with the North American coastline (Baker et al. 1998), and some western North Pacific humpbacks apparently feed off British Columbia (Darling et al. 1996; Calambokidis et al. 1997). The paucity of photo-identification data for the Aleutian Islands, Bering and Okhotsk Seas, and Kamchatcka waters may be somewhat obscuring the true identity of the primary feeding grounds, but this remains to be confirmed. Also, it seems reasonable to assume that the aggregation of humpbacks that feeds around Kodiak Island (Waite et al. 1999) may largely represent individuals from the western North Pacific stock.

The humpback whale has one of the longest migrations known for any mammal; individuals can travel nearly 8,000 km one-way between feeding and breeding areas (Clapham and Mead 1999). The exact migration corridor of whales moving between the Hawaiian Islands breeding ground and the Alaskan feeding ground is not known although it is clear that whales migrate through deep, oceanic waters. Similarly, the specific migration route of whales between Japanese breeding grounds and the apparent Aleutian Island/Bering Sea/Gulf of Alaska feeding grounds is not clear. Migratory transits between the Hawaiian Islands and southeastern Alaska have been documented to take as little as 36 to 39 days (Gabriele et al. 1996; Calambokidis et al. 2001). Based on Japanese whaling records, the migratory sequence of arrival on the Ryukyu Islands grounds is that immature whales arrive first, followed by adult males and non-pregnant females, while late pregnant females and those with newborn calves arrive last (Nishiwaki 1966).

- Information Specific to the Hawaiian Islands OPAREA—Humpback whales utilize Hawaiian waters as a major breeding ground during winter and spring (December through April). Peak abundance around the Hawaiian Islands is from late February through early April (Mobley et al. 2001a; Carretta et al. 2005). During the fall-winter period, primary occurrence is expected from

the coast to 50 NM (93 km) offshore, which takes into consideration both the available sighting data and the preferred breeding habitat (shallow waters) (Herman and Antinoja 1977; Mobley et al. 1999, 2000, 2001a; **Figures B-3a** and **B-3b**). The greatest densities of humpback whales, (including calves) are in the four island region (FIR) consisting of Maui, Molokaʻi, Kahoʻolawe and Lānaʻi, as well as Penguin Bank (Baker and Herman 1981; Mobley et al. 1999; Maldini 2003). Secondary occurrence is expected from seaward of this area, past the OPAREA boundaries. Humpback whales are expected to be rare in Pearl Harbor, though it should be noted that an anomalous sighting of an adult and calf was reported during 1998 (DoN 2001a). The occurrence of humpback whales in deeper waters is based on work in the Caribbean (the breeding ground for humpback whales in the North Atlantic), where humpback whale calls were acoustically detected over deep water, far from any banks or islands (Swartz et al. 2002).

During the spring-summer period, secondary occurrence is expected offshore out to 50 NM (93 km), mainly to account for the possible occurrence of humpback whales during the end of the breeding season (April) (**Figures B-3a** and **B-3c**). Occurrence further offshore, as well as in Pearl Harbor, is expected to be rare.

Behavior and Life History—Humpback whales are arguably the most social of all the baleen whales. Group size can range from single individuals to large groups of up to 20 or more whales. These groups are, however, typically small and unstable, with the exception of mother/calf pairs (Clapham and Mead 1999). On the feeding grounds, relatively large numbers of humpbacks may be observed within a limited area to feed on a rich food source. While large aggregations are often observed, it is not clear if there are stable associations between individuals, or if this is simply a reflection of a concentration of animals brought together by a common interest in locally abundant prey (Clapham 2000). On the breeding grounds, small groups of males may occur to compete for access to females (Tyack and Whitehead 1983; Baker and Herman 1984; Pack et al. 1998). On rare occasions, competitive groups have been observed on the feeding grounds (Weinrich 1995).

Humpback whales feed on a wide variety of invertebrates and small schooling fishes. The most common invertebrate prey are euphausiids (krill); the most common fish prey are herring, mackerel, sand lance, sardines, anchovies, and capelin (Clapham and Mead 1999). These whales are lunge feeders, taking in huge batches of prey items as they lunge laterally, diagonally, or vertically through patches of prey (Clapham 2002). Feeding behavior is highly diverse, and humpbacks employ unusual behaviors, such as bubble netting, to corral prey (Jurasz and Jurasz 1979; Weinrich et al. 1992). This is the only species of baleen whale that shows some evidence of cooperation when feeding in large groups (D'Vincent et al. 1985). Humpback whales are not typically thought to feed on the wintering grounds; however, Salden (1989) observed apparent feeding by a juvenile humpback whale off the Hawaiian Islands.

Female humpbacks become sexually mature at 4 to 9 years of age (Clapham 1996). Gestation is approximately one year. Calves are weaned before one year of age. Calving intervals are usually 2 to 3 years although females occasionally give birth to calves in successive years (Clapham 1996). Males compete for access to receptive females by aggressive, sometimes violent interactions, as well as vocal displays (Clapham 1996; Pack et al. 1998).

Humpback whale diving behavior depends on the time of year (Clapham and Mead 1999). In summer, most dives last less than 5 min; those exceeding 10 min are uncommon. In winter (December through March), dives average 10 to 15 min and dives greater than 30 min have been recorded (Clapham and Mead 1999). Although humpback whales have been recorded to dive as deep as 500 m (Hamilton et al. 1997; Dietz et al. 2002) on the feeding grounds, they spend the majority of their time in the upper 120 m of the water column (Dolphin 1987; Dietz et al. 2002). Humpback whales on the wintering grounds are known to dive deeply; Baird et al. (2000) recorded dives deeper than 100 m.

Acoustics and Hearing—Humpback whales are known to produce three classes of vocalizations: (1) "songs" in the late fall, winter, and spring by solitary males; (2) social sounds made within groups on

the wintering (calving) grounds; and (3) sounds made on the feeding grounds (Thomson and Richardson 1995).

The best-known types of sounds produced by humpback whales are songs, which are thought to be breeding displays produced only by adult males (Helweg et al. 1992). Singing is most common on breeding grounds during the winter and spring months but is occasionally heard outside breeding areas and out of season (Matilla et al. 1987; Clark and Clapham 2004). Humpback song is an incredibly elaborate series of patterned vocalizations which are hierarchical in nature (Payne and McVay 1971). There is geographical variation in humpback whale song, with different populations singing different songs, and all members of a population using the same basic song. The song evolves over the course of a breeding season but remains nearly unchanged from the end of one season to the start of the next (Payne et al. 1983).

Social calls are from 50 Hz to over 10 kHz in frequency with the highest energy below 3 kHz (Silber 1986). Female vocalizations appear to be simple; Simão and Moreira (2005) noted little complexity. The male song, however, is complex and changes between seasons. Components of the song range from under 20 Hz to 4 kHz and occasionally 8 kHz, with source levels of 144 to 174 dB re 1 μPa-m, with a mean of 155 dB re 1 μPa-m. Au et al. (2001) recorded high-frequency harmonics (out to 13.5 kHz) and source levels (between 171 and 189 dB re 1 μPa-m) of humpback whale songs. Songs have also been recorded on feeding grounds (Mattila et al. 1987; Clark and Clapham 2004). The main energy lies between 0.2 and 3.0 kHz with frequency peaks at 4.7 kHz. “Feeding” calls, unlike song and social sounds, are highly stereotyped series of narrow-band trumpeting calls. They are 20 Hz to 2 kHz, less than 1 sec in duration, and have source levels of 175 to 192 dB re 1 μPa-m. The fundamental frequency of feeding calls is approximately 500 Hz (D’Vincent et al. 1985).

No tests on humpback whale hearing have been conducted. Houser et al. (2001) produced a humpback audiogram using a mathematical model. The predicted audiogram indicates sensitivity to frequencies from 700 Hz to 10 kHz with maximum relative sensitivity between 2 and 6 kHz.

- Sei Whale (*Balaenoptera borealis*)

Description—Adult sei whales are up to 18 m in length and are mostly dark gray in color on the back and sides with a lighter belly (Jefferson et al. 1993). There is a single prominent ridge on the rostrum and a slightly arched rostrum with a downturned tip (Jefferson et al. 1993). The dorsal fin is prominent and very falcate. Sei whales are quite similar in appearance to Bryde’s whales, and it is difficult to differentiate them at sea and even in some cases, on the beach (Mead 1977).

Status—The sei whale is listed as endangered under the ESA, and as a result is considered to be depleted under the MMPA and is a strategic stock. The International Whaling Commission (IWC) designates the entire North Pacific Ocean as one sei whale stock unit (Donovan 1991), although some evidence exists for multiple stocks (NMFS 1998a; Carretta et al. 2005). For the NOAA stock assessment reports, sei whales within the Pacific EEZ are divided into three discrete, non-contiguous areas: (1) the Hawaiian stock; (2) the California/Oregon/Washington stock; and (3) the Eastern North Pacific (Alaska) stock (Carretta et al. 2005). The best available estimate of abundance is 77 sei whales for the Hawaiian Islands EEZ (Barlow 2003; Carretta et al. 2005).

The taxonomy of the baleen whale group formerly known as sei and Bryde’s whales is currently confused and somewhat controversial (see Reeves et al. 2004 for a recent review, also see the Bryde’s whale species account below for further explanation).

Habitat Preferences—Sei whales are most often found in deep, oceanic waters of the cool temperate zone. They appear to prefer regions of steep bathymetric relief, such as the continental shelf break, canyons, or basins situated between banks and ledges (Kenney and Winn 1987; Schilling et al. 1992; Gregr and Trites 2001; Best and Lockyer 2002). These areas are often the location of persistent hydrographic features, which may be important factors in concentrating zooplankton, especially copepods. On the feeding grounds, the distribution is largely associated with

oceanic frontal systems (Horwood 1987). In the North Pacific, sei whales are found feeding particularly along the cold eastern currents (Perry et al. 1999). Characteristics of preferred breeding grounds are unknown. Sei whales are typically distributed far out to sea and do not appear to be associated with coastal features (Carretta et al. 2005).

Distribution—Sei whales have a worldwide distribution, but are found primarily in cold temperate to subpolar latitudes, rather than in the tropics or near the poles (Horwood 1987). Sei whales are also known for occasional irruptive occurrences in areas followed by disappearances for sometimes decades (Horwood 1987; Schilling et al. 1992; Clapham et al. 1997).

Sei whales spend the summer months feeding in the subpolar higher latitudes and return to the lower latitudes to calve in winter. There is some evidence from whaling catch data of differential migration patterns by reproductive class, with females arriving at and departing from feeding areas earlier than males (Horwood 1987; Perry et al. 1999). For the most part, the location of winter breeding areas remains a mystery (Rice 1998; Perry et al. 1999).

In the North Pacific, sei whales are thought to occur mainly south of the Aleutian Islands. They are present all across the temperate North Pacific north of 40°N (NMFS 1998a) and are seen at least as far south as 20°N (Horwood 1987). In the east, they range as far south as Baja California, Mexico, and in the west, to Japan and Korea (Reeves et al. 1999). As noted by Reeves et al. (1999), reports in the literature from any time before the mid-1970s are suspect because of the frequent failure to distinguish sei from Bryde's whales, particularly in tropical to warm temperate waters where Bryde's whales are generally more common than sei whales.

- Information Specific to the Hawaiian Islands OPAREA—The sei whale is considered to be rare in Hawaiian waters based on reported sighting data and the species' preference for cool, temperate waters. Secondary occurrence is expected seaward of the 3,000 m isobath on the north side of the islands only (**Figures B-4a** and **B-4b**). This pattern was based on sightings made during the NMFS-SWFSC shipboard survey assessment of Hawaiian cetaceans (see Barlow et al. 2004). Sei whales are expected to be rare throughout the remainder of the OPAREA (**Figures B-4a** and **B-4b**). Occurrence patterns are expected to be the same throughout the year.

Behavior and Life History—Sei whales are typically found in groups of one to five individuals (Leatherwood et al. 1976). The sei whale is atypical of rorquals in that it primarily "skims" its food (although it does some "gulping," as other rorquals do) (Pivorunas 1979). In the North Pacific, sei whales take a diversity of prey, including calanoid copepods, krill, fish, and squid (Nemoto and Kawamura 1977). Sei whales typically follow a reproductive cycle of two years including a gestation period of about 10 to 12 months and a lactation period of 6 to 9 months (Gambell 1985).

Acoustics and Hearing—Sei whale vocalizations have been recorded only on a few occasions. They consist of paired sequences (0.5 to 0.8 sec, separated by 0.4 to 1.0 sec) of 7 to 20 short (4 milliseconds [msec]) frequency-modulated (FM) sweeps between 1.5 and 3.5 kHz; source level is not known (Thomson and Richardson 1995). While no data on hearing ability for this species are available, Ketten (1997) hypothesized that all mysticetes have acute infrasonic hearing.

- Fin Whale (*Balaenoptera physalus*)

Description—The fin whale is the second-largest whale species, with adults reaching 24 m in length (Jefferson et al. 1993). Fin whales have a very sleek body of various shades of gray, with a pale, V-shaped chevron on the back just behind the head. The dorsal fin is prominent, but with a shallow leading edge and is set back two-thirds of the body length from the head (Jefferson et al. 1993). The head color is asymmetrical, with a lower jaw that is white on the right and black or dark gray on the left. Fin and sei whales are very similar in appearance and have sometimes been misidentified, which has resulted in confusion about the distribution of both species (NMFS 1998a).

Status—Fin whales are classified as endangered under the ESA, and as a result, are considered to be depleted under the MMPA and a strategic stock. There is no designated critical habitat for this species in the North Pacific. The IWC recognizes two management stocks in the North Pacific: a single widespread stock in the North Pacific and a smaller stock in the East China Sea (Donovan 1991). The NOAA stock assessment report recognizes three stocks of fin whales in the North Pacific: (1) the Hawai‘i stock; (2) the California/Oregon/Washington stock; and (3) the Alaska stock (Carretta et al. 2005). The best available estimate of abundance for the Hawaiian stock of the fin whale is 174 individuals (Barlow 2003; Carretta et al. 2005).

Habitat Preferences—The fin whale is found in continental shelf and oceanic waters (Gregr and Trites 2001; Reeves et al. 2002). Globally, this species tends to be aggregated in locations where populations of prey are most plentiful, irrespective of water depth, although those locations may shift seasonally or annually (Payne et al. 1986, 1990; Kenney et al. 1997; Notarbartolo-di-Sciara et al. 2003). Fin whales in the North Pacific spend the summer feeding along the cold eastern boundary currents (Perry et al. 1999). Fin whales feeding in the Bering Sea were most abundant along the deeper contours between 50 and 200 m depth (Moore et al. 2002a). The steep walls of undersea canyons appear to concentrate their invertebrate prey. Littaye et al. (2004) determined that fin whale distribution in the Mediterranean Sea was linked to frontal areas and upwelling, within large zooplankton patches.

Distribution—Fin whales are broadly distributed throughout the world’s oceans, usually in temperate to polar latitudes, and less commonly in the tropics (Reeves et al. 2002). Fin whales are distributed across the North Pacific during the extended summer (May through October) from the southern Chukchi Sea (69°N) south to the Subarctic Boundary (approximately 42°N) and to 30°N in the California Current (Mizroch et al. 1999). They have been observed during the summer in the central Bering Sea (Moore et al. 2000). During the extended winter (November through April), fin whales are sparsely distributed from 60°N south to the northern edge of the tropics, near which it is assumed that mating and calving take place (Mizroch et al. 1999). However, some fin whales have been sighted as far north as 60°N all winter (Mizroch et al. 1999). Recoveries of marked whales demonstrate long migrations from low-latitude winter grounds to high-latitude summer grounds, and extensive longitudinal movements both within seasons and between years, within and between the main summer concentration areas (Mizroch et al. 1999). There is also some evidence of a resident population of fin whales in the Gulf of California, Mexico (Tershy et al. 1993) and in the East China Sea (Mizroch et al. 2005). Such cases indicate that not all members of the species necessarily make the long, north/south migrations that are typical of the species.

- <u>Information Specific to the Hawaiian Islands OPAREA</u>—Fin whales are not common in the Hawaiian Islands. Sightings were reported north of O‘ahu in May 1976, in the Kaua‘i Channel in February 1979, and north of Kaua‘i during February 1994 (Shallenberger 1981; Mobley et al. 1996). Thompson and Friedl (1982) suggested that fin whales migrate into Hawaiian waters mainly during fall and winter, based on acoustic recordings off the islands of Oahu and Midway (Northrop et al. 1971; McDonald and Fox 1999). Primary occurrence is expected seaward of the 100 m isobath during the fall-winter period to account for possible stragglers migrating through the area (**Figures B-5a** and **B-5b**). There is a rare occurrence for the fin whale from the shore to the 100 m isobath and in Pearl Harbor during this period. There is a rare occurrence of fin whales throughout the Hawaiian Islands during the spring-summer period (**Figures B-5a** and **B-5c**).

Behavior and Life History—Fin whales feed by “gulping” (Pivorunas 1979). In the North Pacific, fin whales appear to prefer krill and large copepods, followed by schooling fish such as herring, walleye pollock, and capelin (Nemoto and Kawamura 1977). Single fin whales are most common. A fin whale was sighted off Hawai‘i in association with an adult humpback whale (Mobley et al. 1996), while a group of 8 to 12 fin whales 400 km south of Hawai‘i was in a mixed-species aggregation with dolphins (Balcomb 1987).

Female fin whales in the North Pacific mature at 8 to 12 years of age (Boyd et al. 1999). Peak calving is in October through January (Hain et al. 1992) after a gestation period of approximately 11 months.

Weaning may occur at 6 months (Boyd et al. 1999). The calving interval for fin whales ranges between two to three years (Agler et al. 1993).

Fin whale dives are typically 5 to 15 min long, separated by sequences of 4 to 5 blows at 10 to 20 sec intervals (CETAP 1982; Stone et al. 1992; Lafortuna et al. 2003). Kopelman and Sadove (1995) found significant differences in blow intervals, dive times, and blows per hour between surface-feeding and non-surface-feeding fin whales. Croll et al. (2001) determined that fin whales dived to 97.9 (± standard deviation [S.D.] 32.59) m with a duration of 6.3 (±S.D. 1.53) min when foraging and to 59.3 (±S.D. 29.67) m with a duration of 4.2 (±S.D. 1.67) min when not foraging. Fin whale dives exceeding 150 m and coinciding with the diel migration of krill were reported by Panigada et al. (1999).

Acoustics and Hearing—Fin and blue whales produce calls with the lowest frequency and highest source levels of all cetaceans. Infrasonic, pattern sounds have been documented for fin whales (Watkins et al. 1987; Clark and Fristrup 1997; McDonald and Fox 1999). Fin whales produce a variety of sounds with a frequency range up to 750 Hz. The long, patterned 15 to 30 Hz vocal sequence is most typically recorded; only males are known to produce these calls (Croll et al. 2002). The most typical fin whale sound is a 20 Hz infrasonic pulse (actually an FM sweep from about 23 to 18 Hz) with durations of about 1 sec, and it can reach source levels of 184 to 186 dB re 1 μPa-m (maximum up to 200) (Thomson and Richardson 1995; Charif et al. 2002). Croll et al. (2002) recently suggested that these long, patterned vocalizations might function as male breeding displays, much like those that male humpback whales sing. While no data on hearing ability for this species are available, Ketten (1997) hypothesized that mysticetes have acute infrasonic hearing.

- Blue Whale (*Balaenoptera musculus*)

Description—Blue whales are the largest living animals. Blue whale adults in the northern hemisphere reach 22.9 to 28.0 m in length (Jefferson et al. 1993). The rostrum of a blue whale is broad and U-shaped, with a single prominent ridge down the center (Jefferson et al. 1993). The tiny dorsal fin is set far back on the body and appears well after the blowholes when the whale surfaces (Reeves et al. 2002). This species is blue-gray with light mottling on a darker background or sometimes the reverse.

Status—Blue whales are classified as endangered under the ESA and as a result, depleted under the MMPA and a strategic stock. The blue whale was severely depleted by commercial whaling in the twentieth century (NMFS 1998b). There is no designated critical habitat for this species in the North Pacific. Acoustic data suggest that there are two stocks: the western North Pacific stock (that includes Hawai‘i) and the eastern north Pacific stock (Stafford et al. 2001; Stafford 2003). No estimate of abundance is available for the western North Pacific stock of the blue whale (Carretta et al. 2005).

Habitat Preferences—Blue whales inhabit both coastal and oceanic waters in temperate and tropical areas (Yochem and Leatherwood 1985). Feeding grounds have been identified in coastal upwelling zones off the coast of California (Croll et al. 1998; Fiedler et al. 1998; Burtenshaw et al. 2004; Croll et al. 2005), Baja California (Reilly and Thayer 1990), and off southern Australia (Gill 2002). Blue whales feeding in Monterey Bay concentrate their activities along the steep edges of the Monterey Submarine Canyon, mostly in waters between the 100 and 500 m contours (Schoenherr 1991). The steep walls of undersea canyons appear to concentrate their invertebrate prey. Blue whales also feed in cool, offshore, upwelling-modified waters in the eastern tropical and equatorial Pacific (Reilly and Thayer 1990; Palacios 1999). Moore et al. (2002b) determined that blue whale call locations in the western North Pacific were associated with relatively cold, productive waters and fronts.

Distribution—Blue whales are distributed from the ice edges to the tropics in both hemispheres (Jefferson et al. 1993). Blue whales as a species are known to summer in high latitudes and move into the subtropics and tropics during the winter (Yochem and Leatherwood 1985). Data from both the Pacific and Indian Oceans, however, indicate that some individuals may remain in low latitudes year-round, such as over the Costa Rican Dome (Wade and Friedrichsen 1979; Reilly and Thayer 1990).

The productivity of the Costa Rican Dome may allow blue whales to feed during their winter calving/breeding season and not fast, like humpback whales do (Mate et al. 1999).

The range of the blue whale is known to encompass much of the North Pacific Ocean, from Kamchatka (Russia) to southern Japan in the west, and from the Gulf of Alaska south to at least Costa Rica in the east (NMFS 1998b). Blue whales from the eastern North Pacific stock winter off Mexico, Central America, and as far south as 8°C (Stafford et al. 1999), and they feed during the summer off the west coast of the U.S. and to a lesser extent in the Gulf of Alaska and in central North Pacific waters (Carretta et al. 2005). Blue whales belonging to the western North Pacific stock appear to feed during summer southwest of Kamchatka, south of the Aleutians, and in the Gulf of Alaska (Stafford 2003; Watkins et al. 2000), and in winter they migrate to lower latitudes in the western Pacific and less frequently in the central Pacific, including Hawai‘i (Stafford et al. 2001; Carretta et al. 2005).

The only (presumably) reliable sighting report of this species in the central North Pacific was a sighting made from a scientific research vessel about 400 km northeast of Hawai‘i in January 1964 (NMFS 1998b). Blue whale call locations in the western North Pacific suggest that there is an association between whale distribution and the Emperor Seamounts, the steep continental slope off the Kamchatka Peninsula, and the Aleutian Island chain (Moore et al. 2002b). Moore et al. (2002b) noted a seasonal progression of call-location concentrations over the seamounts in winter, the Kamchatka Peninsula and seamounts in spring, the Kamchatka Peninsula and waters between the seamounts and Aleutian Islands in summer, and then the seamounts again in fall.

- Information Specific to the Hawaiian Islands OPAREA—There is a rare occurrence for the blue whale year-round throughout the entire OPAREA (**Figures B-6a** and **B-6b**). Blue whale calls have been recorded off Midway and O‘ahu (Northrop et al. 1971; Thompson and Friedl 1982; McDonald and Fox 1999); these provide evidence of blue whales occurring within several hundred kilometers of these islands (NMFS 1998b). The recordings made off O‘ahu showed bimodal peaks throughout the year, suggesting that the animals were migrating into the area during summer and winter (Thompson and Friedl 1982; McDonald and Fox 1999). In locales where blue whales are regularly sighted (such as Monterey Bay), the greatest likelihood of encountering individuals is in waters with a bottom depth greater than 100 m (e.g., Schoenherr 1991).

Behavior and Life History—Blue whales are found singly or in groups of two or three (Yochem and Leatherwood 1985). As noted by Wade and Friedrichsen (1979), apparently solitary whales are likely part of a large dispersed group. Blue whales, like other rorquals, feed by “gulping” (Pivorunas 1979) almost exclusively on krill (Nemoto and Kawamura 1977). Female blue whales reach sexual maturity at 5 to 15 years of age (Yochem and Leatherwood 1985). There is usually a two year interval between calves. Calving occurs primarily during the winter (Yochem and Leatherwood 1985).

The usual duration of blue whale dives is 3 to 20 min (Wynne and Schwartz 1999). Croll et al. (2001) determined that blue whales dived to an average of 140.0 (±S.D. 46.01) m and for 7.8 (±S.D. 1.89) min when foraging and to 67.6 (±S.D. 51.46) m and for 4.9 (±S.D. 2.53) min when not foraging. Calambokidis et al. (2003) deployed tags on blue whales and collected data on dives as deep as 300 m.

Acoustics and Hearing—Blue and fin whales produce calls with the lowest frequency and highest source levels of all cetaceans. Blue whale vocalizations are long, patterned low-frequency sounds with durations up to 36 sec (Thomson and Richardson 1995) repeated every 1 to 2 min (Mellinger and Clark 2003). Their frequency range is 12 to 400 Hz, with dominant energy in the infrasonic range at 12 to 25 Hz (Ketten 1998; Mellinger and Clark 2003). Source levels are up to 188 dB re 1 μPa-m (Ketten 1998; McDonald et al. 2001). During the Magellan II Sea Test (at-sea exercises designed to test systems for antisubmarine warfare), off the coast of California in 1994, blue whale vocalization source levels at 17 Hz were estimated in the range of 195 dB re 1 μPa-m (Aburto et al. 1997). Vocalizations of blue whales appear to vary among geographic areas (Rivers 1997), with clear

differences in call structure suggestive of separate populations for the western and eastern regions of the North Pacific (Stafford et al. 2001). While no data on hearing ability for this species are available, Ketten (1997) hypothesized that mysticetes have acute infrasonic hearing.

- Sperm Whale (*Physeter macrocephalus*)

Description—The sperm whale is the largest toothed whale species. Adult females can reach 12 m in length, while adult males measure as much as 18 m in length (Jefferson et al. 1993). The head is large (comprising about one-third of the body length) and squarish. The lower jaw is narrow and underslung. The blowhole is located at the front of the head and is offset to the left (Rice 1989). Sperm whales are brownish gray to black in color with white areas around the mouth and often on the belly. The flippers are relatively short, wide, and paddle-shaped. There is a low rounded dorsal hump and a series of bumps on the dorsal ridge of the tailstock (Rice 1989). The surface of the body behind the head tends to be wrinkled (Rice 1989).

Status—The sperm whale is classified as endangered under the ESA and, as a result, is considered depleted under the MMPA and is a strategic stock. There is no designated critical habitat for this species in the North Pacific.

It should be noted that the sperm whale's ESA status as endangered is somewhat political, and the species is actually in no immediate danger of global extinction (unlike some species, such as the North Pacific right whale, which clearly are). Although many sperm whale populations have been depleted to varying degrees by past whaling activities, sperm whales remain one of the more globally common great whale species. In fact, in some areas, they are actually quite abundant. For example, there are estimated to be about 21,200 to 22,700 sperm whales in the eastern tropical Pacific Ocean (Wade and Gerrodette 1993).

For management purposes, the IWC has divided the North Pacific into two management regions defined by a zig-zag line which starts at 150°W at the equator, is at 160°W between 40° to 50°N, and ends up at 180°W north of 50°N (Donovan 1991). Preliminary genetic analyses reveal significant differences between sperm whales off the coast of California, Oregon, and Washington and those sampled offshore to the Hawaiian Islands (Mesnick et al. 1999; Carretta et al. 2005). The NOAA stock assessment report divides sperm whales within the U.S. Pacific EEZ into three discrete, non-contiguous areas: (1) waters around the Hawaiian Islands, (2) California, Oregon, and Washington waters, and (3) Alaskan waters (Carretta et al. 2005). The best available abundance estimate for the Hawaiian Islands stock of the sperm whale is 7,082 individuals (Barlow 2003; Carretta et al. 2005). Sperm whale abundance in the eastern temperate North Pacific is estimated to be 32,100 individuals and 26,300 individuals by acoustic and visual detection methods, respectively (Barlow and Taylor 2005).

Habitat Preferences—Sperm whales show a strong preference for deep waters (Rice 1989), especially areas with high sea floor relief. Sperm whale distribution is associated with waters over the continental shelf edge, over the continental slope, and into deeper waters (Hain et al. 1985; Kenney and Winn 1987; Waring and Finn 1995; Gannier 2000; Gregr and Trites 2001; Waring et al. 2001). However, in some areas, such as off New England, on the southwestern and eastern Scotian Shelf, or in the northern Gulf of California, adult males consistently use waters with bottom depths less than 100 m and sometimes as shallow as 40 m (Whitehead et al. 1992; Scott and Sadove 1997; Croll et al. 1999; Garrigue and Greaves 2001). Worldwide, females rarely enter the shallow waters over the continental shelf (Whitehead 2003).

Sperm whale concentrations in the Pacific Ocean have been correlated with high secondary productivity and steep underwater topography (Jaquet and Whitehead 1996). Sperm whales are more frequently found in certain geographic areas, which whalers learned to exploit (e.g., whaling "grounds") encompassing 300 to 1,500 km^2 (Townsend 1935). These main sperm whaling grounds are usually correlated with areas of increased primary productivity caused by upwelling, with a space and time lag between peaks in chlorophyll concentrations and peaks in sperm whale density (Jaquet

et al. 1996). In the ETP, sperm whale habitat use is significantly related to SST and depth of the thermocline (Polacheck 1987). Gregr and Trites (2001) reported that female sperm whales off British Columbia were relatively unaffected by the surrounding oceanography.

Off the eastern U.S., sperm whales are found in regions of pronounced horizontal temperature gradients, along the edges of the Gulf Stream and warm-core rings (Waring et al. 1993; Griffin 1999; Jaquet et al. 1996). It is likely that these habitats are regions where oceanographic conditions are optimal for the aggregation of prey, such as squid. Waring et al. (2003) conducted a deepwater survey south of Georges Bank in 2002 and examined fine-scale habitat use by sperm whales. Sperm whales were located in waters characterized by a SST of 23.2° to 24.9°C and a bottom depth of 325 to 2,300 m (Waring et al. 2003). Sperm whales in the Gulf of Mexico aggregate along the continental slope, in or near cyclonic (cold-core) eddies (Biggs et al. 2000; Davis et al. 2002). These eddies are mesoscale features with locally enhanced plankton stocks (Wormuth et al. 2000). Data suggest that sperm whales appear to adjust their movements to stay in or near cold-core rings (Davis et al. 2000, 2002). This would demonstrate that sperm whales shift their movements in relation to prey concentrations.

Distribution—Sperm whales are found from tropical to polar waters in all oceans of the world between approximately 70°N and 70°S (Rice 1998). Females use a subset of the waters where males are regularly found. Females are normally restricted to areas with SSTs greater than approximately 15ºC, whereas males, especially the largest males, can be found in waters as far poleward as the pack ice with temperatures close to 0ºC (Rice 1989). The thermal limits on female distribution correspond approximately to the 40º parallels (50º in the North Pacific) (Whitehead 2003).

- Information Specific to the Hawaiian Islands OPAREA—Sperm whales are widely distributed throughout the Hawaiian Islands year-round (Rice 1960; Shallenberger 1981; Lee 1993; and Mobley et al. 2000). Sperm whale clicks recorded from hydrophones off O‘ahu confirm the presence of sperm whales near the Hawaiian Islands throughout the year (Thompson and Friedl 1982). Globally, sperm whales are typically distributed in waters over the shelf break and continental slope. The primary area of occurrence for the sperm whale is seaward of the shelf break in the Hawaiian Islands OPAREA (**Figures B-7a** and **B-7b**). There is a rare occurrence of sperm whales from the shore to the shelf break (**Figures B-7a** and **B-7b**). This occurrence prediction is based on the possibility of this typically deepwater species being found in insular shelf waters that are in such close proximity to deep water. Occurrence patterns are assumed to be similar throughout the year.

Behavior and Life History—Female sperm whales live a highly social life, while large male sperm whales typically occur alone or in pairs, at times joining groups of adult females for breeding (Whitehead 2003). Female and immature sperm whales form groups that move together in a coordinated fashion over periods of days (Whitehead 2003). Mean group size is approximately 20 to 30 individuals although there is much variation (Whitehead 2003). For a review of sperm whale social organization, see Whitehead and Weilgart (2000) and Whitehead (2003). Mating behavior is observed from winter through summer and calving during spring through fall. Gestation is 14 to 15 months, lactation is approximately 2 years, and the typical inter-birth interval is 4 to 7 years. Sperm whales prey on large mesopelagic squid and other cephalopods, as well as a wide variety of demersal fishes and occasionally benthic invertebrates (Rice 1989; Clarke 1996).

Sperm whales forage during deep dives that routinely exceed a depth of 400 m and 30 min duration (Watkins et al. 2002). They are capable of diving to depths of over 2,000 m with durations of over 60 min (Watkins et al. 1993). Sperm whales spend up to 83% of daylight hours underwater (Jaquet et al. 2000; Amano and Yoshioka 2003). Males do not spend extensive periods of time at the surface (Jaquet et al. 2000). In contrast, females spend prolonged periods of time at the surface (1 to 5 hrs daily) without foraging (Whitehead and Weilgart 1991; Amano and Yoshioka 2003). The average swimming speed is estimated to be 0.7 m/sec (Watkins et al. 2002). Dive descents averaged 11 min at a rate of 1.52 m/sec, and ascents averaged 11.8 min at a rate of 1.4 m/sec (Watkins et al. 2002).

Acoustics and Hearing—Sperm whales produce short-duration (generally less than 3 sec), broadband clicks. These clicks range in frequency from 100 Hz to 30 kHz with dominant energy in two bands (2 to 4 kHz and 10 to 16 kHz). Generally, most of the acoustic energy is present at frequencies below 4 kHz although diffuse energy up to past 20 kHz has been reported (Thode et al. 2002). The source levels can be up to 236 dB re 1 μPa-m (Møhl et al. 2003). Thode et al. (2002) suggested that the acoustic directivity (angular beam pattern) from sperm whales must range between 10 and 30 dB re 1 μPa-m in the 5 to 20 kHz region. The clicks of neonate sperm whales are very different from usual clicks of adults in that they are of low directionality, long duration, and low-frequency (centroid frequency between 300 and 1,700 Hz) with estimated source levels between 140 and 162 dB re 1 μPa-m (Madsen et al. 2003). Clicks are heard most frequently when sperm whales are engaged in diving/foraging behavior (Whitehead and Weilgart 1991; Miller et al. 2004; Zimmer et al. 2005a). These may be echolocation clicks used in feeding or orientation during dives or contact calls (for communication). When sperm whales are socializing they tend to repeat series of clicks (codas), which follow a precise rhythm and may last for hours (Watkins and Schevill 1977). Codas are shared between individuals of a social unit and are considered to be primarily for intragroup communication (Weilgart and Whitehead 1997; Rendell and Whitehead 2004).

The anatomy of the sperm whale's ear indicates that it hears high-frequency sounds (Ketten 1992). Anatomical studies also suggest that the sperm whale has some ultrasonic hearing but at a lower maximum frequency than many other odontocetes (Ketten 1992). The sperm whale may also possess better low-frequency hearing than some other odontocetes, although not as extraordinarily low as many baleen whales (Ketten 1992). Auditory brainstem response in a neonatal sperm whale indicated highest sensitivity to frequencies between 5 and 20 kHz (Ridgway and Carder 2001).

- Hawaiian Monk Seal (*Monachus schauinslandi*)

Description—Hawaiian monk seals are similar in body shape to female and young elephant seals, with a moderately robust, spindle-shaped body and short muzzle. Adults are 2.1 to 2.4 m in length and weigh 170 to 240 kg, with females growing slightly larger than males (Gilmartin and Forcada 2002). Other than this size difference, there is little noticeable sexual dimorphism. Coloration of Hawaiian monk seals is drab, generally a yellow-brown to silvery-gray color with slight countershading.

Status—The Hawaiian monk seal is listed as endangered under the ESA and depleted under the MMPA (Ragen and Lavigne 1999). The Hawaiian monk seal population is a NOAA Fisheries strategic stock (Carretta et al. 2005). Hawaiian monk seals are managed as a single stock although there are six main reproductive subpopulations at French Frigate Shoals, Laysan Island, Lisianski Island, Pearl and Hermes Reef, Midway Island, and Kure Atoll (Ragen and Lavigne 1999; Carretta et al. 2005). Genetic comparisons between the Northwestern and MHI seals have not yet been conducted, but observed interchange of individuals among the regions is extremely rare, suggesting that these may be more appropriately designated as separate stocks; further research is needed (Carretta et al. 2005).

The best estimate of the total population size for the species is 1,304 individuals (Carretta et al. 2005). In 2001, there was a minimum abundance of 52 seals in the MHI (Baker and Johanos 2004; Carretta et al. 2005); the vast majority of the population occurs in the NWHI. The trend in abundance for the population over the past 20 years has mostly been negative (Baker and Johanos 2004; Carretta et al. 2005). A self-sustaining subpopulation in the MHI may improve the monk seal's long-term prospects for recovery (MMC 2003; Baker and Johanos 2004; Carretta et al. 2005).

Critical habitat for the Hawaiian monk seal is designated from the shore out to 37 m (20 fathoms) in 10 areas of the NWHI (NMFS 1988; **Figure 3-2**).

Habitat Preferences—Breeding habitat for the Hawaiian monk seal primarily consists of sandy beaches although hard substrate beach areas and exposed reef are used at some islands (Gilmartin

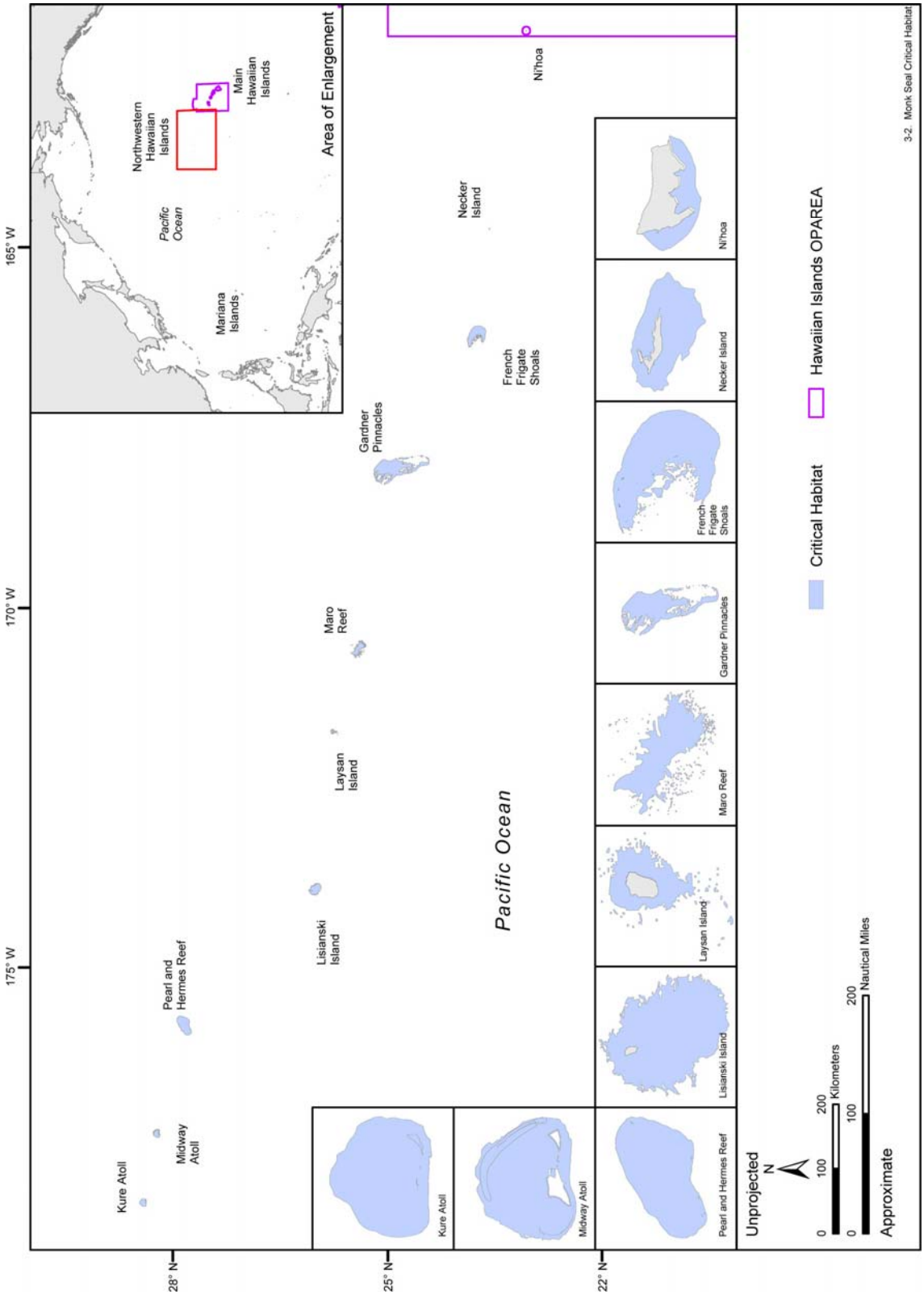

Figure 3-2. Designated critical habitat for the Hawaiian monk seal. Critical habitat is all beach areas, including all beach crest vegetation to its deepest extent inland, lagoon waters, and ocean waters out to a depth of 37 m around the Northwestern Hawaiian Islands. References to beaches or beach areas includes all sand spits and islets. Source data: NOS (2001). Source information: NMFS (1988).

1983). Dry sand areas above the high tide line are preferred (Kenyon 1973; Gilmartin 1983). The breeding beaches are characterized by shallow, protected water adjacent to the shoreline, which may limit access by large predatory sharks (Westlake and Gilmartin 1990).

Foraging habitat near the breeding atolls and seamounts is commonly restricted to waters of less than 100 m in depth (Parrish et al. 2000; Stewart 2004). The inner reef waters adjacent to the islands are critical to weaned pups learning to feed; pups move laterally along the shoreline but do not appear to travel far from shore during the first few months after weaning (Gilmartin 1983). Feeding has been observed in reef caves (Gilmartin 1983). Recent studies have shown that adult seals at French Frigate Shoals forage at depths of 300 to 500 m in deepwater coral beds (Parrish et al. 2002), and 2 to 3 year-olds feed at much shallower depths of 10 to 30 m (Parrish et al. 2005). However, juveniles feed in underwater sand fields with a bottom depth of 50 to 100 m on the atoll's outer slope (Parrish et al. 2005).

Local environmental conditions affect trends in abundance of specific monk seal subpopulations, with areas sharing similar ecological characteristics having similar trends (Schmelzer 2000). Climate-driven changes in oceanic productivity could be decisive in reducing (or enhancing) monk seal reproduction and survival. Juvenile seals feed over deepwater sand fields, and oceanographic conditions are thought to influence survivorship of these seals (Parrish et al. 2005). Polovina et al. (1994) speculated that climate changes in the central North Pacific caused declines in lobster recruitment, which contributed to declines in the numbers of monk seal pups. More recent work suggests that El Niño conditions may actually benefit Hawaiian monk seals by making prey more available and resulting in weaned pups with larger axillary girths (and therefore, presumably better nutritional condition) (Antonelis et al. 2003). Further research is needed to fully understand the implications of climate change on this species.

Distribution—The Hawaiian monk seal occurs only in the central North Pacific. Until recently, the extant population occurred almost exclusively at remote atolls in the NWHI where six major breeding colonies are located: French Frigate Shoals, Laysan and Lisianski Islands, Pearl and Hermes Reef, Midway Island, and Kure Atoll. Sightings and births have now been reported for all the MHI, including Lehua Rock and Kaula Rock (MMC 2003; Baker and Johanos 2004). The highest monk seal counts in the MHI have been on the western islands of Niʻihau and Kauaʻi, with numbers of seals tending to decrease moving southeast along the island chain (Baker and Johanos 2004; Carretta et al. 2005). Although sightings in the MHI include "surplus" males relocated from the NWHI to reduce male aggression leading to injury and death of breeding females (Zevin 1995; Baker and Johanos 2004), these seals account for only a small proportion of sightings in the MHI. Births of Hawaiian monk seal pups have been recorded on all the MHI except Lānaʻi (Baker and Johanos 2004). Hawaiian monk seals wander to Maro Reef and Gardner Pinnacles and have occasionally been reported on nearby island groups, such as Johnston Atoll, Wake Island, and Palmyra Atoll (Rice 1998).

Hawaiian monk seals show very high site fidelity to natal islands, with only about 10% of individuals moving to another island in their lifetime (Gilmartin and Forcada 2002). While monk seals do move between islands, long-distance movements are not common. Seals move distances of up to 250 km on a regular basis, but distances of more than 1,000 km have not been documented (DeLong et al. 1984; Ragen and Lavigne 1999).

- Information Specific to the Hawaiian Islands OPAREA—The highly endangered status of this species and its limited range necessitate a conservative estimate of expected occurrence in the Hawaiian Islands OPAREA. Primary occurrence of monk seals is expected in a continuous band between Nihoa, Kaula Rock, Niʻihau, and Kauaʻi (**Figures B-8a** and **B-8b**). This band extends from the shore to around the 500 m isobath and is based on the large number of sightings and births recorded in this area (Westlake and Gilmartin 1990; Ragen and Finn 1996; MMC 2003; Baker and Johanos 2004). An area of secondary occurrence is expected from the 500 m isobath to the 1,000 m isobath around Nihoa, Kaula Rock, Niʻihau, and Kauaʻi. A continuous area of secondary occurrence is also expected from the shore to the 1,000 m isobath around the other MHI and in Pearl Harbor (**Figures B-8a** and **B-8b**), taking into account sighting records, the

location of deep-sea corals (**Figure 2-22**), and the ability of monk seals to forage in water deeper than 500 m (Parrish et al. 2002; Severns and Fiene-Severns 2002; KBWF 2003; Kubota 2004; Anonymous 2005; Fujimori 2005; Parrish personal communication). Pearl Harbor is included in the area of secondary occurrence based on sightings of this species near the entrance of the harbor (DoN 2001b). There is a rare occurrence of the monk seal seaward of the 1,000 m isobath. Occurrence patterns are expected to be the same throughout the year.

Behavior and Life History—Unlike many other pinniped species, Hawaiian monk seals are not very gregarious on land and are more-or-less solitary when at sea. Although two to 36 individuals have been seen hauled out together, these aggregations likely result more from a desire to rest on a favorable spot than from any type of gregarious tendency (Kenyon and Rice 1959). The monk seal also appears to be intolerant of human presence; occurrence trends at Kure Atoll, Midway Island, and French Frigate Shoals appear to be determined by the pattern of human disturbance from military or USCG activities (Kenyon 1973; MMC 2003; Baker and Johanos 2004; Carretta et al. 2005). Likewise in the MHI, seals tend to frequent remote areas where human access is limited (MMC 2003).

Although births are documented year-round, most pupping occurs during a protracted breeding season mostly from February to August with a peak in March to June (Johanos et al. 1994, Gilmartin and Forcada 2002). The average weaning period is about five weeks (Kenyon and Rice 1959). Sometimes groups of males exhibit an aggressive behavior pattern called “mobbing,” in which they gang together and attempt to mate with, and by doing so, injure and often kill, adult females and immature seals of both sexes (Starfield et al. 1995). This behavior seems to occur to a far greater extent in those subpopulations where there are more males than females.

Hawaiian monk seals have a “catastrophic molt” in which large patches of skin and fur are shed. This type of molt is considered to be very energetically expensive. Molting is documented year-round, with seasonal timing dependent on age, sex, and reproductive status (Johanos et al. 1994; NMFS-PIFSC unpublished data).

Hawaiian monk seals feed opportunistically on a wide variety of at least 40 species of benthic and demersal fishes, cephalopods, and spiny lobster (MacDonald 1982; Goodman-Lowe 1998; Parrish et al. 2000). Juveniles feed on small, cryptic, benthic prey items (Parrish et al. 2005). Monk seals also interact with various fisheries, such as longlines and the lobster fishery (Nitta and Henderson 1993; Carretta et al. 2005). Hawaiian monk seals were previously not thought to be deep divers, with most known dives in the 10 to 40 m depth range (DeLong et al. 1984; Ragen and Lavigne 1999). However, deeper dives to at least 121 m (DeLong et al. 1984) and to over 500 m (Parrish et al. 2002) have recently been recorded.

Acoustics and Hearing—There is no information available regarding underwater sounds produced by Hawaiian monk seals. In-air sounds include: (1) a soft liquid bubble at 100 to 400 Hz; (2) a loud, brief guttural expiration below 800 Hz produced during short-distance agonistic encounters; (3) a roar, also to 800 Hz, for long-distance threat; and (4) a belch cough made by males when patrolling (Miller and Job 1992). Pups emit a <1.4 kHz call; Job et al. (1995) reported that there is apparent lack of vocal recognition of pups by adult females. An underwater audiogram obtained for the Hawaiian monk seal showed relatively poor hearing sensitivity, as well as a narrow range of best sensitivity and a relatively low upper frequency limit (Thomas et al. 1990a). The data demonstrated best underwater hearing at 12 to 28 kHz and 60 to 70 kHz (Thomas et al. 1990a). It should be noted that this audiogram is based on a single animal whose hearing curve had some characteristics suggesting its responses may have been affected by disease or age (Reeves et al. 2001).

3.1.2.3 Non-Threatened and Non-Endangered Marine Mammal Species of the Hawaiian Islands OPAREA

There are 20 non-endangered/non-threatened marine mammal species: two baleen whale species, 17 toothed whale species, and one pinniped species found in the Hawaiian Islands OPAREA and vicinity.

- Minke Whale (*Balaenoptera acutorostrata*)

Description—The minke whale is the smallest balaenopterid species in the North Pacific, with adults reaching lengths of just over 9 m (Jefferson et al. 1993). The head is extremely pointed, and the median head ridge is prominent. The dorsal fin is tall (for a baleen whale), recurved, and is located about two-thirds of the way back from the snout tip (Jefferson et al. 1993). Coloration is distinct: dark gray dorsally grading to white beneath, with streaks of intermediate shades on the sides (Stewart and Leatherwood 1985). The most distinctive light marking is a brilliant white band across each flipper of Northern Hemisphere minke whales (Stewart and Leatherwood 1985).

Status—The IWC recognizes three stocks of minke whales in the North Pacific: one in the Sea of Japan/East China Sea, one in the rest of the western Pacific west of 180ºN, and one in the remainder of the Pacific (Donovan 1991). For the NOAA stock assessment report, there are three stocks of minke whales within the U.S. Pacific EEZ: (1) a Hawaiian stock; (2) a California/Oregon/Washington stock; and (3) an Alaskan stock (Carretta et al. 2005). There currently is no abundance estimate for the Hawaiian stock of minke whales, which appears to occur seasonally (approximately November through March) around the Hawaiian Islands (Carretta et al. 2005).

Habitat Preferences—The minke whale generally occupies waters over the continental shelf, including inshore bays and estuaries (Mitchell and Kozicki 1975; Ivashin and Vitrogov 1981; Murphy 1995; Mignucci-Giannoni 1998; Calambokidis et al. 2004). However, based on whaling catches and surveys worldwide, there is also a deep-ocean component to the minke whale's distribution (Slijper et al. 1964; Horwood 1990; Mitchell 1991; Mellinger et al. 2000; Roden and Mullin 2000). Dorsey et al. (1990) noted minke whales feeding in locations of strong tidal currents in inshore waters.

Distribution—Minke whales are distributed in polar, temperate, and tropical waters of all major oceans (Jefferson et al. 1993); they are less common in the tropics than in cooler waters. Minke whales are present in the North Pacific from near the equator to the Arctic (Horwood 1990). The summer range extends to the Chukchi Sea (Perrin and Brownell 2002). In the winter, minke whales are found south to within 2° of the equator (Perrin and Brownell 2002). The distribution of minke whale vocalizations (specifically "boings") suggests that the winter breeding grounds correspond to the offshore tropical waters of the North Pacific Ocean (Rankin and Barlow 2005). There is no obvious migration from low-latitude, winter breeding grounds to high-latitude, summer feeding locations in the western North Pacific, as there is in the North Atlantic (Horwood 1990); however, there are some monthly changes in densities in both high and low latitudes (Okamura et al. 2001). In the northern part of their range, minke whales are believed to be migratory, wherease they appear to establish home ranges in the inland waters of Washington and along central California (Dorsey et al. 1983) and they exhibit site fidelity to these areas between years (Borggaard et al. 1999).

- Information Specific to the Hawaiian Islands OPAREA—The minke whale is expected to occur seasonally in the OPAREA (Barlow 2003). Abundance is expected to be higher between November and March (Carretta et al. 2005). Therefore, an area of secondary occurrence is seaward of the shoreline during the fall-winter period (**Figures B-9a** and **B-9b**). Both visual and acoustic detections of minke whales have been reported for this area (e.g., Balcomb 1987; Thompson and Friedl 1982; Barlow et al. 2004; Carretta et al. 2005; Norris et al. 2005). The occurrence pattern takes into account both sightings in shallow waters in some locales globally, as well as the anticipated oceanic occurrence of this species (Jefferson personal communication). "Boings" were recorded in waters with a bottom depth of approximately 1,280 m to 3,840 m (Norris et al. 2005). Norris et al. (2005) reported sighting a minke whale 22 km southwest of Kaua'i, in waters with a bottom depth of approximately 2,560 m. Occurrence in Pearl Harbor is expected to be rare during this period. During the spring-summer period, there is a rare occurrence for the minke whale throughout the entire Hawaiian Islands OPAREA (**Figures B-9a** and **B-9c**).

Behavior and Life History—Minke whales are sighted alone or in small groups of 2 to 3 individuals although aggregations of up to 400 sometimes develop in high latitude areas (Perrin and Brownell

2002). Mating is thought to occur in winter or early spring, but has never been observed (Stewart and Leatherwood 1985). Stern (1992) described a general surfacing pattern of minke whales consisting of about four surfacings interspersed by short-duration dives averaging 38 sec. After the fourth surfacing, there was a longer duration dive ranging from approximately 2 to 6 min. Minke whales are "gulpers," like the other rorquals (Pivorunas 1979). Hoelzel et al. (1989) reported on different feeding strategies used by minke whales. In the North Pacific, major food items include krill, Japanese anchovy, Pacific saury, and walleye Pollock (Perrin and Brownell 2002).

Acoustics and Hearing—Recordings in the presence of minke whales have included both high- and low-frequency sounds (Beamish and Mitchell 1973; Winn and Perkins 1976; Mellinger et al. 2000). Mellinger et al. (2000) described two basic forms of pulse trains that were attributed to minke whales: a "speed up" pulse train with energy in the 200 to 400 Hz band, with individual pulses lasting 40 to 60 msec, and a less-common "slow-down" pulse train characterized by a decelerating series of pulses with energy in the 250 to 350 Hz band.

Recorded vocalizations from minke whales have dominant frequencies of 60 to greater than 12,000 Hz, depending on vocalization type (Thomson and Richardson 1995). Recorded source levels, depending on vocalization type, range from 151 to 175 dB re 1 μPa-m (Ketten 1998). Gedamke et al. (2001) recorded a complex and stereotyped sound sequence ("star-wars vocalization") in the Southern Hemisphere that spanned a frequency range of 50 Hz to 9.4 kHz. Broadband source levels between 150 and 165 dB re 1 μPa-m were calculated. "Boings" recorded in the North Pacific have many striking similarities to the star-wars vocalization, in both structure and acoustic behavior. "Boings", recently confirmed to be produced by minke whales (Barlow et al. 2004) and suggested to be a breeding call, consist of a brief pulse at 1.3 kHz, followed by an amplitude-modulated call with greatest energy at 1.4 kHz, with slight frequency modulation over a duration of 2.5 sec (Rankin and Barlow 2005). While no data on hearing ability for this species are available, Ketten (1997) hypothesized that all mysticetes have acute infrasonic hearing.

- Bryde's Whale (*Balaenoptera edeni/brydei*)

Description—Bryde's whales can be easily confused with sei whales. Bryde's whales usually have three prominent ridges on the rostrum (other rorquals generally have only one) (Jefferson et al. 1993). The Bryde's whale's dorsal fin is tall and falcate and generally rises abruptly out of the back. Adults can be up to 15.5 m in length (Jefferson et al. 1993), but there is a smaller "dwarf" species that rarely reaches over 10 m in length (Jefferson personal communication).

It is not clear how many species of Bryde's whales there are, but genetic analyses suggest the existence of at least two species (Rice 1998; Kato 2002). The taxonomy of the baleen whale group formerly known as sei and Bryde's whales is currently confused and highly controversial (see Reeves et al. 2004 for a recent review). It is clear that there are at least three species in this group, the antitropically-distributed sei whale, the tropically-distributed standard form Bryde's whale (probably referable to *Balaenoptera brydei*), and the "dwarf Bryde's whale" (probably referable to *Balaenoptera edeni*), which inhabits tropical waters of the Indo-Pacific (Yoshida and Kato 1999). However, the nomenclature is still not resolved due to questions about the affinities of the type specimens of *Balaenoptera brydei* and *Balaenoptera edeni*.

Another complication is that a new species of whale from this group has recently been described from tropical waters of the Indo-Pacific and the Sea of Japan (Wada et al. 2003). This species, given the name *Balaenoptera omurai*, has not been accepted by the scientific community at large, and there is in fact a push to reject the acceptance of this species, based on a lack of suitable detail in the type description and a purported lack of adequate justification for the split (see Reeves et al. 2004). However, if the species does turn-out to be valid, it probably occurs in the area.

Status—The IWC recognizes three management stocks of Bryde's whales in the North Pacific: western North Pacific, eastern North Pacific, and East China Sea (Donovan 1991). There is currently no biological basis for defining separate stocks of Bryde's whales in the central North Pacific (Carretta

et al. 2005). For the NOAA stock assessment reports, Bryde's whales within the U.S. Pacific EEZ are divided into two areas: (1) Hawaiian waters, and (2) the eastern tropical Pacific (east of 150°W and including the Gulf of California and waters off California) (Carretta et al. 2005).

Habitat Preferences—Bryde's whales are found both offshore and near the coasts in many regions. Off eastern Venezuela, Bryde's whales are often sighted in the shallow waters between Isla Margarita and Peninsula de Araya, as well as into waters where there is a steep slope, such as the Cariaco Trench (Notarbartolo di Sciara 1982). Along the Brazilian coast, distribution and seasonal movements of the Bryde's whale appear to be influenced by the behavior, distribution, and abundance of Brazilian sardine (*Sardinella brasiliensis*) schools which approach the coast to spawn in shallow waters (Zerbini et al. 1997). In the Gulf of Mexico, all Bryde's whale sightings have been near the shelf break in and near DeSoto Canyon (Davis and Fargion 1996; Jefferson and Schiro 1997; Davis et al. 2000). Whaling catches also have shown that the Bryde's whale is not always a coastal species (Ohsumi 1977). The Bryde's whale appears to have a preference for water temperatures between approximately 15° and 20°C (Yoshida and Kato 1999).

Distribution—The Bryde's whale is found in tropical and subtropical waters, generally not moving poleward of 40° in either hemisphere (Jefferson et al. 1993). Long migrations are not typical of Bryde's whales although limited shifts in distribution toward and away from the equator, in winter and summer, respectively, have been observed (Cummings 1985). The Bryde's whales' large wintering grounds may extend from the western North Pacific to the central North Pacific, with 20°N perhaps being the northernmost boundary (Ohizumi et al. 2002). During the winter, Bryde's whales are distributed in the western North Pacific around the Mariana, Ogasawara, Kazan, and Phillippine Islands, as well as near New Guinea (Ohizumi et al. 2002). Tagging data suggest that Bryde's whales undertake considerable east-west migrations, and that the stock in the western and central North Pacific does the same (Kishiro 1996). In summer, the distribution of Bryde's whales in the western North Pacific extends as far north as 40°N, but many individuals remain in lower latitudes, as far south as about 5°N. Data also suggest that winter and summer grounds partially overlap in the central North Pacific (Kishiro 1996; Ohizumi et al. 2002). Bryde's whales are also distributed in the central North Pacific in summer; the southernmost summer distribution of Bryde's whales inhabiting the central North Pacific is at about 20°N (Kishiro 1996). By November, Bryde's whales are usually absent from their central North Pacific summering area (Miyashita et al. 1995); in the western North Pacific, they migrate as far south as the equator in winter (Kishiro 1996; Miyashita et al. 1996). In March, Bryde's whales are found at high densities in several areas of the central Pacific, from approximately 175°E to 150°W and 15°N to 5°S (Miyashita et al. 1995). Some whales remain in higher latitudes (around 25°N) in both winter and summer (Kishiro 1996).

- Information Specific to the Hawaiian Islands OPAREA—Bryde's whales are seen year-round throughout tropical and subtropical waters (Kato 2002) and are also expected in the OPAREA year-round (Jefferson personal communication). It should be noted that more sightings are reported for the NWHI than in the MHI (e.g., Barlow et al. 2004; Carretta et al. 2005). Bryde's whales have been reported to occur in both deep and shallow waters globally. There is a secondary occurrence of Bryde's whales seaward of the 50 m isobath in the OPAREA (**Figures B-10a** and **B-10b**). Bryde's whales are sometimes seen very close to shore and even inside enclosed bays (see Best et al. 1984). Occurrence is expected to be rare inshore of this area, as well as within Pearl Harbor.

Behavior and Life History—This species is generally seen alone or in pairs (Tershy 1992), although they can be seen in groups of up to 10 individuals (Miyazaki and Wada 1978). The Bryde's whale does not have a well-defined breeding season in most areas. There is a 2-year reproductive cycle which is composed of 11 to 12 months gestation, 6 months of lactation, and 6 months resting (Kato 2002). Bryde's whales are lunge-feeders, feeding on schooling fish and krill (Nemoto and Kawamura 1977). Cummings (1985) reported that Bryde's whales may dive as long as 20 min.

Acoustics and Hearing—Bryde's whales produce low frequency tonal and swept calls similar to those of other rorquals (Oleson et al. 2003). Calls vary regionally, yet all but one of the call types

have a fundamental frequency below 60 Hz; they last from one-quarter of a second to several seconds; and they are produced in extended sequences (Oleson et al. 2003). Heimlich et al. (2005) recently described five tone types. While no data on hearing ability for this species are available, Ketten (1997) hypothesized that mysticetes have acute infrasonic hearing.

- Pygmy and Dwarf Sperm Whales (*Kogia breviceps* and *Kogia sima,* respectively)

Description—Pygmy sperm whales have a shark-like head with a narrow underslung lower jaw (Jefferson et al. 1993). The flippers are set high on the sides near the head. The small falcate dorsal fin of the pygmy sperm whale is usually set well behind the midpoint of the back (Jefferson et al. 1993). The dwarf sperm whale is similar in appearance to the pygmy sperm whale, but it has a relatively larger dorsal fin, generally set nearer the middle of the back (Jefferson et al. 1993). The dwarf sperm whale also has a shark-like profile but with a more pointed snout than the pygmy sperm whale. Pygmy and dwarf sperm whales reach body lengths of around 3 and 2.5 m, respectively (Plön and Bernard 1999).

Dwarf and pygmy sperm whales are difficult for the inexperienced observer to distinguish from one another at sea, and sightings of either species are often categorized as simply *Kogia* spp. The difficulty in identifying pygmy and dwarf sperm whales is exacerbated by their avoidance reaction towards ships and change in behavior towards approaching survey aircraft (Würsig et al. 1998). Based on the cryptic behavior of these species and their small group sizes (much like that of beaked whales), as well as similarity in appearance, it is difficult to identify these species in sightings at sea.

Status—Pygmy and dwarf sperm whales within the U.S. Pacific EEZ are each divided into two discrete, non-continguous areas: (1) Hawaiian waters, and (2) waters off California, Oregon, and Washington (Carretta et al. 2005). The best available estimate of abundance for the Hawaiian stock of the pygmy sperm whale is 7,251 individuals (Barlow 2003; Carretta et al. 2005). The best available estimate for the Hawaiian stock of the dwarf sperm whale is 19,172 individuals (Barlow 2003; Carretta et al. 2005).

Habitat Preferences—Both species of *Kogia* generally occur in waters along the continental shelf break and over the continental slope (e.g., Baumgartner et al. 2001; McAlpine 2002; Baird 2005a). Data from the Gulf of Mexico suggest that *Kogia* may associate with frontal regions along the shelf break and upper continental slope, areas with high epipelagic zooplankton biomass (Baumgartner et al. 2001). The zooplankton is likely part of the diet of one or more of the common prey species of *Kogia* (and not of the whales themselves).

There appear to be some habitat preference differences between the two species of the genus *Kogia*. Several studies have suggested that pygmy sperm whales live mostly beyond the continental shelf edge, while dwarf sperm whales tend to occur closer to shore, often over the outer continental shelf (Rice 1998; Wang et al. 2002; MacLeod et al. 2004). In particular, work on strandings and feeding habits in South Africa has indicated this (Ross 1979; Plön et al. 1998). However, after first suggesting this, Ross (1984) later indicated that the difference may be more in terms of a difference between juveniles and adults, with juveniles being more coastal, perhaps in both species. Unfortunately, most such studies are based on stranding records, which do not provide the best evidence on habitat selection, and they often appear to ignore Ross' (1984) later reinterpretation of his own earlier conclusion.

More reliable is a conclusion that the pygmy sperm whale is more temperate, and the dwarf sperm whale more tropical, since it is based at least partially on live sightings at sea from a large database from the eastern tropical Pacific (Wade and Gerrodette 1993). There, the pygmy sperm whale was not seen in truly tropical waters south of the southern tip of Baja California, but the dwarf sperm whale was common in those waters. This idea is also supported by the distribution of strandings in South American waters (Muñioz-Hincapié et al. 1998). Also, in the western tropical Indian Ocean, the dwarf sperm whale was much more common than the pygmy sperm whale, which is consistent with this hypothesis (Ballance and Pitman 1998).

In conclusion, although the dwarf sperm whale does appear to prefer more tropical waters, the exact habitat preferences of the two species are not well-known. Distribution at sea in relation to the shelf edge requires further study. Both species have been seen in both continental shelf and more oceanic waters. It may be that earlier conclusions were misleading, due to biases caused by the inadequacy of stranding data, lack of incorporation of age class effects, and possibly even by local adaptation of each species to the conditions of specific areas.

Distribution—Both *Kogia* species have a worldwide distribution in tropical and temperate waters (Jefferson et al. 1993). Both *Kogia* species occur in deep tropical to temperate waters of the Atlantic, Pacific, and Indian Oceans (Jefferson et al. 1993). The dwarf sperm whale favors more tropical waters, and the pygmy sperm whale appears more at home in temperate waters, but the two species are broadly sympatric. The differences mentioned above probably relate more to one or the other species being more densely distributed in a particular area, rather than a complete separation. However, specifics of the distribution are poorly-known for most areas.

- Information Specific to the Hawaiian Islands OPAREA—Both species of *Kogia* generally occur in waters along the continental shelf break and over the continental slope (e.g., Baumgartner et al. 2001; McAlpine 2002; Baird 2005a). The primary occurrence for *Kogia* is seaward of the shelf break in the OPAREA (**Figures B-11a** and **B-11b**). This takes into account their preference for deep waters. There is a rare occurrence for *Kogia* inshore of their area of primary occurrence. Occurrence is expected to be the same throughout the year.

Behavior and Life History—*Kogia* species have small group sizes (mean group size is usually about two individuals) (Willis and Baird 1998). A recent study of *Kogia* in South Africa has determined that these two species have a much earlier attainment of sexual maturity and shorter life span than other similarly-sized toothed whales (Plön and Bernard 1999). Sexual maturity is attained at around 4 years in both sexes of both species. *Kogia* feed on cephalopods and, less often, on deep-sea fishes and shrimps (Caldwell and Caldwell 1989; Baird et al. 1996; Willis and Baird 1998; Wang et al. 2002). A typical observation of this species is animals logging at the water surface for periods of up to a few minutes and then slowly sinking or slow rolling out of sight and not being resighted (e.g., Baird 2005a). Willis and Baird (1998) reported that *Kogia* make dives of up to 25 min. A satellite-tagged pygmy sperm whale released off Florida was found to make long nighttime dives, presumably indicating foraging on squid in the DSL (Scott et al. 2001).

Acoustics and Hearing—Pygmy sperm whale clicks range from 60 to 200 kHz, with a dominant frequency of 120 kHz (Thomson and Richardson 1995). There is no information available on dwarf sperm whale vocalizations or hearing capabilities. An auditory brainstem response study indicated that pygmy sperm whales have their best hearing between 90 and 150 kHz (Ridgway and Carder 2001).

- Beaked Whales (Family Ziphiidae)

Description—There are seven species of beaked whales known to occur in the North Pacific Ocean (MacLeod et al. in press); only three are expected to occur in the Hawaiian Islands OPAREA: Cuvier's beaked whale, Blainville's beaked whale, and Longman's beaked whale.

The Cuvier's beaked whale is relatively robust compared to other beaked whale species. Male and female Cuvier's beaked whales may reach 7.5 and 7.0 m in length, respectively (Jefferson et al. 1993). This species has a relatively short beak, which along with the curved jaw, is said to resemble a goose beak. The body is spindle-shaped, and the dorsal fin and flippers are small, as is typical for beaked whales. A useful diagnostic feature is a concavity on the top of the head, which becomes more prominent in older individuals. Cuvier's beaked whales are dark gray to light rusty brown in color, often with lighter color around the head. In adult males the head and much of the back can be light gray to white in color, and they also often have many light scratches and circular marks on the body (Jefferson et al. 1993).

The Blainville's beaked whale appears to reach a maximum of around 4.7 m in length and weigh up to 1,033 kg (Jefferson et al. 1993). Adults are blue-gray on their dorsal side and white below (Jefferson et al. 1993). Some individuals often have diatoms growing on them that can change the coloration from a grayish-brown to tan/brown, particularly around the head and dorsal fin (Baird personal communication). Individuals in some areas can have large numbers of oval white scars indicative of cookie-cutter shark bite wounds (Baird personal communication). There is sexual segregation in scarring, with males having high levels of scarring and females having relatively little (MacLeod 1998). All *Mesplodon* species have a relatively small head, large thorax and abdomen, and short tail. *Mesoplodon* species all have a pair of throat grooves on the ventral side on the lower jaw. Beaked whales in the genus *Mesoplodon* are characterized by the presence of a single pair of sexually-dimorphic tusks, which erupt only in adult males. The lower jaw of the Blainville's beaked whale is highly arched and massive flattened tusks extend above the upper jaw in adult males (Jefferson et al. 1993).

The species we now know as Longman's beaked whale was often referred to as the "tropical bottlenose whale" in the past. This was due to the fact that whales now known to be of this species had been sighted in various locations in the tropical/subtropical Indo-Pacific but not identified to species (Pitman et al. 1999). At the time, this species was known only from a handful of skulls, and the external appearance of the species was undescribed. Until several stranded specimens were identified as Longman's beaked whales based on skull morphology and genetics (Dalebout et al. 2003), the sighted whales were thought to be members of the *Hyperoodon* genus (either far-ranging southern bottlenose whales or possibly an undescribed tropical species). We now know these animals to be Longman's beaked whales. The Longman's beaked whale looks very much like the southern bottlenose whale (*Hyperoodon planifrons*) in general shape and coloration although it is more slender (Pitman et al. 1999; Dalebout et al. 2003). The estimated adult length is 7 to 8 m (Pitman et al. 1999). The tall, falcate dorsal fin is set far back on the body (Pitman et al. 1999; Dalebout et al. 2003). The head has a well-rounded melon in profile and the beak length is variable, suggesting developmental changes in beak size (Pitman et al. 1999; Dalebout et al. 2003). This species has a single pair of teeth that are set close to the tip of the lower jaw; it is suspected that, like most other beaked whales species, only adult males will have erupted teeth (Dalebout et al. 2003). The body color has been described as variable but is dominated by tan to grayish-brown tones (Pitman et al. 1999). Young animals are distinctively patterned; they are darker gray-brown above with a conspicuous pale melon and white sides (Pitman et al. 1999). The light area on the head extends only as far back as the blowhole.

Status—The best available estimate of abundance for the Hawaiian stock of the Cuvier's beaked whale is 12,728 individuals (Barlow 2003; Carretta et al. 2005). The best available estimate for the Hawaiian stock of the Blainville's beaked whale is 2,138 individuals (Barlow 2003; Carretta et al. 2005). The best available estimate of abundance for the Hawaiian stock of the Longman's beaked whale is 766 individuals (Barlow 2003; Carretta et al. 2005).

Habitat Preferences—Beaked whales in general normally inhabit deep, oceanic waters (>2,000 m) or continental slopes (200 to 2,000 m) and only rarely stray over the continental shelf (Pitman 2002). Ferguson et al. (2001) noted that offshore waters beyond the continental slope are not often identified as beaked whale habitat, yet this may be a function of lack of survey effort rather than a reflection of the animals' true habitat.

Cuvier's beaked whales are generally sighted in waters with a bottom depth greater than 200 m and are frequently recorded at depths of 1,000 m or more (Gannier 2000; MacLeod et al. 2004). They are commonly sighted around seamounts, escarpments, and canyons. In the eastern tropical Pacific, the mean bottom depth for Cuvier's beaked whales is approximately 3,400 m, with a maximum depth of over 5,100 m (Ferguson 2005). Both Baird et al. (2004) and MacLeod et al. (2004) reported that Cuvier's beaked whales are found in deeper waters than Blainville's beaked whales in the Hawaiian Islands and the Bahamas, respectively.

Most of the ecological information for the Blainville's beaked whale comes from the northern Bahamas (MacLeod et al. 2004; MacLeod and Zuur 2005). In the northern Bahamas, this species was most often sighted in waters with a bottom depth of 200 to 1,000 m (MacLeod and Zuur 2005); the majority of its time was spent along the canyon wall, where water depth is less than 800 m (Claridge 2003; MacLeod et al. 2004; MacLeod and Zuur 2005). In the Society Islands, Blainville's beaked whales were observed in waters with a bottom depth of 300 to 1,400 m (Gannier 2000). Ritter and Brederlau (1999) reported sightings of this species in waters with a bottom depth less than 500 m, and as shallow as 100 m, off the island of La Gomera in the Canary Islands. In the eastern tropical Pacific, the mean bottom depth for Blainville's beaked whale sightings is just over 3,500 m, and the maximum depth is 5,750 m (Ferguson 2005).

The Longman's beaked whale appears to have a preference for warm tropical water, with most sightings occurring in waters with a SST warmer than 26ºC (Pitman et al. 1999). It is also a deepwater species.

Distribution—The Cuvier's beaked whale is the most widely distributed of all beaked whale species, occurring in all three major oceans and most seas (Heyning 1989). This species occupies almost all temperate, subtropical, and tropical waters, as well as subpolar and even polar waters in some areas (MacLeod et al. in press).

The Blainville's beaked whale occurs in temperate and tropical waters of all oceans (Jefferson et al. 1993). The distribution of *Mesoplodon* species in the western North Atlantic may relate to water temperature (Mead 1989; MacLeod 2000), with Blainville's beaked whale generally occurring in warmer southern waters (MacLeod 2000). In the eastern Pacific, where there are about a half-dozen *Mesoplodon* species known, the Blainville's beaked whale is second only to the pygmy beaked whale (*Mesoplodon peruvianus*) in abundance in tropical waters (Wade and Gerrodette 1993).

Longman's beaked whale is known from tropical waters of the Pacific and Indian Oceans (Pitman et al. 1999; Dalebout et al. 2003). Ferguson and Barlow (2001) reported that all Longman's beaked whale sightings were south of 25ºN.

- Information Specific to the Hawaiian Islands OPAREA—For beaked whales, the area of primary occurrence is seaward of the shelf break (**Figures B-12a** and **B-12b**). A narrow band of secondary occurrence extends from the 50 m isobath to the 200 m isobath, which takes into account that deep waters come very close to the shore in this area. There is a rare occurrence for beaked whales from the shore to the 50 m isobath, since sightings in more shallow waters could occasionally occur (**Figures B-12a** and **B-12b**). Occurrence patterns are expected to be the same throughout the year. It should be noted that there have been resightings of some photo-identified Blainville's and Cuvier's beaked whales from the island of Hawai'i indicating some site fidelity (Baird et al. 2005; Carretta et al. 2005).

Behavior and Life History—Life history data on beaked whale species are extremely limited for the Cuvier's, Blainville's, and Longman's beaked whales. Most sightings of beaked whales are brief; these whales are often difficult to approach and they actively avoid aircraft and vessels (Würsig et al. 1998). Observed group sizes for the Blainville's beaked whale are generally small, with single individuals or pairs being most common (Jefferson et al. 1993); the maximum group size from Hawaiian waters is nine individuals (Baird et al. 2004). In the MHI, reported group sizes for the Blainville's beaked whale range from one to nine individuals (Baird et al. 2004). In the northern Bahamas, groups of one to seven individuals have been reported; groups in this area contain females and juveniles, and it is rare for more than one adult male to be present (MacLeod et al. 2004). Baird et al. (2004) reported Cuvier's beaked whale group sizes to range from one to five individuals in the MHI. Groups of Longman's beaked whales are relatively large and range in size from one to an estimated 100 individuals; mean group size for this species is 18.5 individuals (Pitman et al. 1999).

Analyses of stomach contents from captured and stranded individuals suggest that all beaked whales are deep-diving animals, feeding by suction (Heyning 1989; Heyning and Mead 1996; Santos et al.

2001; MacLeod et al. 2003). MacLeod et al. (2003) speculated that all species of beaked whales probably feed at or close to the bottom in deep oceanic waters, taking whatever suitable prey they encounter or feeding on whatever species are locally abundant. More recently, however, Baird et al. (2005) suggested that based on tagging data, feeding might actually occur at mid-water rather than only at or near the bottom. Stomach contents of Cuvier's beaked whales primarily contain cephalopods, and rarely, fish (MacLeod et al. 2003). *Mesoplodon* species feed on small cephalopods (Mead 1989; MacLeod et al. 2003). There is no information available regarding feeding behavior and preferred prey of the Longman's beaked whale.

Baird et al. (2004) documented a tagged Cuvier's beaked whale diving for as long as 87 min. Dives as deep as 1,450 m are recorded for this species (Baird et al. 2005). Durations of long dives for *Mesoplodon* species are typically over 20 min (Barlow 1999; Baird et al. 2005). Tagged Blainville's beaked whales have been recorded to dive to depths as great as 1,408 m, with dive durations as long as 54 min (Baird et al. 2005). Individual dive times of 18 and 25 min have been reported for the Longman's beaked whale (Gallo-Reynoso and Figueroa-Carranza 1995).

Acoustics and Hearing—Very little information is available on characteristics of sound produced by beaked whales. MacLeod (1999) suggested that beaked whales use frequencies of between 300 Hz and 129 kHz for echolocation, and between 2 and 10 kHz, and possibly up to 16 kHz, for social communication.

Click pulses of Cuvier's beaked whales recorded by Frantzis et al. (2002) had a peak frequency between 13 and 17 kHz. An acoustic recording tag was attached to two Cuvier's beaked whales in the Ligurian Sea; at depth, the whales produced echolocation clicks with center frequencies at around 42 kHz and source levels up to 214 dB re 1 μPa-m (Zimmer et al. 2005b). Recording tags attached to two Blainville's beaked whales in the Ligurian Sea showed this species to be highly vocal, producing high-frequency echolocation clicks with no significant energy below 20 kHz (Johnson et al. 2004). The source level of these clicks ranged from 200 to 220 dB re 1 μPa-m (Johnson et al. 2004). Madsen et al. (2005) reported interclick intervals of 300 to 400 ms for Blainville's beaked whales. There is no information available for Longman's beaked whale vocalizations.

There is no empirical information available on the actual hearing abilities of beaked whales (MacLeod 1999). Beaked whale ears are predominantly adapted to hear ultrasonic frequencies (MacLeod 1999). Based on the anatomy of the ears of beaked whales, these species may be more sensitive than other cetaceans to low frequency sounds; however, as noted earlier, there is no direct evidence to confirm this idea (MacLeod 1999).

- Rough-toothed Dolphin (*Steno bredanensis*)

Description—This is a relatively robust dolphin with a cone-shaped head, and it is the only one with no demarcation between the melon and beak (Jefferson et al. 1993). The "forehead" slopes smoothly from the blowhole onto the long narrow beak (Reeves et al. 2002). The rough-toothed dolphin has large flippers that are set far back on the sides and a prominent falcate dorsal fin (Jefferson et al. 1993). The body is dark gray, with a prominent narrow dorsal cape that dips slightly down onto the side below the dorsal fin. The lips and much of the lower jaw are white, and many individuals have white scars and splotches. The rough-toothed dolphin reaches 2.8 m in length (Jefferson et al. 1993).

Status—Nothing is known about the population structure of the rough-toothed dolphin in the North Pacific (Carretta et al. 2005). The best available estimate of abundance for the Hawaiian stock of the rough-toothed dolphin is 19,904 individuals (Carretta et al. 2005).

Habitat Preferences—The rough-toothed dolphin is regarded as an offshore species that prefers deep waters; however, it can occur in waters with variable bottom depths (e.g., Gannier and West 2005). It rarely occurs close to land, except around islands with steep drop-offs nearshore (Reeves et al. 2002; Gannier and West 2005). In the Gulf of Mexico, the rough-toothed dolphin occurs primarily over the deeper waters off the continental shelf (bottom depths of 950 to 1,100 m) (Davis et al. 1998)

although off the Florida panhandle, they can be found over the continental shelf (Fulling et al. 2003). In some regions, this species may regularly frequent coastal waters and areas with shallow bottom depths. For example, there are reports of rough-toothed dolphins over the continental shelf in shallow waters around La Gomera, Canary Islands (Ritter 2002), Puerto Rico and the U.S. Virgin Islands (USVI) (Mignucci-Giannoni 1998), and in coastal waters off Brazil, including even in a lagoon system (Flores and Ximenez 1997; Lodi and Hetzel 1999). At the Society Islands, rough-toothed dolphins were sighted in waters with a bottom depth less than 100 m to over 3,000 m, although apparently favoring the 500 to 1,500 m range (Gannier 2000). In the MHI, this species is found in waters with bottom depths ranging from 250 m to 4,320 m, with sighting rates highest in the deepest portions (2,000 to 4,000 m) (Baird personal communication).

Distribution—Rough-toothed dolphins are found in tropical to warm-temperate waters globally, rarely ranging north of 40ºN or south of 35ºS (Miyazaki and Perrin 1994). They generally occur in the Atlantic, Pacific, and Indian oceans. Rough-toothed dolphins have an oceanic distribution, but they also appear to be found around some island archipelagos. In the MHI, this species appears to demonstrate site fidelity to specific islands (Baird personal communication).

- Information Specific to the Hawaiian Islands OPAREA—Primary occurrence for the rough-toothed dolphin is from the shelf break to seaward of the OPAREA boundaries (**Figures B-13a** and **B-13b**). There is also an area of rare occurrence of rough-toothed dolphins from the shore to the shelf break (**Figures B-13a** and **B-13b**). This takes into consideration the possibility of encountering rough-toothed dolphins in more shallow waters, based on distribution patterns for this species in other tropical locales, as well as Baird et al. (2003a) noting that rough-toothed dolphins are rarely seen in nearshore waters of the MHI. Occurrence patterns are expected to be the same throughout the year.

Behavior and Life History—Small groups of 10 to 20 rough-toothed dolphins are most common, with herds up to 50 animals reported (Miyazaki and Perrin 1994; Reeves et al. 1999; Baird personal communication). Rough-toothed dolphins often associate with other cetacean species (Miyazaki and Perrin 1994; Nekoba-Dutertre et al. 1999; Ritter 2002; Wedekin et al. 2004). In the Society, Marquesas, and Windward islands, rough-toothed dolphins are sometimes sighted in association with large schools of melon-headed whales and Fraser's dolphins, short-finned pilot whales, as well as with humpback whales (Gannier 2000, 2002; Gannier and West 2005). Rough-toothed dolphins tend to associate with floating objects in the eastern tropical Pacific and Gulf of Mexico (Pitman and Stinchcomb 2002; Fulling et al. 2003). Cephalopods and fish, including large fish such as dorado, are consumed as prey (Miyazaki and Perrin 1994; Reeves et al. 1999; Pitman and Stinchcomb 2002). Reef fish are also preyed upon; Perkins and Miller (1983) noted that parts of reef fish had been found in the stomachs of stranded rough-toothed dolphins in Hawai'i. Gannier and West (2005) observed rough-toothed dolphins feeding during the daytime on epipelagic fishes, including flying fishes. Rough-toothed dolphins are known to interact with fisheries in tropical areas, for example, pulling fish from longlines (Schlais 1984; Nitta and Henderson 1993; Nekoba-Dutertre et al. 1999). Female rough-toothed dolphins reach sexual maturity at between 4 and 6 years of age; males attain sexual maturity between 5 and 10 years (Mead et al. 2001). Rough-toothed dolphins may stay submerged for up to 15 min and, from limited data, are known to dive as deep as 70 m, but can probably dive much deeper (Miyazaki and Perrin 1994).

Acoustics and Hearing—The vocal repertoire of the rough-toothed dolphin includes broad-band clicks, barks, and whistles (Yu et al. 2003). Echolocation clicks of rough-toothed dolphins are in the frequency range of 0.1 to 200 kHz, with a peak of about 25 kHz (Miyazaki and Perrin 1994; Yu et al. 2003). Whistles show a wide frequency range: 0.3 to >24 kHz (Yu et al. 2003). There is no published information on hearing ability of this species.

- Common Bottlenose Dolphin (*Tursiops truncatus*)

Description—Bottlenose dolphins (genus *Tursiops*) are medium-sized, relatively robust dolphins that vary in color from light gray to charcoal. *Tursiops* is named for its short, stocky snout that is

distinctively set off from the melon by a crease (Jefferson et al. 1993). There is striking regional variation in body size; adult body length ranges from 1.9 to 3.8 m (Jefferson et al. 1993). The dorsal fin is tall and falcate.

The taxonomy of *Tursiops* continues to be in flux; two species are currently recognized, the common bottlenose dolphin (*Tursiops truncatus*) and the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) (Rice 1998; IWC 2004), with additional species likely to be recognized with more genetic analyses (Natoli et al. 2004). The common bottlenose dolphin occurs as two morphotypes (or forms): a nearshore (coastal) and an offshore form (Hersh and Duffield 1990; Hoelzel et al. 1998). There is a clear distinction between the nearshore and offshore forms of the bottlenose dolphin in the western North Atlantic and western North Pacific suggesting that the two forms may eventually be considered two different species (Curry and Smith 1997; Hoelzel et al. 1998; Kingston and Rosel 2004).

Genetic analyses of biopsied bottlenose dolphins in the MHI revealed one animal with a mitochondrial haplotype typical of the Indo-Pacific bottlenose dolphin, which suggests the possibility of two species of bottlenose dolphins in Hawaiian waters (Baird personal communication). In the meantime, however, we present information on the one confirmed *Tursiops* species for this OPAREA.

Status—Only a single stock is recognized in the Hawaiian Islands. The best available estimate of abundance for the Hawaiian stock of the bottlenose dolphin is 3,263 individuals (Barlow 2003; Carretta et al. 2005).

Habitat Preferences—*Tursiops* live in coastal areas of all continents (except Antarctica), around many oceanic islands and atolls, and over shallow offshore banks and shoals. In the eastern tropical Pacific and elsewhere, there are pelagic populations that range far from land (Scott and Chivers 1990; Reeves et al. 2002). The common bottlenose dolphin has a wider range than the Indo-Pacific bottlenose dolphin; it ranges beyond the tropics and subtropics into temperate waters (Reeves et al. 2002). One satellite-tagged common bottlenose dolphin in the western North Atlantic moved into waters with a bottom depth greater than 5,000 m (Wells et al. 1999).

Risk of predation and food availability influence bottlenose dolphin habitat use (Shane et al. 1986; Wells et al. 1987; Allen et al. 2001; Heithaus and Dill 2002). Predation risk is determined by the number of predators in an area, the ability of predators and prey to detect each other, and the probability of capture after detection; predation risk can be influenced by a suite of habitat attributes, such as water clarity and depth (Heithaus 2001).

Distribution—The overall range of the common bottlenose dolphin is worldwide in tropical to temperate waters. *Tursiops* generally do not range poleward of 45º, except around the United Kingdom and northern Europe (Jefferson et al. 1993).

Bottlenose dolphins found in nearshore waters around the MHI are island-associated, with all sightings occurring in relatively nearshore and shallow waters (<200 m), and no apparent movement between the islands (Baird et al. 2002, 2003a) although Baird et al. (2001a) noted the possibility that individuals could move between islands. Baird et al. (2003a) mentioned the possibility of a second population of bottlenose dolphins in the Hawaiian Islands, based on sighting data, with a preference for deeper (bottom depth of 400 to 900 m) waters.

Climate changes can contribute to range extensions. For example, a 600 km northward range extension to Monterey Bay (for some bottlenose dolphins known from the San Diego, California, area) was linked to the 1982/1983 El Niño event (Wells et al. 1990). Some dolphins remain to this day in the northern waters following return to normal water temperatures, suggesting that the dolphins might have responded more to secondary effects of the warm-water incursion, such as changes in prey distribution, than to the temperature changes themselves (Wells and Scott 1999).

- Information Specific to the Hawaiian Islands OPAREA—Bottlenose dolphins are regularly found around the MHI in both nearshore and offshore waters (Rice 1960; Shallenberger 1981; Mobley

et al. 2000; Baird et al. 2003a). Based on photo-identification studies and sighting data, there is the possibility of separate island populations with different preferences for shallow (<200 m) and deep (400 to 900 m) waters (Baird et al. 2003a). Therefore, an area of primary occurrence is expected from the shore to the 1000 m isobath in the Hawaiian Islands OPAREA, excluding Nihoa due to lack of survey effort (**Figures B-14a** and **B-14b**). This area is continuous between Niʻihau and Kauaʻi and between Oʻahu, Molokaʻi, Lānaʻi, Maui, and Kahoʻolawe to account for possible movements between islands. There is a secondary occurrence seaward of the 1,000 m isobath and seaward from the shoreline of Nihoa. Bottlenose dolphins might have inhabited Pearl Harbor prior to dramatic increases in industrial and shipping presence (Jefferson personal communication). It is possible that individuals might continue to use this area although this is not preferred habitat; therefore, Pearl Harbor is an area of secondary occurrence for bottlenose dolphins. Occurrence patterns are expected to be the same throughout the year.

Behavior and Life History—*Tursiops* are gregarious; they are typically found in groups of 2 to 15 individuals, although groups of up to 100 or more have been reported in some areas (Shane et al. 1986). Based on photo-identification techniques using dorsal fin shapes and markings (Würsig and Würsig 1977; Würsig and Jefferson 1990), it is well known that *Tursiops* has a fluid social organization (Connor et al. 2000). Habitat structure, in terms of complexity and water depth, is generally a major force that shapes bottlenose dolphin groupings (Shane et al. 1986). Shallow-water areas typically have smaller group sizes than open or oceanic areas (Wells et al. 1980). Open coastlines, however, differ in habitat structure and prey distribution from more protected areas. Protected areas have been found to foster relatively small school sizes, some degree of regional site fidelity, and limited movement patterns (Wells et al. 1987). In contrast, semi-open habitats often sustain larger school sizes, diminished levels of site fidelity, and more expansive home ranges (Defran and Weller 1999). In waters of the eastern tropical Pacific, group size estimates range into the thousands, and herds of over 100 are not uncommon (Scott and Chivers 1990). In the eastern tropical Pacific, bottlenose dolphin groups around offshore islands and near coastlines average between 72 and 94 individuals, and groups in more offshore locations average around 40 to 44 dolphins (Scott and Chivers 1990).

Along the Atlantic coast of the U.S., where the majority of detailed work on bottlenose dolphins has been conducted, male and female bottlenose dolphins reach physical maturity at 13 years, with females reaching sexual maturity as early as 7 years (Mead and Potter 1990). Bottlenose dolphins are flexible in their timing of reproduction. Seasons of birth for bottlenose dolphin populations are likely responses to seasonal patterns of availability of local resources (Urian et al. 1996). For the same central U.S. Atlantic coast areas, Hohn (1980) reported one (spring) and possibly two calving seasons (spring and fall), whereas Mead and Potter (1990) reported a prolonged calving season with a spring peak. There is a gestation period of one year (Caldwell and Caldwell 1972). Calves of bottlenose dolphins typically remain with their mothers for 3 to 6 years (Wells et al. 1987). In the Pacific, there is clearly much geographical variation among various coastal and offshore populations (Walker 1981; Kasuya et al. 1997). In Japanese waters, calves are born at a length of around 128 cm, with a calving peak in June (Kasuya et al. 1997). Sexual maturity appears to be reached at similar ages as in the Atlantic (5 to 13 years for females and 9 to 11+ for males) (Kasuya et al. 1997).

Tursiops are opportunistic feeders, taking a wide variety of fishes, cephalopods, and shrimp (Wells and Scott 1999) using a wide variety of feeding strategies (Shane 1990). In addition to use of active echolocation to find food, bottlenose dolphins likely detect and orient to fish prey by listening for the sounds they produce—so-called passive listening (Barros and Myrberg 1987; Gannon et al. 2005). Nearshore bottlenose dolphins prey predominately on coastal fish and cephalopods, while offshore individuals prey on pelagic cephalopods and a large variety of epi- and mesopelagic fish species (Walker 1981; Van Waerebeek et al. 1990; Mead and Potter 1995).

Navy bottlenose dolphins have been trained to reach maximum diving depths of about 300 m (Ridgway et al. 1969). Reeves et al. (2002) noted that the presence of deep-sea fish in the stomachs of some offshore individual bottlenose dolphins suggests that they dive to depths of more than 500 m.

Dive durations up to 15 min have been recorded for trained individuals (Ridgway et al. 1969). Typical dives, however, are more shallow and of a much shorter duration.

Acoustics and Hearing—Sounds emitted by bottlenose dolphins have been classified into two broad categories: pulsed sounds (including clicks and burst-pulses) and narrow-band continuous sounds (whistles), which usually are FM. Clicks and whistles have a dominant frequency range of 110 to 130 kHz and a source level of 218 to 228 dB re 1 μPa-m (Au 1993) and 3.5 to 14.5 kHz and 125 to 173 dB re 1 μPa-m, respectively (Ketten 1998). Generally, whistles range in frequency from 0.8 to 24 kHz (Thomson and Richardson 1995).

The bottlenose dolphin has a functional high-frequency hearing limit of 160 kHz (Au 1993) and can hear sounds at frequencies as low as 40 to 125 Hz (Turl 1993). Inner ear anatomy of this species has been described (Ketten 1992). Electrophysiological experiments suggest that the bottlenose dolphin brain has a dual analysis system: one specialized for ultrasonic clicks and the other for lower-frequency sounds, such as whistles (Ridgway 2000). The audiogram of the bottlenose dolphin shows that the lowest thresholds occurred near 50 kHz at a level around 45 dB re 1 μPa-m (Nachtigall et al. 2000). Below the maximum sensitivity, thresholds increased continuously up to a level of 137 dB at 75 Hz. Above 50 kHz, thresholds increased slowly up to a level of 55 dB at 100 kHz, then increased rapidly above this to about 135 dB at 150 kHz. Scientists have reported a range of best sensitivity between 25 and 70 kHz, with peaks in sensitivity occurring at 25 and 50 kHz at levels of 47 and 46 dB re 1 μPa-m (Nachtigall et al. 2000). Richardson (1995) noted that the differences between the reported audiograms for these two studies might be attributable in part to conducting the experiments in tanks. A neurophysiological method was used to determine the high-frequency audiograms (5 to 200 kHz) of five bottlenose dolphins (Richardson 1995). Temporary threshold shifts (TTS) in hearing have been experimentally induced in captive bottlenose dolphins (Ridgway et al. 1997; Schlundt et al. 2000; Nachtigall et al. 2003). Ridgway et al. (1997) observed changes in behavior at the following minimum levels for 1 sec tones: 186 dB at 3 kHz, 181 dB at 20 kHz, and 178 dB at 75 kHz (all re 1 μPa-m). TTS levels were 194 to 201 dB at 3 kHz, 193 to 196 dB at 20 kHz, and 192 to 194 dB at 75 kHz (all re 1 μPa-m). Schlundt et al. (2000) exposed bottlenose dolphins to intense tones (0.4, 3, 10, 20, and 75 kHz); the animals demonstrated altered behavior at source levels of 178 to 193 dB re 1 μPa-m, with TTS after exposures generally between 192 and 201 dB re 1 μPa-m (though one dolphin exhibited TTS after exposure at 182 dB re 1 μPa-m). Nachtigall et al. (2003) determined threshold for a 7.5 kHz pure tone stimulus. No shifts were observed at 165 or 171 dB re 1 μPa-m, but when the noise level reached 179 dB re 1 μPa-m, the animal showed the first sign of TTS. Recovery apparently occurred rapidly, with full recovery apparently within 45 min following noise exposure. TTS measured between 8 and 16 kHz (negligible or absent at higher frequencies) after 30 minutes of noise exposure (4 to 11 kHz) at 160 dB re 1 μPa-m (Nachtigall et al. 2004).

- Pantropical Spotted Dolphin (*Stenella attenuata*)

Description—The pantropical spotted dolphin is a rather slender dolphin. This species has a dark dorsal cape, while the lower sides and belly of adults are gray. The beak is long and thin; the lips and beak tip tend to be bright white. A dark gray band encircles each eye and continues forward to the apex of the melon; there is also a dark gape-to-flipper stripe (Jefferson et al. 1993). Pantropical spotted dolphins are born spotless and develop spots as they age although the degree of spotting varies geographically (Perrin and Hohn 1994). Some populations may be virtually unspotted (Jefferson personal communication). Adults may reach 2.6 m in length (Jefferson et al. 1993).

Status—The best available estimate of abundance for the pantropical spotted dolphin within the Hawaiian Islands EEZ is 10,260 individuals (Barlow 2003; Carretta et al. 2005). A single stock is recognized.

Habitat Preferences—In the eastern Pacific, the pantropical spotted dolphin is an inhabitant of the tropical, equatorial and southern subtropical water masses characterized by a sharp thermocline at less than 50 m depth, surface temperatures greater than 25ºC, and salinities less than 34 parts per thousand (ppt) (Au and Perryman 1985). Most sightings of this species in the Gulf of Mexico and

Caribbean occur over the lower continental slope (Davis et al. 1998; Mignucci-Giannoni et al. 2003). In some areas, such as in the Phillipines, pantropical spotted dolphins occur in deep water close to shore (Perrin 2001). Pantropical spotted dolphins may also be sighted in shallow waters near the edge of the continental shelf (Peddemors 1999; Gannier 2002).

Distribution—The pantropical spotted dolphin is distributed in tropical and subtropical waters worldwide (Perrin and Hohn 1994). Range in the central Pacific is from around the Hawaiian Islands in the north to at least the Marquesas in the south (Perrin and Hohn 1994).

- Information Specific to the Hawaiian Islands OPAREA—Based on known habitat preferences and sighting data, the primary occurrence for the pantropical spotted dolphin is between the 100 and 4,000 m isobaths throughout the OPAREA (**Figures B-15a** and **B-15b**). This area of primary occurrence also includes a continuous band connecting all the MHI, Nihoa, and Kaula Rock, taking into account possible inter-island movements. Secondary occurrence is expected from the shore to the 100 m isobath, as well as seaward of the 4,000 m isobath (**Figures B-15a** and **B-15b**). Pantropical spotted dolphins are expected to be rare in Pearl Harbor. Occurrence patterns are expected to be the same throughout the year.

Behavior and Life History—Group size for the pantropical spotted dolphin may range from just a few dolphins to several thousand (Jefferson et al. 1993). Observations of dolphin groups caught in tuna purse seines in the eastern tropical Pacific show that there are subgroups containing mother/calf pairs, adult males, or juveniles (Pryor and Shallenberger 1991). Pantropical spotted dolphins in the eastern tropical Pacific Ocean and Indian Ocean are often found in mixed species aggregations that include spinner dolphins, tunas, and various oceanic bird species. In the eastern tropical Pacific, where this species has been best studied, there are two calving peaks—one in spring and one in fall (Perrin and Hohn 1994). Pantropical spotted dolphins prey on epipelagic fish, squid, and crustaceans, with mesopelagic species dominating stomach contents (Perrin and Hohn 1994; Robertson and Chivers 1997; Perrin 2001; Wang et al. 2003). Results from various tracking and food habit studies suggest that pantropical spotted dolphins in the eastern tropical Pacific and off the Hawaiian Islands feed primarily at night on epipelagic species and on mesopelagic species that rise towards the water's surface after dark (Robertson and Chivers 1997; Scott and Cattanach 1998; Baird et al. 2001b). Dives during the day are generally shorter and shallower than dives at night; rates of descent and ascent are higher at night than during the day (Baird et al. 2001b). Similar mean dive durations and depths have been obtained for tagged pantropical spotted dolphins in the eastern tropical Pacific and off the Hawaiian Islands (Baird et al. 2001b).

Acoustics and Hearing—Pantropical spotted dolphin whistles have a dominant frequency range of 6.7 to 17.8 kHz (Ketten 1998). Click source levels between 197 and 220 dB re 1 μPa-m have been recorded for pantropical spotted dolphins (Schotten et al. 2004). There are no published hearing data for pantropical spotted dolphins (Ketten 1998). Anatomy of the ear of the pantropical spotted dolphin has been studied (Ketten 1992, 1997). Ketten (1997) found that, like other delphinids studies, the pantropical spotted dolphin has a Type II cochlea with 2.5 turns.

- Spinner Dolphin (*Stenella longirostris*)

Description—This is a slender dolphin that has a very long, slender beak (Jefferson et al. 1993). The dorsal fin ranges from slightly falcate to triangular or even canted forward in some geographic forms. The spinner dolphin generally has a dark eye-to-flipper stripe and dark lips and beak tip (Jefferson et al. 1993). This species typically has a three-part color pattern (dark gray cape, light gray sides, and white belly). Adults can reach 2.4 m in length (Jefferson et al. 1993). There are four known subspecies of spinner dolphins and probably other undescribed ones (Perrin 1998; Perrin et al. 1999).

Status—The best available estimate of abundance for the Hawaiian stock of the spinner dolphin is 2,805 individuals (Barlow 2003; Carretta et al. 2005).

Habitat Preferences—Spinner dolphins occur in both oceanic and coastal environments. Most sightings of this species have been associated with inshore waters, islands, or banks (Perrin and Gilpatrick 1994). Oceanic populations, such as those in the eastern tropical Pacific, often are found in waters with a shallow thermocline (Au and Perryman 1985; Reilly 1990). The thermocline concentrates pelagic organisms in and above it; spinner dolphins feed on this aggregation of prey. In the ETP, spinner dolphins are associated with tropical surface water typified by extensive stable thermocline ridging and relatively little annual variation in surface temperature (Reeves et al. 1999). Coastal populations usually are found in island archipelagos where they are tied to trophic and habitat resources associated with the coast (Norris and Dohl 1980; Poole 1995). Norris et al. (1994) suggested that the availability of prey and resting habitats are the primary limiting factors influencing the occurrence of spinner dolphins in the Hawaiian Islands. As noted by Lammers (2004), presumably these are the same constraints faced by populations at other islands.

Spinner dolphins at islands and atolls rest during daytime hours in shallow, wind-sheltered nearshore waters and forage over deep waters at night (Norris et al. 1994; Östman 1994; Poole 1995; Gannier 2000, 2002; Lammers 2004; Östman-Lind et al. 2004). Suitable habitat for resting includes bay complexes around islands (Poole 1995) or shallow waters near the coast (Lammers 2004); Lammers (2004) noted a preference for the 10 fathom isobath. It should be noted, however, that while certain bays or shoal areas are repeatedly occupied, others are only infrequently visited or not occupied at all (Norris et al. 1985; Poole 1995). Spinner dolphins often rest in lagoons (Gannier 2000; Trianni and Kessler 2002). Preferred resting habitat is usually more sheltered from prevailing tradewinds than adjacent areas, and the bottom substrate is generally dominated by large stretches of white sand bottom rather than the prevailing reef and rock bottom along most other parts of the coast (Norris et al. 1994; Lammers 2004). These clear, calm waters and light bottom substrates provide a less cryptic backdrop for predators like large sharks (Norris et al. 1994; Lammers 2004).

Distribution—The spinner dolphin is found in tropical and subtropical waters worldwide. Limits are near 40ºN and 40ºS (Jefferson et al. 1993). This species occurs near islands such as the Hawaiian Islands, the Mariana Islands, and islands of the South Pacific, the Caribbean, and Fernando de Noronha Island off Brazil. Spinner dolphins have been documented to travel distances of up to 40 km between the MHI (Maldini 2003). Long-term studies of island-associated spinner dolphins in the Pacific have been conducted since the 1970s along the Kona coast of Hawaiʻi (Norris et al. 1994; Östman 1994; Östman-Lind et al. 2004) and since the 1980s at Moʻorea, French Polynesia (Poole 1995). In the Hawaiian Islands, spinner dolphins occur along the leeward coasts of all the major islands and around several of the atolls northwest of the main island chain. Long-term site fidelity has been noted for spinner dolphins along the Kona coast of Hawaiʻi, along Oʻahu, and off the island of Moorea in the Society Islands (Norris et al. 1994; Östman 1994; Poole 1995; Marten and Psarakos 1999), with some individuals being sighted for up to 12 years at Moorea (Poole 1995).

- Information Specific to the Hawaiian Islands OPAREA—Spinner dolphins occur year-round throughout the Hawaiian Islands OPAREA, with primary occurrence from the shore to the 4,000 m isobath (**Figures B-16a** and **B-16b**). This takes into account nearshore resting habitat and offshore feeding areas. Spinner dolphins are expected to occur in shallow water (50 m or less) resting areas throughout the middle of the day, moving into deep waters offshore during the night to feed. Primary resting areas are along the west side of Hawaiʻi, including Makako Bay, Honokohau Bay, Kailua Bay, Kealakekua Bay, Honaunau Bay, Kauhako Bay, and off Kahena on the southeast side of the island (Östman-Lind et al. 2004). Along the Waianae coast of Oʻahu, spinner dolphins rest along Makua Beach, Kahe Point, and Pokai Bay during the day (Lammers 2004). Kilauea Bay in northeast Kauaʻi and Manele Bay in southeast Lāna'i are also popular resting bays for spinner dolphins (Baird personal communication; Jefferson personal communication). There is an area of secondary occurrence seaward of the 4,000 m isobath (**Figures B-16a** and **B-16b**). Although sightings have been recorded around the Pearl Harbor area (Lammers 2004), spinner dolphin occurrence is expected to be rare in Pearl Harbor due to the concentrated industrial/shipping presence. Occurrence patterns are assumed to be the same throughout the year. It is currently not known whether individuals regularly move between islands or island groups (Carretta et al. 2005).

Behavior and Life History—Group sizes range from less than 50 up to several thousand individuals (Jefferson et al. 1993). Seasonal and geographic variations in group size have been recorded (Norris et al. 1985). Reported group sizes in the Hawaiian Islands range from 1 to over 200 individuals with most groups consisting of less than 45 individuals (Norris and Johnson 1994; Östman-Lind et al. 2004; Karczmarski et al. 2005).

Social groupings in this species are typically very fluid in Hawaiian waters; large groups form, break-up, and re-form with different subgroups throughout the day (Norris et al. 1994). In the offshore eastern tropical Pacific, there is some segregation by age and sex among dolphin groups (Perrin and Gilpatrick 1994). In contrast, Karczmarski et al. (2005) observed that at the isolated Midway Atoll, there were actually long-term bonds between individuals and the society was closed. Karczmarski et al. (2005) suggested that the difference in the overall society structure of spinner dolphins is caused by the variable influence of available resting places; at Midway Atoll, a lagoon is the only major resting site available.

In the eastern tropical Pacific and Indian Ocean, spinner dolphins are often seen with pantropical spotted dolphins and tuna (Perrin and Gilpatrick 1994; Ballance and Pitman 1998). Island-associated spinner dolphins, such as those at Hawai‘i and Mo‘orea, do not have tuna associated with them, at least not while the dolphins are in their daytime rest areas (Poole 1995). Island-associated spinner dolphins have been observed associating with bottlenose dolphins and pantropical spotted dolphins (Gabriele et al. 2003; Psarakos et al. 2003; Lammers 2004; Östman-Lind et al. 2004).

The studies of spinner dolphins along the Hawaiian Islands provide the current framework for our understanding of spinner dolphin behavior and social organization; this was detailed first by Norris and Dohl (1980) and later by Norris et al. (1994), Östman (1994), and Lammers (2004). Spinner dolphins at different islands and atolls carry out their daily cycle in the same general behavior pattern in the sense that groups come into shallow waters to rest and socialize and then move further offshore in the late afternoon or early evening to forage. There are typically groups of 20 to 100+ individual dolphins that enter the shallow waters in the morning and gradually descend into a state of lowered activity level for several hours (Norris and Dohl 1980; Norris et al. 1994; Östman 1994; Lammers 2004). Periods of rest are characterized by very cohesive group formations and an almost total absence of acoustic activity. In the late afternoon/early evening, following a period of renewed social and aerial activity, groups move offshore again towards their evening foraging grounds. The cycle is repeated almost daily with the only seasonal changes being adjustments in the timing of events, which reflects shifts in day length. Similar patterns of spinner dolphin foraging and resting cycles also have been observed at other island habitats such as Moorea in French Polynesia (Poole 1995), Midway Atoll (Karczmarski et al. 2005), and off Brazil (Silva-Jr et al. 2004).

Spinner dolphins feed primarily on small mesopelagic fishes, squids, and sergestid shrimps, and they dive to at least 200 to 300 m (Perrin and Gilpatrick 1994). Foraging takes place primarily at night when the mesopelagic community migrates vertically towards the surface and also horizontally towards the shore at night (Benoit-Bird et al. 2001; Benoit-Bird and Au 2004). Rather than foraging offshore for the entire night, spinner dolphins track the horizontal migration of their prey (Benoit-Bird and Au 2003). This tracking of the prey allows spinner dolphins to maximize their foraging time while foraging on the prey at its highest densities (Benoit-Bird and Au 2003; Benoit-Bird 2004). Spinner dolphins begin foraging at a protruding bank, most likely because the prey layer enters shallow waters here before anywhere else along the coast (Lammers 2004). Spinner dolphins dive to meet the rising layer of prey organisms and forage cooperatively (Benoit-Bird and Au 2003). The life history of the spinner dolphin has been well-described for the eastern tropical Pacific Ocean where the species is killed in large numbers in tuna purse seine nets (reviewed in Perrin 1998). Gestation lasts about 10 months, length of lactation is about 1 to 2 years, and sexual maturity occurs at lengths and ages of 1.65 to 1.70 m and 4 to 7 years (females) and 1.60 to 1.80 m and 7 to 10 years (males). There is some geographic variation, but other spinner dolphin populations probably have life history characteristics similar to those listed.

Sazima et al. (2003) and Silva-Jr. et al. (2004) reported that spinner dolphins off northeast Brazil vomit after a meal rich in squid, and that reef fishes were observed feeding on this vomit. Würsig et al. (1994) did not report similar vomiting behavior for Hawaiian spinner dolphins possibly due to their feeding primarily on fishes. Trianni and Kessler (2002) reported on a stranded individual in Saipan with its stomach engorged with seagrass.

Spinner dolphins are well known for their propensity to leap high into the air and spin before landing in the water; the purpose of this behavior is unknown. Norris and Dohl (1980) also described several other types of aerial behavior, including several other leap types, backslaps, headslaps, noseouts, tailslaps, and a behavior called "motorboating." Undoubtedly, spinner dolphins are one of the aerially-active of all dolphin species. Calving peaks in different spinner dolphin populations range from late spring to fall (Jefferson et al. 1993).

Acoustics and Hearing—Pulses, whistles, and clicks have been recorded from this species. Pulses and whistles have dominant frequency ranges of 5 to 60 kHz and 8 to 12 kHz, respectively (Ketten 1998). Spinner dolphins consistently produce whistles with frequencies as high as 16.9 to 17.9 kHz with a maximum frequency for the fundamental component at 24.9 kHz (Bazúa-Durán and Au 2002; Lammers et al. 2003). Clicks have a dominant frequency of 60 kHz (Ketten 1998). The burst pulses are predominantly ultrasonic, often with little or no energy below 20 kHz (Lammers et al. 2003). Source levels between 195 and 222 dB re 1 µPa-m have been recorded for spinner dolphin clicks (Schotten et al. 2004).

- Striped Dolphin (*Stenella coeruleoalba*)

Description—The striped dolphin is uniquely marked with black lateral stripes from eye to flipper and eye to anus. There is also a white V-shaped "spinal blaze" originating above and behind the eye and narrowing to a point below and behind the dorsal fin (Leatherwood and Reeves 1983). There is a dark cape and white belly. This is a relatively robust dolphin reaching 2.6 m in length with a long, slender beak and prominent dorsal fin.

Status—The best available estimate of abundance for the Hawaiian stock of the striped dolphin is 10,385 individuals (Barlow 2003; Carretta et al. 2005).

Habitat Preferences—Striped dolphins are usually found beyond the continental shelf, typically over the continental slope out to oceanic waters, often associated with convergence zones and waters influenced by upwelling (Au and Perryman 1985). In the eastern Pacific, striped dolphins inhabit areas with large seasonal changes in surface temperature and thermocline depth, as well as seasonal upwelling (Au and Perryman 1985; Reilly 1990). This species appears to avoid waters with sea temperatures of less than 20ºC (Van Waerebeek et al. 1998). Off the coast of Japan, striped dolphins congregate at the periphery of the Kuroshio Current where warm water meets up with cold water (Miyazaki et al. 1974). Gannier (1999) noted diel variations in distribution in the northwestern Mediterranean Sea consistent with nocturnal feeding by dolphins close to the shelf break with a diurnal offshore-inshore movement.

Distribution—The striped dolphin has a worldwide distribution in cool-temperate to tropical waters. This species is well documented in both the western and eastern Pacific off the coasts of Japan and North America (Perrin et al. 1994a); the northern limits are the Sea of Japan, Hokkaido, Washington state, and along roughly 40ºN across the western and central Pacific (Reeves et al. 2002). Scattered records exist from the South Pacific as well (Perrin et al. 1994a).

- Information Specific to the Hawaiian Islands OPAREA—The striped dolphin regularly occurs throughout the Hawaiian Islands OPAREA. Primary occurrence for the striped dolphin is seaward of the 1,000 m isobath based on sighting records and the species' known preference for deep waters (**Figures B-17a** and **B-17b**). Striped dolphins are occasionally sighted closer to shore (Mobley et al. 2000); therefore, an area of secondary occurrence is expected from the 100 m to the 1000 m isobaths. There is a rare occurrence from the shore to the 100 m isobath, including

Pearl Harbor. In 1958, a striped dolphin was captured in the Ala Wai Canal, which runs through Honolulu behind Waikiki Beach (Hubbs et al. 1973). Occurrence patterns are assumed to be the same throughout the year.

Behavior and Life History—Striped dolphins are found in large groups numbering between 100 and 500 individuals, although sometimes they gather in the thousands. Striped dolphins have been found in association with seabirds and other species of marine mammals (Baird et al. 1993).

Life history information is based mostly on western North Pacific specimens (Archer and Perrin 1999). Males reach sexual maturity between 7 and 15 years of age, at an average body length of 2.2 m. Females become sexually mature between 5 and 13 years of age (Archer and Perrin 1999). Off Japan, where their biology has been studied most intensively, there are two calving peaks: one in summer and another in winter (Perrin et al. 1994a).

Striped dolphins often feed in pelagic or benthopelagic zones along the continental slope or just beyond in oceanic waters. A majority of the prey possess luminescent organs, suggesting that striped dolphins may be feeding at great depths, possibly diving to 200 to 700 m to reach potential prey (Archer and Perrin 1999). Striped dolphins may feed at night in order to take advantage of the DSL's diurnal vertical movements. Small, mid-water fishes (in particular, myctophids or lanternfish) and squids are the dominant prey (Perrin et al. 1994a).

Acoustics and Hearing—Striped dolphin whistles range from 6 to 24+ kHz, with dominant frequencies ranging from 8 to 12.5 kHz (Thomson and Richardson 1995). The striped dolphin's range of most sensitive hearing (defined as the frequency range with sensitivities within 10 dB re 1 μPa-m of maximum sensitivity) was determined to be 29 to 123 kHz, using standard psycho-acoustic techniques; maximum sensitivity occurred at 64 kHz (Kastelein et al. 2003). Hearing ability became less sensitive below 32 kHz and above 120 kHz (Kastelein et al. 2003).

- Risso's Dolphin (*Grampus griseus*)

Description—Risso's dolphins are moderately large, robust dolphins reaching at least 3.8 m in length (Jefferson et al. 1993). The head is blunt without a distinct beak, and there is a vertical crease on the front of the melon. The dorsal fin is tall and falcate and the flippers are long and sickle-shaped. Young Risso's dolphins range from light gray to dark, brownish-gray and are relatively unmarked (Jefferson et al. 1993). Adults range from dark gray to nearly white and are covered with white scratches and splotches.

Status—The best available estimate of abundance for the Hawaiian stock of the Risso's dolphin is 2,351 individuals (Barlow 2003; Carretta et al. 2005).

Habitat Preferences—Risso's dolphins occur most commonly in deep water beyond the continental slope. Several studies have noted that Risso's dolphins are most commonly found along the continental slope (CETAP 1982; Baumgartner 1997; Davis et al. 1998; Mignucci-Giannoni 1998; Kruse et al. 1999). Baumgartner (1997) hypothesized that the strong correlation between Risso's dolphin distribution and the steeper portions of the upper continental slope in the Gulf of Mexico is most likely the result of cephalopod distribution in the same area.

Distribution—Risso's dolphin is distributed worldwide in tropical to cool-temperate waters, roughly between 60ºN and 60ºS, where surface water temperature is usually greater than 10ºC (Kruse et al. 1999). Water temperature appears to be a factor that affects the distribution of Risso's dolphins in the Pacific (Kruse et al. 1999). Changes in local distribution and abundance along the California coast are probably in response to protracted or unseasonal warm-water events, such as El Niño events (Shane 1994). Changes in both abundance and shoreward shifts of Risso's dolphin distribution have been reported during such periods.

- Information Specific to the Hawaiian Islands OPAREA—There is an area of secondary occurrence between the 100 and 5,000 m isobaths based on the known habitat preferences of this species, as well as the paucity of sightings, even though there is extensive aerial and boat-based survey coverage near the islands (**Figures B-18a** and **B-18b**). There is a narrow band of rare occurrence from the shore to the 100 m isobath, including Pearl Harbor that takes into consideration the possibility that this species, with a preference for waters with steep bottom topography, might swim into areas where deep water is close to shore. Risso's dolphins are expected to be rare seaward of the 5,000 m isobath (**Figures B-18a** and **B-18b**). Occurrence patterns are assumed to be the same throughout the year.

Behavior and Life History—Little is known about the life history of this species. Risso's dolphins are quite social; groups usually average about 30 individuals but can range up to over several hundred (Kruse et al. 1999) or even several thousand (Jefferson personal communication). Risso's dolphins occur in stable, age- and sex-segregated groups, which interact fluidly with a larger population. This species commonly associates with other cetacean species (Kruse et al. 1999). They may remain submerged on dives for up to 30 min; typical swimming speeds are 1.67 to 1.94 m/sec (Kruse et al. 1999). Cephalopods are the primary prey (Clarke 1996).

Acoustics and Hearing—Risso's dolphin vocalizations include broadband clicks, barks, buzzes, grunts, chirps, whistles, and simultaneous whistle and burst-pulse sounds (Corkeron and Van Parijs 2001). The combined whistle and burst pulse sound appears to be unique to Risso's dolphin (Corkeron and Van Parijs 2001). Corkeron and Van Parijs (2001) recorded five different whistle types ranging in frequency from 4 to 22 kHz. Broadband clicks had a frequency range of 6 to greater than 22 kHz. Low-frequency narrowband grunt vocalizations had a frequency range of 0.4 to 0.8 kHz. A recent study established empirically that Risso's dolphins echolocate; estimated source levels were up to 216 dB re 1 μPa-m (Philips et al. 2003).

Nachtigall et al. (1995) conducted baseline audiometric work. Because of the natural background noise (the study was conducted in a natural setting), it was not possible to precisely determine peak (or best) hearing sensitivity in the species. Maximum reported sensitivity occurred between 8 and 64 kHz. Reported thresholds (all re 1 μPa-m) were 124 dB at 1.6 kHz, 71.7 dB at 4 kHz, 63.7 dB at 8 kHz, 63.3 dB at 16 kHz, 66.5 dB at 32 kHz, 67.3 dB at 64 kHz, 74.3 dB at 80 kHz, 124.2 dB at 100 kHz, and 122.9 dB at 110 kHz.

- Melon-headed Whale (*Peponocephala electra*)

Description—Melon-headed whales closely resemble pygmy killer whales at sea; both species have a blunt head with little or no beak. Melon-headed whales have pointed (versus rounded) flipper tips and a more triangular head shape than pygmy killer whales (Jefferson et al. 1993). The body is charcoal gray to black with unpigmented lips (which often appear light gray, pink, or white) and a white urogenital patch (Perryman et al. 1994). This species also has a triangular face "mask" and indistinct cape (which dips much lower below the dorsal fin than that of pygmy killer whales). Melon-headed whales reach a maximum length of 2.75 m (Jefferson et al. 1993).

Status—The best available estimate of abundance for the Hawaiian stock of the melon-headed whale is 2,947 individuals (Barlow 2003; Carretta et al. 2005).

Habitat Preferences—Melon-headed whales are most often found in deep, offshore waters. For example, most melon-headed whale sightings in the Gulf of Mexico have been in deep waters well beyond the edge of the continental shelf (Mullin et al. 1994; Davis and Fargion 1996) and in waters over the abyssal plain (Jefferson personal communication). Melon-headed whales in the MHI are found in waters with bottom depths ranging from 255 to 4,407 m, with a preference for waters with a bottom depth greater than 2,000 m (Baird personal communication; Baird et al. 2003a). Nearshore sightings are generally from areas where deep, oceanic waters are found near the coast (Perryman 2002). Melon-headed whales are found close to shore (within a few kilometers) around the Society and Marquesas Islands of French Polynesia (Gannier 2000, 2002), and Lembata Island of the

Indonesian archipelago (Rudolph et al. 1997), as well as in some waters of the Philippines (Leatherwood et al. 1992). In the eastern tropical Pacific, this species is primarily found in upwelling-modified and equatorial waters (Au and Perryman 1985; Perryman et al. 1994).

Distribution—Melon-headed whales are found worldwide in tropical and subtropical waters. They have occasionally been reported from higher latitudes, but these sightings are often associated with incursions of warm water currents (Perryman et al. 1994). Preliminary results from photo-identification work in the MHI suggest inter-island movements by some individuals (e.g., between the islands of Kaua‘i and Hawai‘i) as well as some residency by other individuals (e.g., at the island of Hawai‘i) (Baird personal communication).

- Information Specific to the Hawaiian Islands OPAREA—The melon-headed whale is an oceanic species. Melon-headed whales are primarily expected to occur from the shelf break to seaward of the Hawaiian Islands OPAREA and vicinity (**Figure B-19a** and **B-19b**). There is rare occurrence from the shore to the shelf break which would take into account any sightings that could occur closer to shore (since deep water is very close to shore at these islands). Occurrence patterns are assumed to be the same throughout the year.

Behavior and Life History—Melon-headed whales are typically found in large groups ranging between 150 and 1,500 individuals (Perryman et al. 1994; Gannier 2002) although Watkins et al. (1997) described smaller groupings of 10 to 14 individuals. In the MHI, group sizes range from 17 to 800 individuals (Baird personal communication; Baird et al. 2003a). These animals often log at the water’s surface in large schools composed of noticeable subgroups. Melon-headed whales are often found in mixed-species aggregations, commonly with Fraser's dolphins (Miyazaki and Wada 1978; Perryman et al. 1994; Jefferson and Barros 1997; Reeves et al. 1999; Gannier 2000) and occasionally with spinner, bottlenose, or rough-toothed dolphins, as well as short-finned pilot whales (Reeves et al. 1999; Gannier 2000; Migura and Meadows 2002; Perryman 2002; Baird personal communication).

Very few data are available on life history of this species. It is unclear whether there is significant seasonality in calving (Jefferson and Barros 1997). Females reach sexual maturity at about 11.5 years and males at 16.5 years (Jefferson and Barros 1997). These life history parameters are estimated from work on a single school of melon-headed whales that mass-stranded at Aoshima, southern Japan (Miyazaki et al. 1998) and, therefore, must be taken as highly preliminary. Melon-headed whales prey on squid, pelagic fishes, and occasionally crustaceans. Most of the fish and squid families eaten by this species consist of mesopelagic forms found in waters up to 1,500 m deep suggesting that feeding takes place deep in the water column (Jefferson and Barros 1997). There is no empirical information on specific diving depths for melon-headed whales.

Acoustics and Hearing—The only published acoustic information for melon-headed whales is from the southeastern Caribbean (Watkins et al. 1997). Sounds recorded included whistles and click sequences. Whistles had dominant frequencies of around 8 to 12 kHz; higher-level whistles were estimated at no more than 155 dB re 1 μPa-m (Watkins et al. 1997). Clicks had dominant frequencies of 20 to 40 kHz; higher-level click bursts were judged to be about 165 dB re 1 μPa-m (Watkins et al. 1997). No data on hearing ability for this species are available.

- Fraser's Dolphin (*Lagenodelphis hosei*)

Description—Fraser's dolphin reaches a maximum length of 2.7 m and is generally more robust than other small delphinids (Jefferson et al. 1993). This species has a short, stubby beak, small flippers, and a small, subtriangular dorsal fin. The most conspicuous feature of the Fraser's dolphin coloration is the dark band running from the face to the anus, although it is not present in younger animals (Jefferson et al. 1997). The stripe is set off from the surrounding areas by thin, pale, cream-colored borders. There is also a dark chin-to-flipper stripe.

Status—The best available estimate of abundance for the Hawaiian stock of the Fraser's dolphin is 16,836 individuals (Barlow 2003; Carretta et al. 2005).

Habitat Preferences—This is an oceanic species except in places where deep water approaches the coast (Dolar 2002). Fraser's dolphins are found close to shore in some regions, such as around the Society Islands of French Polynesia (Gannier 2000), around several islands of the Indo-Malay archipelago in the Indo-Pacific area (Rudolph et al. 1997), and in some waters of the Philippines (Leatherwood et al. 1992). In the offshore eastern tropical Pacific, this species is distributed mainly in upwelling-modified waters (Au and Perryman 1985).

Distribution—Fraser's dolphin is found in tropical and subtropical waters around the world, typically between 30ºN and 30ºS (Jefferson et al. 1993). Strandings in temperate areas are considered extralimital and are usually associated with anomalously warm-water temperatures (Perrin et al. 1994b). As noted by Reeves et al. (1999), the documented distribution of this species is skewed towards the eastern Pacific, which may reflect the intensity of research associated with the tuna fishery there, rather than an actual higher density of occurrence there than in other tropical regions.

- Information Specific to the Hawaiian Islands OPAREA—Fraser's dolphins have only recently been documented in Hawaiian waters (Carretta et al. 2005). Sightings have been recorded in the NWHI but not within the MHI (Barlow 2003). There is a rare occurrence of the Fraser's dolphin from the shore to seaward of the OPAREA (**Figures B-20a** and **B-20b**) that takes into account that this is an oceanic species that can be found closer to the coast, particularly in locations where the shelf is narrow and deep waters are nearby. Occurrence patterns are assumed to be the same throughout the year.

Behavior and Life History—Fraser's dolphins are usually seen in large, fast-moving groups. Most sightings have been of groups ranging between 100 and 1,000 individuals. Fraser's dolphins have been seen in mixed-species aggregations with melon-headed whales in the eastern tropical Pacific, South Pacific, and Gulf of Mexico (Jefferson and Leatherwood 1994; Reeves et al. 1999; Gannier 2000). Very little is known of the natural history of this species, including reproduction. Available data do not show strong evidence of calving seasonality. Sexual maturity for both sexes occurs at about 7 years of age (Jefferson and Leatherwood 1994). Fraser's dolphins feed on mid-water fishes, squids, and shrimps (Jefferson and Leatherwood 1994; Perrin et al. 1994b). There is no information available on depths to which Fraser's dolphins dive, but they are thought to be capable of deep dives.

Acoustics and Hearing—Very little is known of the acoustic abilities of the Fraser's dolphin. Fraser's dolphin whistles have a frequency range of 7.6 to 13.4 kHz (Leatherwood et al. 1993). There are no hearing data for this species.

- Pygmy Killer Whale (*Feresa attenuata*)

Description—The pygmy killer whale is often confused with the melon-headed whale and less often with the false killer whale. Flipper shape is the best distinguishing characteristic; pygmy killer whales have rounded flipper tips (Jefferson et al. 1993). The body of the pygmy killer whale is somewhat slender (especially posterior to the dorsal fin) with a rounded head that has little or no beak (Jefferson et al. 1993). The color of this species is dark gray to black with a prominent narrow cape that dips only slightly below the dorsal fin and a white to light gray ventral band that widens around the genitals. The lips and snout tip are sometimes white. Pygmy killer whales reach lengths of up to 2.6 m (Jefferson et al. 1993).

Status—The best available estimate of abundance for the Hawaiian stock of the pygmy killer whale is 817 individuals (Barlow 2003; Carretta et al. 2005).

Habitat Preferences—The pygmy killer whale is considered to be an oceanic species. In the northern Gulf of Mexico, this species is found primarily in deeper waters off the continental shelf (Davis and Fargion 1996; Davis et al. 2000; Würsig et al. 2000) to waters out over the abyssal plain

(Jefferson personal communication). In some areas, pygmy killer whales are found within a few kilometers of shore over the shelf, such as around the Marquesas Islands of French Polynesia (Gannier 2002), off Lembata Island of the Indonesian archipelago (Rudolph et al. 1997), as well as in some waters off the Philippines (Leatherwood et al. 1992).

Distribution—This species has a worldwide distribution in deep tropical and subtropical oceans. Pygmy killer whales generally do not range north of 40ºN or south of 35ºS (Jefferson et al. 1993). Reported sightings suggest that this species primarily occurs in equatorial waters, at least in the eastern tropical Pacific (Perryman et al. 1994). Most of the records outside the tropics are associated with strong, warm western boundary currents that effectively extend tropical conditions into higher latitudes or unseasonable intrusions of warm water (Ross and Leatherwood 1994).

- Information Specific to the Hawaiian Islands OPAREA—Pygmy killer whales regularly occur in the Hawaiian Islands OPAREA. Pygmy killer whales are easily confused with false killer whales and melon-headed whales, which are two species that also have expected occurrence in the Hawaiian Islands study area. The pygmy killer whale is primarily expected to occur from the shelf break to seaward of the OPAREA boundaries (**Figures B-21a** and **B-21b**). There is a rare occurrence from the shore to the shelf break which takes into account any sightings that could occur just inshore of the shelf break, since deep water is very close to shore here. Occurrence patterns are assumed to be the same throughout the year. Pygmy killer whales off the island of Hawai‘i appear to demonstrate tremendous site fidelity to the island (Baird personal communication).

Behavior and Life History—Almost nothing is known about the reproductive biology and social organization of this species. This species usually forms relatively small groups (Ross and Leatherwood 1994). Pygmy killer whales eat mostly fish and squid, and sometimes attack other dolphins (Perryman and Foster 1980; Ross and Leatherwood 1994). In the Hawaiian Islands, they often feed on mahimahi, squid, and tuna (Balcomb 1987). They occur in small to moderate herds of most often less than 50 to 60 individuals. Based on preliminary data at the island of Hawai‘i, association patterns between individuals appear to be strong and long-term (Baird personal communication). There is no information available on diving behavior of this species.

Acoustics and Hearing—The pygmy killer whale emits short duration, broadband signals similar to a large number of other delphinid species (Madsen et al. 2004). Clicks produced by pygmy killer whales have centroid frequencies between 70 and 85 kHz; there are bimodal peak frequencies between 45 and 117 kHz. The estimated source levels are between 197 and 223 dB re 1 µPa-m (Madsen et al. 2004). These clicks possess characteristics of echolocation clicks (Madsen et al. 2004). There are no hearing data available for this species.

- False Killer Whale (*Pseudorca crassidens*)

Description—The false killer whale is a large, dark gray to black dolphin with a faint gray patch on the chest and sometimes light gray areas on the head (Jefferson et al. 1993). The false killer whale has a long slender body, a rounded overhanging forehead, and little or no beak (Jefferson et al. 1993). The dorsal fin is falcate, slender, and typically rounded at the tip. The flippers have a characteristic hump on the leading edge—this is perhaps the best characteristic for distinguishing this species from the other “blackfish” (pygmy killer, melon-headed, and pilot whales) (Jefferson et al. 1993). Individuals reach maximum lengths of 6.1 m (Jefferson et al. 1993).

Status—The best available estimate of abundance for the Hawaiian stock of the false killer whale is 268 individuals (Barlow 2003; Carretta et al. 2005). This stock is listed as a strategic stock by NMFS because the estimated level of serious injury and mortality from the Hawai‘i-based tuna and swordfish longline fishery is greater than the potential biological removal (PBR) (Carretta et al. 2005). Genetic evidence suggests that the Hawaiian stock might be a reproductively isolated population from false killer whales in the eastern tropical Pacific (Chivers et al. 2003). Baird et al. (2005) noted that more

work was needed to determine if false killer whales using coastal waters might be a discrete population from those in offshore waters and waters off the NWHI.

Habitat Preferences—This species is found primarily in oceanic and offshore areas although they do approach close to shore at oceanic islands (Baird 2002). False killer whales have been known to approach very close to shore in such areas as the inshore waters of Washington and British Columbia (Baird et al. 1989), the coast and estuaries of China (Zhou et al. 1982), the Marquesas Islands of French Polynesia (Gannier 2002), and Lembata Island of the Indonesian archipelago (Rudolph et al. 1997).

Distribution—False killer whales are found in tropical to temperate waters, generally between 50ºS and 50ºN latitude with a few records north of 50ºN in the Pacific and the Atlantic (Odell and McClune 1999). Seasonal movements in the western North Pacific may be related to prey distribution (Odell and McClune 1999). Baird et al. (2005a) noted considerable inter-island movements of individuals in the Hawaiian Islands.

- Information Specific to the Hawaiian Islands OPAREA—False killer whales are commonly sighted in nearshore waters from small boats and aircraft, as well as offshore from longline fishing vessels (e.g., Mobley et al. 2000; Baird et al. 2003a; Walsh and Kobayashi 2004). Baird et al. 2005 reported that false killer whales in the Hawaiian Islands occur in waters from about 40 m to 4,000 m deep. There is an area of primary occurrence for the false killer whale from the shore to the 2,000 m isobath, with the exception of Pearl Harbor, where there is a rare occurrence for this species (**Figures B-22a** and **B-22b**). There is an additional area of primary occurrence seaward of the 4,000 m isobath on the south side of the islands, which takes into account false killer whale sighting and bycatch data in the southwestern portion of the OPAREA (Forney 2004; Walsh and Kobayashi 2004; Carretta et al. 2005). The area of secondary occurrence includes a narrow band between the 2,000 m and 4,000 m isobaths south of the islands and the entire area north of the islands seaward of the 2,000 m isobath. It has been suggested that false killer whales using coastal waters might be a discrete population from those in offshore waters and waters off the NWHI (Baird et al. 2005a; Carretta et al. 2005). The area of secondary occurrence takes into account the possibility of two different stocks, with a possible hiatus in their distribution (Jefferson personal communication). Occurrence patterns are assumed to be the same throughout the year.

Behavior and Life History—This species may occur in large groups; group sizes as large as 300 have been reported (Brown et al. 1966). No seasonality in reproduction is known for the false killer whale (Jefferson et al. 1993). False killer whales primarily eat deep-sea cephalopods and fish (Odell and McClune 1999), but they have been known to attack other cetaceans, including dolphins (Perryman and Foster 1980; Stacey and Baird 1991), sperm whales (Palacios and Mate 1996), and baleen whales (Jefferson personal communication). False killer whales in Hawai‘i are known to prey on mahimahi (*Coryphaena hippurus*), yellowfin tuna (*Thunnus albacares*), and billfish (marlin and spearfish) (Shallenberger 1981; Nitta and Henderson 1993; Wilson 2003). False killer whales in many different regions (including Hawaiian waters) are known to take tuna from longlines (Mitchell 1975; Nitta and Henderson 1993; Forney 2004; Walsh and Kobayashi 2004; Baird and Gorgone 2005). The maximum known dive depth is about 500 m (Odell and McClune 1999). Shallower dive depths (maximum of 53 m; averaging from 8 to 12 m) have been recorded for false killer whales in Hawaiian waters); this is likely due to the surface-oriented prey, such as mahimahi and yellowfin tuna (Ligon and Baird 2001).

Acoustics and Hearing—The dominant frequencies of false killer whale whistles are 4 to 9.5 kHz; those of their clicks are 25 to 30 kHz and 95 to 130 kHz (Thomas et al. 1990b; Thomson and Richardson 1995). The reported source level is 220 to 228 dB re 1 μPa-m (Ketten 1998). Best hearing sensitivity measured for a false killer whale was around 16 to 64 kHz (Thomas et al. 1988, 1990b).

- Killer Whale (*Orcinus orca*)

Description—This is probably the most instantly-recognizable of all the cetaceans. The black-and-white color pattern of the killer whale is striking, as is the tall, erect dorsal fin of the adult male (1.0 to 1.8 m in height). The white oval eye patch and variably-shaped saddle patch, in conjunction with the shape and notches in the dorsal fin, help in identifying individuals. The killer whale has a blunt head with a stubby, poorly-defined beak and large, oval flippers. Females may reach 7.7 m in length and males 9.0 m (Dahlheim and Heyning 1999). The killer whale is the largest member of the dolphin family.

Status—The best available estimate of abundance for the Hawaiian stock of the killer whale is 430 individuals (Barlow 2003; Carretta et al. 2005). Genetic analyses of two biopsy samples taken in Hawai‘i was most closely associated with mammal-eating killer whales in Alaska (see Baird et al. 2003a; Baird personal communication).

Habitat Preferences—Killer whales can be found in the open sea, as well as in coastal areas (Dahlheim and Heyning 1999). Offshore concentrations of killer whales in the eastern tropical Pacific occur within the divergence zones of the NEC and the Equatorial Counter Current (Dahlheim et al. 1982). Killer whales have the most ubiquitous distribution of any species of cetacean, and they have been observed in virtually every marine habitat, from the tropics to the poles, and from shallow, inshore waters (and even rivers) to deep, oceanic regions (Dahlheim and Heyning 1999). Although they are not common in most of these habitat types, there is a possibility of seeing killer whales just about anywhere in the marine environment.

Distribution—The killer whale is a cosmopolitan species found throughout all oceans and contiguous seas, from equatorial regions to the polar pack-ice zones. This species has sporadic occurrence in most regions (Ford 2002). Although found in tropical waters and the open ocean, killer whales as a species are most numerous in coastal waters and at higher latitudes (Mitchell 1975; Miyazaki and Wada 1978; Dahlheim et al. 1982). Sightings in many tropical waters, although not common, are widespread (Visser and Bonoccorso 2003).

- Information Specific to the Hawaiian Islands OPAREA—Killer whales, in general, are uncommon in most tropical areas (Jefferson personal communication). The distinctiveness of this species would lead it to be reported more than any other member of the dolphin family, if it occurs in a certain locale. A review of 24 killer whale sightings from 1994 through 2005 revealed that killer whales are seen throughout the year (Baird personal communication). Killer whales are infrequently sighted and found stranded around the Hawaiian Islands (Shallenberger 1981; Tomich 1986; Mobley et al. 2001b; Baird et al. 2003a; Baird personal communication) although with increasing numbers of boaters, sightings each year could be expected (Baird personal communication). Since the killer whale has a sporadic occurrence in tropical waters and can be found in both coastal areas and the open ocean, there is a rare occurrence of this species in the Hawaiian Islands OPAREA from the shoreline to seaward of the OPAREA boundaries (**Figures B-23a** and **B-23b**). Occurrence patterns are assumed to be the same throughout the year.

Behavior and Life History—Killer whales have the most stable social system known among all cetaceans. In all areas where longitudinal studies have been carried out, there appear to be long-term associations among individuals and limited dispersal from maternal groups called pods (Baird 2000). Groups of up to 6 individuals have been sighted in Hawaiian waters (Shimote 2001). Pods in other areas may contain dozens or even hundreds of individuals (Jefferson personal communication).

Killer whales have a diverse diet consisting of bony fishes, elasmobranchs, cephalopods, seabirds, sea turtles, and other marine mammals (Jefferson et al. 1991; Fertl et al. 1996). Diet is specific to the type of killer whale. Transients are primarily mammal-eaters, residents are mostly fish-eaters, and offshores appear to eat mostly fish as well. Killer whales in the tropics have been observed feeding on fishes, cephalopods, elasmobranchs, and sea turtles (e.g., Fertl et al. 1996; Shimote 2001; Gannier 2002; Visser and Bonoccorso 2003; Pitman and Dutton 2004). Killer whales sighted off

Lāna'i were observed feeding on fish and octopus (Shimote 2001; TenBruggencate 2002), while individuals sighted between Kaua‘i and Ni‘ihau were observed feeding on a humpback whale (Baird personal communication). Killer whale interference with fisheries in the tropics is also well known; for example, they remove fish from longlines (Iwashita et al. 1963; Visser and Bonoccorso 2003), including one observation off Hawai‘i (Carretta et al. 2005). Killer whales use passive listening as a primary means of locating prey and use different echolocation patterns for different hunting strategies (Barrett-Lennard et al. 1996). For example, they mask their clicks and encode their signals in background noise when hunting other cetaceans, prey that can hear their high-frequency clicks. In contrast, killer whales do not mask their high-frequency signals when hunting fish that are not capable of hearing in this frequency range.

The maximum depth recorded for free-ranging killer whales diving off British Columbia is 264 m (Baird et al. 2005b). However, less than 1% of all dives examined from seven tagged individuals were to depths greater than 30 m (Baird et al. 2003a). A trained killer whale dove to a maximum of 260 m (Dahlheim and Heyning 1999). The longest duration of a recorded dive from a radio-tagged killer whale was 17 min (Dahlheim and Heyning 1999).

Acoustics and Hearing—The killer whale produces a wide variety of clicks and whistles, but most of its sounds are pulsed and are at 1 to 6 kHz (Thomson and Richardson 1995). Source levels of echolocation signals range between 195 and 224 dB re 1 μPa-m (Au et al. 2004). Acoustic studies of resident killer whales in British Columbia have found that there are dialects in their highly stereotyped, repetitive discrete calls, which are group-specific and shared by all group members (Ford 2002). These dialects are likely used to maintain group identity and cohesion and may serve as indicators of relatedness that help in the avoidance of inbreeding between closely-related whales (Ford 2002). Dialects also have been documented in killer whales occurring in northern Norway and likely occur in other locales as well (Ford 2002).

The killer whale has the lowest frequency of maximum sensitivity and one of the lowest high-frequency hearing limits known among toothed whales (Szymanski et al. 1999). The upper limit of hearing is about 100 kHz for this species. The most sensitive frequency, in both behavioral and in auditory brainstem response audiograms, has been determined to be 20 kHz (Szymanski et al. 1999).

- Short-finned Pilot Whale (*Globicephala macrorhynchus*)

Description—There are two species of pilot whales worldwide; only the short-finned pilot whale is expected to occur in the Hawaiian Islands study area. Pilot whales are among the largest members of the family Delphinidae. In general, the short-finned pilot whale is smaller than the long-finned pilot whale (*Globicephala melas*), reaching lengths of 5.5 m (females) and 6.1 m (males) (Jefferson et al. 1993).

Pilot whales have bulbous heads with a forehead that sometimes overhangs the rostrum; there is little or no beak (Jefferson et al. 1993). The dorsal fin is distinctive, being generally broader-based than it is tall. It is falcate and usually rounded at the tip and is set well forward of the middle of the back. The flippers of the short-finned pilot whale are long and sickle-shaped and range from 16% to 22% of the total body length (Jefferson et al. 1993). Both pilot whale species are black on the back and sides; in many individuals there is a light gray saddle patch located behind the dorsal fin. Pilot whales also have a white to light gray anchor-shaped patch on the chest (Jefferson et al. 1993).

Status—The best available estimate of abundance for the Hawaiian stock of the short-finned pilot whale is 8,846 individuals (Barlow 2003; Carretta et al. 2005). Stock structure of short-finned pilot whales has not been well-studied in the North Pacific Ocean, except in Japanese waters (Carretta et al. 2005). Two stocks have been identified in Japan based on pigmentation patterns and differences in the head shape of adult males (Kasuya et al. 1988). Pilot whales in Hawaiian waters are similar morphologically to the Japanse southern form (Carretta et al. 2005). Genetic analyses of tissue samples collected near the MHI indicate that the Hawaiian population is reproductively-isolated from short-finned pilot whales found in the eastern North Pacific Ocean (Carretta et al. 2005).

Habitat Preferences—Pilot whales are found over the continental shelf break, in slope waters, and in areas of high topographic relief (Olson and Reilly 2002). While pilot whales are typically distributed along the continental shelf break, movements over the continental shelf are commonly observed in the northeastern U.S. (Payne and Heinemann 1993) and close to shore at oceanic islands where the shelf is narrow and deeper waters are nearby (Mignucci-Giannoni 1998; Gannier 2000). A number of studies in different regions suggest that the distribution and seasonal inshore/offshore movements of pilot whales coincide closely with the abundance of squid, their preferred prey (Hui 1985; Waring et al. 1990; Payne and Heinemann 1993; Waring and Finn 1995; Bernard and Reilly 1999). Short-finned pilot whale occurrence in the Caribbean seems to coincide with the inshore movement of spawning octopus (Mignucci-Giannoni 1998). Short-finned pilot whale distribution off Catalina Island in southern California changed dramatically after the El Niño event in 1982 through 1983, when squid did not spawn as usual in the area, and pilot whales virtually disappeared from the area for nine years (Shane 1994).

Distribution—The short-finned pilot whale is found worldwide in tropical to warm-temperate seas, generally in deep offshore areas. The short-finned pilot whale usually does not range north of 50ºN or south of 40ºS (Jefferson et al. 1993). The long-finned pilot whale is not known to presently occur anywhere in the North Pacific (Kasuya 1975); the range of the short-finned pilot whale appears to be expanding to fill the former range of the long-finned pilot whale (Bernard and Reilly 1999). Pilot whales are sighted throughout the Hawaiian Islands (e.g., Shallenberger 1981).

- Information Specific to the Hawaiian Islands OPAREA—Short-finned pilot whales are expected to occur year-round throughout the Hawaiian Islands OPAREA. They are commonly found in deep waters with steep bottom topography, including deepwater channels between the MHI, such as the Alenuihaha Channel between Maui and Hawai‘i (Balcomb 1987). The area of primary occurrence for this species is seaward of the 200 m isobath (**Figures B-24a** and **B-24b**). Considering the narrow insular shelf and deep waters in close proximity to the shore, secondary occurrence is between the 50 m and 200 m isobaths. Short-finned pilot whales are expected to be rare between the shore and the 50 m isobath, including Pearl Harbor. Occurrence patterns are assumed to be the same throughout the year. Photo-identification work suggests a high degree of site fidelity around the island of Hawai‘i (Shane and McSweeney 1990).

Behavior and Life History—Pilot whales are very social and may be seen in groups of several individuals to upwards of several hundreds. They typically travel in groups of 20 to 40 individuals in Hawaiian waters (Balcomb 1987). They appear to live in relatively stable female-based groups (Jefferson et al. 1993). Pilot whales are often sighted associated with other cetaceans (e.g., Bernard and Reilly 1999; Gannier 2000). These are the most frequently reported mass-stranded marine mammals globally (Nelson and Lien 1996; Mazzuca et al. 1999).

Average age at sexual maturity for short-finned pilot whales is 9 years for females and 17 years for males (Bernard and Reilly 1999). The gestation period for short-finned pilot whales is 15 to 16 months with a mean calving interval of 4.6 to 5.7 years (Bernard and Reilly 1999). Calving peaks in the northern hemisphere vary by stock (Jefferson et al. 1993).

Kasuya and Marsh (1984) found some interesting aspects in the life history of the short-finned pilot whale off Japan. Females may live up to 63 years although they have their last calf by about 40. Older females may, therefore, increase their reproductive success by nursing their last calf for a considerably longer period than is typical for earlier calves (a minimum of 2 years). Alhough only speculation, it is possible that this may provide an edge to these offspring, making them more likely to survive and reproduce successfully.

Pilot whales are deep divers; the maximum dive depth measured is 971 m (Baird personal communication). Pilot whales feed primarily on squid but also take fish (Bernard and Reilly 1999). Interactions with the Hawaii-based longline fishery have been reported (Forney 2004; Walsh and Kobayashi 2004; Carretta et al. 2005). Pilot whales are not generally known to prey on other marine mammals; however, records from the eastern tropical Pacific suggest that the short-finned pilot whale

does occasionally chase, attack, and may eat dolphins during fishery operations (Perryman and Foster 1980), and they have been observed harassing sperm whales in the Gulf of Mexico (Weller et al. 1996).

Acoustics and Hearing—Short-finned pilot whale whistles and clicks have a dominant frequency range of 2 to 14 kHz and a source level of 180 dB re 1 μPa-m (Ketten 1998). In a study of short-finned pilot whales in the three areas of the eastern Pacific (eastern tropical Pacific, Channel Islands, and mainland coastal California), Evans et al. (1984) found that pilot whale vocalizations consisted of whistles, FM sweeps, and pulses. There was a significant amount of variation among the areas in the temporal and spectral characteristics of the whistles (i.e., shorter in the ETP). There are no published hearing data available for this species.

- Northern Elephant Seal (*Mirounga angustirostris*)

Description—The northern elephant seal is the largest pinniped in the Northern Hemisphere (the second-largest in the world, after the southern elephant seal *Mirounga leonina*). It is one of the most sexually dimorphic mammals, with adult males being much larger than adult females (Deutsch et al. 1994). The northern elephant seal reaches a standard length of up to 2.8 to 3.0 m and weights of 360 to 710 kg (females) and 3.8 to 4.1 m and 2,300 kg (males) (Stewart and Huber 1993; Deutsch et al. 1994). As males reach adulthood, they also develop other secondary sexual characteristics. These include the nose being enlarged into an overhanging proboscis (thus the name “elephant seal”) and the development of a highly cornified and wrinkled chest shield which often becomes heavily scarred (and, therefore, reddish or pinkish) from fighting with other males. Females and young males lack these exaggerated characters; their appearance is more similar to that of the related monk seals. The coloration of the northern elephant seal is simple countershading with a dark brown back and slightly lighter belly.

Status—The northern elephant seal population has recovered dramatically after being reduced to several dozen to perhaps no more than a few animals in the 1890s (Bartholomew and Hubbs 1960; Stewart et al. 1994). Although movement and genetic exchange continues between rookeries, most elephant seals return to their natal rookeries when they start breeding (Huber et al. 1991). The California and Mexican breeding groups may be demographically isolated and are currently considered two separate stocks (Carretta et al. 2005).

The population size has to be estimated since all age classes are not ashore at any one time of the year (Carretta et al. 2005). There is a conservative minimum population estimate of 60,547 elephant seals in the California stock (Carretta et al. 2005). Based on trends in pup counts, abundance in California is increasing by around 6% annually, but the Mexican stock is evidently decreasing slowly (Stewart et al. 1994; Carretta et al. 2005).

Habitat Preferences—Breeding and molting habitat for northern elephant seals is characterized by sandy beaches, mostly on offshore islands, but also in some mainland locations along the coast (Stewart et al. 1994). When on shore, seals will also use small coves and sand dunes behind and adjacent to breeding beaches (Stewart personal communication). They rarely enter the water during the breeding season, but some seals will spend short periods in tide pools and alongshore; these are most commonly weaned pups that are learning to swim (Le Boeuf et al. 1972).

Feeding habitat is mostly in deep, offshore waters of warm temperate to subpolar zones (Stewart and DeLong 1995; Stewart 1997; Le Boeuf et al. 2000). Some seals will move into subtropical or tropical waters while foraging (Stewart and DeLong 1995).

The effects of El Niño events on some pinniped species in the North Pacific can be severe. Stewart and Yochem (1991) studied the effects of the strong 1982/1983 ENSO on northern elephant seals breeding in the southern California Channel Islands. They found that females arrived 5 to 8 days later, gave birth earlier, and spent less overall time ashore nursing their pups during that winter season. Females appeared to be in poorer physical condition and to be less productive over the next

year. However, these effects were not particularly severe and were of short duration. Stewart and Yochem (1991) speculated that the deep-diving habits of elephant seals make them less vulnerable to the detrimental effects of El Niño events than other, more shallow-water, pinnipeds.

Distribution—The northern elephant seal is endemic to the North Pacific Ocean, occurring almost exclusively in the eastern and central North Pacific. However, vagrant individuals do sometimes range to the western North Pacific. Northern elephant seals occur in Hawaiian waters only rarely as extralimital vagrants. The most far-ranging individual appeared on Nijima Island off the Pacific coast of Japan in 1989 (Kiyota et al. 1992). This demonstrates the great distances that these animals are capable of covering.

Northern elephant seals breed on island and mainland rookeries from central Baja California, Mexico, to northern California (Stewart and Huber 1993). The foraging range extends thousands of kilometers offshore from the breeding range into the central North Pacific. Adult males and females segregate while foraging and migrating (Stewart and DeLong 1995; Stewart 1997). Adult females mostly range west to about 173°W between the latitudes of 40° and 45°N, whereas adult males range further north into the Gulf of Alaska and along the Aleutian Islands to between 47° and 58°N (Stewart and Huber 1993; Stewart and DeLong 1995; Le boeuf et al. 2000). Females may cover over 5,500 km and males over 11,000 km during these post-breeding migrations (Stewart and DeLong 1994).

- Information Specific to the Hawaiian Islands OPAREA—There is a rare occurrence of northern elephant seals throughout the Hawaiian Islands OPAREA year-round (**Figures B-25a** and **B-25b**). There are several unconfirmed reports of elephant seals at Midway Atoll, Pearl and Hermes Reef, and Kure Atoll (Antonelis personal communication). The first confirmed sighting of a northern elephant seal in the Hawaiian Islands was a female found on Midway Island in 1978 that had been tagged earlier at San Miguel Island (off the coast of southern California) (NWAFC 1978). The first sighting of an elephant seal in the MHI occurred on the Kona coast of Hawai‘i in January 2002; a juvenile male was sighted hauled out at Kawaihae Beach and later at the Kona Village Resort (Fujimori 2002; Antonelis personal communication). Based on these sightings and documented long-distance movements as far west as Japan (NWAFC 1978; Antonelis and Fiscus 1980; Tomich 1986; Kiyota et al. 1992; Fujimori 2002), rare encounters with northern elephant seals in the Hawaiian Islands OPAREA are possible.

Behavior and Life History—Elephant seals are gregarious during the breeding season, but appear to be relatively solitary at sea. Adult elephant seals spend from 8 to 10 months at sea and undertake two annual migrations between haulout and feeding areas (Stewart and DeLong 1995). They haul out on land to give birth and breed, and after spending time at sea to feed (post-breeding migration), they generally return to the same areas to molt (Stewart and Yochem 1984; Stewart and DeLong 1995). The different age and sex classes have somewhat differing annual cycles and migration patterns (Stewart 1997). After weaning their pups in late winter, adult females forage at sea for about 70 days before returning to land to molt their pelage. Following one month ashore, the females return to sea for eight months (coincident with gestation), before returning to the rookery to give birth. Elephant seals do not necessarily return to the same beaches for breeding and molting. For example, Huber et al. (1991) found that female northern elephant seals often molt on one island and breed on another. Adult males spend approximately four months at sea following the breeding season, returning to shore in summer to molt. After one month ashore, they return to sea for four months before returning to the rookery for the breeding season.

In December, male elephant seals haul out for the breeding season; many individuals remain there continuously until March. In January, after many males have been on land for several weeks, the adult females come ashore, give birth, suckle their young for about 27 days, breed, and depart (Le Boeuf and Peterson 1969; Stewart and Huber 1993). Gestation is about 11 months, but there is a two to three month period of delayed implantation. During the breeding season, elephant seals congregate in large numbers on their breeding rookeries. Animals of all ages and both sexes are present on these beaches although yearlings generally do not return during the breeding season and are rare at rookeries. Large rookeries, such as those on Año Nuevo Island and peninsula and the

Channel Islands, may contain thousands of seals, which mostly arrange themselves in harems consisting of up to several dozen breeding females, a single dominant (alpha) male, and the newborn pups. Other animals, especially other bulls seeking to challenge the alpha male or sneak copulations, often surround the harems.

Males reach sexual maturity at about 6 or 7 years, but do not reach "social maturity" until 9 or 10 years. Most adult males do not have high enough social status to do much breeding—a few high ranking males called "alpha males" actually do the vast majority of the fertilization of the females (Le Boeuf 1974). Both males and females lose a large proportion of their body mass while fasting during the breeding season, and they must feed intensively after returning to sea to regain weight.

During the molting period, which is at different times of the year for different age classes, seals lose their fur in large patches with the underlying epidermis. This is called a "catastrophic molt" and molting seals look very ragged (Stewart and Huber 1993). Adults return to land between March and August to molt, with males returning later than females (Carretta et al. 2005).

Elephant seals are probably the deepest and longest diving pinnipeds; few marine mammals can match their abilities. Adults dive continuously, day and night, during their feeding migrations (DeLong and Stewart 1991; Le Boeuf et al. 1986, 1989). Elephant seals may spend as much as 90% of their time submerged (DeLong and Stewart 1991); this year-round pattern of continuous, long, deep dives explains why northern elephant seals are rarely seen at sea and why their oceanic whereabouts and migrations have long been unknown (Stewart and DeLong 1995). The average diving cycle consists of a 23 min dive, followed by a 2 to 4 min surface interval (Le Boeuf et al. 1986, 1989; DeLong and Stewart 1991). The longest known dive is 106 min (Le Boeuf and Crocker 2005). Dives average between 350 and 550 m in depth, with dives as deep as 1,561 m (females) and 1,585 m (males) (Stewart and Huber 1993). Males and females pursue different foraging strategies. Females range widely over deep water, apparently foraging on patchily distributed, vertically migrating, pelagic prey, whereas males forage along the continental margin at the distal end of their migration, and they may at times feed on benthic prey (Le Boeuf et al. 2000).

Northern elephant seals feed primarily on cephalopods, hake, and other epipelagic, mesopelagic, and bathypelagic fishes and crustaceans, such as pelagic red crabs (Condit and Le Boeuf 1984; DeLong and Stewart 1991; Stewart and Huber 1993; Antonelis et al. 1994). Most significant prey species make vertical migrations and are part of the deep scattering layer (Antonelis et al. 1994).

Acoustics and Hearing—The northern elephant seal produces loud, low-frequency in-air vocalizations (Bartholomew and Collias 1962). The mean fundamental frequencies are in the range of 147 to 334 Hz for adult males (Le Boeuf and Petrinovich 1974). The mean source level of the male-produced vocalizations during the breeding season is 110 dB (Sanvito and Galimberti 2003). In-air calls made by aggressive males include: (1) snoring, which is a low-intensity threat; (2) a snort (0.2 to 0.6 kHz) made by a dominant male when approached by a subdominant male; and (3) a clap threat (<2.5 kHz) which may contain signature information at the individual level (Thomson and Richardson 1995). Seismic (low frequency) vibrations accompany these in-air vocalization; they are produced as the males move about and vocalize on sand beaches (Shipley et al. 1992). These sounds appear to be important social cues (Shipley et al. 1992). The mean fundamental frequency of airborne calls for adult females is 500 to 1,000 Hz (Bartholomew and Collias 1962). In-air sounds produced by females include a <0.7 kHz belch roar used in aggressive situations and a 0.5 to 1 kHz bark used to attract the pup (Bartholomew and Collias 1962). Pups use a <1.4 kHz call to maintain contact with the mother (Bartholomew and Collias 1962). As noted by Kastak and Schusterman (1999), evidence for underwater sound production by this species is scant. Except for one unsubstantiated report (Poulter 1968), none have been definitively identified (Fletcher et al. 1996; Burgess et al. 1998). Burgess et al. (1998) detected possible vocalizations, in the form of click trains that resembled those used by males for communication in air.

The audiogram of the northern elephant seal indicates that this species is well-adapted for underwater hearing; sensitivity is best between 3.2 and 45 kHz, with greatest sensitivity at 6.4 kHz

and an upper frequency cutoff of approximately 55 kHz (Kastak and Schusterman 1999). Elephant seals exhibit the greatest sensitivity to low-frequency (<1 kHz) sound of seals whose hearing has been tested (Kastak and Schusterman 1998). In-air hearing is generally poor, but is best for frequencies between 3.2 and 15 kHz, with greatest sensitivity at 6.3 kHz (Kastak and Schusterman 1999). The upper frequency limit in air is approximately 20 kHz (Kastak and Schusterman 1999). Elephant seals are relatively good at detecting tonal signals over masking noise (Southall et al. 2000).

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3.2 SEA TURTLES

3.2.1 Introduction

Sea turtles are long-lived reptiles that can be found throughout the world's tropical, subtropical, and temperate seas (CCC and STSL 2003). There are seven living species of sea turtles from two distinct families, the Cheloniidae (hard-shelled sea turtles; six species) and the Dermochelyidae (leatherback sea turtle; one species). These two families can be distinguished from one another on the basis of their carapace (upper shell) and other morphological features. Sea turtles are an important marine resource in that they provide nutritional, economic, and existence (non-use) value to humans (Witherington and Frazer 2003). Over the last few centuries, sea turtle populations have declined dramatically due to anthropogenic activities such as coastal development, oil exploration, commercial fishing, marine-based recreation, pollution, and over-harvesting (NRC 1990; Eckert 1995). As a result, all six species of sea turtles found in U.S. waters are currently listed as either threatened or endangered under the ESA.

Sea turtles are highly adapted for life in the marine environment. Unlike terrestrial and freshwater turtles, sea turtles possess powerful, modified forelimbs (or flippers) that enable them to swim continuously for extended periods of time (Wyneken 1997). They also have compact and streamlined bodies that help to reduce drag. Additionally, sea turtles are among the longest and deepest diving of the air-breathing vertebrates, spending as little as 3 to 6% of their time at the water's surface (Lutcavage and Lutz 1997). These physiological traits and behavioral patterns allow for highly efficient foraging and traveling. Sea turtles often travel thousands of kilometers between their nesting beaches and feeding grounds, which makes the aforementioned suite of adaptations very important (Ernst et al. 1994; Meylan 1995). Sea turtle traits and behaviors also help protect them from predation. Sea turtles have a tough outer shell and grow to a large size as adults; mature leatherback turtles can weigh up to 916 kg (Eckert and Luginbuhl 1988). Sea turtles cannot withdraw their head or limbs into their shell, so growing to a large size as adults is important. As juveniles, some species of sea turtles evade predation by residing in habitats that are either structurally complex or moderately shallow. This prohibits marine predators such as sharks, marine crocodiles, and large fishes from easy access (Musick and Limpus 1997).

Although they are specialized for life at sea, sea turtles begin their lives on land. Aside from this brief terrestrial period, which lasts approximately three months as eggs and an additional few minutes to a few hours as hatchlings scrambling to the surf, sea turtles are rarely encountered out of the water. Sexually mature females return to land in order to nest, while certain species in the Hawaiian Islands, Australia, and the Galapagos Islands haul out on land in order to bask (Carr 1995; Spotila et al. 1997). Sea turtles bask to thermoregulate, elude predators, avoid harmful mating encounters, and possibly to accelerate the development of their eggs, accelerate their metabolism, and destroy epiphytic growth on their carapaces (Whittow and Balazs 1982; Spotila et al. 1997). On occasion, sea turtles can unintentionally end up on land if they are dead, sick, injured, or cold-stunned. These events, also known as strandings, can be caused by either biotic (e.g., predation and disease) or abiotic (e.g., water temperature) factors.

Female sea turtles nest in tropical, subtropical, and warm-temperate latitudes, often in the same region or on the same beach where they hatched (Miller 1997). Upon selecting a suitable nesting beach, most sea turtles tend to re-nest in close proximity during subsequent nesting attempts. The leatherback turtle is a notable divergence from this pattern. This species nests primarily on high-energy beaches with little reef or rock offshore. On these types of beaches stochastic erosion reduces the probability of nest survival. To compensate, leatherbacks scatter their nests over larger geographic areas and lay on average two times as many clutches as other species (Eckert 1987).

At times, sea turtles may fail to nest after emerging from the ocean. These non-nesting emergences, known as false crawls, can occur if sea turtles are obstructed from laying their eggs (by debris, rocks, roots, or other obstacles), are distracted by surrounding conditions (by noise, lighting, or human presence), or are uncomfortable with the consistency or moisture of the sand on the nesting beach. Individuals that are successful at nesting usually lay several clutches of eggs during a nesting season with each clutch containing between 50 and 200 eggs depending upon the species (Witzell 1983; Dodd 1988; Hirth 1997). Most sea turtles, with the possible exception of Kemp's ridley turtles (*Lepidochelys*

kempii), do not nest in consecutive years; instead, they will often skip two or three years before returning to the nesting grounds (Márquez-M. 1990; Ehrhart 1995). Nesting success is vital to the long-term existence of sea turtles since it is estimated that only 1 out of every 1,000 hatchlings survives long enough to reproduce (Frazer 1986).

During the nesting season, daytime temperatures can be lethal on tropical, subtropical, and warm-temperate beaches. As a result, adult sea turtles most often nest and hatchlings most often emerge from their nest at night (Miller 1997). After emerging from the nest, sea turtle hatchlings use visual cues (e.g., light intensity or wavelengths) to orient themselves towards the sea (Lohmann et al. 1997). Hatchlings have a strong tendency to crawl in the direction of the brightest light, which on most beaches is towards the ocean/sky horizon (Ernst et al. 1994). However, some hatchlings never make it into the water. On the beach, sea turtle hatchlings are easy prey for seabirds during the day, and scavenging crabs and mammals at night (Ehrhart 1995; Miller 1997). Hatchlings can also be disoriented if artificial beachfront lighting appears brighter than the seaward horizon (Witherington and Bjorndal 1991).

Hatchlings that make it into the water will end up spending the first few years of their lives in offshore waters, drifting in convergence zones or amidst floating vegetation, where they find food (mostly pelagic invertebrates) and refuge in flotsam that accumulates in surface circulation features (Carr 1987). Originally labeled the “lost year,” this stage in a sea turtle’s life history is now known to be much longer in duration, possibly lasting a decade or more (Chaloupka and Musick 1997; Bjorndal et al. 2000). Sea turtles will spend several years growing in the “early juvenile nursery habitat,” which is usually pelagic and oceanic, before migrating to distant feeding grounds that comprise the “later juvenile developmental habitat,” which is usually demersal and neritic (Musick and Limpus 1997; Frazier 2001). Hard-shelled sea turtles most often utilize shallow nearshore and inshore waters as later juvenile developmental habitats; whereas leatherback turtles, depending on the season, can utilize either coastal feeding areas in temperate waters or offshore feeding areas in tropical waters (Frazier 2001).

Once in the later juvenile developmental habitat, most sea turtles change from surface to benthic feeding and begin to feed upon larger items such as crustaceans, mollusks, sponges, coelenterates, fishes, macroalgae, and seagrasses (Bjorndal 1997). An exception is the leatherback turtle, which will feed on pelagic soft-bodied invertebrates at both the surface and at depth (S. Eckert et al. 1989). Sea turtles do not have teeth, but their jaws have modified “beaks” suited to their particular diet (Mortimer 1995). A sea turtle’s diet varies according to its feeding habitat and its preferred prey. Upon moving from the later juvenile developmental habitat to the adult foraging habitat, sea turtles may demonstrate further changes in prey preference, dietary composition, and feeding behavior (Bjorndal 1997; Musick and Limpus 1997).

Throughout their life cycles sea turtles undergo complex seasonal movements. Sea turtle movement patterns are influenced by changes in ocean currents, turbidity, salinity, and food availability. In addition to these factors, the distribution of many sea turtle species is dependent upon and often restricted by water temperature (Epperly et al. 1995; Davenport 1997; Coles and Musick 2000). Most sea turtles become lethargic at temperatures below 10°C and above 40°C (Spotila et al. 1997). Coles and Musick (2000) observed that loggerhead turtles off North Carolina only inhabited waters between 13.3 and 28°C. This suggests that sea turtles are not randomly distributed in ocean waters but choose to stay within certain temperature ranges. Preferred temperature ranges vary among age classes, species, and seasons. As a species, the leatherback turtle has a much wider range of preferred water temperatures than other species because its thermoregulatory capabilities allow it to maintain a warm body temperature in temperate waters and avoid overheating in tropical waters (Spotila et al. 1997).

Although sea turtles are nearsighted out of water, their vision underwater is very good. Their sense of smell is also very keen and sea turtles are believed to use olfaction in conjunction with sight during foraging (Ernst et al. 1994). Sea turtle hearing sensitivity is not well studied. Reception of sound through bone conduction, with the skull and shell acting as receiving structures, is hypothesized to occur in some sea turtle species (Lenhardt et al. 1983). A few preliminary investigations using adult green, loggerhead, and Kemp’s ridley turtles suggest that these sea turtles are most sensitive to low-frequency sounds (Ridgway et al. 1969; Lenhardt et al. 1983; Bartol et al. 1999).

The range of maximum sensitivity for sea turtles is 100 to 800 Hz, with an upper limit of about 2,000 Hz (Lenhardt 1994). Hearing below 80 Hz is less sensitive but still potentially usable to the animal (Lenhardt 1994). Green turtles are most sensitive to sounds between 200 and 700 Hz, with peak sensitivity at 300 to 400 Hz. They possess an overall hearing range of approximately 100 to 1,000 Hz (Ridgway et al. 1969). Bartol et al. (1999) reported that juvenile loggerhead turtles hear sounds between 250 and 1,000 Hz. Finally, sensitivity even within the optimal hearing range is apparently low—threshold detection levels in water are relatively high at 160 to 200 dB re 1 µPa-m (Lenhardt 1994).

For more information on the biology, life history, and conservation of sea turtles, the following websites can be consulted: seaturtle.org (http://www.seaturtle.org), the Caribbean Conservation Corporation (http://www.cccturtle.org), and the Archie Carr Center for Sea Turtle Research (http://accstr.ufl.edu/index.html). Other important resources include NMFS and USFWS authored sea turtle recovery plans (http://www.nmfs.noaa.gov/pr/recovery/#turtles), NMFS compiled Proceedings of the Annual Symposia on Sea Turtle Biology and Conservation (http://www.nmfs.noaa.gov/pr/species/turtles/symposia.htm), Bjorndal (1995), Lutz and Musick (1997), Bolten and Witherington (2003), Lutz et al. (2003), and Gulko and Eckert (2004).

3.2.2 Sea Turtles of the Hawaiian Islands OPAREA

Five of the seven living species of sea turtles are known to occur in the Hawaiian Islands OPAREA: the green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*), olive ridley (*Lepidochelys olivacea*), and leatherback (*Dermochelys coriacea*) turtles (**Table 3-2**). Each of these species is protected under the ESA. However, critical habitat has not yet been designated for any of these species in the U.S. Pacific. A draft proposed rule was prepared in 1980 to designate critical habitat for the green turtle in the Hawaiian Islands, American Samoa, and the Trust Territories of the U.S., but it was never approved by the USFWS (Eckert 1993).

Table 3-2. Sea turtle species with known occurrence in the Hawaiian Islands OPAREA. Taxonomy follows Pritchard (1997).

	Scientific Name	ESA Status	Occurrence[1]
Order Testudines (turtles)			
Family Cheloniidae (hard-shelled sea turtles)			
Green turtle	*Chelonia mydas*	Threatened	Regular
Hawksbill turtle	*Eretmochelys imbricata*	Endangered	Regular
Loggerhead turtle	*Caretta caretta*	Threatened	Regular
Olive ridley turtle	*Lepidochelys olivacea*	Threatened	Regular
Family Dermochelyidae (leatherback sea turtle)			
Leatherback turtle	*Dermochelys coriacea*	Endangered	Regular

[1] A species' occurrence in the OPAREA can be described as one of the following: Regular—occurs as a regular or normal part of the fauna in the study area, regardless of how abundant or common it is; Rare—occurs in the study area sporadically; or Extralimital—does not normally occur in the study area and occurrences there are considered beyond the species' normal range.

The distribution of all available sea turtle occurrence records in the Hawaiian Islands OPAREA and vicinity by season (fall/winter: October through February; spring/summer: March through September) is presented in **Appendix C**, **Figures C-1a**. The distributions of available sea turtle records by season for individual species are presented in **Figures C-2a** through **C-6a**. Sea turtle occurrence records include sightings from NMFS surveys (bold colored circles), sightings from non-NMFS surveys and opportunistic encounters (light colored circles), strandings (triangles), and incidental fisheries bycatch records (squares). Also depicted on all maps in Appendix C are tracklines from NMFS shipboard surveys for which occurrence data were collected for this assessment. Since a large number of occurrence records (including nearly all of the stranding records) were collected from areas very close to shore, zoom-in maps for the nearshore waters surrounding the MHI and Nihoa have also been provided. These maps are referenced in this section and in Appendix C as **Figures C-1b** through **C-6b**.

It should be noted that the number of sea turtle records in a given season or portion of the OPAREA is often a function of the source or type of data, level of effort, and sighting conditions. For this MRA, most sea turtle occurrence records for the OPAREA are incidental bycatch records. These records are highly correlated to fishery effort in both time and space. Thus, these records do not adequately represent the distribution of sea turtles within the OPAREA. They do, however, provide information that sea turtles were located broadly throughout the OPAREA during the time that fishing vessels were present (Eckert personal communication).

Unidentified sea turtles (individuals that could not be identified to species) account for a large number of occurrence records, particularly sightings and bycatches. The hard-shelled sea turtles (green, hawksbill, loggerhead, and olive ridley) are often difficult to distinguish to species, particularly when they are young (i.e., small size classes), during aerial surveys, and/or when the observers do not have a high level of experience (Kenney personal communication). Species identification is less reliable when individuals from the general public (e.g., commercial and recreational fishermen, beachgoers) sight sea turtles. The reliability of species recognition may also be in question when sea turtles strand or nest, especially if qualified individuals are not present to make an accurate identification (Lund 1985).

A listing and description of data sources used to determine each species' occurrence in the Hawaiian Islands OPAREA and vicinity is found in Appendix A-3, while the process used to create the map figures is described in Section 1.4.2.2. On the map figures, various types of shading and terminology designate the areas of occurrence for each sea turtle species. Areas of "primary" occurrence (shaded in dark blue) are defined as areas and habitats where a species is primarily found. Areas of "secondary" occurrence (shaded in medium blue) are areas and habitats where a species may be found, especially during seasonal events such as reproductive migrations. Areas of "rare" occurrence (shaded in light blue) are areas and habitats where a species is not expected to be found with any regularity. Areas identified as "no survey effort" (hatched) are habitats that have not been adequately surveyed. Protected species biologists with the NMFS-SWFSC ultimately devised these qualitative terms.

Green, hawksbill, loggerhead, olive ridley, and leatherback turtles are all regular inhabitants of the Hawaiian Islands OPAREA (i.e., they occur as a regular or normal part of the fauna in the OPAREA, regardless of how abundant or common they are). Green and hawksbill turtles are most common in nearshore waters around the MHI and Nihoa, as they prefer to reside in reef-type environments that are less than 100 m in depth (Eckert personal communication). The green turtle is by far the most common species occurring in the nearshore waters around the Hawaiian Islands; this is highly evidenced by the available stranding data for the MHI (**Figure C-1b**). More than 90% of all green turtle breeding and nesting activity in Hawaiian waters occurs at French Frigate Shoals in the NWHI, yet a substantial foraging population resides in and returns to the shallow, coastal waters surrounding the MHI (especially around Maui and Kaua'i). Hawksbill turtles are the second most common species in the nearshore waters of the Hawaiian Islands, as also reflected by the stranding records (**Figure C-1b**), yet they are far less abundant than green turtles. Hawksbills occur around and nest on several of the MHI. Hawksbill nesting occurs primarily on the southeastern end of Hawai'i and on the eastern end of Moloka'i (Aki et al. 1994).

Further offshore (in waters beyond the 100 m isobath), juvenile loggerheads forage in or migrate through the OPAREA as they move between North American developmental habitats and Japan. The highest densities of loggerheads can be found just north of the OPAREA within the North Pacific transition zone (Polovina et al. 2000). The highest densities of olive ridleys, on the other hand, are likely found just south of the OPAREA. The distribution of the olive ridley in the central Pacific Ocean is primarily tropical; as a result, they are often found in warmer waters than loggerheads (Polovina et al. 2004). The primary migration corridor for leatherbacks moving west from U.S. west coast foraging areas to western Pacific nesting and foraging areas lies along the southern edge of the OPAREA, while an eastward return corridor appears to pass through the northern portion of the OPAREA (Eckert personal communication).

Loggerhead, leatherback, olive ridley, and green turtles are occasionally captured incidental to longline fishing operations throughout the OPAREA (Kobayashi and Polovina 2005; **Figure C-1a**). In oceanic waters of the central Pacific, incidental bycatch records are often the only sources of data on sea turtle occurrence. The vast majority of loggerhead captures in the Hawai'i-based longline fishery have occurred

in the northern half of the OPAREA, while most olive ridley captures have occurred in the southern half (**Figure C-1a**). This may indicate a tendency for these species to prefer distinct portions of the OPAREA, although caution must be taken since longline bycatch data is heavily biased as to area and season (Eckert personal communication). However, given that abiotic factors (e.g., temperature structuring, convergence zones), which can serve to concentrate sea turtles in certain areas, are lacking within the OPAREA, it is likely that distribution of these species is somewhat homogeneous, and that fishery bycatch data is representative of non-fished areas as well. There does not appear to be any trend in the distribution of leatherback bycatch records within the OPAREA (**Figure C-1a**). Green turtles captured in oceanic regions of the OPAREA may represent pelagic life stage turtles that have not yet settled into coastal areas or reproductive age turtles that are migrating between the MHI and the NWHI seasonally to breed. Green turtle migration routes tend to be oceanic between these island groups (Balazs 1983).

Due to the nearshore habitat preferences of the green and hawksbill turtles and the oceanic habitat preferences of the loggerhead, olive ridley, and leatherback turtles, the entire OPAREA is recognized as an area of primary occurrence for sea turtles (**Figure C-1a** and **C-1b**). Since the Hawaiian Islands are situated in tropical waters that are warm year-round, the area of primary occurrence is the same in fall and winter as it is in spring and summer. Sea turtles are also known to come ashore at several locations throughout the MHI, be it for terrestrial basking (green turtles only) or nesting (primarily green and hawksbill turtles). Nesting/basking sites for sea turtles occur on all eight of the MHI (**Figure 3-3**). Of note are green turtle nesting/basking beaches located at PMRF Barking Sands on Kaua‘i and a green turtle basking beach located along Kiholo Bay off the northwestern shore of Hawai‘i (NOS 2001; DoN 2004). These beaches are located in areas where the Hawaiian Islands OPAREA runs right up to the shoreline.

Each sea turtle species known to occur in the Hawaiian Islands OPAREA is listed below with its description, status, habitat preferences, distribution (including location and seasonal occurrence in the Hawaiian Islands OPAREA), behavior, and life history. Species appearance within the text follows the taxonomic order as presented in **Table 3-2**.

- Green Turtle (*Chelonia mydas*)

  Description—The green turtle, known in the Hawaiian Islands as the “honu,” is the largest hard-shelled sea turtle. Adult green turtles commonly exceed 100 cm in carapace length and 100 kg in weight. Adult carapaces range in color from solid black to gray, yellow, green, and brown in muted to conspicuous patterns. Hatchlings are distinctively black on the dorsal surface and white on the ventral (NMFS and USFWS 1998a, 1998b).

  The genus *Chelonia* includes a single species, *Chelonia mydas*, with two distinct subpopulations in the Pacific, the East Pacific green turtle (or black turtle) and the green turtle. The East Pacific green turtle is conspicuously smaller, typically darker in color, and has a narrower, more strongly vaulted carapace than the green turtle (NMFS and USFWS 1998a, 1998b). According to genetic analyses, the East Pacific green turtle is not a unique lineage relative to other green turtle populations throughout the world (Bowen and Karl 1997). Despite the belief that the Hawaiian population of green turtles is genetically distinct and geographically isolated, the genus *Chelonia* is considered monotypic in this report and any mention of “green turtle” will be in reference to the species, *Chelonia mydas*. This is due to the fact that green turtles from both subpopulations are known to occur in Hawaiian waters, as evidenced through genetic sampling of individuals incidentally captured in the Hawaiian longline fishery (HDLNR 2002). In San Diego Bay, and possibly off Baja California, resident populations of *Chelonia mydas* have also shown physical and genetic characteristics of both eastern Pacific and Hawaiian breeding populations (Dutton and McDonald 1990; Nichols et al. 2000a).

  Status—Green turtles are classified as threatened under the ESA throughout their Pacific range, except for the population that nests on the Pacific coast of Mexico, which is classified as endangered. Although green turtle populations are in serious decline throughout much of the Pacific Ocean, their status is currently improving in Hawaiian waters, presumably due to effective protection at primary nesting areas in the NWHI and better enforcement of regulations prohibiting take of the species. However, the relatively recent increase in fibropapillomatosis, a tumor-producing disease in green

turtles that is likely caused by a herpes-type virus, threatens to eliminate improvements in the status of the Hawaiian stock. Other primary threats to green turtles in the Pacific region include entanglement in debris, boat collisions, increased coastal development on nesting beaches, and illegal harvesting of turtles and eggs. There are no estimates of the current population size of green turtles in the Pacific Ocean (NMFS and USFWS 1998a, 1998b).

Habitat Preferences—In the Pacific Ocean, the early juvenile developmental habitat of the green turtle is unknown. After hatchlings leave the nesting beach, they apparently move into convergence zones in the open ocean where they spend an undetermined amount of time in the pelagic environment (Balazs 2004). In recent years, small numbers of early juveniles have been captured by commercial driftnet vessels fishing in international waters to the north and west of the Hawaiian Islands (NMFS and USFWS 1998a). Once green turtles reach a certain carapace length, which can be anywhere from 20 to 45 cm (depending upon the population), they migrate to shallow nearshore areas where they spend the majority of their lives as late juveniles and adults (Balazs 1980; Bjorndal and Bolten 1988; Ernst et al. 1994; NMFS and USFWS 1998a, 1998b).

The optimal habitats for late juveniles and adults (i.e., benthic life stages) are warm, quiet, and shallow (3 to 10 m deep) waters that possess an abundance of submerged aquatic vegetation (seagrasses and/or algae) and are located in close proximity to nearshore reefs or rocky areas used for resting (Ernst et al. 1994). Green turtles can feed as deep as their primary food source will grow. Around the Hawaiian Islands, green turtles often forage in coastal waters less than 10 m deep, but have been known to forage and also rest at depths of 20 to 50 m (Balazs 1980; Brill et al. 1995). Important resident areas in the MHI where adult green turtles feed and rest are: Kau and North Kohala Districts (Hawaiʻi), Hana District and Paia (Maui), coastal areas bordering the Kalohi and Auʻau Channels (Lānaʻi), coastal areas from Kamalo to Halena (Molokaʻi), Kailua and Kaneʻohe Bays (Oʻahu), coastal areas from Mokuleia to Kawailoa Beach (Oʻahu), Princeville and Na Pali (Kauaʻi), and coastal areas from Kukuiula to Makahuena Point (Kauaʻi) (Balazs 1980).

Distribution—Green turtles are distributed worldwide in tropical and subtropical waters and prefer temperatures above 20°C (NMFS and USFWS 1998a, 1998b). The most important nesting and feeding grounds lie within the tropics (Pritchard 1997). In U.S. Pacific waters, green turtles are regularly found in San Diego Bay and off the coasts of the Hawaiian Islands, American Samoa, Guam, the Northern Mariana Islands, and several of the unincorporated U.S. territories such as Wake Island and Palmyra Atoll (NMFS and USFWS 1998a). During warm spells, green turtles have been sighted in waters as far north as Alaska, where 15 occurrences have been documented since 1960 (Eckert 1993; Wing and Hodge 2002). However, most of these encounters involved individuals that were either cold-stressed, likely to become cold-stressed, or already dead (Hodge and Wing 2000). Green turtles occur in the coastal waters surrounding the MHI throughout the year and also migrate seasonally to the NWHI in order to reproduce.

As they grow, juvenile green turtles are known to move through a series of developmental feeding habitats, which are often separated by thousands of kilometers (Hirth 1997). Mixed-stock analyses on juvenile foraging populations have revealed that developmental feeding habitats likely contain green turtles from multiple stocks. Green turtles captured on foraging grounds off Baja California and in San Diego Bay have shown physical and genetic characteristics of both the Mexican Pacific and Hawaiian breeding populations (Dutton and McDonald 1990; Nichols et al. 2000a). However, little is known regarding the stock compositions of juvenile foraging populations in the insular Pacific Ocean.

Adult green turtles are known to undertake extensive migrations, the longest of which are between their foraging habitats and nesting beaches. Long-distance reproductive migrations have been noted for green turtles nesting at a number of locations in the Pacific Ocean including the NWHI, Taiwan, Hong Kong, American Samoa, and Guam (Balazs 1976, 1980, 1983; Cheng 2000; Chan 2003; Craig et al. 2004; Gutierrez 2004). Adult green turtles that breed in the NWHI make regular reproductive migrations from their foraging grounds either around the MHI or around the westernmost atolls in the NWHI. This has been evidenced by frequent mark-recapture and satellite-tracking studies on both

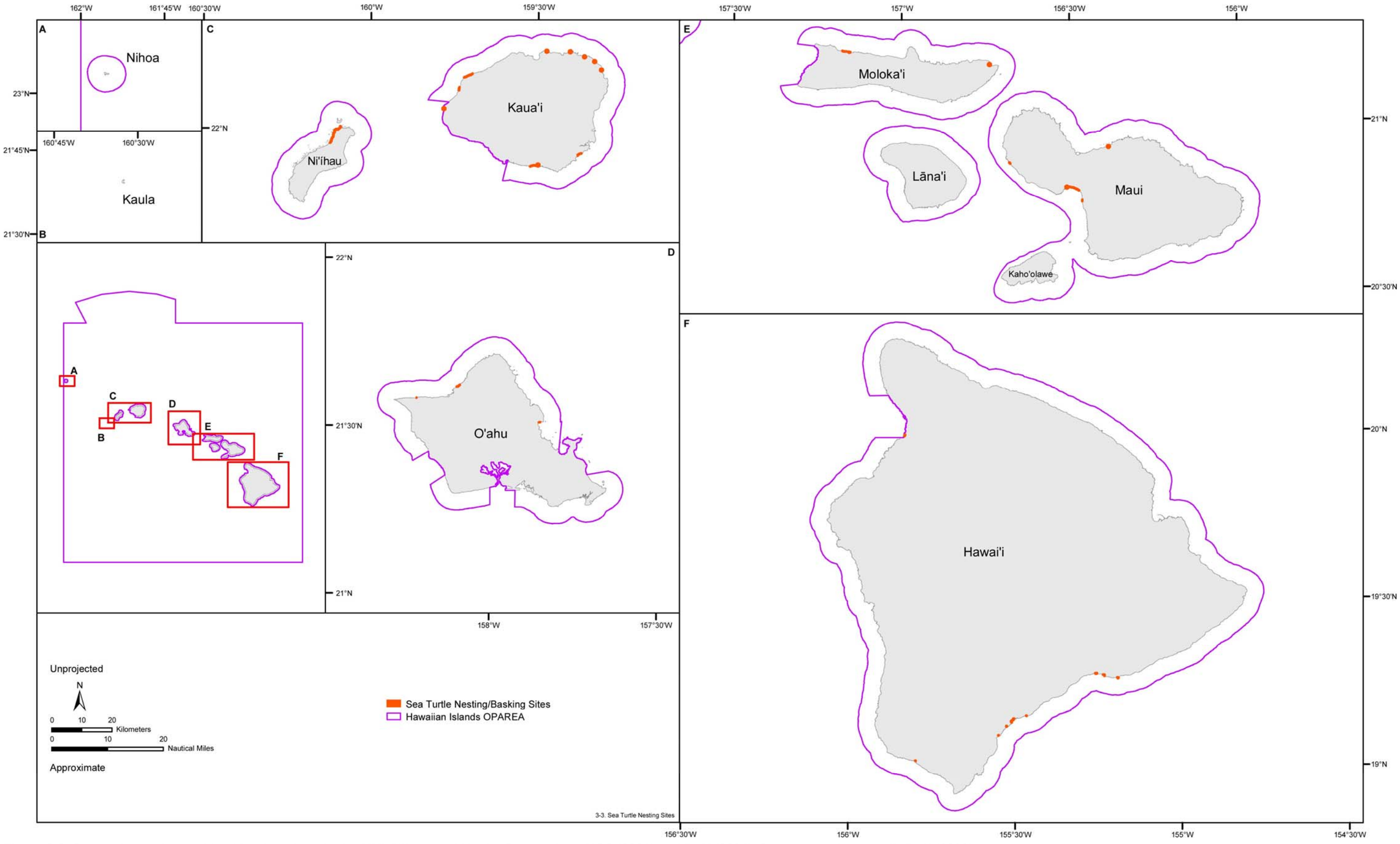

Figure 3-3. Sea turtle nesting and basking locations in the MHI, Nihoa, and Kaula. Source data: NOS (2001) and DoN (2004). Source map (scanned): DoN (2002).

adult male and female green turtles (Balazs 1976, 1983; Balazs and Ellis 2000; Balazs et al. 1994). Juvenile green turtles can also make long-range movements throughout the Hawaiian archipelago. From June 2002 to March 2003, a captive-reared green turtle released off northwestern Hawai‘i traveled over 4,800 km around the Hawaiian Islands, swimming as far west as the waters between Nihoa and Necker Islands before turning around and heading back to the MHI (Thompson 2003).

Green turtles nest throughout the Pacific Ocean, with active nesting colonies in the eastern, central, and western regions. Major nesting colonies in the eastern Pacific are located in Mexico and the Galapagos Islands, while high-density nesting sites in the western Pacific are found primarily in eastern Australia along the Great Barrier Reef. Green turtle nesting populations in the central Pacific Ocean are relatively small. The largest nesting colony in the central Pacific occurs at French Frigate Shoals in the NWHI, where about 200 to 700 females nest each year. Elsewhere in the U.S. Pacific, low-level nesting (less than ten individuals per year) occurs at scattered locations in the Northern Mariana Islands, Guam, and American Samoa (NMFS and USFWS 1998a). On occasion, green turtles also nest in the MHI. The most famous nesting green turtle in the MHI is turtle 5690, known by sea turtle biologists as “Maui Girl.” This turtle, which was raised to a year old at O‘ahu’s Sea Life Park and then tagged and released, has nested on beaches near Lahaina, Maui in 2000, 2002, and 2004 (Leone 2004). Other sporadic nesting events in the MHI have occurred along the north shore of Moloka‘i, the northwest shore of Lāna‘i, and the south, northeast, and southwest shores of Kaua‘i (DoN 2001a, 2002; NOS 2001).

- Information Specific to the Hawaiian Islands OPAREA—Based on the available sighting and stranding data for the OPAREA, green turtles outnumber all other species combined in the nearshore waters of the Hawaiian archipelago. The area of year-round primary occurrence for green turtles is located in waters inshore of the 100 m isobath around all of the MHI and Nihoa (**Figures C-2a** and **C-2b**). It is in these areas where reefs, their preferred habitats for foraging and resting, are most abundant. The area of secondary occurrence encompasses an oceanic zone surrounding the Hawaiian Islands. This area is frequently inhabited by adults that are migrating to the NWHI to reproduce and by pelagic stage individuals that have yet to settle into coastal feeding grounds of the MHI. Further offshore of this seasonal use zone is the area of year-round rare occurrence, as green turtles are not likely to be found in portions of the OPAREA that are extremely far from land.

Behavior and Life History—Adult green turtles feed primarily on seagrasses (e.g., turtle grass, manatee grass, shoal grass, and eelgrass), macroalgae, and reef-associated organisms (Burke et al. 1992; Ernst et al. 1994; Bjorndal 1997). Observations of foraging adult green turtles around the Hawaiian Islands suggest that when benthic age classes feed, they generally lie down on the sea bottom and, when food is no longer within reach, they crawl or swim to a nearby site (Hochscheid et al. 1999). Juveniles are omnivorous; they feed on a variety of algae, invertebrates, and small fishes (Ernst et al. 1994). It is not unusual for juvenile green turtles in the Hawaiian archipelago to bite on fishing hooks baited with squid, shrimp, and fish flesh (Balazs 1980). Russell and Balazs (1994), Keuper-Bennett and Bennett (2002), and Russell et al. (2003) have documented that green turtles in Hawaiian waters feed on a wide variety of both native and invasive species of seagrass and marine algae. Two species of green algae (*Codium spp.* and *Ulva spp.*) and two species of red algae (*Pterocladia capillacea* and *Amansia glomerata*) appear to be the major food sources for green turtles in the MHI (Balazs 1980). At times, green turtles may even exit the water to feed on algae that grow on rocks that are exposed during low tide.

Green turtles residing in the waters around the Hawaiian Islands are highly unique among sea turtles in that a number of them periodically come ashore during the day to bask. Terrestrial basking, where turtles lie motionless and soak up the heat of the sun, most often occurs on undisturbed beaches where there is little to no human interaction. As a result, this behavior is much more common in the NWHI than it is in the MHI. This behavior is not specific to a certain sex or life stage, although adults tend to bask on land more frequently than juveniles. Basking activity is most prevalent during the day, but can also occur at night (Balazs 1980; Spotila et al. 1997; Gulko and Eckert 2004).

Green turtles take between 27 and 50 years to reach sexual maturity, the longest age to maturity for any sea turtle species (Frazer and Ehrhart 1985). In the NWHI, mature females nest from one to six times in a season (one to two is typical) at approximately 10 to 15 day intervals, and reproduce every 2 to 3 years (Balazs 1980). In contrast, over half of all adult male green turtles return to the breeding grounds every year. During the breeding season (mid-April to early June), green turtle courtship and copulation occur in waters proximal to the nesting beach; at French Frigate Shoals, they occur within 2 km of the 11 small islands that constitute the atoll (Owens 1980; NMFS and USFWS 1998a). The nesting season for Hawaiian green turtles commences in April and May, peaks between mid-June and early August, and tapers off in September and October. From 1986 through 1991, green turtle nests at Tern Island, French Frigate Shoals contained an average of 92.4 eggs with a mean incubation period of 66 days (Niethammer et al. 1997).

Green turtles typically make dives shallower than 30 m (Hochscheid et al. 1999; Hays et al. 2000). In the eastern Pacific Ocean, green turtles have been observed at depths of 73 to 110 m (Berkson 1967). In 1997, a maximum dive depth of 164.5 m was recorded for a post-nesting female from Japan's Ogasawara Islands (Matsuzawa personal communication). The maximum dive time recorded for a juvenile green turtle around the Hawaiian Islands is 66 min, with routine dives ranging from 9 to 23 min (Brill et al. 1995).

- Hawksbill Turtle (*Eretmochelys imbricata*)

Description—The hawksbill turtle, also known in the Hawaiian Islands as the "honu'ea," is a small to medium-sized sea turtle. Adults range between 65 and 90 cm in carapace length and typically weigh around 80 kg (Witzell 1983). Hawksbills are distinguished from other sea turtles by their hawk-like beaks, posteriorly overlapping carapace scutes, and two pairs of claws on their flippers. The carapace of this species is often brown or amber with irregularly radiating streaks of yellow, orange, black, and reddish-brown (NMFS and USFWS 1998c).

Status—Hawksbill turtles are classified as endangered under the ESA and are second only to the Kemp's ridley turtle in terms of global endangerment (Bass 1994; NMFS and USFWS 1998c). Only five regional populations worldwide remain with more than 1,000 females nesting annually (Seychelles, the Mexican Atlantic, Indonesia, and two in Australia) (Meylan and Donnelly 1999). A lack of regular quantitative surveys for hawksbill turtles in the Pacific Ocean and the discrete nature of this species' nesting have made it extremely difficult for scientists to assess the distribution and population status of hawksbills in the region (NMFS and USFWS 1998c; Seminoff et al. 2003). The status of the hawksbill is clearly of a higher concern for the Pacific due to the serious depletion of the species caused by international harvest and habitat destruction (NMFS and USWFS 1998c). Hawksbill populations in the insular Pacific Ocean are believed to be very depleted, although there are currently no measurable trends in stock numbers, either up or down (NMFS and USFWS 1998c; Meylan and Donnelly 1999).

Habitat Preferences—In the Atlantic Ocean and Caribbean Sea, early juveniles are known to inhabit oceanic waters, where they are sometimes associated with drift lines and floating patches of *Sargassum* (Parker 1995). In the Pacific Ocean, the oceanic whereabouts of this early life stage is unknown (NMFS and USFWS 1998c). However, it is likely that they would occur in similar areas of advection where flotsam accumulates (HDLNR 2002).

It is believed that hawksbill turtles migrate to benthic foraging grounds when they reach 20 to 25 cm in length (Meylan 1988). Late juvenile and adult hawksbill turtles forage around coral reefs, mangroves, and other hardbottom habitats in open bays and coastal zones throughout the tropical Pacific Ocean, with adults occupying somewhat deeper waters (to 24 m) than late juveniles (to 12 m) due to their ability to make deeper dives (Eckert 1993).

Distribution—Hawksbill turtles are circumtropical in distribution, generally occurring from 30°N to 30°S latitude within the Atlantic, Pacific, and Indian Ocean basins (NMFS and USFWS 1998c). Around the Hawaiian Islands, hawksbills are only known to occur in the coastal waters of the eight

main and inhabited islands of the archipelago. Hawksbills forage throughout the MHI, although in much fewer numbers than green turtles. Hawksbills have been captured at several locations including Kiholo Bay and Kau (Hawaiʻi), Palaʻau (Molokaʻi), and Makaha (Oʻahu) (HDLNR 2002). Strandings have been reported in Kaneʻohe and Kahana Bays (Oʻahu) as well as in other locations throughout the MHI (Eckert 1993; NMFS and USFWS 1998c). There have been no recorded sightings within Pearl Harbor and no reliable reports are known from Niʻihau (DoN 2001a, 2001b). Hawksbills are much more abundant in the shallow, nearshore waters of the Hawaiian Islands than they are in deeper, offshore waters of the central Pacific Ocean.

Hawksbills were originally thought to be a non-migratory species because of the close proximity of their nesting beaches to their coral reef feeding habitats and the high rates of local recapture. Hawksbills are now known to travel long distances over the course of their lives (Meylan 1999). Tag return, genetic, and satellite telemetry studies have indicated that hawksbill turtles utilize multiple developmental habitats as they age. However, within a given life stage, such as the later juvenile stage, some hawksbills may remain at a specific developmental habitat for a long period of time (Meylan 1999). Foraging hawksbills in the MHI may come from a number of different natal beaches, so it is possible that some of them are unrelated to the females that nest there (HDLNR 2002).

Hawksbill nesting in the North Pacific Ocean is widespread and occurs at scattered locations in very small numbers (Eckert 1993). Hawksbill turtles that nest in the Hawaiian Islands only do so on the main islands of the archipelago. Balazs et al. (1992) estimated that probably no more than 12 hawksbills nest on Hawaiʻi and Molokaʻi each year. However, recent nesting surveys indicate that around 20 to 30 hawksbills likely nest in the MHI annually (HDLNR 2002). The most consistently used sites seem to be Kamehame and Apua Points (on the east coast of Hawaiʻi) and a black sand beach at the river mouth of Halawa Valley (on the east end of Molokaʻi) (Katahira et al. 1994; NMFS and USFWS 1998c). Hawksbill nesting also occurs on Maui (e.g., Keālia Beach) and may occur on Oʻahu (Eckert 1993; Jensen 2000; Mangel et al. 2000). Although they are known to occur in ocean waters off Kauaʻi, there are no records of hawksbills nesting near PMRF Barking Sands (DoN 2001a).

- Information Specific to the Hawaiian Islands OPAREA—Throughout the year, the area of primary occurrence for hawksbill turtles can be found in OPAREA waters shoreward of the 100 m isobath (**Figures C-3a** and **C-3b**). Hawksbills are known to both forage around and nest on beaches in the MHI. Coral reefs and hardbottom habitats are their preferred habitats, which are seldom found in waters deeper than the shelf break. The lack of hawksbill sightings during aerial and shipboard surveys is likely reflective of the species' small size and difficulty to identify from a distance. Beyond the 100 m isobath, hawksbill occurrence is rare year round. Pelagic stage individuals may occur in oceanic waters off the MHI and Nihoa, but these life stages are nearly impossible to sight during surveys and rarely, if ever, interact with the pelagic longline fishery. Of the five sea turtle species known to occur in the OPAREA, the hawksbill is the only one that is not taken by Hawaiian longliners (Kobayashi and Polovina 2005).

Behavior and Life History—Early juveniles are believed to utilize pelagic *Sargassum* or other flotsam as a developmental habitat, but little is known about their diets during this stage. Upon recruiting to benthic feeding habitats, hawksbills are known to become omnivorous and will feed on encrusting organisms such as sponges, tunicates, bryozoans, algae, mollusks, and a variety of other items such as crustaceans and jellyfish (Bjorndal 1997). Older juveniles and adults are more specialized and feed primarily on sponges. Sponges comprise as much as 95% of their diet in some locations (Witzell 1983; Meylan 1988).

Hawksbill turtles often nest in multiple, small, scattered colonies. The nesting season for hawksbills in the Hawaiian Islands is likely from late May to early December, with a peak in nesting activity from late July through early September (Eckert 1993; Katahira et al. 1994). Very few data are available for hawksbills that nest in this region. Much of what is known about hawksbill nesting has been learned from studies at rookeries in the Caribbean, Indian Ocean, and western Pacific regions. Mating is believed to take place in the shallow waters adjacent to the nesting beach. Nesting occurs on both low- and high-energy beaches in tropical latitudes. It is often a nocturnal activity that occurs on

beaches with sufficient vegetative cover. Females nest between two and five times per season and inter-nesting intervals last around 14 to 16 days. The typical remigration interval (the number of years between successive nesting seasons) is two to three years. Clutch sizes in the Pacific Ocean are relatively large at 110 to 150 eggs, and incubation time is 50 to 61 days (NMFS and USFWS 1998c).

Hawksbills may have the longest routine dive times of all sea turtles. Starbird et al. (1999) reported that dive times for inter-nesting females at Buck Island, St. Croix, USVI averaged 56.1 min with a maximum of 73.5 min. Mean time at the surface was about 2 min. Average dives during the day ranged from 34 to 65 min, while those at night were between 42 and 74 min. The movements of all the turtles studied were confined to an area less than 1.5 km^2. Data from time-depth recorder studies in Puerto Rico indicate that foraging dives of immature hawksbills range from 8.6 to 14 min and have a mean depth of 4.7 m (van Dam and Diez 1996). These individuals were found to be most active during the day.

- Loggerhead Turtle (*Caretta caretta*)

Description—The loggerhead turtle is a large hard-shelled sea turtle that is named for its proportionately large head and powerful jaws. The average carapace length of an adult female loggerhead is between 90 and 95 cm and the average weight is 100 to 150 kg (Dodd 1988; NMFS and USFWS 1998d). Adult loggerheads usually possess a reddish-brown carapace with scutes that are bordered with yellow (NMFS and USFWS 1998d).

Status—Loggerhead turtles are classified as threatened under the ESA. Recent data suggest that loggerhead nesting populations in Japan are in considerable decline (Sato et al. 1997; Kikukawa et al. 1999; Suganuma 2002; Kamezaki et al. 2003; STAJ 2005). Field studies in eastern Australia are also indicating significant declines in Pacific loggerhead nesting activity (Limpus and Limpus 2003). A few thousand to hundreds of thousands of loggerheads likely comprise the juvenile foraging population off Baja California (Pitman 1990), yet it is probable that there are fewer than 1,000 females nesting annually in Japan (Kamezaki et al. 2003). Long-term counts of loggerheads in all parts of southern Japan have shown that the number of loggerheads breeding there has decreased by more than half since 1990 (Sato et al. 1997; Hatase et al. 2002a; STAJ 2005).

Incidental bycatch in commercial fisheries is a tremendous source of loggerhead mortality. Lewison et al. (2004) noted that an estimated 30,000 to 75,000 loggerhead turtles were taken as pelagic longline bycatch in the Pacific Ocean in 2000. Rapid declines in nesting females at all major Pacific rookeries suggest that longline bycatch is leading to increased levels of loggerhead mortality in the Pacific Ocean (Kamezaki et al. 2003; Limpus and Limpus 2003). In 2004, the NMFS concluded that the pelagic longline fishery is likely to jeopardize the continued existence of loggerhead turtles in the Pacific Ocean. As a protective measure, the NMFS placed a number of restrictions on the Hawai‘i-based longline fishery for swordfish. These include gear restrictions (both bait and hooks), incidental take limits, fleet-wide fishing effort limits, and other mitigation measures (NMFS 2004).

Habitat Preferences—The loggerhead turtle occurs worldwide in habitats ranging from coastal estuaries, bays, and lagoons to waters far beyond the continental shelf (Dodd 1988). Early juvenile loggerheads are primarily oceanic, occurring in pelagic convergence zones where they are transported throughout the ocean by dominant currents (Carr 1987). A common pattern in the developmental migration of this species is to reside on the eastern side of the Atlantic or Pacific Ocean (e.g., around the Azores, Madeira, and inside the western Mediterranean, or just offshore of Baja California, Mexico) for a number of years and then migrate back to coastal waters on the western side of these same ocean basins. Late juvenile and adult loggerheads are generally found around reefs and other hardbottom habitats (Dodd 1988).

Satellite-tracking studies on loggerheads captured in pelagic longline fishing gear indicate that individuals traveling west in pelagic waters of the North Pacific Ocean move north and south on a seasonal basis. These individuals move primarily through the region bounded by 28° and 40°N and occupy SSTs between 15° and 25°C. The Transition Zone Chlorophyll Front (TZCF) and the Kuroshio

Extension Current appear to be important foraging and migration habitats for loggerhead turtles in the central North Pacific (Polovina et al. 2004). Polovina et al. (2000) noticed that juvenile loggerheads often follow the 17° and 20°C isotherms north of the Hawaiian Islands.

Distribution—The loggerhead turtle is a circumglobal species inhabiting the temperate, subtropical, and tropical waters of the Atlantic, Pacific, and Indian Oceans (Ernst et al. 1994). Polovina et al. (2000) inferred that the distribution of loggerheads is continuous across the Pacific Ocean, although Eckert (1993) and the NMFS and USFWS (1998d) indicated that they are less common in the central Pacific than they are in the eastern and western Pacific. In the eastern Pacific Ocean, loggerheads are documented to occur as far north as Alaska and as far south as Chile (Bane 1992; Donoso-P. et al. 2000). The largest juvenile foraging population in the North Pacific Ocean is found off the west coast of Baja California Sur, in a band starting about 30 km offshore and extending out at least another 30 km (NMFS and USFWS 1998d; Nichols et al. 2000b).

The NMFS and USFWS (1998d) listed four records of this species for the Hawaiian Islands: two from the southeastern end of the archipelago, one from Kure Atoll (recovered from the stomach of a tiger shark), and a fourth from the coast of O‘ahu (seen just offshore of the Sheraton Waikiki hotel). All four individuals were identified as juvenile loggerheads and most likely drifted or traveled to the region from either Mexico or Japan. A single male loggerhead turtle has also been reported to visit Lehua Channel and Keamano Bay (located off the north coast of Ni‘ihau) every June through July (DoN 2001a; NOS 2001). Only one loggerhead stranding has been recorded in the Hawaiian Islands since researchers began documenting them in 1982. This event, which was recorded along the shores of Kane‘ohe Bay, O‘ahu, was determined to be the result of a shark attack (NMFS-PIFSC 2004).

Genetic analyses indicate that nearly all of the loggerheads found in the North Pacific Ocean are born on nesting beaches in Japan (Bowen et al. 1995; Resendiz et al. 1998). Pacific loggerheads appear to utilize the entire North Pacific Ocean during the course of development, much like Atlantic loggerheads use the North Atlantic Ocean. There is substantial evidence that both stocks make two separate transoceanic crossings. The first crossing (west to east) is made immediately after hatching from the nesting beach, while the second (east to west) is made upon reaching either the late juvenile or adult life stage. In the North Atlantic Ocean, hatchlings born on beaches in the western Atlantic swim with the North Atlantic Gyre system in order to reach developmental habitats in the eastern Atlantic (around the Azores and Madeira) (Bolten et al. 1998). In the North Pacific Ocean, hatchlings born on beaches in the western Pacific swim with the NPSG system in order to reach developmental habitats in the eastern Pacific (off southern California and Mexico) (Polovina et al. 2000). Unlike the case in the eastern Atlantic, where nesting grounds actually do exist (e.g., in the Mediterranean Sea along the coast of Greece), all juvenile loggerheads found in the eastern Pacific must eventually return to the western Pacific in order to reproduce. Nichols et al. (2000c) concluded that loggerhead turtles are highly capable of transpacific migration and that the band of water between 25°N and 30°N, also known as the Subtropical Frontal Zone, may be an important migratory corridor for loggerheads returning to the western Pacific. In 1996 and 1997, over the course of 368 days, a captive-reared loggerhead turtle named “Adelita” migrated over 11,000 km across the Pacific Ocean from a juvenile feeding area off Santa Rosalita, Baja California, Mexico to an adult feeding area at Sendai Bay, Japan (**Figure 3-4**). From 1998 to 2000, several other transoceanic migrations of captive-reared loggerhead turtles were monitored through the use of satellite telemetry, this time from waters off San Diego, California to Japan (Parker et al. 2004; Eckert personal communication).

Major nesting grounds are located in warm, temperate, and subtropical regions, with some scattered nesting in the tropics. The world’s largest loggerhead nesting colonies are found at Masirah Island, Oman (bordering the Arabian Sea) and along the Atlantic coast of Florida. Nesting in the Pacific basin is restricted to the western region (primarily Japan and Australia). There is no loggerhead nesting on Pacific beaches under U.S. jurisdiction (NMFS and USFWS 1998d).

- Information Specific to the Hawaiian Islands OPAREA—In the central Pacific Ocean, loggerhead turtles are believed to occur primarily in deep, oceanic waters. Loggerheads utilize these waters

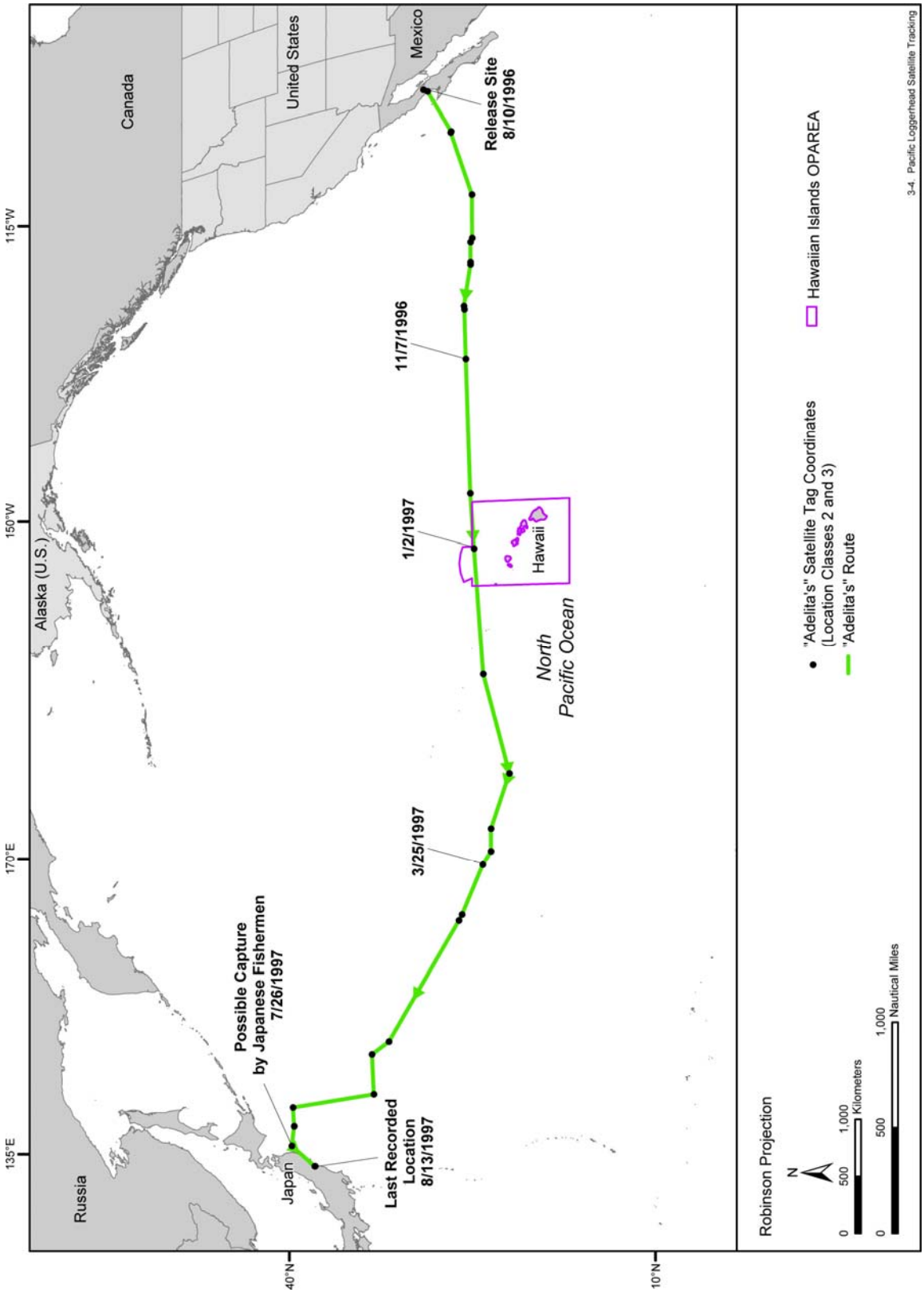

Figure 3-4. The transpacific migration of loggerhead turtle "Adelita" from Baja California, Mexico to Sendai Bay, Japan between August 1996 and August 1997. Satellite-tag coordinates with location classes (LC) of 2 (accurate to within 350 m) and 3 (accurate to within 150 m) are presented. Source data: Nichols et al. (2000c).

as a transitional habitat during migrations between developmental habitats in the eastern Pacific and adult nesting/foraging habitats in the western Pacific. The area of primary occurrence for the loggerhead turtle spans all ocean waters off the MHI and Nihoa beyond the 100 m isobath (**Figures C-4a** and **C-4b**). This area, like the area of rare occurrence, which can be found between the Hawaiian Islands shoreline and the 100 m isobath, is the same throughout the year. Occurrence in nearshore waters is believed to be rare due to a lack of sighting and stranding records in those waters. Except for the four sighting and one stranding records listed previously, loggerheads have not been recorded at all on the Hawaiian shelf.

Behavior and Life History—The diet of a loggerhead turtle changes with age and size. The gut contents of post-hatchlings found in masses of *Sargassum* contained parts of *Sargassum,* zooplankton, jellyfish, larval shrimp and crabs, insects, and gastropods (Richardson and McGillivary 1991; Witherington 1994). Late juvenile loggerhead turtles are omnivorous, foraging on pelagic crabs, mollusks, jellyfish, and vegetation captured at or near the surface (Dodd 1988). Off Baja California Sur, the distribution of juvenile loggerheads coincides with that of a large population of pelagic red crabs (NMFS and USFWS 1998d). This indicates that juvenile loggerheads in the eastern Pacific are probably feeding on dense concentrations of this highly abundant crustacean. Adult loggerheads are generally carnivorous, often choosing to forage on benthic invertebrates (mollusks, crustaceans, and coelenterates) and sometimes fish in nearshore waters. However, in deep waters of the western and central North Pacific Ocean, adult loggerheads may also feed on nutrient-poor items such as jellyfish, salps, and other gelatinous animals (Dodd 1988; Hatase et al. 2002b).

Loggerhead nesting in the North Pacific Ocean occurs between April and August, when nearshore water temperatures reach 20°C and above (NMFS and USFWS 1998d). Females from the Japanese nesting stock nest at least three times per season, at about two-week intervals (Eckert 1993). Loggerhead clutches contain between 60 and 150 eggs and often take about 60 days to incubate. Dodd (1988) estimated that the global average hatching success for loggerheads is nearly 75%. Adult females nest at multiple year intervals, with the majority nesting every two years (Frazer 1995).

On average, loggerhead turtles spend over 90% of their time underwater (Byles 1988; Renaud and Carpenter 1994). Dive-depth distributions compiled by Polovina et al. (2003) in the North Pacific Ocean indicate that loggerheads tend to remain at depths shallower than 100 m. Routine dive depths are typically shallower than 30 m, although dives of up to 233 m were recorded for a post-nesting female loggerhead off Japan (Sakamoto et al. 1990). Routine dives can last from 4 to 172 min (Byles 1988; Sakamoto et al. 1990; Renaud and Carpenter 1994).

- Olive Ridley Turtle (*Lepidochelys olivacea*)

Description—The olive ridley is a small, hard-shelled sea turtle named for its olive green colored shell. Adults often measure between 60 and 70 cm in carapace length and rarely weigh over 50 kg. The carapace of an olive ridley turtle is wide and almost circular in shape. The olive ridley differs from the Kemp's ridley, the other member of the genus *Lepidochelys*, in that it possesses a smaller head, a narrower carapace, and several more lateral carapace scutes (NMFS and USFWS 1998e).

Status—Olive ridleys are classified as threatened under the ESA, although the Mexican Pacific coast nesting population is labeled as endangered. There has been a general decline in the abundance of this species since its listing in 1978. Until the advent of commercial exploitation, the olive ridley was highly abundant in the eastern tropical Pacific, probably outnumbering all other sea turtle species combined in the area (NMFS and USFWS 1998e). Clifton et al. (1995) estimated that a minimum of 10 million olive ridleys were present in ocean waters off the Pacific coast of Mexico prior to 1950. Even though there are no current estimates of worldwide abundance, the olive ridley is still considered the most abundant of the world's sea turtles. However, the number of olive ridley turtles occurring in U.S. territorial waters is believed to be small (NMFS and USFWS 1998e).

Habitat Preferences—Olive ridley turtles typically inhabit offshore waters, foraging either at the surface or at depth. They usually feed down to depths of 150 m, although one individual was observed feeding on crustaceans at a depth of 290 m. This deep-diving individual was originally

thought to be a green turtle (Landis 1965), although it was later verified by Eckert et al. (1986) that it was in fact an olive ridley. The habitat preferences of the olive ridley more closely parallel those of the leatherback rather than those of its relative, the Kemp's ridley (NMFS and USFWS 1998e). Olive ridleys and leatherbacks both occupy oceanic habitats and nest primarily on the Pacific shores of the American tropics and in the Guianas. Both species also nest in moderate numbers in southern Asia and in very small numbers elsewhere (e.g., in Australia and on small oceanic islands in the Pacific Ocean). Polovina et al. (2004) noted that olive ridleys in the North Pacific Ocean are found primarily between 8° and 31°N latitude in waters between 23° and 28°C.

Distribution—The olive ridley turtle is a pantropical species, occurring worldwide in tropical and warm temperate waters. It is by far the most common and widespread sea turtle in the North Pacific Ocean; individuals regularly occur in waters as far north as California and as far south as Ecuador (Pitman 1990; NMFS and USFWS 1998e). In offshore areas far from North and South America, olive ridley turtles become increasingly uncommon, both at sea and around oceanic islands (Balazs 1995). However, small numbers of olive ridleys are known to forage in the central North Pacific Ocean. This is evidenced by infrequent captures of this species in the Hawai'i-based longline fishery (Dutton et al. 2000a; Polovina et al. 2003, 2004). Olive ridleys are rare visitors to the nearshore waters around the Hawaiian Islands, although they have been recorded in increasing numbers over the past two decades. Juveniles and adults have become entangled in fishing gear and other marine debris in nearshore waters off Hawai'i, Moloka'i, Maui, and O'ahu (Eckert 1993). A total of 26 olive ridley turtles have stranded in the Hawaiian Islands since 1982, making it the third most common species to strand after greens and hawksbills (HDLNR 2002). Available information suggests that olive ridleys traverse through the oceanic waters surrounding the Hawaiian Islands during foraging and developmental migrations (Nitta and Henderson 1993).

Bordering the Indian Ocean, the shores of Orissa, India are home to the world's largest nesting aggregation of olive ridley turtles (Shanker et al. 2003). The world's second largest nesting population of olive ridleys occurs in the eastern Pacific Ocean, along the west coasts of Mexico and Central America (NMFS and USFWS 1998e). The largest rookeries in this region are found in southern Mexico (La Escobilla) and northern Costa Rica (Playas Nancite and Ostional), with some individuals nesting as far north as Baja California Sur (Fritts et al. 1982; López-Castro et al. 2000). Olive ridley nesting also takes place in the western Pacific Ocean along the shores of Malaysia and Thailand, but in smaller numbers (Eckert 1993). Due to their preference for beaches located along continental margins, female olive ridleys are not expected to nest in the central Pacific Ocean. In the Hawaiian Islands, a single nesting was recorded along Pā'ia Bay, Maui in September 1985; however, there was no successful hatching associated with this event (Balazs and Hau 1986; NOS 2001). Since there are no other known nesting records for the central Pacific Ocean, the above nesting attempt should be considered an anomaly (NMFS and USFWS 1998e).

Genetic analysis of olive ridleys taken in the Hawaiian longline fishery has shown that individuals from both eastern and western Pacific nesting populations forage in the central North Pacific Ocean (Dutton et al. 1999). However, olive ridleys born on eastern Pacific beaches appear to utilize different oceanic habitats in the region from those used by individuals born on western Pacific beaches. Olive ridleys of western Pacific origin have been observed in association with major ocean currents of the central North Pacific, specifically the southern edge of the Kuroshio Extension Current, the NEC, and the Equatorial Counter Current. These habitats, which are also frequented by Pacific loggerhead turtles, are probably not used as frequently by olive ridleys of eastern Pacific origin. Instead, olive ridleys from eastern Pacific nesting populations seem to inhabit waters in the center of the NPSG system, which are characterized by warmer temperatures, weaker currents, greater vertical stratification, and a deeper thermocline (Polovina et al. 2003, 2004; **Figure 2-8**). About two-thirds of all olive ridleys found in the vicinity of the Hawaiian Islands are derived from eastern Pacific nesting populations, while the remaining one-third originate in the western Pacific or Indian Ocean. As a result, the Hawaiian Islands represent a point of convergence for these source areas (HDLNR 2002).

- Information Specific to the Hawaiian Islands OPAREA—Based on the oceanic habitat preferences of this species throughout the Pacific Ocean, it has been determined that the area of

year-round primary occurrence in the Hawaiian Islands OPAREA lies in waters beyond the 100 m isobath (**Figures C-5a** and **C-5b**). Olive ridleys are frequently captured by pelagic longline fishermen in deep, offshore waters of the Hawaiian Islands OPAREA, especially during spring and summer (**Figure C-5a**). Inside of the 100 m isobath, olive ridley occurrence in the OPAREA is rare year round. Like the loggerhead turtle, there have been few recorded sightings and strandings of this species in the nearshore waters of the MHI and Nihoa (as compared to the green and hawksbill turtles, which are primarily nearshore species). A significant number of strandings in an area likely indicates a strong presence in waters nearby, which is not the case here. A single recorded nesting attempt for the olive ridley over the past 20 years also indicates the lack of a need for this species to enter coastal waters surrounding the Hawaiian Islands.

Behavior and Life History—The olive ridley turtle is considered omnivorous, eating a variety of benthic and pelagic prey items including fish, crabs, shrimp, snails, oysters, sea urchins, jellyfish, salps, fish eggs, and vegetation (NMFS and USFWS 1998e). However, crustaceans and fish serve as their primary food source. Olive ridleys that interact with the Hawaiian longline fishery are known to feed predominantly on tunicates (salps and pyrosomas), which are found well below the water surface (Polovina et al. 2004).

At sea, olive ridleys readily associate with floating objects such as logs, plastic debris, and even dead whales (Arenas and Hall 1992; Pitman 1992). Scientists believe that olive ridley turtles associate with flotsam since it provides them with shelter from predators and an abundance of prey items (NMFS and USFWS 1998e). Olive ridleys in the eastern Pacific Ocean are also known to bask at the surface, where they are often accompanied by seabirds that will roost upon their exposed carapaces and feed on fish that aggregate beneath them (Pitman 1993). Surface basking allows an olive ridley turtle to conserve energy, avoid predators, and raise its body temperature (Gulko and Eckert 2004).

Unlike all other species of sea turtle except the Kemp's ridley, the olive ridley is known for nesting en masse. This type of nesting activity is known as an *arribada* (Spanish for "arrival"). During an *arribada*, hundreds to tens of thousands of breeding olive ridleys congregate in the waters in front of the nesting beach and then, signaled by some unknown cue, emerge from the sea in unison. There is currently no estimate of the age at which females begin to reproduce; however, the average length of nesting adults at Playa Nancite, Costa Rica is 63.3 cm. Nesting occurs throughout the year, peaking from August to December in the eastern Pacific, from February to July in Malaysia, and from October to February in Thailand. Females usually nest every one to two years. A typical female produces two clutches per nesting season, with each clutch averaging 105 eggs. Lone individuals nest at 15 to 17 day intervals while mass nesters arrive to the nesting beach at 28 day intervals. Incubation time from deposition to emergence is approximately 55 days (Eckert 1993; NMFS and USFWS 1998e).

Relatively few studies have investigated the diving behavior of olive ridley turtles. In the eastern tropical Pacific Ocean, olive ridleys make more frequent submergences and spend more time at the surface during the day than at night (Beavers and Cassano 1996; Parker et al. 2003). As a result, nighttime dives are longer in duration (reaching a maximum of 95.5 min). Olive ridleys have been observed at depths of 300 m, although only about 10% of their time is spent at depths greater than 100 m (S. Eckert et al. 1986; Polovina et al. 2003). It appears that the eastern tropical Pacific's permanent thermocline, located at depths between 20 and 100 m, is an important foraging area for adult olive ridleys, as at least 25% of their total dive time is spent there (Parker et al. 2003).

- Leatherback Turtle (*Dermochelys coriacea*)

Description—The leatherback turtle is the largest living sea turtle. These turtles are placed in the family Dermochelyidae, a separate family from all other sea turtles, in part because of their unique carapace structure. A leatherback turtle's carapace lacks the outer layer of horny scutes (bony external plates or scales) possessed by all other sea turtles; instead, it is composed of a flexible layer of dermal bones underlying tough, oily connective tissue and smooth skin. The body of a leatherback is barrel-shaped and tapered to the rear, with seven longitudinal dorsal ridges, and is almost completely black with variable spotting. All adults possess a pink spot on the dorsal surface of their

head, a marking that has been used by scientists to identify specific individuals (McDonald and Dutton 1996). Adult carapace lengths range from 119 to 176 cm with an average around 145 cm (NMFS and USFWS 1998f). Adult leatherbacks weigh between 200 and 700 kg. Genetic analyses of leatherbacks sampled in the Pacific Ocean indicate that gene flow between eastern and western Pacific nesting populations is restricted (Dutton et al. 1998, 1999, 2000a, 2000b).

Status—Leatherback turtles in the Pacific Ocean are highly endangered and may become extinct in the next several decades if current trends in mortality persist. Lewison et al. (2004) estimated that more than 50,000 leatherbacks were taken as pelagic longline bycatch in 2000 and that thousands of these turtles die each year from longline gear interactions in the Pacific Ocean alone. Leatherbacks are seriously declining at most Pacific Ocean rookeries, including Indonesia, Malaysia, and Mexico (NMFS and USFWS 1998f). No attempts have been made to assess the status of foraging populations. The most recent estimate of the worldwide leatherback population was 34,500 nesting females, with a lower and upper limit of 26,200 and 42,900 nesting females (Spotila et al. 1996).

Habitat Preferences—There is limited information available regarding the habitats utilized by early juvenile leatherbacks because this age class is entirely oceanic. However, scientists are relatively certain that these individuals do not associate with floating debris or vegetation, as is the case for the other five sea turtle species found in U.S. waters (NMFS and USFWS 1998f). It is also known that juveniles up to 100 cm in curved carapace length (CCL) are generally restricted to lower latitudes, where water temperatures are greater than 26°C. The transition at 100 cm is relatively abrupt, with leatherbacks as small as 107 cm CCL having been observed in waters as cold as 12°C. It appears that some juveniles migrate seasonally to higher latitudes, but only when water temperatures there reach 26°C and above (Eckert 2002).

Late juvenile and adult leatherback turtles are known to range from mid-ocean to the continental shelf and nearshore waters (Schroeder and Thompson 1987; Shoop and Kenney 1992; Grant and Ferrell 1993). Juvenile and adult foraging habitats include both coastal feeding areas in temperate waters and offshore feeding areas in tropical waters (Frazier 2001). The movements of adult leatherbacks appear to be linked to the seasonal availability of their prey and the requirements of their reproductive cycle (Collard 1990; Davenport and Balazs 1991). Leatherbacks prefer convergence zones and upwelling areas in the open ocean, along continental margins, or near large archipelagos (HDLNR 2002; Eckert personal communication).

Distribution—The leatherback turtle is distributed circumglobally in tropical, subtropical, and warm-temperate waters throughout the year and into cooler, temperate waters during late summer and early fall (NMFS and USFWS 1998f; James et al. 2005a, 2005b; Eckert personal communication). The wide range of leatherbacks is a result of their highly evolved thermoregulatory capabilities. Leatherbacks can maintain body core temperatures well above the ambient water temperature. For example, a leatherback caught off Nova Scotia, Canada had a body temperature of 25.5°C in water that was 7.5°C (Frair et al. 1972). A variety of studies have shown that leatherbacks have a range of anatomical and physiological adaptations that enable them to regulate internal body temperatures (Mrosovsky and Pritchard 1971; Greer et al. 1973; Neill and Stevens 1974; Paladino et al. 1990).

Leatherbacks in the North Pacific Ocean are broadly distributed from the tropics to as far north as Alaska, where 19 occurrences were documented between 1960 and 2001 (Eckert 1993; Wing and Hodge 2002). This species migrates further and moves into cold waters more than any other sea turtle species (Bleakney 1965; Lazell 1980; Shoop and Kenney 1992). The leatherback is also the most oceanic and wide-ranging of sea turtles, undertaking extensive migrations along distinct depth contours for hundreds to thousands of kilometers (Morreale et al. 1996; Hughes et al. 1998). Using satellite telemetry, Morreale et al. (1996), Eckert and Sarti-M. (1997), and Eckert (1999) determined that post-nesting leatherbacks in the eastern Pacific Ocean use similar, and in some cases identical, migratory pathways. These studies, which were initiated on nesting beaches in Costa Rica and Mexico, demonstrated that leatherback turtles from eastern Pacific nesting stocks will navigate to South American waters after egg-laying is complete. Migratory corridors for leatherbacks are also

believed to exist in the pelagic zone surrounding the Hawaiian Islands (Nitta and Henderson 1993; NMFS and USFWS 1998f).

There are few quantitative data available concerning the seasonality, abundance, or distribution of leatherbacks in the central North Pacific Ocean. The leatherback is not typically associated with insular habitats, such as those characterized by coral reefs, yet individuals are occasionally encountered in deep ocean waters near prominent archipelagos such as the Hawaiian Islands (Eckert 1993). Leatherbacks are regularly sighted by fishermen in offshore waters surrounding the Hawaiian Islands, generally beyond the 183 m contour, and especially at the southeastern end of the island chain and off the north coast of O‘ahu (Nitta and Henderson 1993; Balazs 1995, 1998). Leatherbacks encountered in these waters, including those caught incidental to fishing operations, may represent individuals in transit from one part of the Pacific Ocean to another (NMFS and USFWS 1998f). Leatherbacks apparently have a wide geographic distribution throughout the region where the Hawaiian longline fishery operates, with sightings and reported interactions commonly occurring around seamount habitats located above the NWHI (from 35° to 45°N and 175° to 180°W) (Skillman and Balazs 1992; Skillman and Kleiber 1998). McCracken (2000) has also documented incidental captures of leatherbacks at several offshore locations around the MHI. Although leatherback bycatch events are common occurrences off the archipelago, leatherback stranding events on its beaches are not. Since 1982, only five leatherbacks have stranded in the Hawaiian Islands (NMFS-PIFSC 2004).

Historically, some of the world’s largest nesting populations of leatherback turtles were found in the Pacific Ocean, although nesting on Pacific beaches under U.S. jurisdiction has always been rare (NMFS and USFWS 1998f). The Pacific coast of Mexico used to be regarded as the most important leatherback breeding ground in the world (Sarti-M. et al. 1996). In the late 1970’s, roughly one-half of the world’s leatherback population nested there (Pritchard 1982). Recent data, however, suggest that the world's largest nesting population of leatherbacks has collapsed (Sarti-M. et al. 1996). Other principal nesting sites in the Pacific Ocean include beaches in Malaysia, Indonesia, Papua New Guinea, and Costa Rica (Spotila et al. 1996). Leatherbacks generally do not nest in the central Pacific and are not known to nest in the Hawaiian Islands, except for an isolated incident on Lāna‘i where a female laid infertile eggs (Eckert 1993; HDLNR 2002). It is not known whether most leatherbacks encountered in the central Pacific Ocean come from eastern or western Pacific nesting beaches, although genetic analysis of 14 individuals incidentally captured in the Hawaiian longline fishery revealed that a majority (12) came from the western Pacific nesting population (HDLNR 2002).

- Information Specific to the Hawaiian Islands OPAREA—Satellite-tracking studies, a lack of Hawaiian stranding records, and occasional incidental captures of the species in the Hawai‘i-based longline fishery indicate that deep, oceanic waters are the most preferred habitats of leatherback turtles in the central Pacific Ocean. As a result, the area of year-round primary occurrence for the leatherback turtle encompasses all OPAREA waters beyond the 100 m isobath (**Figures C-6a** and **C-6b**). Inshore of the 100 m isobath is the area of rare leatherback occurrence. This area is also the same year round. Leatherbacks were not sighted during any of the aerial surveys for which data were collected; all of which took place over waters lying in close proximity to the Hawaiian shoreline. Leatherbacks were not sighted during any of the NMFS shipboard surveys either, although their deep diving capabilities and long submergence times lessen the probability that observers will be able to spot them during marine surveys.

Behavior and Life History—Leatherback turtles feed upon gelatinous zooplankton such as cnidarians (jellyfish and siphonophores) and tunicates (salps and pyrosomas); however, a wide variety of other prey items are known (Bjorndal 1997; NMFS and USFWS 1998f). Eisenberg and Frazier (1983) recorded an adult leatherback feeding on *Aurelia* jellyfish in waters off the coast of Washington while Stinson (1984) noted that sightings of leatherbacks off Oregon often corresponded with large aggregations of *Velella* jellyfish. In California’s Monterey Bay, leatherbacks are believed to feed on several species of large jellyfish known as scyphomedusae (Starbird et al. 1993). In offshore waters of the North Pacific Ocean, leatherbacks appear to feed primarily on pyrosomas, although they have also been known to ingest longline hooks baited with sama (tuna bait) and squid (swordfish bait) (Davenport and Balazs 1991; Skillman and Balazs 1992; Grant 1994; Work and Balazs 2002).

Leatherbacks feed throughout the water column and dive as deep as 1,200 m (Eisenberg and Frazier 1983; Davenport 1988; S. Eckert et al. 1989). Studies of leatherback turtle diving patterns off St. Croix suggested that they forage at night on the DSL, a strata of vertically migrating zooplankton (primarily siphonophores, salps, and jellyfish) that concentrates below 600 m during the day and moves to the surface at night (S. Eckert et al. 1989). However, away from tropical waters, where the DSL is less distinct, leatherbacks rarely dive to great depths. In temperate waters of the North Pacific Ocean, they spend most of their time at depths less than 100 m, although occasionally they'll make a deep dive (Dutton personal communication; Eckert personal communication). During migrations or long distance movements, leatherbacks maximize swimming efficiency by traveling within 5 m of the surface (Eckert 2002; Eckert personal communication).

Mating is thought to occur prior to or during the migration from temperate to tropical waters in some populations (Eckert and Eckert 1988). However, in other populations, males have been shown to arrive one to two months before the onset of nesting and remain until peak nesting. This latter behavior is consistent with the expectation that mating takes place directly off the nesting beach 30 to 60 days before egg production (Eckert personal communication). Typical clutches range in size from 50 to over 150 eggs, with clutch sizes in the western Pacific being generally larger than in the eastern Pacific. The incubation period lasts from 55 to 75 days. Females nesting on the Pacific coast of Mexico lay between one and 11 clutches in a single season at nine to ten day intervals (NMFS and USFWS 1998f). Females remain in the general vicinity of the nesting habitat during inter-nesting intervals, with total residence in the nesting/inter-nesting habitat lasting up to four months (K. Eckert et al. 1989; Keinath and Musick 1993). Most adult females return to nest on their natal beach every two to three years; however, remigration intervals between one and five years have been recorded (Boulon et al. 1996). In the Mexican Pacific, the nesting season of the leatherback extends from November to February, with some females arriving as early as August (Fritts et al. 1982; NMFS and USFWS 1998f). In the western Pacific, nesting peaks in May and June in China, June and July in Malaysia, and December and January in Queensland, Australia (NMFS and USFWS 1998f).

The leatherback is the deepest diving sea turtle. Leatherbacks in open ocean environments frequently exhibit V-shaped dive patterns (in which they descend to a certain depth and then immediately ascend to the surface), whereas leatherbacks in shallow water environments more often exhibit U-shaped dive patterns (in which they swim down to the ocean floor, remain near the bottom for several minutes, and then return directly to the surface) (Eckert et al. 1996). Average dive depths for post-nesting leatherbacks off the continental shelf of St. Croix ranged from 35 to 122 m, with estimated maximum depths of over 1,000 m (S. Eckert et al. 1989; Eckert et al. 1996). Typical dive durations averaged 6.9 to 14.5 min per dive, with a maximum of 42 min (Eckert et al. 1996). On average, day dives in tropical waters tend to be deeper, longer, and less frequent than those at night (S. Eckert et al. 1989).

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3.3 BIRDS

3.3.1 Introduction

Seabirds are found in localized areas in which sufficient food and adequate sea conditions are available, resulting in a heterogeneous distribution, over what appears to be a homogenous environment (Harrison 1990). Primary factors affecting seabird production include local water temperature and upwelling that in turn serve to concentrate prey near the water surface. Colder waters tend to be more productive and upwelling brings nutrients up from depth to stimulate primary production (Robertson and Burchett 1996). The Hawaiian Islands are located along the northern edge of the tropics; however, the climate can be considered subtropical throughout the year. Pacific water masses converge to the north and south of the Hawaiian Islands, creating a permanent thermocline that separates the warm surface layer from the cold, deep North Pacific water (Harrison 1990). The Hawaiian Islands are considered to be oligotrophic and are among the least productive regions of the entire ocean (USFWS 2005a), typical of the NPSG (see Chapter 2) (Sheppard 2000). Consequently, foraging opportunities for Hawaiian seabirds tend to be localized to regions of enhanced productivity.

Small pulses of productivity are associated with localized upwelling zones, leeward eddies, seamounts, and shallow reefs (Harrison 1990; USFWS 2005a). In addition, prey that migrate to the islands along with warm, summer waters are important to Hawaiian seabirds. Ommastrephid squid, flyingfish, and flyingfish egg masses are favored by local seabirds (Harrison 1990; USFWS 2005a). Many Hawaiian seabirds also forage in association with tuna schools as the predatory tuna drive prey (e.g., mackerel scad) to the surface. Further offshore, local seabirds follow migratory skipjack tunas, while nearshore birds forage in association with non-migratory little tunas (Harrison 1990). Most seabirds local to the Hawaiian Islands OPAREA feed by surface-picking and plunging, rather than by diving (USFWS 2005a).

Although more seabirds nest in the NWHI, the MHI and their associated near and offshore waters are important to several species, including some of conservation concern. In the MHI, most nesting seabirds are found in relatively high mountain areas with cliff faces and volcanic crater walls or on coastal headlands. The prevalence of introduced land predators has rapidly become a major factor in nesting locations. High rocky prominences and even dense vegetation can provide protection from predation. Small islets off the MHI are often protected nesting sites for local seabirds (Harrison 1990).

3.3.2 Birds of the Hawaiian Islands OPAREA

The Hawaiian Islands are important habitat for marine birds in the central North Pacific Ocean. The shoreline, estuarine, and open water environments support a wide variety and large populations of bird species by providing important nesting and feeding habitats. The Hawaiian Islands are located in the warm, subtropic, oligotrophic NPCW (USFWS 2005a). Despite low levels of localized production, recent research estimates that 15 million seabirds inhabit the Hawaiian Islands (Harrison 1990). Twenty-two species of marine birds regularly nest in the Hawaiian Islands and many more pass through on migration to and from their breeding grounds elsewhere in the Pacific (Birding Hawaii 2004). Consultation between the USFWS and the Navy resulted in the decision that nine seabird species of particular concern would be addressed in this MRA, including the short-tailed albatross, black-footed albatross, Laysan albatross, Hawaiian petrel, Christmas shearwater, Newell's shearwater, band-rumped storm-petrel, Tristram's storm-petrel, and blue-gray noddy (**Table 3-3**).

The process used to create the map figures is described in Section 1.4.2.2. On some of the map figures, various types of shading and terminology designate the occurrence of these birds in the Hawaiian Islands OPAREA. "Common" is defined as expected daily in appropriate local habitat and in appropriate season. "Uncommon" is expected monthly in appropriate local habitat and season. "Rare" is not expected; always unusual to see; occurrence often less than annual in appropriate local habitat and season.

Table 3-3. Seabird species of concern with known or potential occurrence in the Hawaiian Islands OPAREA.

	Scientific Name[1]	ESA/BCC Status[2]
Class Aves (birds)[1]		
Family Diomedeidae (albatrosses)		
Short-tailed Albatross	*Phoebastria albatrus*	Endangered
Black-footed Albatross	*Phoebastria nigripes*	BCC
Laysan Albatross	*Phoebastria immutabilis*	BCC
Family Procellariidae (shearwaters and gadfly petrels)		
Hawaiian Petrel	*Pterodroma sandwichensis*[3]	Endangered
Christmas Shearwater	*Puffinus nativitatis*	BCC
Newell's Shearwater	*Puffinus auricularis newelli*[4]	Threatened
Family Hydrobatidae (storm-petrels)		
Band-rumped Storm-Petrel	*Oceanodroma castro*[5]	Candidate ESA/BCC
Tristram's Storm-Petrel	*Oceanodroma tristrami*	BCC
Family Laridae (gulls, terns, and noddies)		
Blue-gray Noddy	*Procelsterna cerulea*	BCC

1 Classification follows the AOU (1998) and 43rd Supplement (Banks et al. 2002), except where noted.
2 BCC = Birds of Conservation Concern (USFWS 2002).
3 Hawaiian Petrel was recently split from the Dark-rumped Petrel (*Pterodroma phaeopygia*) (Banks et al. 2002).
4 Newell's Shearwater is currently recognized as an endemic Hawaiian subspecies of Townsend's Shearwater. It was formerly regarded as a distinct species (see AOU 1998).
5 Also known in literature as Madeira or Harcourt's Storm-Petrel.

- Short-tailed Albatross (*Phoebastria albatrus*)

Description—The short-tailed albatross (formerly in the genus *Diomedea* and known as Steller's albatross) is the largest of the North Pacific albatrosses. It is nearly 1.0 m in length with a wingspan of 2.1 to 2.3 m. In adult plumage, this is the only North Pacific albatross with a white body (Harrison 1983).

At sea, distinction between juvenile individuals of this species and younger age classes of the black-footed albatross can be difficult. If seen at close range, the large pink bill and light feet of juvenile short-tailed albatrosses are distinctive from the dark bill and feet of black-footed albatrosses. The plumage of juvenile short-tailed albatrosses is initially dark brown overall and gradually lightens with each subsequent molt. Adults are quite identifiable by size and color pattern; the body is completely white. The head is white with a strong cast of golden yellow on the crown and often on the nape and neck. The upper wings are mostly white with black primaries, primary coverts, secondaries (partially) and tertials. The underwings are mostly white with narrow black margins. The rump and tail appear white with a black terminal band (Harrison 1983).

Status—The short-tailed albatross is widely regarded as one of the rarest species of albatrosses (Harrison 1983; Haley 1984) and as one of the world's rarest birds. For a brief period following WWII, it was thought to be extinct (Austin 1949; Haley 1984), largely as a consequence of nesting ground slaughter for the millinery trade (USFWS 2005a). It is listed as endangered under the ESA throughout its range (USFWS 2000; NatureServe 2004a). No critical habitat is designated for this species (USFWS 2000). It is also listed as endangered by the State of Hawai'i (USFWS 2005a). The latest population estimate is 1,500 birds with 715 of breeding age (NatureServe 2004a).

Habitat Preferences—Short-tailed albatrosses are pelagic and tend to concentrate along the edge of the continental shelf (NatureServe 2004a). They are seen regularly in the NPCW (USFWS 2005a). They typically nest on isolated, windswept, offshore islands that have restricted human access (USFWS 2000). In one case, they nest on open ground of fairly steep volcanic ash slopes and seem

to require clumps of grass or shrubbery. In another case, they nest on a rocky terrace of a steep cliff (USFWS 2005a). Both habitats allow for safe, open takeoffs and landings.

Distribution—Short-tailed albatrosses once ranged throughout the North Pacific. They now breed on only two islands south of Japan. Torishima in the Izu Shoto Island Group is about 600 km south of Tokyo and belongs to Japan. Minami-Kojima lies near Taiwan in the southwestern Ryuku Islands and is claimed by several nations, including Japan. Nests have been attempted at Midway Atoll and other NWHI, but none have been confirmed successful (USFWS 2005a). Short-tailed albatrosses disperse throughout the North Pacific when they are not breeding. Their range extends from Siberia south to the China coast, into the Bering Sea and Gulf of Alaska south to Baja California, Mexico, and throughout the North Pacific including the NWHI (Harrison 1983; Roberson 2000). The short-tailed albatross regularly occurs on Midway Atoll and has been observed at other NWHI (USFWS 2005a). The breeding season in Japanese waters is from late October to mid June (USFWS 2005a), and juvenile and immature short-tailed albatrosses are most likely to be found elsewhere at sea at that time.

- Information Specific to the Hawaiian Islands OPAREA—Short-tailed albatross at this time cannot be considered more than accidental in the Hawaiian Islands OPAREA. There is only one unconfirmed sighting at Barking Sands on Kaua‘i during March 2000 (Birding Hawaii 2004; **Table 3-4**; **Figure 3-5**). Otherwise, the closest known occurrences to the OPAREA are reports of single birds (in 1976 and 1981) at French Frigate Shoals in the NWHI (NPPSD 2005).

Table 3-4. General distribution and sightings of the short-tailed albatross.

Location	Notes	Source
General Range		
Alaska	Gulf of Alaska, Bering Sea, Aleutians, 158 records since 1997	1, 2, 4, 8
Canada (British Columbia)	3 records	3, 8
Oregon	1 record	1
California	12 recent records	1, 5
Japanese waters	breeding sites	4
North Pacific Ocean	rare	3
Sightings in the Hawaiian Islands outside the Hawaiian Islands OPAREA		
Northwestern Hawaiian Islands	stragglers occur; records from Kure Atoll, Midway Atoll, Laysan Island, FrenchFrigate Shoals	3, 4, 6, 9
French Frigate Shoals	individuals seen 1976, 1981	10
Sightings within the Hawaiian Islands OPAREA		
Kaua‘i, Barking Sands	1 observed offshore - Mar. 2000	7

1. Roberson (2000)
2. CDFG (2005)
3. Harrison (1983)
4. USFWS (2005a)
5. McCaskie and Garrett (2001)
6. Harrison et al. (1984)
7. Birding Hawaii (2004)
8. IPHC (2004)
9. USFWS (2000)
10. NPPSD (2005)

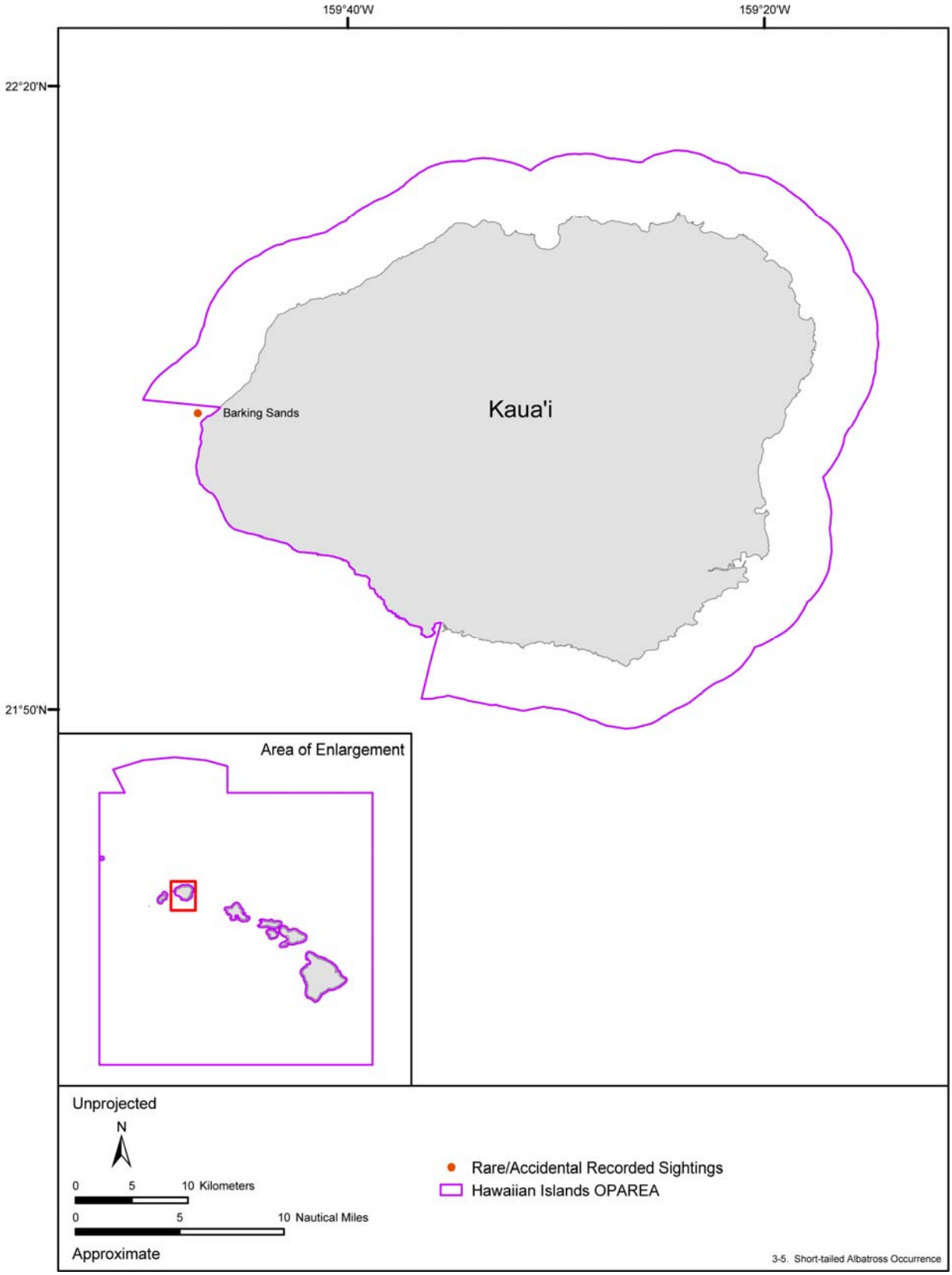

Figure 3-5. Single reported occurrence of the short-tailed albatross in the Hawaiian Islands OPAREA and vicinity. Source information: refer to Table 3-4.

Behavior and Life History—The short-tailed albatross is generally long-lived and slow to mature; most Hawaiian albatrosses first breed between seven and nine years (Harrison 1990; USFWS 2005a). Short-tailed albatrosses are monogamous and return to the same breeding site annually. Egg-laying begins in late October and runs through early November. Females lay a single egg which is not replaced if it fails for any reason. Hatching occurs from late December through early January. In late May through June, adults abandon their nests and chicks fledge soon after the adults leave the colony. Short-tailed albatrosses are surface feeders and scavengers and often feed around fishing vessels. Unlike other North Pacific albatrosses, short-tailed albatrosses frequently feed in sight of land. Known diet in Japanese waters includes crustaceans, squid, and flyingfish (USFWS 2005a). Average population survival rate is 96% and the current annual population growth is greater than 6% (USFWS 2005a).

- Black-footed Albatross (*Phoebastria nigripes*)

Description—The black-footed albatross (formerly in the genus *Diomedea*) is a relatively small albatross; it is the only uniformly dark albatross (in all age classes) in North Pacific waters. It is about 0.6 to 0.7 m in length, with a wingspan of 1.9 to 2.1 m. The body is entirely dusky-brown except for subtle white coloration below the eye and at the base of the bill. Approximately 10% of the population exhibits a white rump and undertail coverts. The bill and feet are typically dark (Whittow 1993a) although some have pinkish bills like the short-tailed albatross. See the before-mentioned short-tailed albatross description for additional distinctions between the black-footed albatross and immature short-tailed albatross.

Status—Although the black-footed albatross is not listed under the ESA, there is widespread concern for its condition. It has been identified by the USFWS as a BCC (USFWS 2003) and is considered to be threatened by the State of Hawai‘i (USFWS 2005a). Within the Hawaiian Islands Bird Conservation Region, the black-footed albatross is regarded as highly imperiled with primary concerns being threats to both breeding and nonbreeding populations (USFWS 2003). This species is considered endangered by the International Union for Conservation of Nature (IUCN) Red List (IUCN 2004). The black-footed albatross population seriously declined in the 1950s and 1960s in response to albatross control programs to protect aircraft on Midway Atoll; this species has more recently suffered from longline fishing for swordfish in the North Pacific (IUCN 2004; NatureServe 2004b; USFWS 2005a). The population is expected to decline by over 20% during the next 60 years (NatureServe 2004b). The worldwide breeding population is estimated at around 58,000 breeding pairs; more than 95% of these nest in the Hawaiian Islands (USFWS 2005a).

Habitat Preferences—The black-footed albatross is a pelagic species that favors offshore continental waters. They are seldom seen in sight of land. During the winter nesting season, they forage closer to nesting colonies (Whittow 1993a; USFWS 2005a).

Nesting occurs on oceanic low coral and sand islands. Black-footed albatrosses prefer sandy beaches or dunes and other sandy locations but will utilize artificially cleared soil and even grassy areas that border runways and taxiways on the NWHI (Whittow 1993a).

Distribution—Black-footed albatrosses occur throughout the North Pacific year-round, but most adults forage close to the Hawaiian Islands nesting colonies during the winter and spring nesting season. Following nesting, this species tends to move east and northeast to the offshore continental waters west of the North American Pacific coast, with some trending northward into the Sea of Okhotsk and the western Bering Sea. A small subset occupies the western North Pacific (Springer et al.1999). Sanger (1974) presented substantial details on the black-footed albatrosses pattern of North Pacific occupation.

More than 95% of black-footed albatrosses nest in the Hawaiian Islands although some also nest on small islands off Japan, in particular Torishima in the Izu Shoto Islands. In the Hawaiian Islands, nesting colonies are located on Kure Atoll, Midway Atoll, Pearl and Hermes Reef, Lisianski Island,

Table 3-5. General distribution and sightings of the black-footed albatross.

Location	Notes	Source
General Range		
North Pacific, north of 10°	Ranges widely at sea, concentrating in the eastern North Pacific along west coast of North America but also north to Bering Sea and west to East China Sea	1, 2, 3, 4, 10
Sightings in the Hawaiian Islands outside of the Hawaiian Islands OPAREA		
Kure Atoll	700 to 1,300 breeding pairs estimated 1972	5, 6, 7
Kure Atoll	2 specimens, MVZ, U.C. Berkeley, CA, 3 Jan 1967	9
Midway Atoll	20,400 breeding pairs estimated 1998	3, 8
Midway Atoll	2 specimens, MVZ, U.C. Berkeley, CA, 8 Dec 1958	9
Pearl and Hermes Reef	8,000 to 11,000 breeding pairs estimated 1974	5, 6, 7
Lisianski Island	2,800 to 3,800 breeding pairs estimated 1975	5, 6, 7
Laysan Island	19,400 breeding pairs estimated 1998	3
French Frigate Shoals	4,000 to 4,500 breeding pairs estimated 1971	5, 6, 7
Necker Island	200 to 250 breeding pairs estimated 1977	5, 6, 7
Sightings within the Hawaiian Islands OPAREA		
Nihoa	40 to 60 breeding pairs estimated 1984	5, 6, 7
Niʻihau	unknown number breeding	5, 6, 7
Lehua Rock	50 breeding pairs estimated 2002	6
Kaula Rock	20 to 70 breeding pairs estimated 1970s	5, 6, 7
At sea in MHI OPAREA	numerous sightings north, west & south of islands	11, 12
Kauaʻi, Nawiliwili Lighthouse	1 observed from land, 29 Jan 1998	6
Kauaʻi, Nawiliwili Lighthouse	7 observed from land, 1 Feb 1998	6
Kauaʻi, Kilauea Point	1 observed from land, 8 Feb 2000	6
Kauaʻi vicinity	2 observed from boat, Kaula Kahi Channel, 11 Jan 2002	6
Oʻahu, James Campbell NWR	2 observed from land, 9 Feb 2002	6
Kauaʻi, Mokuʻaeʻae Island	1 observed flying over island off Kilauea Point, 17 Apr 2002	6
Lehua Rock	1 observed on rock, 3 Sept 2002	6
Kauaʻi vicinity	4 observed from boat, Kaula Kahi Channel, 25 Jan 2003	6
Lehua Rock	2 observed from boat, 18 Apr 2003	6
Lehua Rock	1 observed from boat, 2 May 2003	6
Kauaʻi, Kilauea Point	1 observed from land, 19 June 2003	6
Kauaʻi, Kilauea Point	1 observed from land, 20 June 2003	6
Kauaʻi, Kilauea Point	1 observed from land, 5 Jan 2004	6
Lehua Rock	1 observed from boat, 31 Jan 2004	6
Kauaʻi, Kilauea Point	1 observed from land, 4 Feb 2004	6
Kauaʻi, Kilauea Point	1 observed from land, 12 Feb 2004	6
Oʻahu, Kaena Point	3 observed from land, 28 Feb 2004	6
Kauaʻi, Barking Sands	2 observed from land, 9 Mar 2004	6

1. Sanger (1974)
2. Harrison (1983)
3. USFWS (2005a)
4. AOU (1998)
5. Harrison et al. (1984)
6. Birding Hawaii (2004)
7. Harrison (1990)
8. MANWR (2000)
9. GBIF (2004)
10. Springer et al. (1999)
11. NMFS-PIR (2005)
12. NMFS-SWFSC (2005)

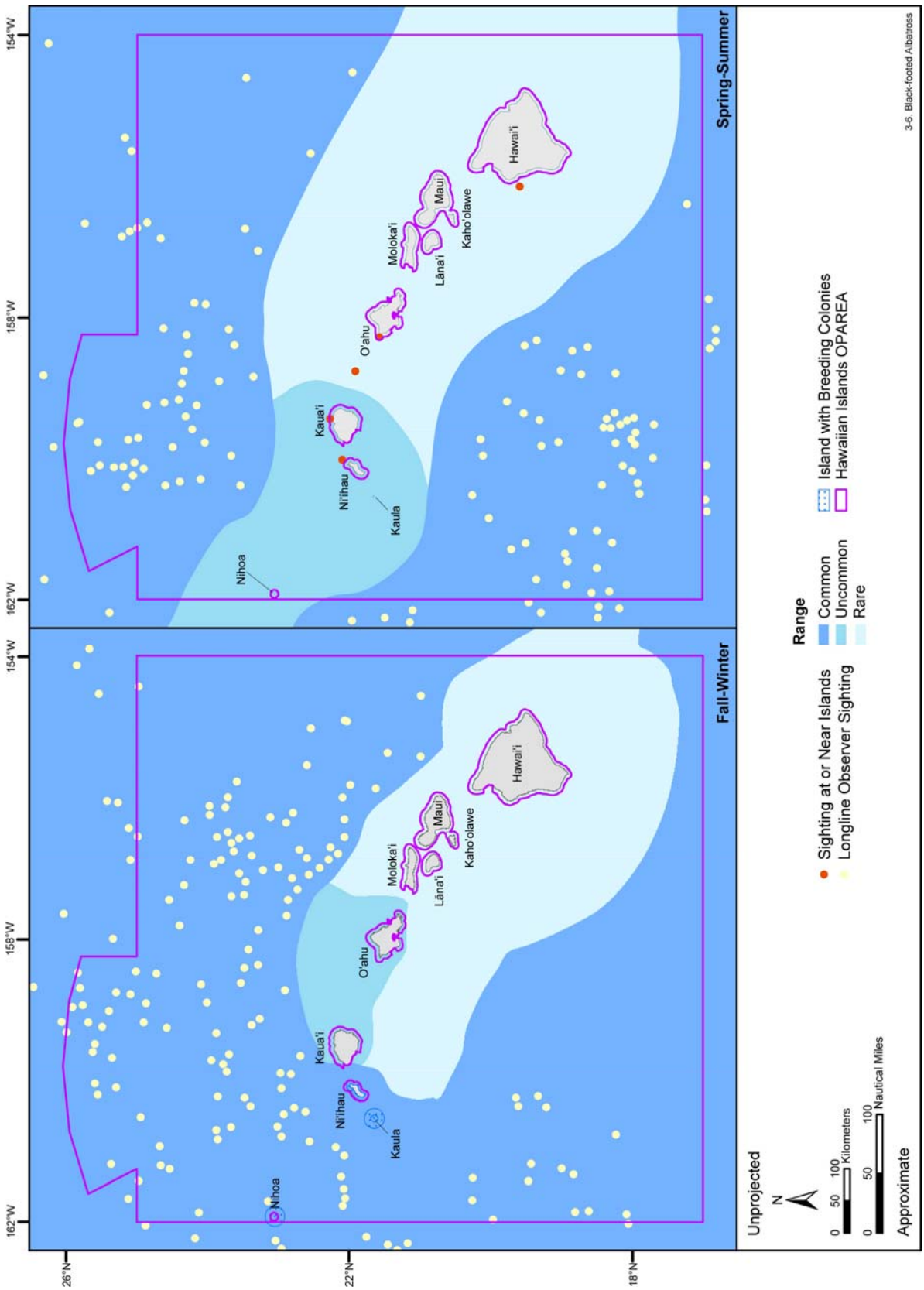

Figure 3-6. General range and recorded sightings of the black-footed albatross in the Hawaiian Islands OPAREA and vicinity. Source data: CRC (2005). Source information: refer to Table 3-5.

Laysan Island, French Frigate Shoals, Necker Island, and Nihoa. In the MHI, colonies are known or suspected on Lehua Rock, Niʻihau, and Kaula Rock (Sanger 1974; USFWS 2005a; **Table 3-5**). The majority of black-footed albatrosses nest on Midway Atoll (20,400 pairs) and Laysan Island (19,500 pairs) (USFWS 2005a). Small nesting colonies have recently been reported off western Mexico on San Benedicto in the Revillagigedo Islands (Pittman and Balance 2002) and on Guadalupe Island (NatureServe 2004b).

- Information Specific to the Hawaiian Islands OPAREA—In the Hawaiian Islands OPAREA, black-footed albatrosses nest on Nihoa, Niʻihau, Lehua Rock, and Kaula Rock (**Table 3-5**; **Figure 3-6**). The breeding season is from November until mid-June. By mid-July, all birds including fledglings are at sea (Sanger 1974). Although adults caring for chicks feed well offshore of the nesting islands (USFWS 2005a), they regularly occur in small numbers close to the islands as they pass to and from the nesting colonies. Black-footed albatrosses regularly move hundreds and even thousands of kilometers in the span of two or three days. They are regular and widespread throughout the Hawaiian Islands OPAREA from about 40 km north of the islands and 160 km south of the islands and then outward to the boundaries of the OPAREA (**Figure 3-6**).

  Black-footed albatross may occur within sight of any of the islands in the OPAREA year-round (Birding Hawaii 2004), but following completion of nesting in early to mid-summer, most of this species moves well north and east of the Hawaiian Islands, concentrating in the eastern North Pacific (Sanger 1974). Most sightings in the OPAREA and vicinity in recent years are between February and August, during the spring-summer period, and concentrated at or near Kauaʻi, with fewer reports at Oʻahu (Birding Hawaii 2004; **Table 3-5**).

Behavior and Life History—The black-footed albatross is a long-lived species, with one individual known to reach at least 43 years in age (USFWS 2005a). This species practices permanent monogamy with the breeding pair returning to nesting islands during October. They construct a simple nest of bits of grass or shrubbery and scraped sand. A single egg is laid November to early December. Eggs hatch after 65 days with both parents incubating. Unsuccessful eggs are not replaced that season. Adults that experience failed nesting can be seen at sea beginning in January. Fledging occurs June to mid-July. Parents usually leave the nesting colony for the season before chicks are capable of flight (MANWR 2000). Black-footed albatrosses, unlike their close relatives the Laysan albatrosses, are diurnal foragers. They feed by settling onto the water and dipping the bill to seize prey. Their diet consists of squid, deep-water crustaceans, fish, zooplankton and especially flyingfish eggs which comprise greater than 40% of their diet (USFWS 2005a).

- Laysan Albatross (*Phoebastria immutabilis*)

Description—Laysan albatross (formerly in the genus *Diomedea*) is a small gull-like albatross, reaching a length of about 0.8 m and a wingspan of 1.9 to 2.0 m. The body is white and the mantle and upper wing surfaces are blackish-gray. The underwing is mainly white with black trim. The tail is black with rump and both upper and lower tail coverts white. The face is distinctly different from the only other white-headed albatross (short-tailed albatross) in the North Pacific. There is a gray-black patch in front of the eye that lightens to grayish in the cheek area (Harrison 1983; Whittow 1993b). The bill is pinkish with a gray hooked tip. The legs and feet are flesh pink (Whittow 1993b). The Laysan albatross is easily distinguished from the other two North Pacific albatrosses. The black-footed albatross is sooty dark all over and older age classes of short-tailed albatross are much larger with a yellow-gold wash on the white head and neck and with a white mantle (Harrison 1983).

Status—The Laysan albatross is not listed under the ESA, but the U.S. does regard it as a BCC. Within the Hawaiian Islands Bird Conservation Region, the Laysan albatross is evaluated as a species of high concern because of breeding distribution and threats to both breeding and nonbreeding populations (USFWS 2003). The Hawaiian Islands does not list the species (USFWS 2005a). The IUCN Red List (IUCN 2004) classifies it as vulnerable based on more than a 30% decline in population over the past three generations (80 years). The Laysan albatross population is estimated to be 630,000 breeding pairs worldwide (USFWS 2005a). Most Laysan albatrosses nest in

the NWHI with more than 90% of those on Midway Atoll (441,000 pairs) and Laysan Island (145,000 pairs) (USFWS 2005a). Many Laysan albatrosses were killed in drift net fishery operations until an international ban on the practice in 1993. The most recent major problem for them has been longline fishing in the North Pacific (USFWS 2005a).

Habitat Preferences—The Laysan albatross is a pelagic species of the North Pacific. During nonbreeding time at sea, Laysan albatrosses typically remain 20 to 30 km offshore (MANWR 2000) and are more common than other North Pacific albatrosses in deep water away from the continental shelf (Springer et al. 1999). Nesting occurs predominantly on low coral and sand oceanic islands. Laysan albatrosses usually choose nest sites closer to vegetation than do black-footed albatrosses. They nest in steep rocky areas as on Nihoa and Lehua Rock (USFWS 2005a).

Distribution—The Laysan albatross occupies the North Pacific Ocean from 8°N (just south of Hawai‘i) to 59°N (in the western Bering Sea). East to west, it is found from the Pacific coast of North America to the Commander and Japanese Islands (Fisher and Fisher 1972; Harrison 1983; Whittow 1993b). As a deep water species, Laysan albatrosses seldom approach continental shelves (Whittow 1993b). They tend (particularly with younger age classes) to occur more frequently in the Western Subarctic Gyre, east of Japan and south of the western Aleutian Islands (Fisher and Fisher 1972).

A few Laysan albatrosses nest in the Bonin Islands off Japan and on islands off the Pacific coast of Mexico (Guadalupe Island, San Benedicto Island, Isla Clarion, and Alijos Rocks), but the majority nest in the NWHI from Kure Atoll to Nihoa and in the MHI on Ni‘ihau, Lehua Rock, Kaua‘i, and O‘ahu (Whittow 1993b; USFWS 2005a). Breeding began on the western MHI in the 1970s, and to date the colonies remain small with significant losses from predation and human disturbance (Birding Hawaii 2004). There is some indication of Laysan albatrosses recolonizing Johnston and Wake Atolls west of the Hawaiian Islands (USFWS 2005a).

- Information Specific to the Hawaiian Islands OPAREA—Laysan albatrosses occur from October to July around Nihoa, Kaula Rock, Ni‘ihau, Lehua Rock, Kaua‘i, and O‘ahu when nesting (**Figure 3-7**). Although adults feeding chicks are known to forage up to 1,770 km away from their nest island, most of them forage within 500 km (Birding Hawaii 2004). Laysan albatrosses may be seen at sea from land observation points on all of the MHI from Ni‘ihau to Hawai‘i year-round. They are frequently reported close to and even passing over land. Laysan albatrosses are seen most frequently from Kaua‘i headlands (Kilauea Point, Ha‘ena Point, Nawiliwili Lighthouse, Makahuena Point, and Polihale) and O‘ahu headlands mostly along north and east shores, as well as Ka‘ena Point on the southwest tip of the island from November through April (**Table 3-6**; **Figure 3-7**). These birds are increasingly scarce from Maui to Hawai‘i (Birding Hawaii 2004).

Behavior and Life History—The Laysan albatross is long-lived; the oldest recorded Laysan albatross was 51 years of age (USFWS 2005a). They are monogamous, but death of a mate usually results in securing a new mate. About 20% of adults do not nest in a given year and remain at sea. The others arrive on nesting islands as early as October and lay their one egg in November or early December (MANWR 2000). The nest is usually a scrape in the sand close to vegetation (USFWS 2005a). Nearby grasses or shrubbery are incorporated into the simple nest. Incubation is about 65 days; chicks hatch from late January to February and fledge from late June to late July. The chicks are fed a fatty solution of squid oil, flyingfish eggs, and stomach oil. As adults forage hundreds of kilometers away, the chick can be alone for several days. Adults abandon fat chicks before the juveniles can fly (MANWR 2000). More than 50% of Laysan albatross diet is squid captured nocturnally. They also eat deep-water crustaceans, fish, and flyingfish eggs. Laysan albatrosses forage by settling on the water and dipping the bill into the water (USFWS 2005a).

- Hawaiian Petrel (*Pterodroma sandwichensis*)

Description—The Hawaiian petrel (formerly dark-rumped petrel, *Pterodroma phaeopygia*) is one of the larger gadfly petrels with a body length of 40 cm and a wingspread approaching 1.0 m. The upper

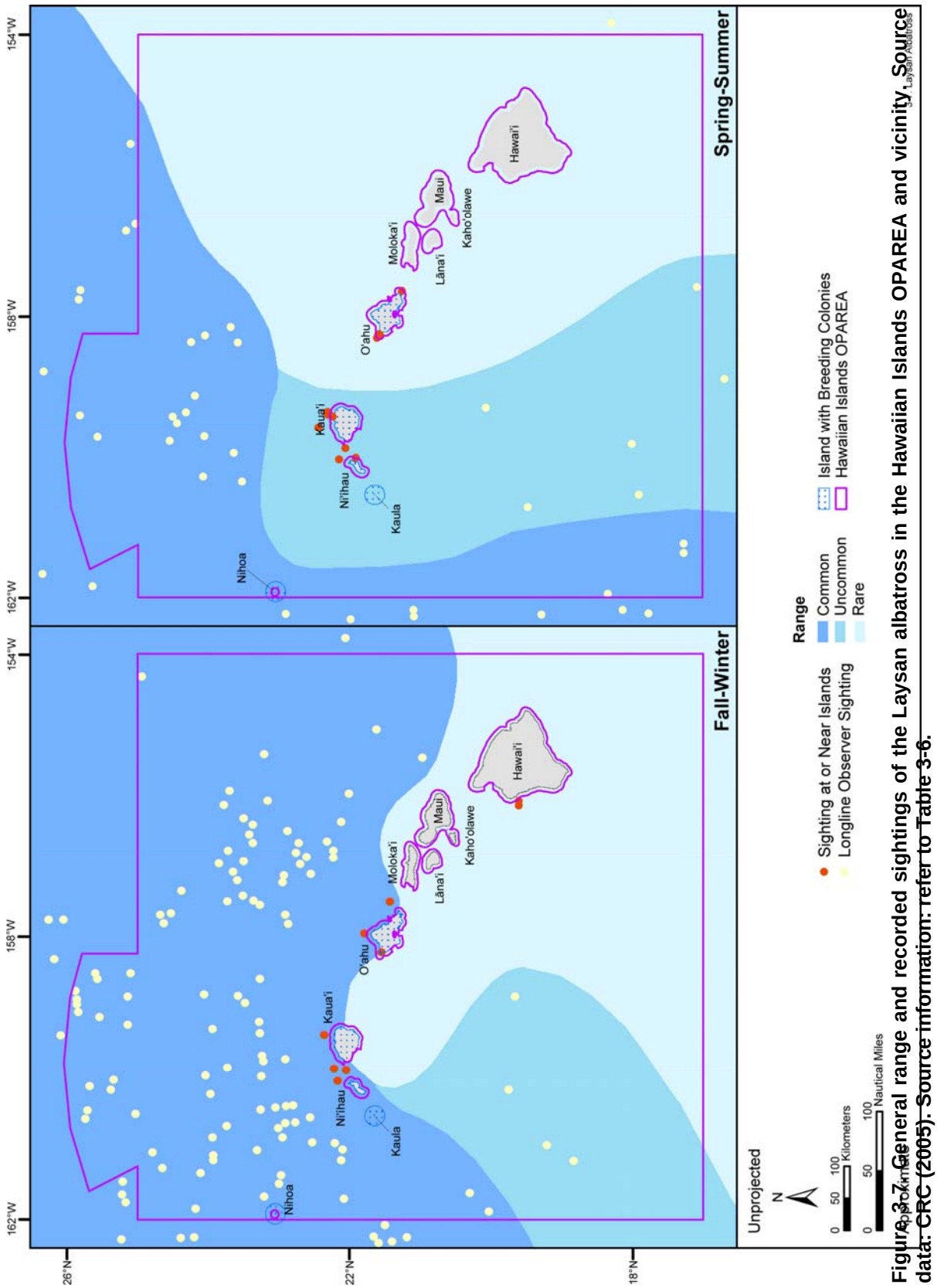

Figure 3-7. General range and recorded sightings of the Laysan albatross in the Hawaiian Islands OPAREA and vicinity. Source data: CRC (2005). Source information: refer to Table 3-6.

Table 3-6. General distribution and sightings of the Laysan albatross.

Location	Notes	Sources
General Range		
North Pacific, north of 8°	Ranges widely at sea, concentrating in the western Pacific (Western Subarctic Gyre), but range extends east to Bering Sea, Alaska, Canada, continental U.S., and Baja California	1, 2, 3
Sightings in the Hawaiian Islands outside of the Hawaiian Islands OPAREA		
Kure Atoll	3,000 to 4,000 breeding pairs estimated 1972	4, 5
Midway Atoll	441,000 breeding pairs estimated 2004	1
Pearl and Hermes Reef	9,000 to 12,000 breeding pairs estimated 1974	4, 5
Lisianski Island	23,000 to 30,000 breeding pairs estimated 1975	4, 5
Laysan Island	145,000 breeding pairs estimated 2004	1
Gardner Pinnacles	10 to 15 breeding pairs estimated 1960s	4, 5
French Frigate Shoals	900 to 1,000 breeding pairs estimated 1971	4, 5
Necker Island	450 to 550 breeding pairs estimated 1977	4, 5
Sightings within the Hawaiian Islands OPAREA		
Nihoa	1 to 5 breeding pairs estimated 1984	4, 5
Kaula Rock	25 to 50 breeding pairs estimated 1970s	4, 5
Niʻihau	150 to 200 breeding pairs estimated 1984	4, 5
Lejua Rock	Unknown number of breeding pairs present	1, 6
Kauaʻi	30 to 50 breeding pairs estimated 1990	4, 5
Oʻahu	Unknown number of breeding pairs present	5, 7
Kaena Point, Oʻahu	36 eggs, 24 chicks and 18 or 19 fledglings in 2005	8
Kua o ka la, Mahaka, Oʻahu	nesting with successful breeding	8
At sea	Numerous sightings, north, west, and south of islands	7
Oʻahu, Mokapu Crater	2 observed from land, 26 Dec. 2001	6
Kauaʻi vicinity	24 observed from boat, Kaulakahi Channel, 11 Jan. 2002	6
Kauaʻi, off Kilauea Point	Unknown number of number observed from land, Mokuʻaeʻae, 17 Apr. 2002	6
Kauaʻi vicinity	10 observed from boat, Kaulakahi Channel, 3 Jan. 2003	6
Lehua Rock	8 observed from boat, 25 Feb 2003	6
Oʻahu, Manana Island	1 observed from land, 4 Mar 2003	6
Lehua Rock	2 observed from boat, 18 Apr 2003	6
Kauaʻi vicinity	2 observed from boat, Kaulakahi Channel, 18 Apr 2003	6
Lehua Rock	2 observed from boat, 2 May 2003	6
Kauaʻi	1 observed from land, 4 June 2003	6
Lehua Rock	2 observed from boat, 31 Jan 2004	6
Lehua Rock	3 observed from boat, 6 Feb 2004	6
Kauaʻi vicinity	7 observed from boat, Kaulakahi Channel, 6 Feb 2004	6
Lehua Rock, near	3 observed from boat, 9 Mar 2004	6
Kauaʻi, off Barking Sands	5 observed from boat, 9 Mar 2004	6
Oʻahu, James Campbell NWR	2 observed from land, 27 Jan 2005	6

1. USFWS (2005a)
2. Whittow (1993b)
3. Harrison (1983)
4. Harrison et al. (1984)
5. Harrison (1990)
6. Birding Hawaii (2004)
7. NMFS-PIR (2005)
8. Gagne (personal communication)

surface is typically dark gray but appears blackish at sea. Some variants show whitish patches on sides of rump. The forehead, loreal area between bill and eye, cheek and throat and underside of body are bright white. A broad, dark collar extends partially down the side of the neck. The underwings are white with dark tips on the primaries, the trailing edge of wing, and the line from the base of outer primaries inward to base of outer secondaries (Harrison 1983). Hawaiian petrels have a diagnostic bounding flight pattern of rising with three or four quick wing beats followed by gliding descent on downward-bowed wings. The wing beat phase is peculiar with a side to side pendulum motion (Harrison 1983; Simons and Hodges 1998). In high wind conditions they mostly glide in high, broad 30 m arcs. There are nine other regularly occurring procellariids in MHI waters from which Hawaiian petrel must be distinguished (Birding Hawaii 2004). Bulwer's petrel, dark morph wedge-tailed shearwater, sooty shearwater, short-tailed shearwater, and Christmas shearwater are dark all over. Mottled petrel and Buller's shearwater are grayish on the back and upper wing surface with a darker "M" shape superimposed. Newell's shearwater is colored like the Hawaiian petrel but is noticeably smaller with white patches well up on the sides of rump. It also has a faster flight that is typically lower to the water. The most serious identification distinction is with the Bonin petrel which is very similar to Hawaiian petrel. The Bonin petrel is smaller with a lighter gray back and somewhat different underwing markings (Harrison 1983).

Status—The endemic Hawaiian petrel is listed as endangered throughout its range under the ESA (USFWS 1983, 2005a, 2005b); there is no designated critical habitat. It is listed endangered by the State of Hawai'i (USFWS 2005a). The IUCN Red List (IUCN 2004) lists this species as vulnerable based on the small number of nesting locations. The species nests entirely within the MHI with a breeding population estimated at 4,500 to 5,000 pairs (Spear et al. 1995; USFWS 2005a). The total species population is estimated at approximately 20,000 (Spear et al. 1995; USFWS 2005a). The greatest threat to adult survival and breeding success is predation by introduced animals such as mongooses, cats, and rats. In some cases there has been more than 70% nesting failure from predation (USFWS 2005a). Collisions with artificial lights, utility poles, and fences cause mortality on some islands (Simons and Hodges 1998).

Habitat Preferences—The Hawaiian petrel is a pelagic species of the central tropical Pacific (USFWS 2005a). It stages close to shore before flying inland to nesting colonies (Simons and Hodges 1998; Flint personal communication). Typical foraging areas are at least 5 to 10 NM offshore on windward sides of the Hawaiian Islands (Simons and Hodges 1998) although Spears and Ainley (1999) found Hawaiian petrels within 73 km and as far as 370 km south of Hawai'i. The Hawaiian petrel feeds well offshore but tends to forage closer to shore (0 to 73 km) during spring than in fall (most abundant at 272 to 370 km) (Spear et al. 1999). The Hawaiian petrel favors offshore water conditions with an average SST of 26.7°C, sea-surface salinity (SSS) of 34.43 ppt, wind speed of 31 kilometers per hour (km/h), and a wave height of 1.4 m. It also prefers a shallow thermocline depth averaging 56 m (Spear et al. 1995).

Under pressure of predation, most nesting habitat is at the highest elevations available in the MHI. Most sites (Haleakala National Park in Maui; Mauna Kea, Mauna Loa, and Kilauea in Hawai'i) are characterized by high elevation (2,000 to 3,000 m), dry climate, and sparse vegetation (less than 10% plant cover). The vegetation zones there are subhumid to subalpine, and environments are extreme for the subtropics. On other islands, nesting habitat is poorly known. There is some evidence that petrels dig burrows on cliff faces or very steep slopes beneath dense vegetation, in particular uluhe fern, on interior mountains or in heads of valleys. These conditions are much wetter than the cold, dry sites on Maui and Hawai'i (Simons and Hodges 1998).

Distribution—At sea, the Hawaiian petrel occurs largely in equatorial waters of the eastern tropical Pacific, generally from 10°S to 20°N. Due to difficulty in identification, the precise southeastern extent of the Hawaiian petrel and northwestern extent of the similar Galapagos petrel remain uncertain (Spear et al. 1995). Records of Hawaiian petrels off the west coast of North America are suspected but unconfirmed (Roberson 2001). There are specimen records from Japan, Philippines, and Mollucas at the western edge of the distribution (Simons and Hodges 1998).

The Hawaiian petrel is endemic as a breeding species to the Hawaiian Islands OPAREA only from Lehua Rock to Hawai‘i (Harrison 1983; Harrison 1990; Simons and Hodges 1998; USFWS 2005a).

- Information Specific to the Hawaiian Islands OPAREA—During the nesting season, colony occurrences (**Figure 3-8**) are known or suspected from March through early December. The Hawaiian petrel is present throughout the offshore waters of the Hawaiian Islands OPAREA (Simons and Hodges 1998). Large nesting colonies are found on Kaua‘i and Maui (Day and Cooper 1995; Simons and Hodges 1998), but smaller colonies occur or may occur on Lehua Rock and the other MHI, except O‘ahu (Simons and Hodges 1998; USFWS 2005a; **Table 3-7**). Hawaiian petrel flights onto and off islands in transit to and from nesting colonies occur in dusk and dawn conditions, and there are observations of Hawaiian petrels staging nearshore before flights inland (Ainley et al. 1997a; Simons and Hodges 1998). The staging area on the north shore of Kaua‘i is widely known (Birding Hawaii 2004; Flint personal communication), but the behavior is expected along all shorelines (**Figure 3-8**) with good flight paths to nesting colonies. Based on known or suspected colony sites, staging areas likely occur nearshore of Lehua Rock, Kaua‘i, Moloka‘i, Lāna‘i, Maui, and Hawai‘i (Day and Cooper 1995; Simons and Hodges 1998; Day et al. 2003; USFWS 2005a) and perhaps around Kaho‘olawe (USFWS 2005a).

Behavior and Life History—The Hawaiian petrel is a presumed monogamous species and probably exhibits life-long pair bonding. Hawaiian petrels dig nest burrows (1 to 9 m deep) in soil (USFWS 2005a; Simons and Hodges 1998). Mated pairs arrive at their nest burrow in February for nest cleaning and association. The single egg is laid in late April or early May. Chicks hatch in July and typically fledge in late October to November. Incubation shifts are long, and the foraging member of a pair may fly up to 1,500 km from the nesting island. Most adults leave the chick to forage within two days of chick hatching. Fledglings are assumed to be independent after leaving the nesting colony. First breeding is at six years, and 89% of adults attempt breeding annually. Average annual reproductive success on Maui is 63.4%. Hawaiian petrels eat mostly squid (50 to 75% of diet in one study), fish, and crustaceans. They forage both nocturnally and diurnally and capture prey by resting on the water surface and dipping the bill and by aerial pursuit of flyingfish (Simons and Hodges 1998).

- Christmas Shearwater (*Puffinus nativitatis*)

Description—The Christmas shearwater (also known as the Christmas Island shearwater) is one of the smaller shearwaters with a body length of about 0.3 m and a wingspan of 0.7 to 0.8 m. It has a notably slender body with a short, rounded tail and dark or sooty brown plumage. Flight is direct and rapid with fast, stiff wing-beats followed by long glides close to the water surface (Seto 2001). In higher winds it does the procellariid arc glide up into the air, but it is a lower arc than seen in sooty and short-tailed shearwaters (Seto 2001). Within the Hawaiian Islands OPAREA, there are nine other regularly occurring procellariids (Birding Hawaii 2004). Christmas shearwaters may be easily confused with the other three solid dark species, the wedge-tailed shearwater, sooty shearwater, and short-tailed shearwater. However, these species are larger than the Christmas shearwater. Furthermore, the wedge-tailed shearwater has a distinctive wedge-shaped tail, the sooty shearwater has an underwing flash of white while flying, and the short-tailed shearwater is distinctively paler gray below (Harrison 1983).

Status—The Christmas shearwater is not listed under the ESA, but the USFWS does regard it as a BCC (USFWS 2003). In the Hawaiian Islands Bird Conservation Region, the Christmas shearwater is categorized as a species of high concern because of population size and threats to both breeding and nonbreeding populations within the region (USFWS 2003). The Hawaiian Islands do not list the species (USFWS 2005a). The IUCN Red List (IUCN 2004) evaluates this shearwater as least concern, which is equivalent to no listing. That decision is based on its large range, large population, and population trend of minimal decline (BLI 2004a). The Christmas shearwater is extirpated from numerous western Pacific islands formerly occupied in the 19th century. Populations were decimated by habitat alteration caused by rabbit introduction on Laysan Island and Lisianski Island in the NWHI.

Table 3-7. General distribution and sightings of the Hawaiian petrel.

Location	Notes	Sources
General Range		
East tropical North Pacific, typically 10°S to 20°N	But in summer some north to southern Gulf of Alaska at 50°N. West to at least Japan and at least occasionally to Philippines and east to Oregon and California.	1, 2, 3, 4
Sightings in the Hawaiian Islands outside of the Hawaiian Islands OPAREA		
NWHI	Present west to French Frigate Shoals	1
Sightings within the Hawaiian Islands OPAREA		
MHI, offshore	Present, summer and fall, native fishermen	1
Lehua Rock	6 observed from boat, 18 Apr 2001	5
Lehua Rock vicinity	3 observed from boat, pelagic, 25 May 2004	5
Kaua‘i	110s-1000s breeding pairs, estimated 1995	6
Kaua‘i vicinity	100s staging nearshore before flight inland. Flights across shorelines likely at southern, eastern and northern sites, particularly from Wailua to Kealia and Hanalei toward the Na Pali coast.	7
Kaua‘i, Nawiliwili	2 observed from land, 3 Apr 2002	5
Kaua‘i vicinity	3 observed from boat, Kaulakahi Channel, 29 Jul 2002	5
Kaua‘i vicinity	6 observed from boat, offshore Kilauea Pt., 4 Jun 2003	5
Kaua‘i, Nawiliwiili Lighthouse	10+ observed from land, 15 Apr 2004	5
Kaua‘i, Nawiliwili Lighthouse	6 observed from land, 16 Apr 2004	5
Kaua‘i, Wailua River mouth	20 observed from land, 28 Apr 2004	5
O‘ahu, offshore	Many, observed from boat, 8 June 2003	5
O‘ahu, 17 NM offshore	Many, observed from boat, 9 June 2003	5
Moloka‘i	5-10 birds calling, 1980	1
Lāna‘i	50+ breeding pairs, estimated 1980	1
Maui	450-1,000 breeding pairs, estimated 1994	1, 2
Kaho‘olawe vicinity	Suggested breeding, sea stacks, unknown date	2
Hawai‘i, at sea off Kona coast	3 observed from boat, 20 Jan 2005	5
Hawai‘i, 5-10 NM offshore	Foraging area, fishboat captain testimony	1
Hawai‘i	40-50 breeding pairs, estimated 1995	1
Hawai‘i	Flights across shorelines are Kawaihae, Pololu Valley, Maulua Stream, Akaka Falls, Hilo, Paradise Park, Kehena, and Puanlu‘u	8

1. Simons and Hodges (1998)
2. USFWS (2005a)
3. USFWS (2005b)
4. Harrison (1983)
5. Birding Hawaii (2004)
6. Day and Cooper (1995)
7. Ainley et al. (1997a)
8. Day et al. (2003)

Introduced black rats heavily impacted the population on Midway Atoll. Rabbits were eliminated, rats are being controlled, and the populations of Christmas shearwater are responding positively (Seto 2001; USFWS 2005a).

Habitat Preferences—The Christmas shearwater is a pelagic species whose nonbreeding life at sea is poorly known. At least half of individuals found in one study (Gould 1971) were solitary birds, and about 40% were seen in mixed species flocks. Flocks of boobies, Juan Fernandez petrels, and wedge-tailed shearwaters that also contained Christmas shearwaters frequented tropical waters with

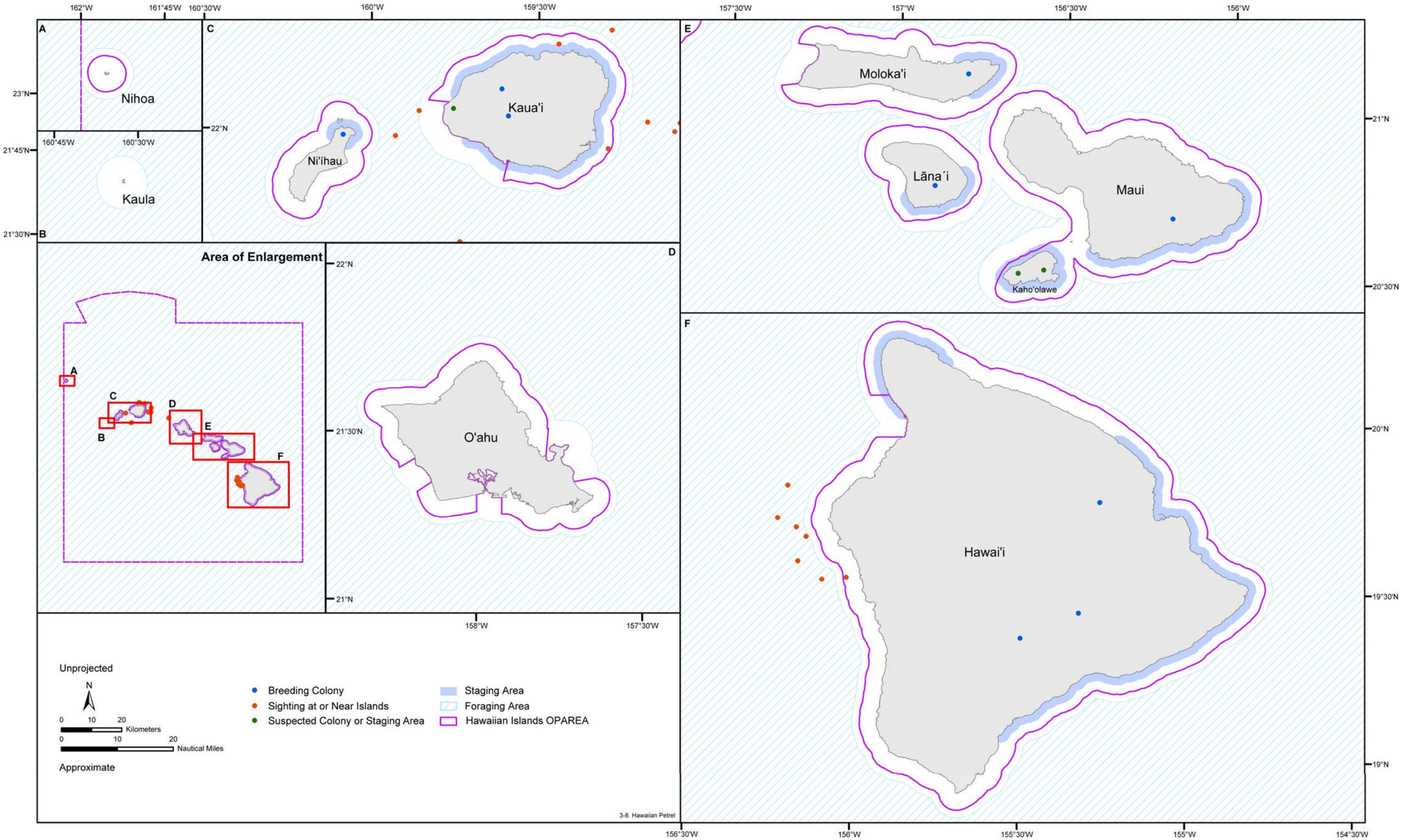

Figure 3-8. General range and recorded sightings of the Hawaiian petrel in the Hawaiian Islands OPAREA and vicinity. Source data: CRC (2005). Source information: refer to Table 3-7.

low and high salinity but with intermediate to shallow thermocline and intermediate to high chlorophyll count. Christmas shearwaters consume prey driven to the surface by schools of predatory fish and dolphins (Ballance and Pitman 1999).

Nesting occurs mostly on small (some no more than 20 m^2), remote, sandy oceanic islands which are subject to flooding during El Niño-associated storms. Christmas shearwaters prefer nest sites under dense ground vegetation. A few nesting islands are more substantial and taller. Christmas shearwaters tend to nest in rock crevices on these islands (Seto 2001).

Distribution—Christmas shearwaters have an extensive distribution in tropical and subtropical waters of the central Pacific. Data on marine distribution are severely limited. What is known is that Christmas shearwaters occur in the eastern Pacific within at least 200 km of coastal Central and South America (Seto 2001) with frequent sightings off the coast of Mexico and Guatemala (Howell and Webb 1995). They also range from 25°S to 25°N in the eastern Pacific. In the western Pacific, Christmas shearwaters occur to around 154°E at Minami Torishima. There are records southwest to New Zealand and the Kermadec group of islands northeast of New Zealand (Seto 2001).

Nesting occurs on the following islands: the Hawaiian Islands, Johnston Atoll, Jarvis Island, Pitcairns, Christmas Island islets of the Line Islands, Societies, Marquesas, Tuamotus, Samoans, Marshalls, Australs, and Phoenix Islands. Christmas shearwaters also breed on Sala-y-Gomez and Motu-Nui off Easter Island in the far eastern Pacific (Seto 2001, USFWS 2005a). In the NWHI, they breed from Kure Atoll to Nihoa, except for Necker and Gardner Pinnacles (Seto 2001). In the MHI, nesting is restricted to Moku Manu (off O‘ahu), Kaula Rock, and Lehua Rock.

- Information Specific to the Hawaiian Islands OPAREA—Christmas shearwaters breed in the Hawaiian Islands OPAREA from February through October (Seto 2001). Nesting area is limited in the MHI, but Christmas shearwaters do nest on Nihoa in NWHI (**Figure 3-9**). The population on Nihoa was estimated at 200 to 250 breeding pairs in 1984 (Seto 2001). Unknown numbers nest on Lehua Rock (Harrison 1990). The population on Kaula Rock is estimated at 75 to 125 breeding pairs (Harrison 1990). The only other locations known within the MHI are Moku Manu and Moku Lua islets, both on the northeast coast of O‘ahu (Harrison 1990; Pyle personal communication; **Table 3-8**) with an estimated population of 40 to 60 breeding pairs on Moku Manu (Harrison 1990). Christmas shearwaters are seen from land and from boats off all of these islands but usually forage more than 15 km offshore (Baird personal communication; **Figure 3-9**). Most of the shearwaters seen nearshore are likely in transit from foraging areas to nesting colonies. There are no frequent records, if any, from islands to the east of O‘ahu. The small breeding population in the MHI results in too few at-sea records to accurately describe the foraging range. Records from the NMFS HICEAS surveys conducted in offshore waters during 2002 (see **Appendix A** for more information on the coverage and timing of these surveys) support the probability that most, if not all, foraging takes place west of Moloka‘i during the breeding season (February through October).

Behavior and Life History—The Christmas shearwater is known to live 17 years (Seto 2001). It is monogamous; pair bonds tend to be long, but mate changing occurs regularly. The species nests in colonies but usually in low densities. Breeders return to colony sites in February. They court, form pairs, and prepare nests in February and March. On most islands, nests are under vegetation in sandy areas. Clutch size is one egg, and if unsuccessful they are not known to reattempt reproduction in the same season. Most eggs are laid in April, hatch in June and July, and the young fledge in September and early October (Seto 2001). Christmas shearwaters feed by surface-seizing, pursuit-plunging, and dipping. Much of feeding is done in mixed-species flocks. The most important food items are squid and fish (Seto 2001), but importance of other items varies by location.

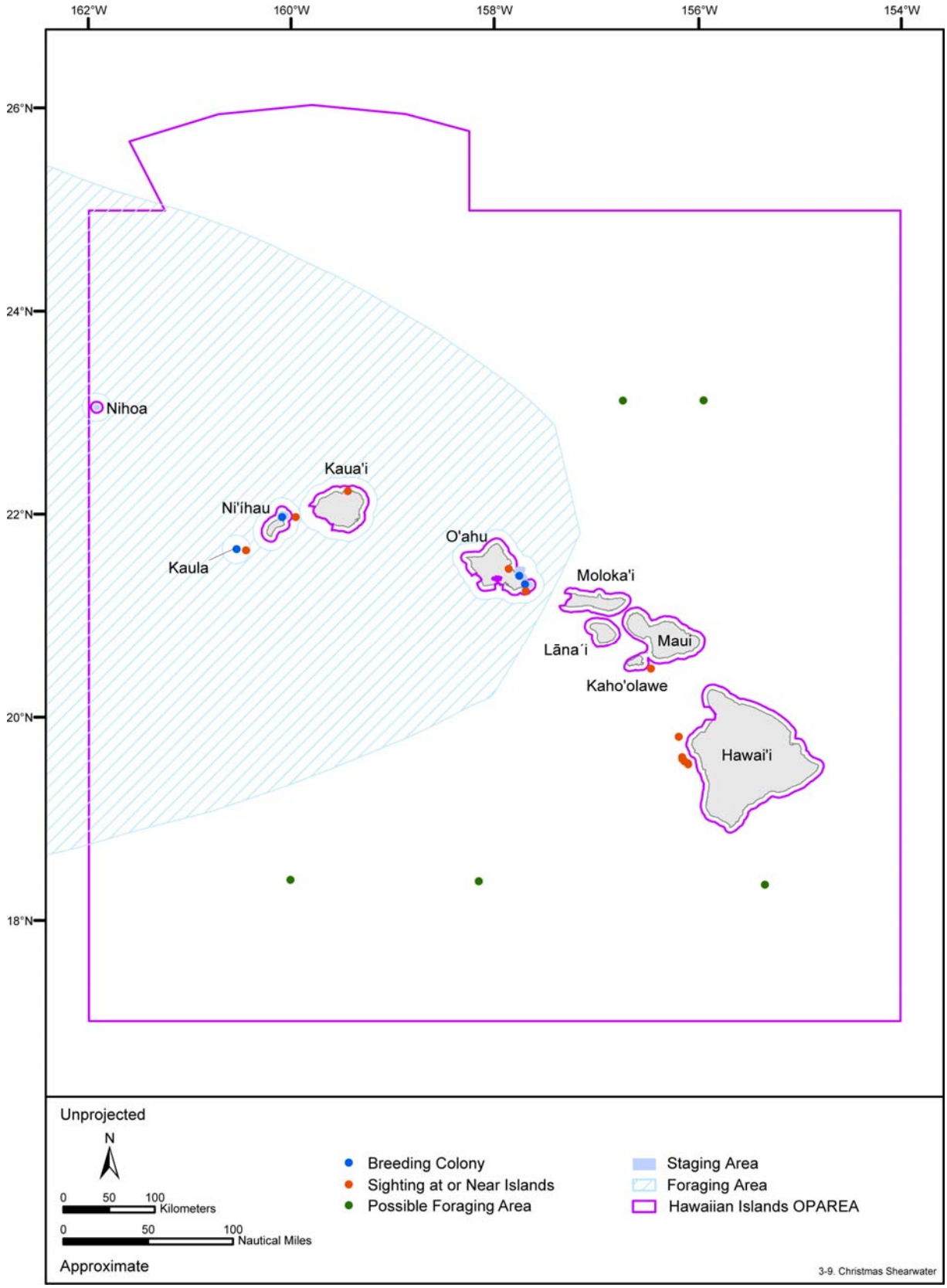

Figure 3-9. General range and recorded sightings of the Christmas shearwater in the Hawaiian Islands OPAREA and vicinity. Source data: CRC (2005). Source information: refer to Table 3-8.

Table 3-8. General distribution and sightings of the Christmas shearwater.

Location	Notes	Source
General Range		
Central Pacific	Ranges from near Central and South American coasts, 25°S to 25°N, northwest toward Philippines, N of equator. Nests in Hawaiian Is., Pitcairn Is., Line Is., Society Is., Tuamatu Is., Marshall Is., Marquesas Is., Samoan Is., Austral Is., Phoenix Is., Johnston Atoll, Jarvis Island, Sala-y-Gomez Island, and Motu-Nui off Easter Island.	1, 2, 3
Sightings in the Hawaiian Islands outside of the Hawaiian Islands OPAREA		
Kure Atoll	20-30 breeding pairs estimated 1972	4, 5
Midway Atoll	ca. 200 breeding pairs estimated 1997	2
Pearl and Hermes Reef	10 breeding pairs estimated 1974	4, 5
Lisianski Island	400 breeding pairs estimated 1975	4, 5
Laysan Island	1500-2000 breeding pairs estimated 1984	2, 4, 5
French Frigate Shoals	15-20 breeding pairs estimated 1971	4, 5
Sightings within the Hawaiian Islands OPAREA		
Nihoa	200-250 breeding pairs estimated 1984	2, 4, 5
Kaula Rock	75-125 breeding pairs estimated 1988	4
Lehua Rock	Unknown number of breeding pairs, nesting confirmed 1988	4
Moku Manu, off O‘ahu	40-60 breeding pairs estimated 1988	4
Moku Lua, off O‘ahu	Unknown number of breeding pairs, nesting claimed, no date	7
Kaua‘i, Nawiliwili Lighthouse	1 observed from land, 17 Jan 1998	6
Kaua‘i vicinity	1 observed from boat, Kaulakahi Channel, 18 Apr 1998	6
Kaua‘i, Kilaeua Point NWR	1 observed from land, 15 Aug 2000	6
Lehua Rock vicinity	1 observed from boat, 24 Aug 2001	6
O‘ahu vicinity	3 observed offshore from boat, 8 Jun 2003	6
O‘ahu vicinity	5 observed from boat, 27 km offshore, 9 Jun 2003	6
Kaua‘i, Kilaeua Point	1 observed from land, 4 Jun 2003	6
Lehua Rock vicinity	4 observed from boat, 9 Mar 2004	6
Lehua Rock vicinity	1 observed from boat, 25 May 2004	6
Kaua‘i	Easily observed from headlands, such as Kilaua‘i Point and Nawiliwili Point	6
O‘ahu	Easily observed from headlands, such as Laie Point and Kahuku Point	6

1. Harrison (1983)
2. Seto (2001)
3. USFWS (2005a)
4. Harrison (1990)
5. Harrison et al. (1984)
6. Birding Hawaii (2004)
7. Pyle (personal communication)

- Newell’s Shearwater (*Puffinus auricularis newelli*)

Description—Newell’s shearwater, also known as Newell’s dark-rumped shearwater, is a medium to small-sized shearwater (USFWS 1983). It has body length of about 0.3 m and a wingspan of 0.76 to 0.89 m. It is basically black above and white below. Unlike the Hawaiian petrel, its forehead is black and not white. The sides of the rump (extending partially onto the dorsal surface) are bright white, which is its most distinctive feature. The upperwing is black and the underwing is white with a black tip and trailing edge (Harrison 1983).

Status—The taxonomic status of the Hawaiian endemic Newell's shearwater is in flux. It was, until recently, regarded by some authorities as a distinct species, *Puffinus newelli* (IUCN 2004). Since 1982, most authorities have considered it a subspecies of Townsend's shearwater, *Puffinus auricularis* (AOU 1998). At least one author (Harrison 1983) regarded Newell's shearwater as a subspecies of Manx shearwater (*Puffinus puffinus newelli*). Newell's shearwater was thought to be extinct by 1908 as a consequence of subsistence hunting by Polynesians and predation by their introduced rats, pigs and dogs. However, they were rediscovered offshore in 1947. One was collected on O'ahu in 1954 (Day et al. 2003), and Newell's shearwaters were confirmed still breeding on Kaua'i in 1967 (USFWS 2005). The species is currently listed as threatened under the ESA and the Hawaiian Islands (USFWS 2005a). A federal recovery plan was finalized in 1983 (USFWS 1983). Within the Hawaiian Islands Bird Conservation Region, Newell's shearwater is evaluated as highly imperiled, the most serious category, because of restricted breeding distribution and threats to breeding populations (USFWS 2003). The IUCN Red List (IUCN 2004) recently downgraded this shearwater's level of concern from vulnerable to endangered. Population declines may have exceeded 50% in the last 3 generations (47 years). The largest known population, on Kaua'i, was devastated by two hurricanes in 1982 and 1992. Since that last storm, the species has been in steady decline on Kaua'i. The remaining nesting birds (adults and fledglings) are suffering significant mortality from utility pole and line strikes (IUCN 2004). Continuing forest habitat destruction and predation from introduced mammals are also taking a toll on this species (IUCN 2004). Population levels in the 1980s and early 1990s were estimated at about 84,000 birds, but numbers in 2,000 may have been only 21% of what they were in 1987 (USFWS 2005a).

Habitat Preferences—Newell's shearwaters come ashore only to nest. They avoid inshore waters for all but staging before flying inland to breeding colonies in the night (Ainley et al. 1997b). They only forage over deep oceanic water of depths reportedly much greater than 2,000 m (Spear et al. 1995). In particular, they find abundant food resources along oceanic fronts like the Equatorial Countercurrent (Spear et al. 1995). Preferred average oceanic variables are 26.8°C SST, 34.5 ppt SSS, and thermocline depth of 76 m (Spear et al. 1995). The meteorological conditions favored by Newell's shearwaters are frequent clouds and rain squalls typical of intertropical convergence zones (Spear et al. 1995).

Newell's shearwaters nest in burrows or deep rock crevices at higher elevations (Reynolds and Richotte 1997). Probably as a consequence of predation pressure from introduced pigs, mongooses, and cats, this species now nests on steep slopes (mostly greater than 65°) where there is either an open canopy of trees and ground cover of uluhe ferns or a dense ground cover of tussock grasses (Ainley et al. 1997b). Some nesting colonies are located far inland. Meteorological conditions at Newell's shearwater nesting sites are remarkable. For example, on Kaua'i, rainfall at these sites is among the heaviest known on Earth (Ainley et al. 1997b).

Distribution—Newell's shearwaters are known to be somewhat sedentary. Their distribution at sea, even in the nonbreeding season, does not extend as much away from their main Hawaiian nesting islands as one might expect for a shearwater. They occur year-round in the eastern tropical Pacific, particularly around the Equatorial Countercurrent from south of Hawai'i east to about 120° W. During the breeding season, many nesting adults forage a bit more to the north and west of the Hawaiian Islands (Ainley et al. 1997b).

Newell's shearwater nesting is entirely confined to the MHI, from Lehua Rock east to Hawai'i. Nesting is known on Lehua Rock, Kaua'i, Moloka'i, and Hawai'i. There is evidence but not confirmation of nesting on O'ahu, Maui, and Lāna'i (Ainley et al. 1997b; USFWS 2005a).

- Information Specific to the Hawaiian Islands OPAREA—About 20 breeding colonies of Newell's shearwaters are known in the MHI (**Table 3-9**; **Figure 3-10**), but others probably exist (Ainley et al. 1997b). In 1992, 11 colonies were known on Kaua'i. Movements between the sea and Kaua'i colonies are known for the northwest, north, east, and south coasts. Small nesting colonies exist on Lehua Rock and Moloka'i, and probably on O'ahu, Maui, and Lāna'i but no population

Table 3-9. General distribution and sightings of Newell's shearwater.

Location	Notes	Source
General Range		
Central subtropical Pacific to Eastern Tropical Pacific.	Fairly sedentary in area of Hawaiian Islands, with nonbreeding season range extending south and east to Equatorial Counter Current, east to about 120°W.	1, 2, 3
Sightings in the Hawaiian Islands outside of the Hawaiian Islands OPAREA		
Apparently rare if not unrecorded from the NWHI.	No specific records, although breeding season foraging range described as extending more to north and west of MHI. Likely most of those birds remain well at sea away from islands.	1, 2, 3
Sightings within the Hawaiian Islands OPAREA		
Lehua Rock	Nesting, but breeding pair population unknown	2, 3, 4
Lehua Rock vicinity	1 observed from boat at sea, 18 Apr 1998	5
Lehua Rock vicinity	2 observed from boat at sea, 21 Apr 2001	5
Lehua Rock	1 observed from boat, 13 Apr 2003	5
Lehua Rock	1 observed from boat, 2 May 2003	5
Lehua Rock	2 observed from boat, 25 May 2004	5
Kaua'i	ca. 11 breeding colonies but breeding pair population unknown	2
Kaua'i, Makahuena Point	2 observed from land, 6 Apr 1998	5
Kaua'i, Kilauea Point NWR	50 observed from land, 17 May 1998	5
Kaua'i, Nawiliwili Lighthouse	250-300 observed from land, 18 Apr 1999	5
Kaua'i, Hanalei NWR	2 observed from land, 1 Apr 2001	5
Kaua'i vicinity	3 observed from boat, Kaulakahi Channel, 29 Jul 2002	5
Kaua'i vicinity	5 observed from boat, Nawiliwili to Kilauea, Jun 2003	5
Kaua'i, Nawiliwili Lighthouse	15+ observed from land, 15 Apr 2004	5
Kaua'i, Nawiliwili Lighthouse	10 observed from land, 16 Apr 2004	5
Kaua'i, Kilauea Point	1+ observed from land, 20 Apr 2004	5
O'ahu	breeding colonies thought to exist, but breeding pair population unknown	2, 3, 4
O'ahu, offshore	1 observed from boat, 27 km offshore, 9 Jun 2003	5
Moloka'i	breeding colonies known to exist, but breeding pair population unknown	2, 3, 4
Lāna'i	breeding colonies thought to exist, but breeding pair population unknown.	2, 3, 4
Maui	breeding colonies thought to exist, but breeding pair population unknown	2, 3, 4
Hawai'i	breeding colonies known to exist, but breeding pair population unknown	2, 3, 4
Hawai'i, Mt. Hualalai	1 observed on land, 23 Apr 2004	5

1. Harrison (1983)
2. Ainley et al. (1997b)
3. USFWS (2005a)
4. Harrison (1990)
5. Birding Hawaii (2004)

estimates are available (Harrison 1990; Day and Cooper 1995; Ainley et al. 1997b; USFWS 2005a; **Table 3-9**). On the island of Hawai'i, Newell's shearwaters fly over the entire island except the southwestern coast. These shearwaters are most numerous flying to and from the Kohala Mountains on the north coast (Day et al. 2003). During adult presence in the breeding season (April to September), Newell's shearwaters stage on the water close to shore (**Figure 3-10**) before flying inland at and after sunset (Ainley et al. 1997b). Even when nesting, they feed over deep waters, in excess of 2,000 m and are typically not within 24 km of island shores (Ainley et al. 1997b; Baird personal communication; **Figure 3-10**). Based on known or suspected colony locations, Newell's shearwaters are expected to be found staging in early evening at Ni'ihau (north end around Lehua Rock), Kaua'i, O'ahu, Maui, Moloka'i, Lāna'i, and Hawai'i.

Newell's shearwaters arrive on their nesting grounds in April, and adults desert nestlings for the sea in September. Some fledglings remain at their burrows until early December (Ainley et al. 1997b), but most occupation of the Hawaiian Islands OPAREA is over by October and does not resume until April (Pyle personal communication).

Behavior and Life History—Newell's shearwaters are long-lived birds with annual adult survivorship of 90%. They first nest at about age six; they exhibit life-long monogamy with pairs forming in the year before first breeding together. Nest burrows are dug in rocky volcanic soil or crevices, usually at the base of a tree. Adults must climb trees or rock promontories to achieve flight from the ground surface. The clutch size is one egg. Incubation time is unknown although it is probably between 51 and 62 days. After hatching, adults visit nest burrows at night to feed nestlings and forage at sea by day. On average, only 46% of adults in a colony actually breed in a given year (Harrison 1990; Slotterback 2002; USFWS 2005a). Although diet is not well known, evidence suggests that squid are a major dietary item. Newell's shearwaters capture food by pursuit-plunging, usually in company with multispecies feeding flocks associated with tuna (Slotterback 2002). Like other smaller shearwaters, its flight is low and fast (Harrison 1983).

- Band-rumped Storm-Petrel (*Oceanodroma castro*)

Description—The band-rumped storm-petrel is also known as Madeira or Madeiran storm-petrel, Harcourt's storm-petrel, or Hawaiian storm-petrel (Harrison 1983; Harrison 1990; AOU 1998). Storm-petrels are the smallest Hawaiian seabirds; at about 17 to 20 cm long and with a wingspan of 44 to 47 cm, band-rumped storm-petrels are medium-sized. Almost all storm-petrels are sooty, dark colored birds and are difficult to identify at sea. The band-rumped storm-petrel is locally distinguishable by having a very shallowly-notched tail and a bright white half-moon patch on the rump at the base of the tail. In migration season, Leach's storm-petrels occur with flocks of band-rumped storm-petrels, but Leach's storm-petrels have a deeply forked tail and the white rump patch is in the form of an inverted V. Tristram's storm-petrel is larger without a white rump patch (Harrison 1983). When flying, band-rumped storm-petrels keep the wings above horizontal and intersperse glides with wing beats. When foraging they hold their wings high, let the feet dangle, and patter gently over the water surface (Harrison 1990).

Status—In the Hawaiian Islands, band-rumped storm-petrels are the rarest breeding seabirds although their global population is secure (Slotterback 2002; USFWS 2005a). Populations are large in Japan and the Galapagos Islands, and there is no concern about their status (Slotterback 2002). The Hawaiian Islands regard the local population as endangered (USFWS 2005a), and it has been a candidate for listing under the ESA since 1989 (USFWS 2004). Band-rumped storm-petrels at-sea have been estimated at about 5,500 individuals, but only a few hundred pairs are thought to breed in the MHI (USFWS 2004). The Hawaiian Islands population are BCC and are regarded as highly imperiled within the Hawaiian Islands Bird Conservation Region due to population size, breeding distribution, and threats to breeding distribution (USFWS 2003). This small seabird is highly vulnerable to predation by introduced rats, mice, cats, mongooses, pigs, and barn owls and to nocturnal striking of power lines and street lights (USFWS 2005a).

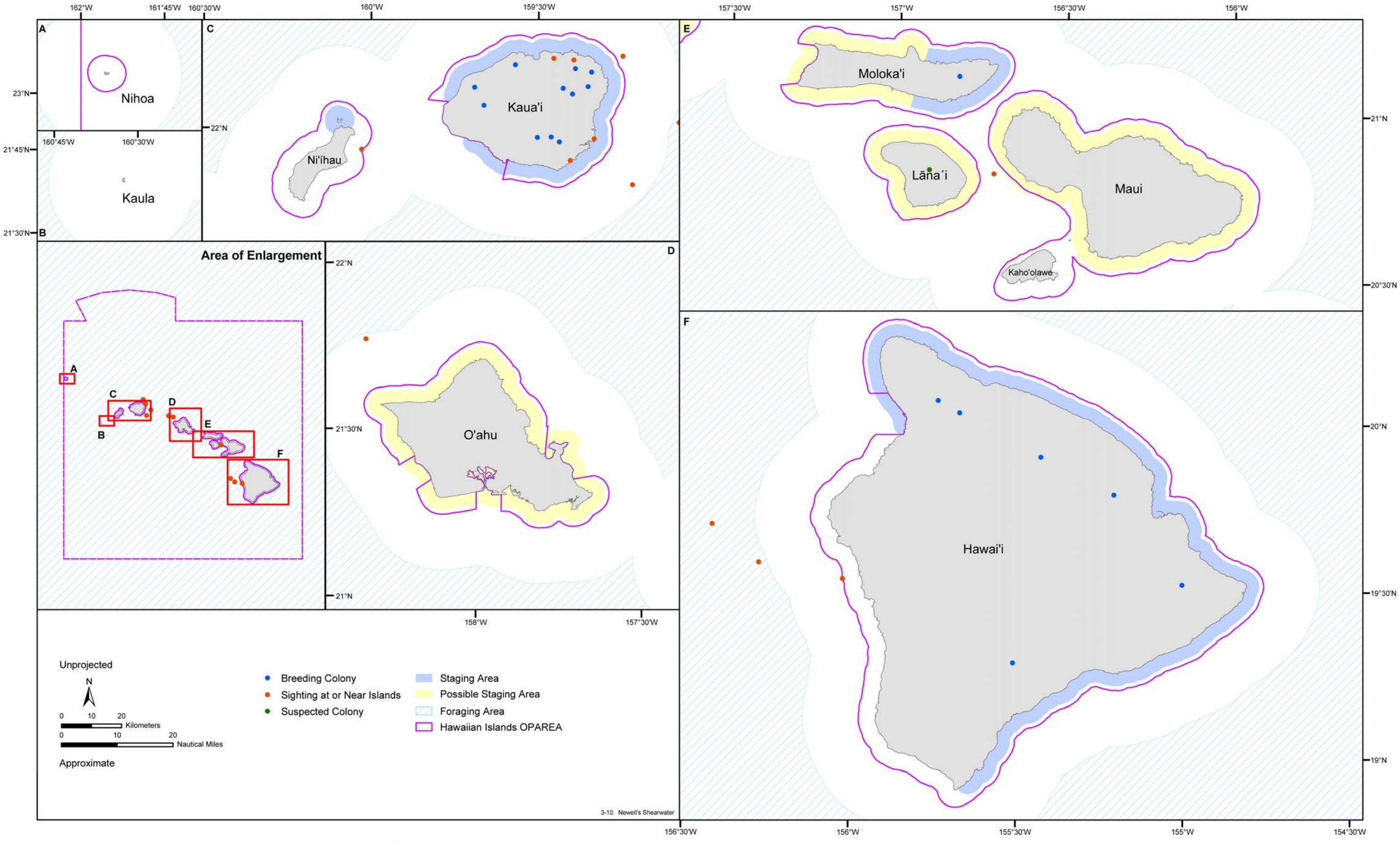

Figure 3-10. General range and recorded sightings of the Newell's shearwater in the Hawaiian Islands OPAREA and vicinity. Source data: CRC (2005). Source information: refer to Table 3-9.

Habitat Preferences—Band-rumped storm-petrels have a preference for warm, deep water (1,000 to 2,000+ m). This species occurs close to land where deep water is in close proximity to an island, such as along the Kona Coast of Hawai‘i. Otherwise, they occur offshore or in upwelling regions (Slotterback 2002). In the Atlantic, 75% of all band-rumped storm-petrel occurrences were at upwellings (Haney 1985). In waters north of Kaua‘i, most of them are encountered at about 5 km north of the Na Pali coast. Preferred waters range from 26.8° to 29.0°C in temperature (Slotterback 2002).

Nesting habitat in the MHI consists of very steep cliffs and barren lava flows at high elevation. These sites may well be the last resort at predator avoidance for a species that formerly most likely nested closer to the coast (Slotterback 2002).

Distribution—Band-rumped storm-petrels occur in the eastern Atlantic, largely off the coast of Africa, and in the Pacific from Japan east to Central America and northern South America (Harrison 1983; **Table 3-10**). Pacific populations are divided into distinct Japanese, Hawaiian, and Galapagos breeding populations (USFWS 2004). The Hawaiian population at sea is thought to remain in the central Pacific, ranging south to the Equatorial Countercurrent. Some are highly pelagic, occurring far offshore from nesting islands; others seem to be sedentary, remaining close to nesting colonies year-round (USFWS 2005a).

Table 3-10. General distribution and sightings of band-rumped storm-petrel.

Location	Notes	Source
General Range		
Atlantic and Pacific	In Pacific, from Japanese Islands east to Central and South American coasts. Breeding populations in Japan, Hawaiian Islands, and Galapagos Islands.	1, 2, 3, 4
Sightings in the Hawaiian Islands outside of the Hawaiian Islands OPAREA		
None	Apparently confined to MHI	1, 2, 3, 4
Sightings within the Hawaiian Islands OPAREA		
MHI	Foraging in deep water, particularly off Kaua‘i and Hawai‘i	2
Lehua	Present, nesting unconfirmed	3, 4
Lehua	4 – seen from boat, 3 Sept 2002	5
Lehua	1 – seen from boat, 3 May 2003	5
Kaua‘i	171-221 breeding pairs estimated in 2002	3
Kaua‘i vicinity	7 – seen from boat, Kaulakahi Channel, 29 July 2002	5
Kaua‘i, offshore Nawiliwili	1 – seen from boat, 13 Apr 2003	5
Kaua‘i, offshore	1 – seen from boat, no detail, 4 June 2003	5
Maui	Nesting suspected, fledglings encountered	2, 3
Kaho‘olawe	Nesting suspected, historical presence	2, 3
Hawai‘i	Nesting confirmed, Mauna Loa	2, 3

1. Harrison (1983)
2. Slotterback (2002)
3. USFWS (2004)
4. USFWS (2005a)
5. Birding Hawaii (2004)

In the Hawaiian Islands, nesting is confined to the MHI; there is no nesting in the NWHI. Within that nesting range, colonies are known or suspected on Lehua Rock, Kaua‘i, Maui, Kaho‘olawe, and Hawai‘i.

- Information Specific to the Hawaiian Islands OPAREA—In 2002, the population on Kaua‘i was estimated at 171 to 221 breeding pairs, most along the Na Pali coast (Pohakuao Valley, Kalalau Valley, Awaawapuhi Valley, Nuololo Aina, and Nuololo Kay) on the west side of the island (**Table 3-10**; **Figure 3-11**). Other colonies are likely in Waimea Canyon and Hanapepe Valley, opening near the south shore of Kaua‘i (**Figure 3-11**). On Hawai‘i, one small population is known to nest on the upper west slope of Mauna Loa (**Figure 3-11**). On the other islands (Lehua Rock, Maui, and Kaho‘olawe) where nesting is suspected, there are no confirmations of occurrence although Lehua Rock and Maui (Haleakala crater) are likely (Slotterback 2002; USFWS 2004; **Figure 3-11**). Nesting in the Hawaiian Islands probably occurs from April through October, largely surmised from known dates in Japan and the Galapagos. Band-rumped storm-petrels are known to stage in nearshore waters (**Figure 3-11**) before flying inland to nesting colonies in the early evening. Foraging is done mostly in deep water in all seasons (**Figure 3-11**). During the nesting season, deep water (>1,000 m) close to shore can be used for foraging, and fishermen report them mostly at about 5 km off the Na Pali coast of Kaua‘i (Slotterback 2002). Band-rumped storm-petrels are known to stage in nearshore waters before flying inland to nesting colonies in the early evening.

  Band-rumped storm petrels are expected to occur in the Hawaiian Islands early in the fall-winter period. Nesting in the Hawaiian Islands probably occurs from April through October, largely surmised from known dates in Japan and the Galapagos.

Behavior and Life History—Band-rumped storm-petrels live around 15 to 20 years. This species is monogamous with fidelity to the burrow largely responsible for maintaining the pair bond. A confirmed nest in the Hawaiian Islands has only recently been found (USFWS 2004), but was not described. The only known nesting colonies are on steep cliff faces (Slotterback 2002; USFWS 2004, 2005a). One egg is laid; both sexes incubate the egg for an average of 42 days. The chick is brooded for only its first two to three days after which the adults return at night only to feed the chick. Chicks in the Galapagos Islands fledge at 70 to 78 days. In the Galapagos Islands, only 60% of eggs hatched and only 30% of chicks fledged. Band-rumped storm-petrels in the Hawaiian Islands probably feed on fish and squid (as is recorded in the Galapagos Islands). Foraging activity is confirmed diurnally and suspected nocturnally. Food is captured by bill snatching, as the bird gently flaps just above the surface of the water (Slotterback 2002).

- Tristram’s Storm-Petrel (*Oceanodroma tristrami*)

Description—Tristram’s storm-petrel, also known as the sooty storm-petrel, may be considered conspecific with Markham’s storm-petrel (*Oceanodroma markhami*). In this case, the combined species will be known as sooty storm-petrel (Sibley and Monroe 1990; AOU 1998). It is the largest storm-petrel in the Hawaiian Islands with a length of 24 cm and a wingspan of 56 cm. The overall color is brownish-gray with a paler wingbar from the carpal joint to the back of the wing. Some individuals have a paler rump, but it is not conspicuous. The tail is deeply notched (Harrison 1983; Slotterback 2002).

Status—Tristram’s storm-petrel is a BCC and is evaluated as high concern within the Hawaiian Islands Bird Conservation Region because of breeding distribution and threats to the breeding distribution (USFWS 2003). Neither the U.S. nor the Hawaiian Islands state government lists the species as threatened or endangered (USFWS 2005a). The IUCN Red List evaluates it as near threatened (IUCN 2004; BLI 2004b). The Hawaiian Islands population is estimated at fewer than 10,000 pairs (USFWS 2005a); Japan’s population is reportedly larger (Slotterback 2002).

Habitat Preferences—Little is known of the marine environment requirements of Tristram’s storm-petrel (Slotterback 2002). In the NWHI, this species breeds on sandy atolls and cliffs of rocky volcanic islands. Most nest burrows on Laysan Island are under vegetation (grass clumps or herbaceous vines) (Slotterback 2002).

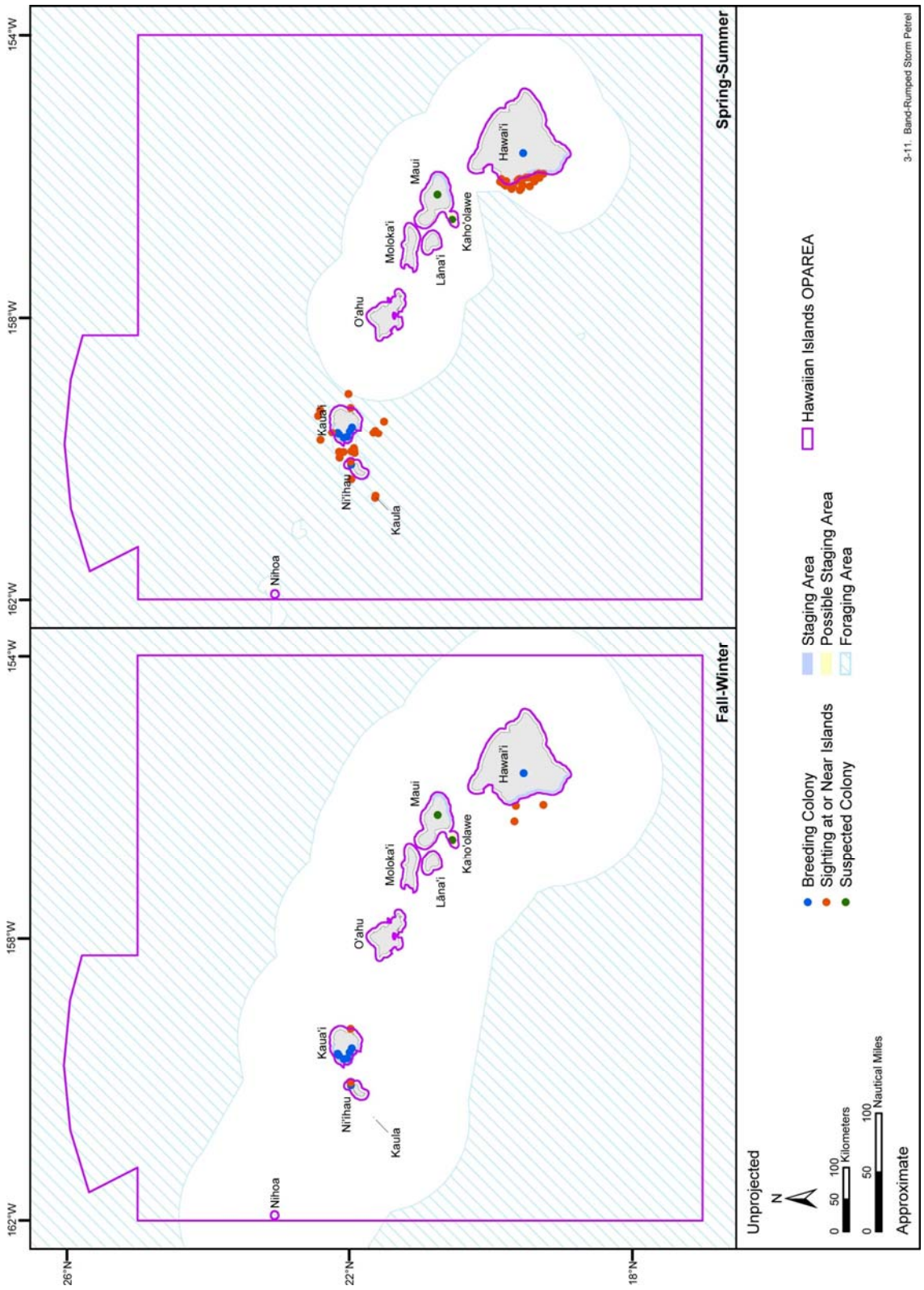

Figure 3-11. General range and recorded sightings of the band-rumped storm-petrel in the Hawaiian Islands OPAREA and vicinity. Source information: refer to Table 3-10.

Distribution—The marine distribution of Tristram's storm-petrel is from the Hawaiian Islands west to Japan (Harrison 1983; Slotterback 2002; USFWS 2005a; **Table 3-11**). In Japanese waters, the Tristram's storm-petrel breeds in the Izu, Bonin, and Volcano Islands. In the NWHI, this storm-petrel breeds from Midway Atoll to Nihoa. Breeding also occurs on Midway Atoll (with no population estimate available), Pearl and Hermes Reef (1,000 to 2,000 pairs) Laysan Island (500 to 2,500 pairs), French Frigate Shoals, and Necker Island (no population estimate available). Nesting might also occur on Kure Atoll, where this species was earlier extirpated, and Lisianski Island (Slotterback 2002; USFWS 2005a). No breeding occurs in the MHI.

Table 3-11. General distribution and sightings of Tristram's storm-petrel.

Location	Notes	Source
General Range		
Central and western Pacific	from Hawaiian Islands to Japan; sedentary.	1, 2, 3
Sightings in the Hawaiian Islands outside of the Hawaiian Islands OPAREA		
Kure Atoll	breeding suspected 1972	3, 4
Midway Atoll	breeding occurs, no estimate of population, 1997	3, 4
Lisianski Island	breeding suspected, 1984	3, 4
Laysan Island	500-2500 breeding pairs estimated 1984	3, 4
Pearl and Hermes Reef	1,000-2,000 breeding pairs estimated 1985, 2002	3, 5
French Frigate Shoals	more than 17 breeding pairs, estimated 2002	3, 4
Necker Island	breeding occurs, no estimate of population, 1977	3, 4
Sightings within the Hawaiian Islands OPAREA		
Nihoa	2,000-3,000 breeding pairs estimated 1981	3, 4
Kaua'i vicinity	2 seen from boat, Kaulakahi Channel, 26 Dec 2001	6
MHI	very rare sighting away from NWHI nesting islands	6

1. Harrison (1983)
2. Slotterback (2002)
3. USFWS (2005a)
4. Harrison et al. (1984)
5. Rauzon et al. (1985)
6. Birding Hawaii (2004)

- Information Specific to the Hawaiian Islands OPAREA—Tristram's storm-petrel breeds during the winter (November through May), occurring in the NWHI including Nihoa (2,000 to 3,000 pairs; **Table 3-11**). Outside of the Nihoa vicinity, Tristram's storm-petrel is not expected to occur regularly within the OPAREA, although individuals are always possibly offshore in the MHI (Birding Hawaii 2004; **Figure 3-12**). Tristram's storm-petrel is largely absent from the OPAREA during the nonbreeding season.

Behavior and Life History—Little information is available on the breeding biology of Tristram's storm-petrel. Tristram's storm-petrel begins breeding at 3 to 5 years of age (USFWS 2005a). Females lay one egg per season and attempt only one brood per season. Hatching success is 33% on Laysan Island; there is no reliable estimate of fledging success. The diet for Tristram's storm-petrel is primarily fish, squid, cnidarians, crustaceans, and amphipods. Prey is mostly captured at night by striking the water surface, while flying low, and pattering the feet in the water (Slotterback 2002).

- Blue-gray Noddy (*Procelsterna cerulea*)

Description—The blue-gray noddy (also known as blue-grey noddy, blue noddy, and Necker Island tern) is the smallest of the world's terns (USFWS 2005a) at about 26 cm long and with a 46 to 60 cm

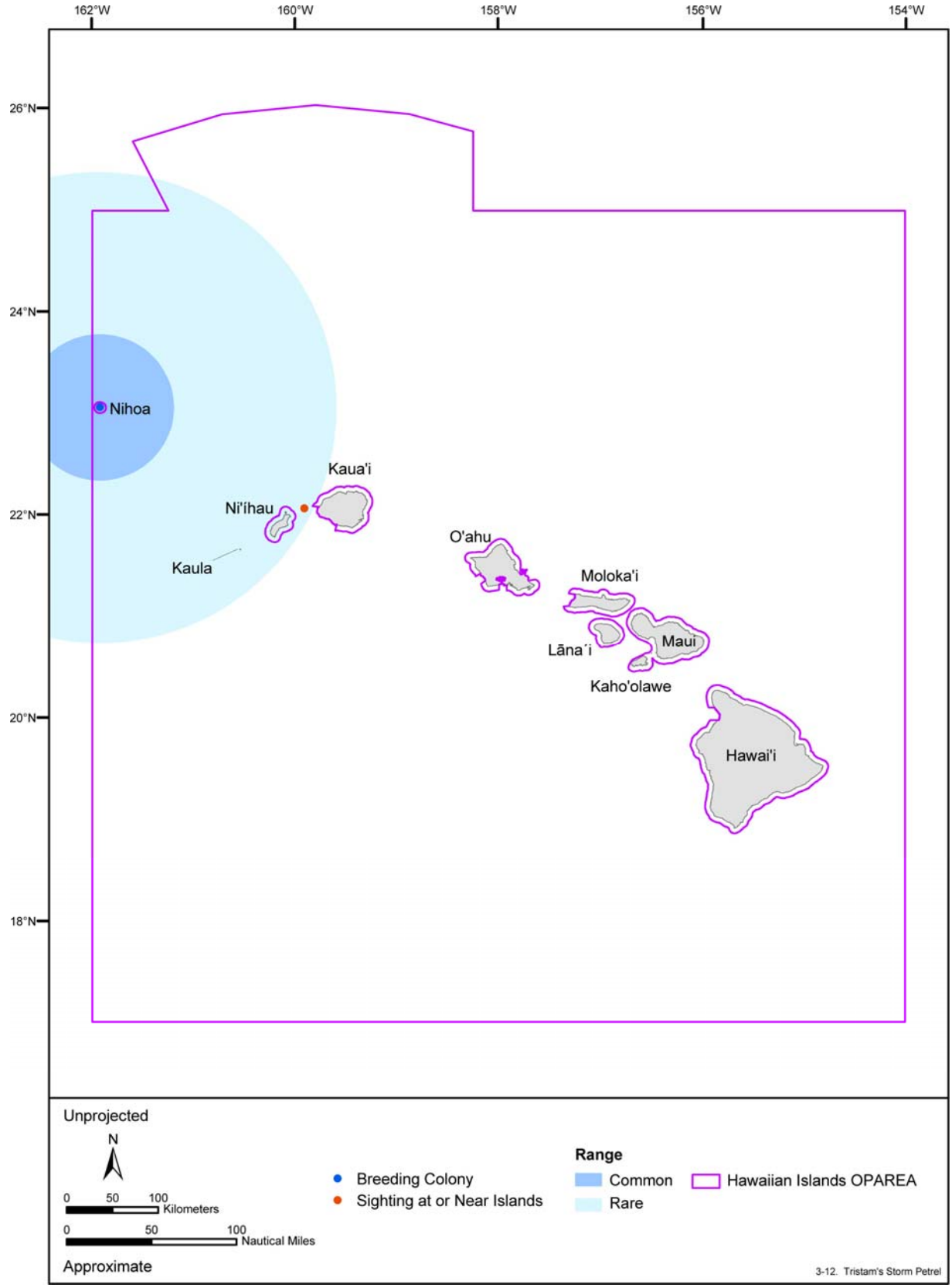

Figure 3-12. General range and recorded sightings of the Tristram's storm-petrel in the Hawaiian Islands OPAREA and vicinity. Source information: refer to Table 3-11.

wingspan (Del Hoyo et al. 1996). The body and head of the blue-gray noddy are gray with slightly paler underparts. The bill is slender and black (Del Hoyo et al. 1996).

Status—The blue-gray noddy is not listed under the ESA or by the State of Hawai‘i, but it is a BCC, being evaluated as high concern within the Hawaiian Islands Bird Conservation Region. The IUCN Red List does not list the blue-gray noddy (IUCN 2004; BLI 2005). In the NWHI, there are an estimated 4,000 breeding pairs plus 8,000 non-breeders. Within the Hawaiian Islands OPAREA, Nihoa has a breeding population estimated at 2,000 to 3,000 adults (Rauzon et al. 1984; USFWS 2005a). The USFWS considers this species to be extirpated from Kaula Rock (USFWS 2005a).

Habitat Preferences—The blue-gray noddy occupies remote marine islands and atolls. Individuals nest on cliffs and rocky areas, or sometimes in vegetation on lower islands. Typically, feeding occurs close to shore at the breeding islands which individuals occupy largely year-round (Rauzon et al. 1984; Del Hoyo et al. 1996; USFWS 2005a).

Distribution—The blue-gray noddy is widely distributed throughout the central and southern Pacific from the Marshall and Hawaiian Islands south to Fiji and Samoa and east to Marquesas, Tuamotu, Henderson, Easter, Sala-y-Gomez, and San Ambrosia (Rauzon et al. 1984; Sibley and Monroe 1990; USFWS 2005a). In the Hawaiian Islands, this species breeds only in the NWHI on La Perouse Pinnacle, Gardiner Pinnacles, French Frigate Shoals, Necker Island, and Nihoa (USFWS 2005a; **Table 3-12**). Individuals move (at least rarely) between islands. The blue-gray noddy tend to be sedentary, remaining close to its nesting islands year-round (Del Hoyo et al. 1996).

Table 3-12. General distribution and sightings of blue-gray noddy.

Location	Notes	Source
General Range		
Widely in Central and South Pacific	From Marshall and Hawaiian Islands south to Fiji and Samoa and east to Marquesas, Tuamotu, Henderson, Easter, Sala-y-Gomez, and San Ambrosia	1, 2, 3, 4
Sightings in the Hawaiian Islands outside of the Hawaiian Islands OPAREA		
La Perouse Pinnacle	Breeding confirmed, small colony, estimated 1982	4
Gardner Pinnacles	Breeding confirmed, small colony, estimated 1982	4, 5
French Frigate Shoals	Breeding confirmed, small colony, estimated 1982	4, 5
Necker Island	1,000-1,500 breeding pairs estimated, 1984	5
Sightings in the Hawaiian Islands OPAREA		
Nihoa	2,000-2,500 breeding pairs estimated, 1984	5
Kaula Rock	Rarely east of Nihoa to this island	6
Kaua‘i, Nawiliwili Lighthouse	1 observed from land, 24 Mar. 1998; “very rare away from breeding islands.”	7

1. Harrison (1983)
2. Rauzon et al. (1984)
3. Sibley and Monroe (1990)
4. USFWS (2005a)
5. Harrison et al. (1984)
6. Pyle (personal communication)
7. Birding Hawaii (2004)

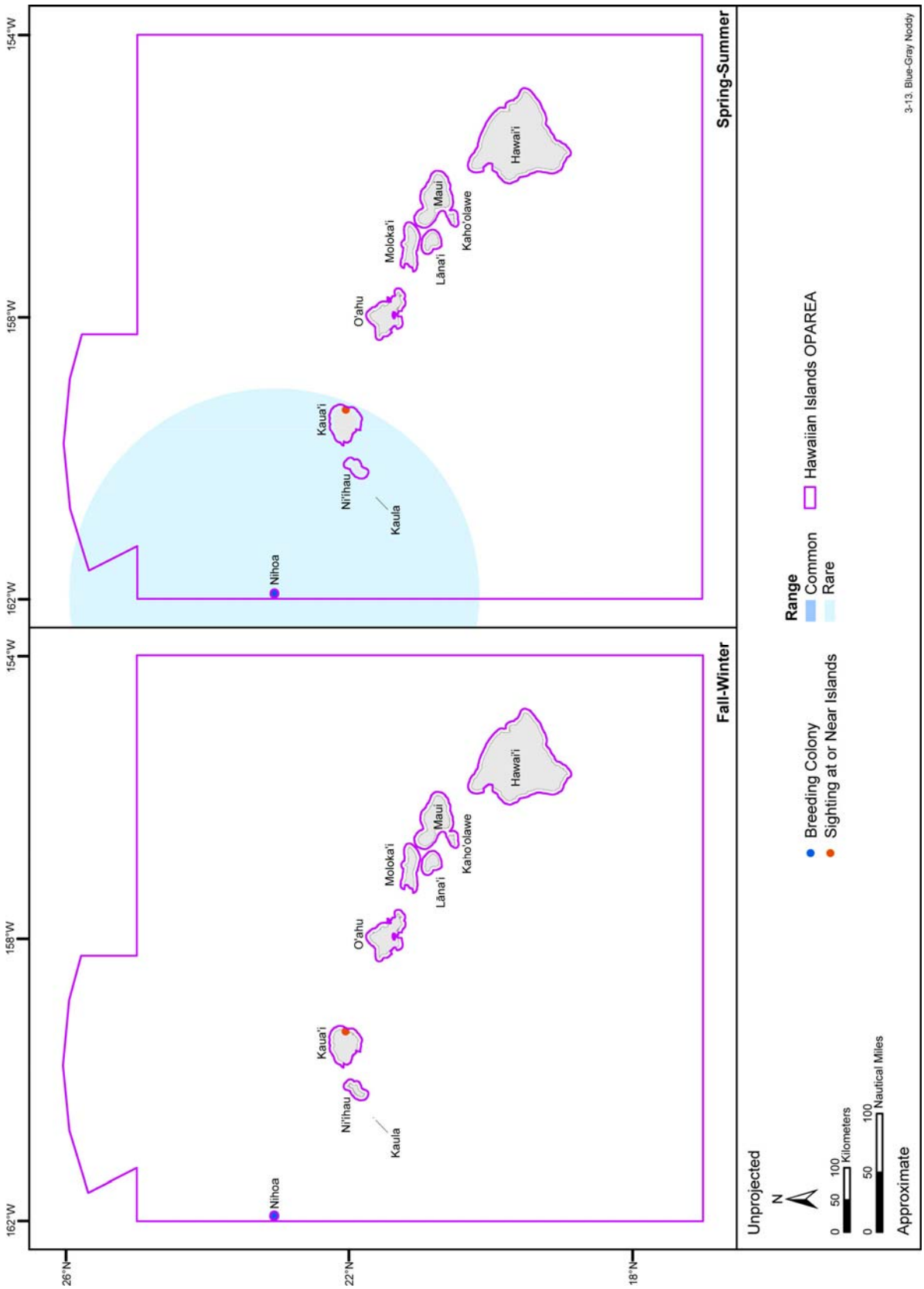

Figure 3-13. General range and recorded sightings of the blue-gray noddy in the Hawaiian Islands OPAREA and vicinity. Source information: refer to Table 3-12.

- Information Specific to the Hawaiian Islands OPAREA—The blue-gray noddy occurs only rarely east of Nihoa, in the MHI (**Figure 3-13**). This species forages close to shore, and generally remain in the vicinity of Nihoa in the nonbreeding season. There are rare nonbreeding season sighting records east of Nihoa at Kaula Rock and Kaua‘i (Birding Hawaii 2004; Pyle personal communication).

Behavior and Life History—The blue-gray noddy breeds from December through at least April, and in some years, to early summer. Clutch size is one egg; duration of the incubation period is unknown. Hatchlings are brooded for 2 to 3 weeks and fed regurgitant. Blue-gray noddies fly low over the water and foot patter at the water surface much like storm-petrels (Del Hoyo et al. 1996; USFWS 2005a). Blue-gray noddies feed by hover-dipping and surface-dipping, almost exclusively at inshore sites. This species feeds on small prey, such as larval fishes, squid, crustaceans and even insects (e.g., sea striders) (Rauzon et al. 1984; Del Hoyo et al. 1996; USFWS 2005a).

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4.0 FISH AND FISHERIES

4.1 FISH/INVERTEBRATES

Distribution and abundance of fisheries, as well as the individual species, depends greatly on the physical and biological factors associated with an ecosystem. Physical parameters include habitat quality variables such as salinity, temperature, dissolved oxygen, and large-scale environmental perturbations (e.g., ENSO). Biological factors affecting distribution are complex and include variables such as population dynamics, predator/prey oscillations, seasonal movements, reproductive/life cycles, and recruitment success (Helfman et al. 1997). A single factor is rarely responsible for the distribution of fishery species; more often, a combination of factors is accountable. For example, pelagic species optimize their growth, reproduction and survival by tracking gradients of temperature, oxygen, or salinity (Helfman et al. 1997). Additionally, the spatial distribution of food resources is variable and changes with prevailing physical habitat parameters. Another major component in understanding species distribution is the location of highly productive regions such as frontal zones. These areas concentrate higher trophic-level predators such as tuna and provide visual clues for the location of target species for commercial fisheries (NMFS 2001).

The prevailing oceanographic current in the Hawaiian archipelago is the NEC (westward). Due to the origin of the NEC (cool waters and distance from Hawai‘i), it is not likely to have had a major impact on fish species occurring in the Hawaiian Islands archipelago. Based on the present current system, most fish larvae would probably arrive at the NWHI via an eddy of the warm Kuroshio Current that bathes southern Japan and heads northeast where it becomes the North Pacific Current (Randall 1998).

Environmental variations, such as ENSO events, change the normal characteristics of water temperature, thereby changing the patterns of water flow. In the northern hemisphere, El Niño events typically result in tropical, warm-water species moving north (extending species range), and cold-water species moving north or into deeper water (restricting their range). Surface-oriented, schooling fish often disperse and move into deeper waters. ENSO events alter normal current patterns, alter productivity, and have dramatic effects on distribution, habitat range, and movement of pelagic species (NMFS 2002a). Fishes that remain in an affected region experience reduced growth, reproduction, and survival (NOAA 2002). El Niño events have caused fisheries such as that of the skipjack tuna (*Katsuwonus pelamis*) to shift over 1,000 km (NMFS 2001).

Coral reef communities in the Hawaiian Islands OPAREA (excluding Nihoa) have a reputation for year-round uniformity and stability. While this is true for most species in the area, there are exceptions. For example, seasonal variations in pelagic species distributions in the area are understood. Several of the reef fish species (bigeye scad [*Selar crumenophthalmus*], mackerel scad [*Decapterus macarellus*], goatfish [Mullidae], and squirrelfish [Holocentridae]) targeted in the study area show seasonal fluctuations, usually related to juvenile recruitment or spawning (ONR 2001).

The Hawaiian archipelago distinquishes itself as a subprovince of the spacious tropical and subtropical Indo-Pacific region which extends from the Red Sea and coast of East Africa to the easternmost islands of Oceania (Hawai‘i and Easter Island). The composition of the Hawaiian marine life varies enough from the rest of the Indo-Pacific to be treated as a distinct faunal subregion. Many of the inshore fishes found in Hawai‘i range all the way to East Africa, however, a surprising 24.3% are endemic (Randall 1998). 20% of Hawai‘i’s marine invertebrates are unique to the island (Hoover 1998). The inshore fish fauna of the Hawaiian Islands also distinguishes itself by the many groups of fishes not found in the archipelago that are present in other areas of the Indo-Pacific. There are no skates (Rajidae), only five shallow-water rays, and no species of the following families of bony fishes that are well represented in continental and insular seas of the rest of the Indo-Pacific: toadfishes (Batrachoididae), flatheads (Platycephalidae), dottybacks (Pseudochromidae), terapons (Teraponidae), fusiliers (Caesionidae), breams (Nemipteridae), porgies (Sparidae), drums and croakers (Sciaenidae), whitings (Sillaginadae), mojarras (Gerreidae), ponyfishes (Leiognathidae), sweepers (Pempheridae), rabbitfishes (Siganidae), jawfishes (Opistognathidae), and clingfishes (Gobiescocidae) (Randall 1995). In addition, two native groupers (giant [Epinelphelus lanceolatus] and Hawaiian [E. quernus]), one emperor fish, the bigeye (*Monotaxis grandoculis*), and no

native snappers of the genus *Lutjanus*, are found in the Hawaiian archipelago. Currently, 566 species of reef and shore fishes are known to occur around the Hawaiian Islands (Randall 1995). Hawai‘i’s unique fish fauna can be explained by its geographical and hydrographical isolation (Randall 1998). Pelagic fishes such as the larger tunas, the billfishes, and some sharks are able to traverse the great distance that separates the Hawaiian Islands from other islands or continents in the Pacific; however, shore fishes are dependent on passive transport as larvae in ocean currents for distribution. As would be expected, the fish families that have a high percentage of species in the Hawaiian Islands compared to elsewhere tend to be those with a long larval life stage, such as the moray eels (Muraenidae) and surgeonfishes (Acanthuridae). Families that contain mainly species with short larval life stages, such as the gobies (Gobiidae), blennies (Blenniidae), and cardinalfishes (Apogonidae), are not as well represented in Hawai‘i as in the rest of the Indo-Pacific region (Randall 1995).

There are eight zoogeographic categories of the native inshore Hawaiian fish fauna: circumglobal, wide-ranging Indo-Pacific, eastern tropical Pacific, Japan to Taiwan, antitropical, central Pacific, waifs, and endemics (Randall 1995). These categories are defined as follows:

- Circumglobal—Species of tropical and/or subtropical seas of the Indo-Pacific and Atlantic (and for some, the eastern Pacific as well).
- Wide-ranging Indo-Pacific—Hawaiian fishes that occur broadly in the tropical and subtropical Indo-Pacific region.
- Eastern tropical Pacific—Fishes common to both the eastern Pacific and the Hawaiian Islands as breeding populations.
- Japan to Taiwan—Fishes shared by the Hawaiian Islands and the region from southern Japan to Taiwan, but not areas to the south.
- Antitropical—Species isolated in temperate latitudes of the northern and southern oceans by warm equatorial waters (Hare 2002). Antitropical species in the Hawaiian Islands are regarded as a separate category even though all of the species are shared with other categories.
- Central Pacific—Fishes common to both the central Pacific and the Hawaiian Islands as breeding populations.
- Waifs—Species that occur so rarely that they are probably not represented by breeding populations in the Hawaiian Islands.
- Endemic—Species only found in the Hawaiian Islands.

4.1.1 Essential Fish Habitat: Distribution and Species

The WPRFMC manages major fisheries within the EEZ around Hawai‘i and the territories and possessions of the U.S. in the Pacific Ocean (WPRFMC 1998, 2001a). The WPRFMC, in conjunction with the State of Hawai‘i, Department of Land and Natural Resources, HDAR, manages the fishery resources in the study area. The WPRFMC focuses on the major fisheries in the study area that require regional management. The WPRFMC currently oversees five major FMPs and their associated amendments for bottomfish, pelagics, crustaceans, precious corals, and coral reef ecosystems.

The MSFCMA, as amended by the SFA, contains provisions for the identification and protection of habitat essential to production of federally managed species. The act requires the NMFS to assist regional FMCs in including EFH in their respective FMP.

EFH provisions impose procedural requirements on both councils and federal agencies. Councils must identify adverse impacts on EFH resulting from both fishing and non-fishing activities, and describe measures to minimize or mitigate these impacts. Councils can also provide comments and make recommendations to federal or state agencies that propose actions that may affect habitat, including EFH, of a managed species. Agencies must then decide how they intend to minimize or mitigate the identified adverse impacts. Fishing activities that may adversely impact EFH include but are not limited to the following: anchor damage from vessels attempting to maintain position over productive fishing habitat, heavy weights and line entanglement occurring during normal hook-and-line fishing operations, lost gear from lobster fishing operations, and remotely operated vehicle tether damage to precious coral during

harvesting operations. Nine non-fishing activities have been identified that directly or indirectly affect habitat used by management unit species and are as follows: infaunal and bottom-dwelling organisms, turbididty plumes, biological availability of toxic substances, damage to sensitive habitat, current patterns/water circulation modification, loss of habitat function, contaminant runoff, sediment runoff, and shoreline stabilization projects (WPRFMC 2001a).

The FMPs developed for federally managed species under the jurisdiction of these FMCs should include identification and description of the EFH, description of fishing and non-fishing threats, and suggested measures to conserve and enhance the EFH. Each of these councils is also required in the FMPs to identify the EFH/HAPC where one or more of the following criteria are demonstrated: (a) ecological function, (b) sensitivity to human-induced environmental degradation, (c) development activities stressing habitat type, or (d) rarity of habitat. In addition to the EFH status, some of these species are assigned status categories in conjunction with the ESA and various federal or international agencies. These status categories will be discussed in the "status" section of the EFH descriptions.

EFH species, as designated by the WPRFMC (2004a), are discussed in the following subsections and are listed in **Table 4-1**. These species have been divided into management units according to their ecological relationships and preferred habitats. Management units include bottomfish management unit species (BMUS), pelagic management unit species (PMUS), crustacean management unit species (CMUS), precious corals management unit species (PCMUS), and coral reef ecosystem management unit species (CRE MUS). For each management unit, the status, distribution (including range), habitat preference (depth, bottom sustrate), life history (migration, spawning), common prey species, and EFH/HAPC designations are provided in the following sections.

4.2 MANAGEMENT UNITS

4.2.1 Bottomfish Management Unit Species

Status—Twenty-two species are currently managed as BMUS by the WPRFMC through the *Bottomfish and Seamount Groundfish Fishery Management Plan* (WPRFMC 1986a) and subsequent amendments (WPRFMC 1998; 2004a; **Table 4-1**). In the Hawaiian archipelago, the BMUS includes 14 deep-slope bottomfish, consisting of shallow-water and deep-water complexes, and three seamount groundfish (Randall 1996). Under Draft Ammendment 8, 13 deep-slope bottomfish from the shallow-water complex have been proposed by the WPRFMC for incorporation into the existing BMUS (WPRFMC 2005a). All of the existing 14 deep-slope bottomfish have viable recreational, subsistence, and commercial fisheries (WPRFMC 2004b). NMFS (2005a) has determined that overfishing is occurring on the bottomfish multi-stock complex around the Hawaiian archipelago, especially the MHI. Large carangids form an important component of shallow-water reef and lagoon fish catches throughtout the Pacific Islands (Haight 2004a). In Hawai'i, jacks are highly valued food and gamefish (Meyer et al. 2001). Within the study area, the Hawaiian grouper (*Epinephalus quernus*) is listed as near threatened on the IUCN Red List of threatened species (Cornish 2004).

Distribution—The deep-slope bottomfish (shallow-water [0 to 100 m] and deep-water [100 to 400 m] complexes) are distributed throughout the tropical and subtropical waters on the coastal shelves and slopes in the Hawaiian archipelago of the western central Pacific (WPRFMC 1998).

Habitat Preference—Bottomfish habitats of the western central Pacific islands are divided into three broad classifications relative to their vertical distribution on the islands' shelves and slopes: shallow-water, deep-water, and seamounts (WPRFMC 1998). Eggs and larvae of all BMUS are pelagic, floating at the surface until hatching, and therefore subject to advection by prevailing ocean currents (WPRFMC 1998). Although both juvenile and adult BMUS habitats are unevenly distributed, they are found in a non-random, patchy fashion within their natural habitats. These habitats are characterized by a mosaic of sandy bottoms and rocky areas of high structural complexity at depths ranging from 60 to 350 m (WPRFMC 1998).

Table 4-1. The fish and invertebrate species with essential fish habitat (EFH) designated in the Hawaiian Islands OPAREA.

Bottomfish Management Unit Species

Shallow-water Species Complex (0-100 m):
Gray jobfish (*Aprion virescens*)
Thick lipped trevally (*Pseudocaranx dentex*)
Giant trevally (*Caranx ignoblis*)
Black jack (*Caranx lugubris*)
Amberjack (*Seriola dumerili*)
Blue stripe snapper (*Lutjanus kasmira*)

Deep-water Species Complex (100-400 m):
Squirrelfish snapper (*Etelis carbunculus*)
Longtail snapper (*Etelis coruscans*)
Pink snapper (*Pristipomoides filamentosus*)
Yellowtail snapper (*Pristipomoides auricilla*)
Pink snapper (*Pristipomoides sieboldii*)
Yellow-barred snapper (*Pristipomoides zonatus*)
Hawaiian grouper (*Epinephelus quernus*)
Silver jaw jobfish (*Aphareus rutilansi*)

Pelagic Management Unit Species

Marketable Species Complex:
Temperate Species
Striped marlin (*Tetrapurus audax*)
Broadbill swordfish (*Xiphias gladius*)
Northern bluefin tuna (*Thunnus thynnus)*
Albacore *(Thunnus alalunga*)
Bigeye tuna (*Thunnus obesus*)
Mackerel (*Scomber* spp.)
Pomfret (Bramidae)
Sickle pomfret (*Taractichthys steindachneri*)
Lustrous pomfret (*Eumegistus illustris*)

Tropical Species
Yellowfin tuna (*Thunnus albacares*)
Kawakawa (*Euthynnus affinis*)
Skipjack tuna (*Katsuwonus pelamis*)
Frigate and bullet tunas (*Auxis thazard, Auxis rochei*)
Slender tunas (*Allothunnus fallai*)
Indo-Pacific blue marlin (*Makaira nigricans*)
Black marlin (*Makaira indica*)
Shortbill spearfish (*Tetrapturus angustirostris*)
Sailfish (*Istiophorus platypterus*)
Dolphinfishes (Coryphaenidae)
Dolphinfish (*Coryphaena hippurus*)
Pompano dolphinfish *(Coryphaena equiselas*)
Wahoo (*Acanthocybium solandri*)
Moonfish (*Lampris guttatus)*

Non-marketable Species Complex:
Snake mackerels or oilfish (Gempylidae)
Escolar (*Lepidocybium flavobrunneum*)
Oilfish (*Ruvettus pretiosus*)

Shark Species Complex
Crocodile shark (*Pseudocarcharias kamoharai*)
Common thresher shark (*Alopias vulpinus*)
Pelagic thresher shark (*Alopias pelagicus)*

Shark Species Complex (continued)
Bigeye thresher shark (*Alopias superciliousus*)
Shortfin mako shark (*Isurus oxyrinchus*)
Longfin mako shark (*Isurus paucus*)
Salmon shark (*Lamna ditropis*)
Silky shark (*Carcharhinus falciformis*)
Oceanic whitetip shark (*Carcharhinus longimanus*)
Blue shark (*Prionace glauca*)

Crustacean Management Unit Species

Spiny and Slipper Lobster Complex
Hawaiian spiny lobster (*Panulirus marginatus*)
Spiny lobster (*Panulirus penicillatus, Panulirus* sp.)
Ridgeback slipper lobster (*Scyllarides haani*)
Chinese slipper lobster (*Parribacus antarticus*)

Kona Crab
Kona crab (*Ranina ranina*)

Precious Corals Management Unit Species

Shallow-water Species Assemblage (18-91 m)
Black coral (*Antipathes dichomata*)
Pine black coral (*Antipathis grandis*)
Fern black coral (*Antipathes ulex*)

Deep-water Species Assemblage (274-1,372 m)
Angel skin coral (*Corallium secundum*)
Red coral (*Corallium regale*)
Pink coral (*Corallium laauense*)
Midway deepsea coral (*Corallium* sp. Nov.)
Hawaiian Gold coral (*Geraddia* sp.)
Gold coral (*Callogorgia gilberti*)
Gold coral (*Narella* sp.*)*
Gold coral (*Calyprophora* spp.*)*
Bamboo coral (*Lepidisis olapa*)
Bamboo coral (*Acanella* sp.*)*

Coral Reef Ecosystem *

Currently Harvested Coral Reef Taxa (CHCRT):
Surgeonfishes (Acanthuridae)
Orange-spot surgeonfish (*Acanthurus olivaceus*)
Yellowfin surgeonfish (*Acanthurus xanthopterus*)
Convict tang (*Acanthurus triostegus*)
Eye-striped surgeonfish (*Acanthurus dussumieri*)
Blue-lined surgeonfish (*Acanthurus* nigroris)
Whitebar surgeonfish (*Acanthurus leucopareius*)
Blue-banded surgeonfish (*Acanthurus lineatus*)
Whitecheek surgeonfish (*Acanthurus nigricans*)
White-spotted surgeonfish (*Acanthurus guttatus*)
Ringtail surgeonfish (*Acanthurus blochii*)
Brown surgeonfish (*Acanthurus nigrofuscus*)
Yellow-eyed surgeonfish (*Ctenochaetus strigosus*)
Bluespine unicornfish (*Naso unicornus*)
Orangespine unicornfish (*Naso lituratus*)
Blacktongue unicornfish (*Naso hexacanthus*)

Table 4-1. The fish and invertebrate species with EFH designated in the Hawaiian Islands OPAREA (continued).

Surgeonfishes (Acanthuridae) (continued)
- Whitemargin unicornfish (*Naso annulatus*)
- Spotted unicornfish (*Naso brevirostris*)
- Gray unicornfish (*Naso caesius*)

Triggerfishes (Balistidae)
- Titan triggerfish (*Balistapus viridescens*)
- Pinktail triggerfish (*Melichtys vidua*)
- Black triggerfish (*Melichtys niger*)
- Blue triggerfish (*Pseudobalistes □rass*)
- Picassofish (*Rhinecanthus aculeatus*)
- Bridled triggerfish (*Sufflamen fraenatus*)

Jacks (Carangidae)
- Bigeye scad (*Selar crumenophthalmus*)
- Mackerel scad (*Decapterus macarellus*)

Requiem Sharks (Carcharhinidae)
- Grey reef shark (*Carcharhinus amblyrhynchos*)
- Galapagos shark (*Carcharhinus galapagenis*)
- Blacktip reef shark (*Carcharhinus melanopterus*)
- Whitetip reef shark (*Triaenodon obesus*)

Soldierfishes/Squirrelfishes (Holocentridae)
- Bigscale soldierfish (*Myripistris berndti*)
- Brick soldierfish (*Myripristis amaena*)
- Whitetip soldierfish (*Myripristis vittata*)
- Yellowfin soldierfish (*Myripristis chryseres*)
- Pearly soldierfish (*Myripristis kuntee*)
- File-lined squirrelfish (*Sargocentron microstoma*)
- Crown squirrelfish (*Sargocentron diadema*)
- Peppered squirrelfish (*Sargocentron punctatissimum*)
- Blue-lined squirrelfish (*Sargocentron tiere*)
- Hawaiian squirrelfish (*Sargocentron xantherythrum*)
- Saber or long jaw squirrelfish (*Sargocentron spiniferum*)
- Spotfin squirrelfish (*Neoniphon* spp.)

Flagtails (Kuhliidae)
- Hawaiian flagtail (*Kuhlia sandvicensis*)

Rudderfishes (Kyphosidae)
- Grey sea chub (*Kyphosus bigibbus*)
- Blue sea chub (*Kyphosus cinerascens*)
- Brassy chub (*Kyphosus vaigenses*)

Wrasses (Labridae)
- Saddleback hogfish (*Bodianus bilunulatus*)
- Razor wrasse (*Xyricthys pavo*)
- Whitepatch wrasse (*Xyrichtes aneitensis*)
- Ring-tailed wrasse (*Oxycheilinus unifasciatus*)
- Cigar wrasse (*Cheilio inermis*)
- Surge wrasse (*Thalassoma purpureum*)
- Redribbon wrasse (*Thalassoma quinquevittatum*)
- Sunset wrasse (*Thalassoma lutescens*)
- Rockmover wrasse (*Novaculichthys taeniourus*)

Goatfishes (Mullidae)
- Yellow goatfish (*Mulloidichthys* spp.)
- Orange goatfish (*Mulloidichthys pfleugeri*)
- Yellowfin goatfish (*Mulloidichthys vanicolensis*)
- Yellowstripe goatfish (*Mulloidichthys flaviolineatus*)
- Doublebar goatfish (*Parupeneus bifasciatus*)
- Yellowsaddle goatfish (*Parupeneus cyclostomus*)
- Side-spot goatfish (*Parupeneus pleurostigma*)
- Multi-barred goatfish (*Parupeneus multifaciatus*)
- Bantail goatfish (*Upeneus arge*)

Mullets (Mugilidae)
- Striped mullet (*Mugil cephalus*)
- Engel's mullet (*Moolgarda engeli*)
- False mullet (*Neomyxus leuciscus*)

Moray Eels (Muraenidae)
- Yellowmargin moray (*Gymnothorax flavimarginatus*)
- Giant moray (*Gymnothorax javanicus*)
- Undulated moray (*Gymnothorax undulatus*)

Octopuses (Octopodidae)
- Day squid (*Octopus cyanea*)
- Night squid (*Octopus ornatus*)

Threadfins (Polynemidae)
- Sixfeeler threadfin (*Polydactylus sexfilis*)

Bigeyes (Pricanthidae)
- Glasseye (*Heteropriacanthus cruentatus*)

Parrotfishes (Scaridae)
- Parrotfish (*Scarus* spp.)
- Stareye parrotfish (*Catolomus carolinus*)

Barracudas (Sphyraenidae)
- Heller's barracuda (*Sphyraena helleri*)
- Great barracuda (*Sphyraena barracuda*)

Aquarium Taxa/Species

Surgeonfishes (Acanhturidae)
- Yelow tang (*Zebrasoma flavescens*)
- Yellow-eyed surgeonfish (*Ctenochaetus strigosus*)
- Achilles tang (*Acanthurus □rasses□*)

Moorish Idols (Zanclidae)
- Moorish idol (*Zanclus cornutus*)

Angelfishes (Pomacanthidae)

Moray Eels (Muraenidae)
- Dragon moray (*Enchelycore pardalis*)

Hawkfishes (Cirrhitidae)
- Longnose hawkfish (*Oxycirrhites typus*)

Table 4-1. The fish and invertebrate species with EFH designated in the Hawaiian Islands OPAREA (continued).

Aquarium Taxa/Species (Continued)
Butterflyfishes (Chaetodontidae)
- Threadfin butterflyfish (*Chaetodon auriga*)
- Raccoon butterflyfish (*Chaetodon lunula*)
- Saddled butterflyfish (*Chaetodon ephippium*)

Damselfishes (Pomacentridae)
Scorpionfishes (Scorpaenidae)
Feather-duster Worms (Sabellidae)

Potentially Harvested Coral Reef Taxa (PHCRT):

Fish Management Unit Species
Other Wrasses (Labridae spp.) [1]
Requiem Sharks (Carcharhinidae spp.) [1]
Hammerhead Sharks (Sphyrnidae spp.) [1]
Whiptail Stingrays (Dasyatididae)
Eagle Rays (Myliobatidae)
Manta Rays (Mobulidae)
Other Groupers (Serranidae spp.) [2]
Jacks/Trevallies (Carangidae) [3]
Other Soldierfishes/Squirrelfishes (Holocentridae spp.) [1]
Other Goatfishes (Millidae) [1]
Other Surgeonfishes (Acanthuridae spp.) [1]
Other Emperor Fishes (Lethrinidae) [4]
False Moray Eels (Chlopsidae) [1]
Conger Eels (Congridae) [1]
Snake Eels (Ophichthidae) [1]
Other Moray Eels (Muraenidae) [1]
Cardinalfishes (Apogonidae)
Bigeyes (Pricanhtidae)
Other Butterflyfishes (Chaetodontidae spp.) [1]
Other Aangelfishes (Pomacanthidae spp.) [1]
Other Damselfishes (Pomacentridae) [1]
Scorpionfishes (Scorpaenidae) [3]
Blennies (Blenniidae)
Other Barracudas (Sphyraenidae spp.) [1]
Sandperches (Pinguipedidae)
Left-eye Flounderes (Bothidae)
Right-eye Flounderes (Pleuronectidae)
Soles (Soleidae)
Trunkfishes (Ostraciidae)
Pufferfishes (Teradontidae)
Porcupinefishes (Diodontidae)
Remoras (Echineididae)
Tilefishes (Malacanthidae)
Coral Crouchers (Caracanthidae)

Fish Management Unit Species (continued)
Soapfishes (Grammistidae)
Trumpetfishes (Aulostomidae)
- Chinese Trumpetfish (*Aulostomus chinensis*)

Cornetfishes (Fistularidae)
- Reef cornetfish (*Fistularia commersoni*)

Herrings and Sardines (Clupeidae)
Anchovies (Engraulidae)
Gobies (Gobiidae)
Other Snapperes (Lutjanidae) [2]
Other Triggerfishes (Balistidae spp.) [1]
Other Filefishes (Monocanthidae spp.) [1]
Rudderfishes (Kyphosidae) [1]
Hawkfishes (Cirrhitidae) [1]
Frogfishes (Antennariidae)
Pipefishes and Seahorses (Syngnathidae)

Invertebrate Management Unit Species
Mollusks (Mollusca) [1]
- Sea Snails and Sea Slugs (Gastropods)
- Bivalve (Oysters and Clams)
  - Black-lipped pearl oyster (*Pinctada margaritifera*)
  - Other Clams

Squids and Octopuses (Cephalopods)
Tunicates (Ascidians)
Moss Animals (Bryozoans)
Mantis Shrimps, Lobsters, Crabs, and Shrimps (Crustacean) [5]
Sea Cucumbers and Sea Urchins (Echinoderms)
Segmented Worms (Annelids)

Sessile Benthos Management Unit Species
Algae (Seaweeds)
Sponges (Porifera)
Corals (Cnidaria)
- Hydrozoans
  - Hydroid Fans (Solanderidae)
- Scleractinian Anthozoans
  - Stony Corals (Scleractinia)
  - Mushroom Corals (Fungiidae)
  - Ahermatypic Corals (Azooxanthellate)
- Non-Scleractinian Anthozoans
  - Anemones (Actinaria)
  - Colonial Anemones or Soft Zoanthid Corals (Zoanthidae)
  - Soft Corals and Gorgonians (Alcyonaria)

Small/Large Polyp Corals
Live Rocks [6]

[1] Species not listed under the Currently Harvested Coral Reef Taxa
[2] Species not managed under Bottomfish FMP or included in proposed Bottomfish Amendment 8 (35 additional species)
[3] Species not listed under Currently Harvested Coral Reef Taxa, managed under Bottomfish FMP, or included in proposed Bottomfish Amendment 8
[4] Excluding hogo (*Pontinus macrocephela*) which is included in proposed Bottomfish Amendment 8 (emperors/snappers)
[5] Species not managed under Crustacean FMP
[6] For a description of deep-sea corals see section 2.7.8.2.

*Includes all other coral reef ecosystem management unit species that are marine plants, invertebrates, and fishes that are not listed under the Currently Harvested Coral Reef Taxa or are not bottomfish management unit species, crustacean management unit species, Pacific pelagic management unit species, precious coral or seamount groundfish.

Habitats encompassing the shallow-water complex consist of shelf and slope areas (Spalding et al. 2001) inhabited by snappers (*Aprion* spp. and *Lutjanus* spp.) and large carangids (jacks/trevallies; WPRFMC 1998; 2004a). The shelf area includes various habitats such as mangrove swamps, seagrass beds, shallow lagoons, coral and rocky substrate, sandy inshore reef flats, deep channels, and hard, flat, coarse sandy bottoms. Seaward reefs, outer deep reef slopes, banks, and deeper waters of coral reefs comprise the slope areas (Allen 1985; Heemstra and Randall 1993; Myers 1999). The deep-water complex consists of high relief areas with hard rocky bottoms such as steep slopes, pinnacles, headlands, rocky outcrops, and coral reefs (Allen 1985; Parrish 1987; Haight et al. 1993) inhabited by deep-water lutjanids (*Etelis* spp., *Pristipomoides* spp., and *Aphareus* spp.) and the endemic Hawaiian grouper (WPRFMC 1998). Habitat requirements for all life stages of the 14 designated EFH shallow-water and deep-water complexes can be found in **Table 4-2**.

Life History—Little is known about the ecology (life history, habitat, feeding, migration, and spawning) of the deep-slope bottomfish in the Hawaiian archipelago (WPRFMC 1998), and limited information is available for larval, juvenile, and adult life stages for various deep-slope bottomfish genera (shallow-water and deep-water complexes).

Jacks/trevallies (carangids) occur singly, in small groups (*Caranx* spp.), or in schools (*Pseudocaranx* spp.); whereas *Seriola* spp. may be found in small to moderate schools within the shallow-water complex (Honebrink 2000). Large jacks are highly mobile, wide-ranging predators that inhabit the open waters above coral reefs or swim in upper levels of the open sea (Sudekum et al. 1991). They spawn pelagically or close to shore at temperatures of 18° to 30°C (Miller et al. 1979; Haight 2004a) and utilize estuaries (Hanalei Bay, Kaua‘i; Kane‘ohe Bay, O‘ahu) as nurseries (Meyer et al. 2001; Smith and Parrish 2005). Spawning seasons for most carangids are fairly long, generally peaking during summer months (e.g., *Caranx* spp: April to November with June/July peak) (Honebrink 2000).

Within the shallow-water complex, snappers form large aggregations (*Lutjanus*) near areas of prominent relief (e.g., coral heads, ledges, caves) and can also be found solitarily or in small groups (WPRFMC 1998; Haight 2004b). In the deep-water complex, eteline snappers (*Pristipomoides* spp., *Etelis* spp., *Aphareus* spp.) and groupers (*Epinephelus* spp.) aggregate near areas of high bottom relief in small and large mixed groups or singularly at depths of 100 to 500 m (Allen 1985; Moffitt 1993; Haight 2004c, 2004d, 2004e; Mazurek 2004). Juvenile eteline snappers (e.g., pink snapper) form patchy aggregations on soft, featureless bottoms with sources of increased suspended materials at depths of 60 to 90 m as nursery areas (Parrish et al. 1997). Both larval snappers and groupers avoid surface waters, are more abundant over the continental shelf, and are more evenly distributed in the water column at night (Leis 1987).

Snappers may be batch or serial spawners, spawning multiple times over the course of the season (spring and summer with peak activity occurring in November and December). Some snapper species have also been known to exhibit a shorter, more well-defined spawning period (July to September), or have a protracted spawning period (June through December peaking in August) (Allen 1985; Parrish 1987; Moffitt 1993). Snapper spawning coincides with lunar periodicity corresponding with new/full moon events (Grimes 1987; Myers 1999). Some snappers (e.g., pink [*Pristipomoides filamentosus]*) display a crepuscular periodicity and migrate diurnally from area of high relief during the day at depths of 100 to 200 m to shallow (30 to 80 m), flat shelf areas at night (Moffitt and Parrish 1996). Other snapper species exhibit higher densities on up-current side islands, banks, and atolls (Moffitt 1993).

Although data on the reproduction of Pacific deep-water grouper species is lacking, all grouper species studied to date have shown to be protogynous hermaphrodites, in which the fish functions first as a female and then changes to a male (WPRFMC 2001). Groupers undergo small, localized migrations of several kilometers to congregate at favored spawning sites (Heemstra and Randall 1993). Their breeding season is abbreviated (peaking one to two months) with an unknown number of spawnings occurring per individual male or female. Spawning is typically seasonal (e.g., Hawaiian grouper: January through June, peaking in April and again in June), synchronized by moon phase, and often takes place in large aggregations (Myers 1999; Cornish 2004).

Table 4-2. Bottomfish Management Unit Species EFH Designations. Habitat: Mangrove (Ma), Lagoon (La), Estuarine (Es), Seagrass Beds (SB), Soft Substrate (Ss), Coral Reef/Hard Substrate (Cr/Hs), Patch Reefs (Pr), Surge Zone (Sz), Deep-slope Terraces (DST), Pelagic/Open Ocean (Pe). Life History Stage: Egg (E), Larvae (L), Juvenile (J), Adult (A).

Management Unit Species/Taxa	Ma	La	Es	SB	Ss	Cr/Hs	Pr	Sz	DST	Pe	Comments
BOTTOMFISH											
Shallow-water Species Complex (0 to 100 m)											
Gray jobfish (*Aprion virescens*)		A		J	J	A,J	A,J		A	E,L	Adult depth of 3-180 m
Thicklip trevally (*Pseudocaranx dentex*)		A	A		J	A,J			A	E,L	Adult depth of 18-183 m
Giant trevally (*Caranx ignoblis*)			J		J					E,L	Adult depth of 80 m
Black jack (*Caranx lugubris*)									A	A,J,L,E	Adult depth of 12-354 m
Amberjack (*Seriola dumerili*)						J	A,J		A	A,J,L,E	Adult depth of 0-250 m
Blue stripe snapper (*Lutjanus kasmira*)		A		J		A,J			A	E,L	Adult depth of 0-265 m
Deep-water Species Complex (100 to 400 m)											
Squirrelfish snapper (*Etelis carbunculus*)						A			A	E,L	Adult depth of 90-350 m
Longtail snapper (*Etelis coruscans*)						A			A	E,L	Adult depth of 164-293 m
Pink snapper (*Pristipomoides filamentosus*)					J				A	E,L	Juvenile depth of 65-100 m; Adult depth of 100-200 m
Yellowtail snapper (*Pristipomoides auricilla*)									A	E,L	Adult depth of 180-270 m
Pink snapper (*Pristipomoides sieboldii*)									A	E,L	Adult depth of 180-360 m
Yellow-barred snapper (*Pristipomoides zonatus*)									A	E.L	Adult depth of 100-200 m
Hawaiian grouper (*Epinephelus quernus*)				J	A	A				E,L	Adult depth of 20-380 m
Silver jaw jobfish (*Aphareus rutilans*)						A			A	E,L	Adult depth of 6-100 m

Source: WPRFMC 1998, 2001a

Common Prey Species—Carangids prey upon fish (parrotfish, roundscad, wrasses, bigeyes, eels), crustaceans (lobsters, crabs, shrimp), gastropods, and cephalopods (squid, octopus) (Sudekum et al. 1991; Honebrink 2000). Snappers feed on a wide range of food items including fish, polychaetes, crabs, shrimp, other benthic crustaceans (stomatopods, lobsters), and large plankton (pelagic larval urochordates, larval gastropods, and larval tunicates); whereas the Hawaiian grouper consumes fish and crustaceans, particularly shrimp (WPRFMC 1998).

EFH Designations—(WPRFMC 1998; **Figures D-1, D-2, D-3, D-4, D-5**, and **D-6**; **Table 4-2**)

- Eggs and Larvae—EFH for these life stages is the water column extending from the shoreline to the outer limit of the EEZ down to a depth of 400 m and encompasses both the shallow-water and deep-water complexes.
- Juveniles and Adults—For these life stages, EFH is the water column and all bottom habitat which encompass steep-slope and high relief habitat extending from the shoreline to a depth of 400 m and includes the shallow-water and deep-water complexes.

HAPC Designations—(WPRFMC 1998; **Figures D-2, D-3, D-4, D-5**, and **D-6**)

Based on the known distribution and habitat requirements, all life stages of the BMUS have HAPC designated in the study area. These areas include all slopes and escarpments between 40 and 280 m. In addition, three known areas of juvenile pink snapper habitat (two off O‘ahu: Kane‘ohe Bay and Kailua Bay and one off southern Moloka‘i: adjacent to Kahanui swamp) have been designated as HAPC. These habitat areas consist of a flat, open bottom of fine, silty sand with little or no relief and close to focused sources of drainage (reef platforms, embayments, and anthropogenic sources) in water depths of 40 to 73 m (Parrish 1989).

4.2.2 Pelagic Management Unit Species

Status—Currently, 32 species and one genus are managed as PMUS by the WPRFMC through the FMP for the Pelagic Fisheries of the Western Pacific Region (WPRFMC 1986b) and subsequent amendments (WPRFMC 1998). PMUS are divided into the following species complex designations: marketable species, non-marketable species, and sharks (**Table 4-1**). The marketable species complex has been further divided into temperate and tropical assemblages. The temperate species complex includes those PMUS that are found in greater abundance outside tropical waters at higher latitudes (e.g., broadbill swordfish [*Xiphias gladius*], bigeye tuna [*Thunnus obesus*], northern bluefin tuna [*T. thynnus*], and albacore tuna [*T. alalunga*]). Additionally, a potential squid pelagic management unit consisting of three flying squids (neon flying squid [*Ommastrephes bartramii*], diamondback squid [*Thysanoteuthis rhombus*], and purpleback flying squid [*Sthenoteuthis oualaniensis*]) has been proposed by the WPRFMC for incorporation into the existing PMUS (NMFS 2004b). Currently, no data are available to determine if the PMUS are approaching an overfished situation (NMFS 2004c), except for the bigeye tuna. The NMFS (2004d) determined that overfishing was occurring Pacific wide on this species. In addition, shark species are afforded protection under the Shark Finning Prohibition Act (NMFS 2002b).

The broadbill swordfish, albacore tuna, common thresher shark (*Alopias vulpinus*), and salmon shark (*Lamna ditropis*) have been listed as data deficient on the IUCN Red List due to inadequate information to make a direct, or indirect assessment of its risk of extinction based on its distribution and/or population status (Safina 1996; Uozumi 1996a; Goldman and Human 2000; Goldman et al. 2001). The shortfin mako shark (*Isurus oxyrinchus*), oceanic whitetip shark (*Carcharhinus longimanus*), crocodile shark (*Pseudocarcharius kamoharai*), blacktip shark (*C. limbatus*), and blue shark (*Prionace glauca*) have been listed as near threatened (Compagno and Musick 2000; Shark Specialist Group 2000a; Smale 2000; Stevens 2000a, 2000b). The bigeye tuna and the great white shark (*Carcharadon carcharias*) are listed as vulnerable on the IUCN Red List (Uozumi 1996b; Fergusson et al. 2000).

Distribution—PMUS occur in tropical and temperate waters of the western Pacific Ocean (NMFS 2001). Geographical distribution among the PMUS is governed by seasonal changes in ocean temperature. These species range from as far north as Japan, to as far south as New Zealand. Albacore tuna, striped

marlin (*Tetrapurus audax*), and broadbill swordfish have broader ranges and occur from 50°N to 50°S (WPRFMC 1998).

Habitat Preference—PMUS are typically found in epipelagic to pelagic waters; however, shark species can be found in inshore benthic, neritic to epipelagic, and mesopelagic waters (**Table 4-3**). Factors such as gradients in temperature, oxygen, or salinity can affect the suitability of a habitat for pelagic fishes. Skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*T. albacares*), and Indo-Pacific blue marlin (*Makaira nigricans*) prefer warm surface layers where the water is well-mixed and relatively uniform in temperature (WPRFMC 1998). Species such as albacore tuna, bigeye tuna, striped marlin, and broadbill swordfish, prefer temperate waters associated with higher latitudes and greater depths (WPRFMC 1998). Certain species, such as broadbill swordfish and bigeye tuna, are known to aggregate near the surface at night. However, during the day broadbill swordfish can be found at depths of 800 m and bigeye tuna around 275 to 550 m (WPRFMC 1998). Juvenile albacore tuna generally concentrate above 90 m with adults found in deeper waters (90 to 275 m) (WPRFMC 1998). Habitat requirements for all life stages of the 32 designated PMUS can be found in **Table 4-3**.

Life History—Migration and life history patterns of most PMUS are poorly understood in the Pacific Ocean (NMFS 2001). Additionally, very little is known about the distribution and habitat requirements of the juvenile life stage of tuna and billfish prior to recruitment into fisheries (WPRFMC 1998). Seasonal movements of temperate tunas, such as the northern bluefin and albacore, are more predictable and better defined than billfish migrations (NMFS 2001). Tuna and related species tend to move toward the poles during the warmer months and return to the equator during cooler months (WPRFMC 1998). Most pelagic species make daily vertical migrations, inhabiting surface waters at night and deeper waters during the day (NMFS 2001). Spawning for pelagic species generally occurs in tropical waters but may include temperate waters during warmer months. Information is lacking about the life history stages of species that are not targeted by fisheries in the Pacific such as gempylids, sharks (e.g., crocodile), and pomfrets (WPRFMC 1998).

Common Prey Species—Major prey items for the PMUS vary substantially depending upon life stage, region, and season. Adults feed on a variety of small fish (scombrids, gempylids, flying fish), squids, and crustaceans (WPRFMC 1998).

EFH Designations—(WPRFMC 1998; **Figure D-7**; **Table 4-3**)

- Eggs/Larvae—EFH for these life stages is the (epipelagic zone) water column down to a depth of 200 m from the shoreline to the outer limit of the EEZ.
- Juveniles/Adults—For these life stages, EFH is the water column down to a depth of 1,000 m from the shoreline to the outer limit of the EEZ.

HAPC Designations—(WPRFMC 1998; **Figure D-7**)

HAPC for this group is the entire water column to a depth of 1,000 m above all seamounts and banks with summits shallower than 2,000 m within the EEZ.of the Hawaiian archipelago.

4.2.3 Crustacean Management Unit Species

Status—Five species and one genus are currently managed as CMUS by the WPRFMC through the FMP of the Spiny Lobster Fisheries of the Western Pacific Region and the Final Combined FMP, EIS, Regulatory Analysis, and Draft Regulations for the Spiny Lobster Fisheries of the Western Pacific Region (WPRFMC 1981, 1982) and subsequent amendments (WPRFMC 1998, 2001a). CMUS are divided into the spiny and slipper lobster complex and the Kona crab (*Ranina ranina*) (WPRFMC 1998). Five species are managed in the spiny and slipper lobster complex by the CMUS and the Potentially Harvested Coral Reef Taxa (PHCRT) of the CRE MUS (WPRFMC 1998, 2001a): Hawaiian spiny lobster (*Panulirus marginatus*), spiny lobster (*P. penicillatus* and *Panulirus* spp.), ridgeback spiny lobster (*Scyllarides haani*), and Chinese slipper lobster (*Parribacus antarticus*). The Kona crab is managed as a single species as

Table 4-3. Pelagic Management Unit Species EFH Designations. Habitat: Mangrove (Ma), Lagoon (La), Estuarine (Es), Seagrass Beds (SB), Soft Substrate (Ss), Coral Reef/Hard Substrate (Cr/Hs), Patch Reefs (Pr), Surge Zone (Sz), Deep-slope Terraces (DST), Pelagic/Open Ocean (Pe). Life History Stage: Egg (E), Larvae (L), Juvenile (J), Adult (A), Spawners (S).

Management Unit Species/Taxa	Ma	La	Es	SB	Ss	Cr/Hs	Pr	Sz	DST	Pe	Comments
PELAGIC											
Marketable Species Complex:											
Temperate Species											
Striped marlin (*Tetrapurus audax*)										A,J.L.E	Depth Distribution: governed by temperature stratification
Broadbill swordfish (*Xiphias gladius*)										A,J.L.E	Depth Distribution: surface to 1,000 m
Northern bluefin tuna (*Thunnus thynnus*)										A,J,L,E	No data
Albacore tuna (*Thunnus alalunga*)										A,J,L	Depth Distribution: surface to 380 m
Bigeye tuna (*Thunnus obesus*)										A,J,L,E	Depth Distribution: surface to 600 m
Mackerel (*Scomber* spp.)										A,J,L,E	No data
Promfet (Bramidae)											
Sickle pomfret (*Tatactichthys steindachneri*)										A,J,L,E	Depth Distribution: surface to 300 m
Lustrous pomfret (*Eumegistus illustris*)										A,J,L,E	Depth Distribution: surface to 549 m
Tropical Species											
Yellowfin tuna (*Thunnus albacares*)										A,J,L,E	Depth Distribution: upper 100 m with marked oxyclines
Kawakawa (*Euthynnus affinis*)										A,J,L,E	Depth Distribution: 36-200 m
Skipjack tuna (*Katsuwonus pelamis*)										A,J,L,E	Depth Distribution: surface to 263 m
Frigate tuna (*Auxis thazard*)										A,J,L,E	No data
Bullet tuna (*Auxis rochei*)										A,J,L,E	No data
Indo-Pacific blue marlin (*Makaira nigricans*)										A,J,L,E	Depth Distribution: 80-100 m
Black marlin (*Makaira indica*)										A,J,L,E	Depth Distribution: 457-914 m
Shortbill spearfish (*Tetrapturus angustirostris*)										A,J,L,E	Depth Distribution: 40-1,830 m
Sailfish (*Istiophorus platypterus*)										A,J,L,E	Depth Distribution: 10-20 to 200-250 m
Dolphinfishes (Coryphaenidae)											
Dolphinfish (*Coryphaena hippurus*)			A,J							A,J,L,E	No data
Pompano dolphinfish (*Coryphaena equiselas*)										A,J,L,E	No data
Wahoo (*Acanthocybium solandri*)										A,J,L,E	Adult depth <200 m
Moonfish (*Lampris guttatus*)										A,J	Depth Distribution: surface to 500 m
Non-marketable Species Complex:											
Snake mackerels/oilfish (Gempylidae)											
Escolar (*Lepidocybium flavobrunneum*)										A,J,L,E	Depth Distribution: surface to 200 m
Oilfish (*Ruvettus pretiosus*)										A,J,L,E	Depth Distribution: surface to 700 m

Table 4-3. Pelagic Management Unit Species EFH Designations. Habitat: Mangrove (Ma), Lagoon (La), Estuarine (Es), Seagrass Beds (SB), Soft Substrate (Ss), Coral Reef/Hard Substrate (Cr/Hs), Patch Reefs (Pr), Surge Zone (Sz), Deep-slope Terraces (DST), Pelagic/Open Ocean (Pe). Life History Stage: Egg (E), Larvae (L), Juvenile (J), Adult (A), Spawners (S) (continued).

Management Unit Species/Taxa	Ma	La	Es	SB	Ss	Cr/Hs	Pr	Sz	DST	Pe	Comments
Shark Species Complex											
Crocodile shark (*Pseudocarcharias kamoharai*)										A,J	Depth Distribution: surface to 300 m
Common thresher shark (*Alopias vulpinus*)		J								A,J	Depth Distribution: surface to 366 m
Pelagic thresher shark (*Alopias pelagicus*)		A				A				A,J	Depth Distribution: surface to 152 m
Bigeye thresher shark (*Alopias superciliosus*)										A,J	Depth Distribution: surface to 500 m
Shortfin mako shark (*Isurus oxyrinchus*)										A,J	Depth Distribution: surface to 500 m
Longfin mako shark (*Isurus paucus*)										A,J	No data
Salmon shark (*Lamna ditropis*)										A,J	Depth Distribution: surface to 152 m
Silky shark (*Carcharhinus falcirormis*)									A	A,J	Adult depth of 18-500 m
Oceanic whitetip shark (*Carcharhinus longimanus*)										A,J	Adult depth of 37-152 m
Blue shark (*Prionace glauca*)										A,J,L,E	Depth Distribution: surface to 152 m

Source: WPRFMC 1998, 2001a

part of the CMUS and PHCRT (WPRFMC 1998; 2001a). Currently, no data are available to determine if these lobster species or the Kona crab of the CMUS are approaching an overfished situation (NMFS 2004b). None of the species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Members of CMUS occur in the Indo-Pacific region (Holthuis 1991; WPRFMC 1998). There are virtually no complete crustacean studies in the area of the tropical island Pacific; therefore, an assessment of their distribution is difficult (Eldredge 1995). There are 13 species of spiny lobster that occur in the tropical and subtropical Pacific between 35°N and 35°S (Holthuis 1991; WPRFMC 1998).

Habitat Preference—In general, adults of the CMUS favor sheltered areas with rocky substrates and/or sandy bottoms (**Table 4-4**). There is a lack of published data pertaining to the preferred depth distribution of decapod larvae and juveniles in this region (WPRFMC 2001a). The spiny lobster is restricted mainly to windward surf zones of oceanic reefs (e.g., NWHI; Pitcher 1993). Adult spiny lobsters are typically found on rocky substrate in well-protected areas, such as in crevices and under rocks (Holthuis 1991; Pitcher 1993). Adult and small juvenile spiny lobsters prefer depths less than 10 m (Holthuis 1991; Pitcher 1993), but can be found at depths of around 110 m (WPRFMC 2001a). The ridgeback spiny lobster likely occurs on rocky bottoms; it is known from depths between 10 and 135 m (Holthuis 1991). The Chinese slipper lobster prefers to live in coral or stone reefs with a sandy bottom (Holthuis 1991). Fishery takes of the Chinese slipper lobster are at depths of 20 to 70 m (Polovina 1993). The Kona crab is found in a number of environments, from sheltered bays and lagoons to surf zones, but prefers sandy habitat in depths of 24 to 115 m (Smith 1993; Poupin 1996; WPRFMC 1998). Habitat requirements for all life stages of the six designated CMUS can be found in **Table 4-4**.

Life History—Decapods exhibit a wide range of feeding behaviors, but most combine nocturnal predation with scavenging; large invertebrates are the typical prey items (WPRFMC 2001a). Both lobsters and crabs are ovigerous (females carry fertilized eggs on the outside of their body). There are limited data available concerning growth rates, reproductive potentials, and natural mortality rates at the various life history stages for members of the CMUS (WPRFMC 1998, 2001a). Spiny lobsters produce eggs in summer and fall. The larvae have a pelagic distribution of about one year and can be transported up to 3,704 km by prevailing ocean currents (WPRFMC 1998). This species is nocturnal, hiding during the daytime in crevices in rocks and coral reefs. At night, this lobster moves up through the surge channels to forage on the reef crest and reef flat (Pitcher 1993). The Kona crab spawns at least twice during each spawning season; there are insufficient data to define the exact spawning season in the study area (WPRFMC 1998). This species remains buried in the substratum during the day, emerging only at night to search for food (Bellwood 2002).

Common Prey Species—Spiny lobsters prey upon echinoderms, crustaceans, mollusks (primarily gastropods), algae, and seagrass (Pitcher 1993). Slipper lobsters feed on mollusks, other reef invertebrates, and animal carrion (Waikiki Aquarium 1998b), whereas the Kona crab is an opportunistic carnivore ingesting food particles and prey (Hoover 1998; WPRFMC 1998).

EFH Designations—(WPRFMC 1998; **Figures D-8**, **D-9**, **D-10**, **D-11**, **D-12**, and **D-13**; **Table 4-4**)

- Larvae—EFH for this life stage is the water column from the shoreline to the outer limit of the EEZ down to a depth of 150 m.
- Juveniles and Adults—For these life stages, EFH is all bottom habitat from the shoreline to a depth of 100 m.

HAPC Designations—(WPRFMC 1998; **Figure D-13**)

All banks in the NWHI with summits less than or equal to 30 m from the surface have been designated as HAPC.

Table 4-4. Crustaceans Management Unit Species EFH Designations. Habitat: Mangrove (Ma), Lagoon (La), Estuarine (Es), Seagrass Beds (SB), Soft Substrate (Ss), Coral Reef/Hard Substrate (Cr/Hs), Patch Reefs (Pr), Surge Zone (Sz), Deep-slope Terraces (DST), Pelagic/Open Ocean (Pe). Life History Stage: Egg (E), Larvae (L), Juvenile (J), Adult (A), Spawners (S).

Management Unit Species/Taxa	Ma	La	Es	SB	Ss	Cr/Hs	Pr	Sz	DST	Pe	Comments
CRUSTACEANS											
Spiny and Slipper Lobster Complex											
Hawaiian spiny lobster (*Panulirus marginatus*)		All			A, J	All	All		All	L	Depth Distribution: 9 to 183
Spiny lobster (*Panulirus penicillatus, Panulirus* sp.)		All			A,J	All	All		All	L	Depth Distribution: 9 to 183 m
Ridgeback slipper lobster (*Scyllarides haani*)						A					Depth Distribution: 10 to 135 m
Chinese slipper lobster (*Parribacus antarticus*)						A					Depth Distribution: 0 to 20 m
Kona Crab											
Kona crab (*Ranina ranina*)					A						Adult depth of 24 to 115 m

Source: WPRFMC 1998, 2001a

4.2.4 Precious Coral Management Unit Species

Status—Thirteen species encompassing 11 known precious coral beds occur in the Hawaiian archipelago. Nine of these precious coral beds are currently managed as PCMUS by the WPRFMC through the FMP for the Precious Corals Fisheries (and Associated Non-Precious Corals) of the Western Pacific Region (WPRFMC 1979) and subsequent amendments (WPRFMC 1998, 2001b, 2002; **Table 4-1**). In the Hawaiian archipelago (NWHI through the MHI), the PCMUS are divided into a shallow-water assemblage and a deep-water assemblage (WPRFMC 2002). Precious coral beds are treated as distinct management units because of their patchy distribution and sessile nature of individual colonies. These distinct management units encompass the deep-water assemblage precious coral beds consisting of pink (or red): *Coralliuim* spp., gold: *Gerardia* spp., *Callogorgia* spp., *Narella* spp., and *Calyptrophora* spp., and bamboo: *Lepidisis* spp. and *Acanella* spp. corals. The coral beds are classified as established (Makapu‘u: 3.6 km^2), conditional (Keahole Point: 0.24 km^2, Kaena Point: 0.24 km^2, and 180 Fathom Bank: 0.8 km^2), refugia (Wespac Bank: 0.8 km^2, and Brooks Bank: 1.6 km^2) or exploratory permit areas. The exploratory permit areas include all unexplored coral beds in the EEZ seaward of Hawai‘i, American Samoa, Guam, and American Flag Pacific Islands [AFPI]) (NOAA 1980; WPRFMC 1998). A fishery for both the shallow-water and deep-water precious coral assemblages has been sustainable for the past 40 years in Hawai‘i (Grigg 2001; WPRFMC 2002). Currently, no data are available to determine if precious coral stocks of the PCMUS are approaching an overfished situation (NMFS 2004c). Commercial or recreational harvesting of precious corals in the Makapu‘u coral bed has not occurred since 2001 (NMFS 2004b).

Distribution—Precious corals are globally distributed with the richest beds occurring on seamounts in the western Pacific Ocean and within caves and crevices in the western Mediterranean Sea (Grigg 1974a; 1993; Australian Gemmologist 2004). Shallow-water (30 to 100 m) and the deep-water (300 to 1,500 m) precious coral assemblages are known to occur in the EEZ around the NWHI and the MHI (Grigg 2002; WPRFMC 2005ba). Precious coral beds are also very likely to exist in the EEZ around American Samoa (WPRFMC 1998), the Northern Mariana Islands archipelago (Grigg and Eldredge 1975), and the remote U.S. Pacific Island possessions (e.g., Wake Island), but nothing is known of their distribution and abundance in these areas (WPRFMC 2002).

Habitat Preference—In the western Pacific region, precious coral polyps form colonies resembling small trees with the colonies forming aggregations referred to as beds. These precious coral beds inhabit distinct depth zones (shallow-water assemblage: black corals and deep-water assemblages: pink/red, gold, and bamboo corals) but have strikingly similar habitat requirements (WPRFMC 1998). All precious corals are non-reef builders, inhabit regions below the euphotic zone, occur on a variety of solid bottom substrates, and colonize areas that are swept by moderate to strong bottom currents (>25 cm/sec) (Grigg 1974a; WPRFMC 1998). Temperature does not appear to be a significant factor in delimiting suitable habitat for deep-water assemblages (e.g., *Corallium* spp.: 8° to 20°C); whereas the lower depth limit may be determined by temperature in the shallow-water assemblages (e.g., black corals) (Grigg 1993; WPRFMC 2001b). The highest densities for precious corals occur in areas of shell sandstone, limestone, and basaltic or metamorphic rock covered by a limestone veneer (WPRFMC 1998). The shallow-water assemblage of black corals (*Antipathes* spp.) is found in water depths ranging between 30 and 100 m, but may occur at depths ranging from 4,000 to 6,000 m (Waikiki Aquarium 1998c). These colonial corals are generally confined to low light areas, either in deep water or in turbid or shaded areas with vertical or near-vertical substrata and on or below undercut terraces (e.g., Kaua‘i and Maui; Grigg 2004). The deep-water assemblages of precious corals encompass two principal deepwater depth zones: 350 to 450 m and 1,000 to 1,500 m. These two zones comprise 1,700 NM^2 and 5,900 NM^2 of potential habitat and range from 18°N to 35°S in the Hawaiian Islands (WPRFMC 1998).

Life History—Little is known about the biology, ecology and dispersal of Hawaiian precious coral species (Baco-Taylor 2003). In general, western Pacific precious corals share several characteristics: slow growth, long-lived, low mortality and recruitment rates, ahermatypic, and filter feeders. Many are fan or bushy-shaped to maximize contact surfaces with particles or microplankton in the water column (Grigg 1993; WPRFMC 1998, 2002). Most species are unisexual or dioecious with reproductive maturity occurring between 12 to 13 years (e.g., angel skin coral [*Corallium secundum*] and black coral [*Antipathes dichotoma*]) and fertilization appearing to take place in the water column (WPRFMC 1998,

2002). *Corallium secundum* reproduces annually with spawning occurring during the summer months of June and July (Grigg 1974b, 1993). Asexual reproduction by fragmentation and re-cementation appears rare (WPRFMC 2001b).

Common Prey Species—Precious corals are filter feeders ingesting particulate organic matter (POM) and microzooplankton (Grigg 1993).

EFH Designations—(WPRFMC 1998, 2004a; **Figures D-14**, **D-15**, **D-16**, and **D-17**; **Table 4-5**)

- Eggs and Larvae—Not applicable.
- Juveniles and Adults—For these life stages, EFH for shallow-water black precious corals has been designated in the MHI between Milolii and South Point on the Big Island of Hawai‘i (at depths between 20 and 100 m), Auau Channel between Maui and Lāna‘i, and the southern border of Kauai (at depths between 20 and 100 m). For the deep-water pink (red), gold, and bamboo precious coral species, EFH is confined to the coral beds located off Keahole Point off the Main Island of Hawai‘i, Makapu‘u and Kaena Point off O‘ahu, and Wespac Bed (between Necker and Nihoa Islands and east of the French Frigate Shoals), Brooks Bank, and 180 Fathom Bank (around Palmyra Island) in the NWHI.

HAPC Designations—(WPRFMC 1998, 2004a; **Figure D-16**)

The HAPC for all life stages of the shallow-water black precious coral is Auau Channel in the MHI. These areas for the deep-water precious corals are Makapu‘u off O‘ahu, and Wespac and Brooks Bank Beds in the NWHI.

4.2.5 Coral Reef Ecosystem Management Unit Species

4.2.5.1 Introduction to Coral Reef Ecosystem Management Unit Species

The CRE FMP manages coral reef ecosystems surrounding the following U.S. Pacific Island areas: the State of Hawai‘i, the Territories of American Samoa and Guam, the Commonwealth of the Northern Mariana Islands (CNMI), and the Pacific remote island areas (PRIA) of Johnston Atoll, Kingman Reef, Palmyra and Midway Atolls, and Jarvis, Howland, Baker, and Wake Islands (WPRFMC 2001a; NMFS 2004e). For the purpose of the FMP, these areas make up the Western Pacific Region and the Currently Harvested Coral Reef Taxa (CHCRT)/PHCRT will only be delineated by specific U.S. Pacific Island areas when information exists. While this MRA focuses on the Hawaiian Islands OPAREA, all family information provided would correspond to the entire western Pacific Region unless otherwise noted.

In addition to EFH, WPRFMC also identifies HAPC which are specific areas within EFH that are essential to the life cycle of important coral reef species. HAPC for all life stages of the CHCRT and PHCRT of the CRE MUS includes all hardbottom substrate between depths of 0 and 100 m in the study area. Within this depth distribution, over 47 HAPC have been identified for the MHI and Nihoa of the NWHI chain. Of these, 9 sites occur within the inshore sections of the study area: 6 on O‘ahu and 3 on Hawai‘i (WPRFMC 2001a; Moncada et al. 2004; Jokiel and Friedlander n.d.; **Figure D-18**; **Table D-1**).

4.2.5.2 Currently Harvested Coral Reef Taxa

The CHCRT are managed under the CRE FMP by the WPRFMC. CHCRT are species that have been identified which: (1) are currently being harvested in state and federal waters and for which some fishery information is available, and (2) are likely to be targeted in the near future based on historical catch data. The WPRFMC has designated EFH for these MUS based on the ecological relationships among the species and their preferred habitat. These species complexes are grouped by the known depth distributions of individual species (WPRFMC 2001a). A complete list of managed species occurring in the study area and their respective fishery management units are found in **Table 4-1**.

Table 4-5. Precious Corals Management Unit Species EFH Designations. Habitat: Mangrove (Ma), Lagoon (La), Estuarine (Es), Seagrass Beds (SB), Soft Substrate (Ss), Hard Substrate (Hs), Patch Reefs (Pr), Surge Zone (Sz), Deep-slope Terraces (DST), Pelagic/Open Ocean (Pe).

Management Unit Species/Taxa	Ma	La	Es	SB	Ss	Hs	Pr	Sz	DST	Pe	Comments
PRECIOUS CORALS											
Shallow-water Species Assemblage (18-91 m)											
Black coral *(Antipathes dichomata)*					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 30-110 m
Pine black coral *(Antipathes grandis)*					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 45-110 m
Fern black coral *(Antipathes ulex)*					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 40-100 m
Deep-water Species Assemblage (274-1,372 m)											
Angel skin coral (*Corallium secundum*)					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 350-475 m
Red coral (*Corallium regale*)					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 380-410 m
Pink coral (*Corallium laauense*)					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 350-1,500 m
Midway deepsea coral (*Corallium* sp. nov)					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 300-1,500 m
Hawaiian gold coral (*Geraddia* sp.)					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 300-400 m
Gold coral (*Callogoria gilberti*)					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 300-1,500 m
Gold coral (*Narella* sp.)					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 300-1,500 m
Gold coral (*Calyprophora* spp.)					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 300-1,500 m
Bamboo coral (*Lepidisis olapa*)					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 300-400 m
Gold coral (*Acanella* sp.)					A,J,S	A,J,S			A,J,S	E,L	Depth Distribution: 300-1,500 m

Source: WPRFMC 1998

4.2.5.2.1 *Fish families*

- **Acanthuridae** (Surgeonfish)

Status—Eighteen of the twenty-four species of acanthurids found in the Hawaiian archipelago are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (Randall 1996; WPRFMC 2001a). In addition, the remaining 6 species of surgeonfishes have EFH designated under the PHCRT (NMFS 2004e). Currently, no data are available to determine if surgeonfish of the CHCRT are approaching an overfished situation (NMFS 2004c). Acanthurids are not of great commercial importance, but may form a significant part of the catch in insular and coastal regions with coral reefs and are valued in the aquarium trade (Randall 2001a). Aquarium species will be discussed further as part of a separate management unit species assemblage (WPRFMC 2001a). There are no endemic species of surgeonfish found in the Hawaiian archipelago but the convict surgeonfish (*Acanthurus triostegus sandvicensis*) is recognized as an endemic subspecies and the yellow tang (*Zebrasoma flavescens*) is abundant only in Hawai‘i even though it's distribution ranges from the north Pacific to southern Japan (WPRFMC 2001a). None of the species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Surgeonfish are found circumtropically around coral reefs with the majority of the species occurring in the Pacific and Indian Oceans (Allen and Steen 1987).

Habitat Preference—Surgeonfish are diurnal herbivores and planktivores seeking shelter on the reef at night. Surgeonfish eggs and larvae have a wide distribution and are found in pelagic waters. The acanthurids of the Hawaiian archipelago can be divided into four major habitat types: mid-water (e.g., Thompson's surgeonfish [*Acanthurus thompsoni*]), sand patch (e.g., eyestripe surgeonfish [*A. dussumieri*]), subsurge reef (e.g., brown surgeonfish [*A. nigrofuscus*]), and seaward reef or surge zone dwellers (e.g., Achilles tang [*A. achilles*]) (WPRFMC 2001a). Larvae are generally found in offshore waters at depths from 0 to 100 m (WPRFMC 2001a). As juveniles, surgeonfish are found in reef areas until they mature. In Hawai‘i, juveniles have been observed in tide pools (WPRFMC 2001a). Adults are found throughout coral reef habitats and are typically associated with subsurge reef habitats at depths from 0 to 150 m, but are more commonly found between 0 and 30 m deep (WPRFMC 2001a).

Life History—Many species of surgeonfish form large single-species or mixed-species schools (some numbering in the thousands) often associated with spawning or feeding behavior. In order to feed, the brown surgeonfish (*A. nigrofuscus*) has been known to migrate 500 to 600 m daily in schools numbering in the thousands (WPRFMC 2001a). Spawning activities are often associated with the lunar cycle and occur throughout the year with peak activity during the winter and early spring (Myers 1999). In the Hawaiian Islands, spawning of the convict surgeonfish (*A. triostegus*) occurs primarily from December to June (WPRFMC 2001a). Surgeonfish may spawn during a new moon or full moon depending on species and geography (Kuiter and Debelius 2001). Generally, spawning occurs at dusk involving groups, pairs, or both (Myers 1991). Schooling behavior is common in acanthurids especially associated with spawning events (WPRFMC 2001a).

Common Prey Species—Most acanthurids feed on benthic algae (Randall 1996).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—The water column from the shoreline to the outer boundary of the EEZ to a depth of 100 m.
- Adult/Juveniles—All bottom habitat and the adjacent water column from 0 to 100 m.

Table 4-6. Coral Reef Ecosystem Management Unit Species EFH Designations. Habitat: Mangrove (Ma), Lagoon (La), Estuarine (Es), Seagrass Beds (SB), Soft Substrate (Ss), Coral Reef/Hard Substrate (Cr/Hs), Patch Reefs (Pr), Surge Zone (Sz), Deep-slope Terraces (DST), Pelagic/Open Ocean (Pe). Life History Stage: Egg (E), Larvae (L), Juvenile (J), Adult (A), Spawners (S).

Management Unit Species/Taxa	Ma	La	Es	SB	Ss	Cr/Hs	Pr	Sz	DST	Pe	Comments
CORAL REEF ECOSYSTEM											
Currently Harvested Coral Reef Taxa											
Surgeonfishes (Acanhturinae)	J	A,J.S	A,J,S	J	A,J,S	A,J,S	A,J,S		A,J	E,L	Adult depth of 0-150 m
Unicornfishes (Nasinae)	J	A,J,S	J		A,S	A,J,S	A,J,S		A,S	All	Adult depth of 0-150 m
Triggerfishes (Balistidae)	J	A,J,S	J	J		A,J,S	A,J,S	A	A,S	E,L	Adult depth of 0-100 m
Jacks (Carangidae)	A,J,S	A,J,S	A,J,S	J	A,J,S	A,J,S	A,J,S		A,J,S	All	Adult depth of 0-350 m
Requiem Sharks (Carcharhinidae)	A,J	A,J	A,J	J	A,J	A,J	A,J		A,J	A,J	Adult depth of 1-300 m
Soldierfishes/Squirrelfishes (Holocentridae)		A,J,S	A,J,S	J		A,J,S	A,J,S		A,S	E,L	Adult depth of 0-235 m
Flagtails (Kuhliidae)	A,J	A,J	A,J	A,J				A		E,L	Adult depth of 3-18 m
Rudderfishes (Kyphosidae)	J	A,J,S	A,J,S		A,J	A,J,S	A,J,S	A,J		All	Adult depth of 1-24 m
Wrasses (Labridae)											
Bodianus and Xyricthys spp.		J	J	J	A,J,S	A,J,S	A,J,S		A,J,S	E,L	Juvenile depth of 2 m; Adult depth of 2-20 m
Cheilinus spp.		A,J	J		A,J,S	A,J,S	A,J,S		A,J,S	E,L	Adult depth of 1-30 m
Oxycheilinus spp.		A,J			A,J,S	A,J,S	A,J,S		A,J,S	E,L	Adult depth of 1-160 m
Cheilio spp.											Adult depth of 1-30 m
Halichoeres spp.		A,J	J		A,J,S	A,J,S		A,J		E,L	Adult depth of 1-30 m
Thalassoma spp.		A,J		J	A,J,S	A,J,S	A,J,S			E,L	Adult depth of 1-30 m
Novaculichthys spp.		A,J			A,J,S	A,J,S		A,J			Adult depth of 1-30 m
Goatfishes (Mullidae)		A,J	A	A,J	A,J	A,J	A,J			E,L	Adult depth of 1-10 m
Mullets (Mugilidae)	J	A,J,S	A,J,S	J		A,J		A		E,L	Adult depth of 0-20 m
Moray Eels (Muraenidae)	A,J,S	A,J,S	A,J,S	A,J	A,J,S	A,J,S	A,J,S	A,J,S	E,L		Adult depth of 0-150 m
Octopuses (Octopodidae)	A,J,S	All	A,J,S	All	All	All	All		All	L	Adult depth of 0-50 m
Threadfins (Polynemidae)	A,J	A,J,S	A,J,S		A,J,S			A,J		E,L	Juvenile depth of 0-100 m; Adult depth of 20-50 m

Table 4-6. Coral Reef Ecosystem Management Unit Species EFH Designations. Habitat: Mangrove (Ma), Lagoon (La), Estuarine (Es), Seagrass Beds (SB), Soft Substrate (Ss), Coral Reef/Hard Substrate (Cr/Hs), Patch Reefs (Pr), Surge Zone (Sz), Deep-slope Terraces (DST), Pelagic/Open Ocean (Pe). Life History Stage: Egg (E), Larvae (L), Juvenile (J), Adult (A), Spawners (S) (continued).

Management Unit Species/Taxa	Ma	La	Es	SB	Ss	Cr/Hs	Pr	Sz	DST	Pe	Comments
Bigeyes (Priacanthidae)						A,J	A,J		A,J	E,L	Adult depth of 5-400 m
Parrotfishes (Scaridae)	J	A,J,S		A,J		A,J,S	A,J,S			E,L	Adult depth of 1-30 m
Barracudas(Sphyraenidae)	A,J	A,J,S	A,J,S	J		A,J,S	A,J,S		A,S	All	Adult depth of 0-100 m
Aquarium Taxa/Species											
Surgeonfishes (Acanthuridae)	J	A,J,S	A,J,S	J	A,J,S	A,J,S	A,J,S		A,J,S	E,L	Adult depth of 1-113 m
Moorish Idols (Zanclidae)		A,J				A,J	A,J			E,L	Adult depth of 3-182 m
Angelfishes (Pomacanthidae)	J	A,J,S	J	J		A,J,S	A,J,S		A,S	E,L	Adult depth of 2-100 m
Hawkfishes (Cirrhitidae)		A,J,S				A,J,S	A,J,S		A,J,S	All	Adult depth of 0-30 m
Butterflyfishes (Chaetodontidae)	J	A,J,S	J	J		A,J,S	A,J,S		A,S	E,L	Adult depth of 0-30 m
Damselfishes (Pomacentirdae)	J	A,J,S	J	J		A,J,S	A,J,S		A,S	E,L	Adult depth of 1-55 m
Scorpionfishes (Scorpaenidae)	J	A,J,S	A,J,S	J		A,J,S	A,J,S			E,L	Adult depth of 10-50 m
Feather-duster Worms (Sabellidae)	A,J,S	A,J,S	A,J,S		A,J,S	A,J,S	A,J,S		A,J,S	E,L	Adult depth of 0-30 m
Potentially Harvested Coral Reef Taxa											
FISH MANAGEMENT UNIT SPECIES											
Hammerhead Sharks (Sphyrnidae)	A,J	A,J	A,J		A,J	A,J	A,J		A,J	A,J	Adult depth of 1-275 m
Whiptail Stingrays, Eagle Rays, and Manta Rays (Dasyatidae, Myliobatidae, and Mobulidae)	A,J	A,J	A,J		A,J	A,J	A,J		A,J	A,J	Adult depth of 0-100 m
Groupers (Serranidae)	J	A,J		J	A,J,S	A,J,S	A,J,S		A,S	E,L	Adult depth of 0-400 m
Emperor Fishes (Lehtrinidae)	J	A,J,S	J	J	A,J,S	A,J,S	A,J,S		A,S	E,L	Adult depth of 0-350 m
False Moray Eels, Conger and Garden Eels, and Snake Eels (Chlopsidae, Congridae, and Ophichthidae)	A,J,S	A,J,S	A,J,S	A,J	A,J,S	A,J,S	A,J,S		A,J,S	E,L	Adult depth of 0-105 m
Cardinalfishes (Apogonidae)	A,J,S	A,J,S	A,J,S	A,J,S		A,J,S	A,J,S		A,J,S	E,L	Adult depth of 0-80 m
Blennies (Blenniidae)		A,J,S	A,J,S		A,J,S	A,J,S	A,J,S		A,J,S	E,L	Adult depth of 1-40 m
Sandperches (Pinguipedidae)				A,J	A,J	A,J	A,J		A	E,L	Adult depth of 1-50 m

Table 4-6. Coral Reef Ecosystem Management Unit Species EFH Designations. Habitat: Mangrove (Ma), Lagoon (La), Estuarine (Es), Seagrass Beds (SB), Soft Substrate (Ss), Coral Reef/Hard Substrate (Cr/Hs), Patch Reefs (Pr), Surge Zone (Sz), Deep-slope Terraces (DST), Pelagic/Open Ocean (Pe). Life History Stage: Egg (E), Larvae (L), Juvenile (J), Adult (A), Spawners (S) (continued).

Management Unit Species/Taxa	Ma	La	Es	SB	Ss	Cr/Hs	Pr	Sz	DST	Pe	Comments
Flounders and Soles (Bothidae, Pleuronectidae, and Soleidae)		A,J				A,J	A,J		A,J	L	Adult depth of 1-100 m
Trunkfishes (Ostraciidae)		A	A	J	A,J	A			A	E,L	Adult depth of 1-100 m
Pufferfishes and Porcupinefishes (Tetradontidae and Diodontidae)	A,J	A,J	A,J		A,J	A,J	A,J		A,J	E,L	Adult depth of 0-100 m
Remoras (Echineididae)						A,J,S	A,J,S		A,J,S	E,L	Adult depth of 0-50 m
Tilefishes (Malacanthidae)		A,J,S			A,J,S	A,J,S	A,J,S			E,L	Adult depth of 6-115 m
Coral Crouchers (Caracanthidae)						A,J,S	A,J,S			E,L	Adult depth of 0-10 m
Soapfishes (Grammistidae)						A,J,S	A,J,S			E,L	Adult depth of 0-150 m
Trumpetfishes (Aulostomidae)	J	A,J,S		A,J	A	A,J,S	A,J,S			E,L	Adult depth of 0-122 m
Cornetfishes (Fistularidae)	J	A,J,S		A,J		A,J,S	A,J,S			E,L	Adult depth of 0-122 m
Herrings and Sardines (Clupeidae)	A,J,S	A,J,S	A,J,S			A,J,S	A,J,S		A,S	All	Adult depth of 0-20 m
Anchovies (Engraulidae)	A,J,S	A,J,S	A,J,S			A,J,S	A,J,S		A,S	All	No data
Gobies (Gobiidae)	All	All	All	All	All	All	All		All	All	Adult depth of 1-48 m
Snappers (Lutjanidae)	A,J,S	A,J,S	A,J,S	J		A,J,S	A,J,S		A,S	E,L	Adult depth of 0-400 m
Filefishes (Monocanthidae)	J	A,J,S	J	J		A,J,S	A,J,S		A,S	E,L	Adult depth of 2-200 m
Frogfishes (Antennariidae)		All		All		All	All			L	Adult depth of 0-20 m
Pipefishes and Seahorses (Syngnathidae)	All	All		All		All	All			L	Adult depth of 0-400 m
INVERTEBRATE MANAGEMENT UNIT SPECIES											
Mollusks (Mollusca)											
Gastropods											
Sea Snails (Prosobranchs)	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S		A,J,S	E,L	Adut depth of 1-24 m
Sea Slugs (Opisthobranchs)	A,J	A,J,S		A,J,S	A,J,S	A,J,S	A,J,S		A,J	E,L	Adult depth of 2-30 m
Bivalves (Oysters and Clams)											
Black-lipped pearl oyster (*Pinctada margartifera*)	A,J	A,J,S				A,J,S	A,J,S		A,J,S	E,L	Depth Distribution: littoral/sublittoral to 40 m
Other Clams	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S		A,J,S	E,L	Depth Distribution: 1-27 m

Table 4-6. Coral Reef Ecosystem Management Unit Species EFH Designations. Habitat: Mangrove (Ma), Lagoon (La), Estuarine (Es), Seagrass Beds (SB), Soft Substrate (Ss), Coral Reef/Hard Substrate (Cr/Hs), Patch Reefs (Pr), Surge Zone (Sz), Deep-slope Terraces (DST), Pelagic/Open Ocean (Pe). Life History Stage: Egg (E), Larvae (L), Juvenile (J), Adult (A), Spawners (S) (continued).

Management Unit Species/Taxa	Ma	La	Es	SB	Ss	Cr/Hs	Pr	Sz	DST	Pe	Comments
Squids (Cephalopods)		All	A,J,S	All	All	All	All		All	E,L	Adult depth from surface to 500 m
Octopuses (Octopodidae)	A,J,S	All	A,J,S	All	All	All	All		All	L	Adult depth of 1-1,000 m
Tunicates (Ascidians)	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A.J,S		A,J,S	E,L	Adult depth of 0-120 m
Moss Animals (Bryozoans)	A,J,S	A,J,S	A,J,S	A,J		A,J,S	A.J,S		A,J,S	E,L	Adult depth of 20-80 m
Crustaceans (Crustacea)											
Lobster: Spiny and Slipper		All			A,J	All	All		All	L	Adult depth of 20-55 m
Shrimps and Mantis Shrimps		All	A,J	A,J	A,J	All	All		All	L	Adult depth of 3-70 m
Crabs: True and Hermit	A,J	All	A,J	A,J	A,J	All	All		All	L	Adult depth of 0-115 m
Sea Cucumbers and Sea Urchins (Echinoderms)	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S		A,J,S	E,L	Adult depth of 0-2,000 m
Segmented Worms (Annelids)	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S		A,J,S	E,L	Adult depth of 30-70 cm to 20 m
SESSILE BENTHOS MANAGEMENT UNIT SPECIES											
Seaweeds (Algae)	All	All	All	All	All	All	All		All		Distribution: exposed shoreline, lagoon, bommies, inner/outer reef flat, reef crest, outer reef slope
Sponges (Porifera)	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S		A,J,S	E,L	Adult depth from intertidal to 50 m
Corals (Cnidaria)											
Hydrozoans											
Hydroid Fans (Solanderidae)	A,J,S	A,J,S	A,J,S			A,J,S	A,J,S		A,J,S	E,L	Depth Distribution: 0-100 m
Scleractinian Anthozoans											
Stony Corals (Scleractinia)		A,J,S	A,J,S			A,J,S	A,J,S		A,J,S	E,L	Depth Distribution: 0-60 m
Mushroom Corals (Fungiidae)		A,J,S	A,J,S			A,J,S	A,J,S		A,J,S	E,L	Depth Distribution: shallow water
Ahermatypic Corals (Azooxanthellate)		A,J,S	A,J,S		A,J,S	A,J,S	A,J,S		A,J,S	E,L	Depth Distribution: 44-1,761 m
Non-Scleractinian Anthozoans											

Table 4-6. Coral Reef Ecosystem Management Unit Species EFH Designations. Habitat: Mangrove (Ma), Lagoon (La), Estuarine (Es), Seagrass Beds (SB), Soft Substrate (Ss), Coral Reef/Hard Substrate (Cr/Hs), Patch Reefs (Pr), Surge Zone (Sz), Deep-slope Terraces (DST), Pelagic/Open Ocean (Pe). Life History Stage: Egg (E), Larvae (L), Juvenile (J), Adult (A), Spawners (S) (continued).

Management Unit Species/Taxa	Ma	La	Es	SB	Ss	Cr/Hs	Pr	Sz	DST	Pe	Comments
Anemones (Actinaria)	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S	A,J,S		A,J,S	E,L	Depth Distribution: 0-40 m
Colonial Anemones or Soft Zoanthid Corals (Zoanthidae)	A,J,S	A,J,S	A,J,S		A,J,S	A,J,S	A,J,S		A,J,S	E,L	Distribution: lagoon floors, back reef flats, reef crests, shallow sub-littoral zone
Soft Corals and Gorgonians (Alcyonaria)		A,J,S			A,J,S	A,J,S	A,J,S		A,J,S	E,L	Depth Distribution - soft corals: 3-30 m and gorgonians: <30-400 m
Small/Large Polyp Corals (Endemic spp.)		A,J				A,J	A,J		A,J		N/A
Live Rocks		A,J	A,J			A,J	A,J		A,J	E,L	N/A

Source: Colin and Arneson 1995; Sorokin 1995; Myers 1999; WPRFMC 2001a

- **Balistidae** (Triggerfishes)

Status—Six of the eleven species of triggerfish found in the Hawaiian archipelago are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (Randall 1996; WPRFMC 2001a). Five additional species of triggerfish have EFH designated under the PHCRT (WPRFMC 2001a). Currently, no data are available to determine if triggerfishes of the CHCRT are approaching an overfished situation (NMFS 2004c). Triggerfish are an important foodfish in western Pacific and some of the more colorful species are popular as aquarium fish (Myers 1999). None of the species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Triggerfish are predominately tropical reef dwellers found in the Atlantic, Indian, and Pacific Oceans (Allen and Steene 1987).

Habitat Preference—Most species of triggerfish are benthic with habitat preferences including protected lagoons, high-energy surge zones, ledges and caves of deep dropoffs, sand bottoms, and rocky coral areas. Adults prefer steeply sloping areas with high coral cover, caves and crevices. Depending on the species, depth preferences may range from shallow subtidal zones to waters deeper than 100 m (Myers 1999). Of the 11 species found in the Hawaiian archipelago, only one, the rough triggerfish (*Canthidermis maculates*), is strictly pelagic (Randall 1998). Balistid larvae are generally pelagic with prejuveniles often being associated with floating algae (WPRFMC 2001a).

Life History—Information is lacking on the spawning and migrational patterns of triggerfish in the western Pacific (WPRFMC 2001a). Triggerfish are generally solitary in habitat but do form pairs during spawning. The rough triggerfish can be found nearshore during spawning events (Randall 1996). Balastid spawning events show some correlation to lunar cycles and eggs are typically deposited in shallow pits excavated by the parents (WPRFMC 2001a).

Common Prey Species—Most triggerfish feed on a wide variety of invertebrates including hardshell mollusks and echinoderms; however, some species do feed on algae or zooplankton (Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—The water column from the shoreline to the outer boundary of the EEZ to a depth of 100 m.
- Adult/Juveniles—All bottom habitat and the adjacent water column from 0 to 100 m.

- **Carangidae** (Jacks)

Status—Two of the six species of scads, the bigeye scad (*Selar crumenophthalmus*) and the mackerel scad (*Decapterus macarellus*), are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (Randall 1996; WPRFMC 2001a). In addition, the remaining four species of scads and eighteen species of jacks have EFH designated under the PHCRT and/or BMUS (NMFS 2004e). Currently, no data are available to determine if the bigeye and mackerel scads of the CHCRT are approaching an overfished situation (NMFS 2004c). In the MHI, the bigeye and mackerel scads comprise the principal component of nearshore commercial fisheries (WPRFMC 2001a). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Carangids are a large family represented in all tropical and temperate seas with the majority being found in coral reef waters (Allen and Steene 1987; Myers 1999).

The mackerel scad is a circumtropical species and is widespread throughout the Indian Ocean. This species ranges from the Indo-West Pacific to the Marquesas Islands in the east, and from Japan in the north, south to Australia (Smith-Vaniz 1999).

Bigeye scad range from Japan and the Hawaiian Islands in the north, south to New Caledonia and Rapa, and throughout Micronesia (Myers 1999).

Habitat Preference—Carangid eggs are planktonic and larvae are common in nearshore waters (Miller et al. 1979). Juveniles can be found in nearshore and estuarine waters and occasionally form small schools over sandy inshore reef flats (Myers 1999). Adults are widely distributed in shallow coastal waters, estuaries, shallow reefs, deep reef slopes, banks, and seamounts (WPRFMC 2001a). Adult Carangids can range from reef habitats to deep slope habitats at depths of 0 to 350 m (WPRFMC 2001a).

Mackerel scad are a schooling species that are most often found in open water and frequently in insular habitats. This species can be found near the surface at times but is commonly taken at depths from 40 to 200 m (Froese and Pauly 2005).

Small to large schools of bigeye scad are typically found inshore or in shallow water and occasionally over shallow reefs in turbid water to depths of 170 m (Smith-Vaniz 1999).

The eggs of both the mackerel and bigeye scad are found in pelagic waters and after hatching, larvae and juvenile fish remain in the pelagic environment where they frequently form large aggregating schools. Juvenile aggregations have been identified as far as 145 km offshore (WPRFMC 2001a). Larval and juvenile fish remain in offshore pelagic waters for the first several months of their life, after which they migrate to the nearshore adult habitat (WPRFMC 2001a).

Life History—Carangid species spawn in pairs within larger aggregations associated with the lunar cycle. Information is lacking about the reproduction of these species but peak spawning occurs between May and August (WPRFMC 2001a). Somes species of scad (*Decapterus* spp. and *Selar* spp.) tend to spawn in pelagic environments. Spawning in these species occurs from March to August, peaking from May to July (WPRFMC 2001a).

Common Prey Species—Scads are planktivores, preying upon zooplankton (copepods, amphipods, crab megalops, fish larvae, and pteropods) as well as small fishes (anchovies and holocentrids), small shrimps, benthic invertebrates, and forams (WPRFMC 2001a; Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—The water column from the shoreline to the outer boundary of the EEZ to a depth of 100 m.
- Adult/Juveniles—All bottom habitat and the adjacent water column from 0 to 100 m.

- **Carcharhinidae** (Requiem sharks)

Status—Four of the eleven carcharhinid sharks found in the Hawaiian archipelago (Taylor 1993) are managed as part of the CHCRT by the WPRFMC (WPRFMC 2001a). The remaining seven species of requiem sharks have EFH designated under the PHCRT and/or the PMUS (NMFS 2004e). Currently, no data are available to determine if requiem sharks of the CHCRT are approaching an overfished situation (NMFS 2004c). Each of the CHCRT species has EFH designated within the boundaries of the study area (WPRFMC 2001a) and are listed on the IUCN Red List of threatened species. The grey reef shark (*C. amblyrhynchos*), blacktip reef shark (*C. melanopterus*), whitetip reef shark (*Triaenodon obesus*), and Galapagos shark (*C. galapagensis*) are categorized by the IUCN as near threatened species (Smale 2000b; 2000c; Heupel 2000; Bennett et al. 2003). In addition, the tiger shark (*Galeocerdo cuvier*) and the sandbar shark (*C. plumbeus*) found in the study area are listed as near threatened on the IUCN Red List of threatened species (Simpfendorfer 2000a; Shark Specialist Group 2000b). All of the requiem sharks are afforded protection under the Shark Finning Prohibition Act (NMFS 2002b).

Distribution—The requiem sharks are some of the most common and wide-ranging species found in all warm and temperate seas (WPRFMC 2001a).

In the western central Pacific, the grey reef shark ranges from Sumatra eastward to the Philippines, Australia, New Guinea, Hawai'i, and the Tuamotu archipelago (Compagno and Niem 1998).

The Galapagos shark is circumtropical in distribution with a preference for waters surrounding oceanic islands. In the tropical regions of the Pacific, the Galapagos shark can be found around Lord Howe Island, the Tuamoto archipelago, Middleton and Elizabeth Reefs, Hawai'i, Revillagigedo, Clipperton, Cocos, and the Galapagos Islands (Compagno 1984).

In the western Pacific, the blacktip reef shark ranges from South Africa, the Red Sea, Pakistan, and India eastward to the western central Pacific (Compagno and Niem 1998).

The whitetip reef shark is common in Polynesia, Melanesia, and Micronesia, northward to the Hawaiian Islands, and southwest to the Pitcairns (Compagno 1984).

Habitat Preference—Most species of requiem sharks inhabit tropical, continental, coastal, and offshore waters, but several species prefer coral reefs and oceanic islands (Compagno 1984). Requiem sharks inhabit a wide variety of coral reef habitats and there seems to be no real preference of any one over the others. Juvenile carcharhinids are often associated with inshore areas such as bays, seagrass beds, and lagoon flats but move into deeper waters as they mature. Adult sharks frequent inshore areas during mating or birthing events and on occasion for foraging (WPRFMC 2001a).

Grey reef sharks prefer open water, associated with coral reefs, particularly along steep outer slopes or dropoffs at depths from 1 to 274 m (Myers 1999).

Adult Galapagos sharks can be found over steep outer reef slopes and offshore banks at depths of 30 to 180 m. Juveniles are more commonly found in waters between 2 and 25 m (Myers 1999).

Blacktip reef sharks are common inshore and occasionally offshore on continental and insular shelves. This species is generally associated with reef flats, shallow lagoons, and reef margins (Compagno and Niem 1998; Myers 1999).

The whitetip reef shark is one of the most common sharks in lagoons and over seaward reefs and is frequently found resting on the bottom over sand patches. This species is generally found at depths greater than 3 m and has been observed as deep as 300 m (Compagno and Niem 1998; Myers 1999).

Life History—Carcharhinid sharks reproduce by internal fertilization and all but one species (tiger shark) in this family are placental viviparous (embryos are nourished by a placenta like organ in the female) (Cahmi et al. 1998; WPRFMC 2001a). Certain species of carcharhinids are demersal, while others range throughout the water column (Grace 2001).

Common Prey Species—Requiem sharks are opportunistic piscivores feeding on fish, elasmobranchs, squids, crustaceans, and mollusks (WPRFMC 2001a; Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figure D-19**; **Table 4-6**)

- Eggs/Larvae—Not applicable.
- Adult/Juveniles—All bottom habitat and the adjacent water column from 0 to 100 m to the outer extent of the EEZ.

- **Holocentridae** (Soldierfishes/Squirrelfishes)

Status—Twelve of the approximately seventeen species of the family Holocentridae (soldierfish/squirrelfish) inhabiting the Hawaiian archipelago are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (WPRFMC 2001a). In addition, the remaining four holocentrid species have EFH designated under the PHCRT (NMFS 2004e). Currently, no data are available to determine if soldierfishes/squirrelfishes of the CHCRT are approaching an overfished situation (NMFS 2004c). These fish are commonly sold in fish markets and are popular aquarium fish (Allen and Steene 1987). Holocentrids, particularly the brick soldierfish (*Myripristis amaena),* are commonly caught throughout the Hawaiian archipelago and maintain an important recreational fishery (WPRFMC 2001a). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Squirrelfish and soldierfish are found throughout the tropical Atlantic, Indian, and Pacific Oceans, with most species occurring in the Indo-Pacific region (Allen and Steene 1987).

Habitat Preference—The majority of soldierfish and squirrelfish occupy relatively shallow water over coral reefs or rocky bottoms (Randall and Greenfield 1999). Most holocentrid fish are nocturnally active and occupy the water column above the reef at night (Myers 1999). During the day, they can be found along dropoffs, in or near caves and crevices, under rocks or coral overhangs, or among branching corals. Holocentrid fish are found from shallow water down to approximately 40 m, with some species occurring as deep as 235 m (WPRFMC 2001a). Adults are usually demersal and larvae are planktonic for several weeks (Froese and Pauly 2005).

Life History—Information is lacking on the embryonic development and larval cycles of Holocentrids (WPRFMC 2001a). For one species of Holocentridae, the brick soldierfish, spawning occurs in open water and peaks from early April to early May, with a secondary peak in September. Spawning for this species is roughly correlated to the lunar cycle (WPRFMC 2001a).

Common Prey Species—Soldierfish feed mainly on large zooplankton (brachyuran crab megalops, hermit crab larvae and shrimps), whereas squirrelfish feed on benthic invertebrates and small fishes (WPRFMC 2001a; Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—The water column from the shoreline to the outer boundary of the EEZ to a depth of 100 m.
- Adult/Juveniles—All rocky and coral areas and the adjacent water column from 0 to 100 m.

- **Kuhliidae** (Flagtails)

Status—Two species of the family Kuhliidae are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). The Kuhliidae family is comprised of a single genus, *Kuhlia* (Myers 1999). Of the two managed species, the Hawaiian flagtail (*K. sandvicensis)*, is the only species found in the study area (Randall 1996). Currently, no data are available to determine if the Hawaiian flagtail of the CHCRT is approaching an overfished situation (NMFS 2004c). The Hawaiian flagtail is a prized foodfish and is endemic to the Hawaiian archipelago (WPRFMC 2001a). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Flagtails are distributed throughout the Indo-Pacific region (WPRFMC 2001a). In the Pacific Ocean, the Hawaiian flagtail is widely distributed around oceanic islands (Froese and Pauly 2005).

Habitat Preference—Hawaiian flagtails can be found in waters from 18° to 33°C and 1 to 39 psu. This species may be associated with a variety of habitats: in shallow waters along sandy beaches,

tide pools, tidal creeks, around mangrove forests, and in the lower reaches of freshwater streams (Benson and Fitzsimons 2002). Hawaiian flagtails form schools on the outer edge of surge-swept reefs where they aggregate under ledges, in holes, or in caves during the day (WPRFMC 2001a; Froese and Pauly 2005). At night, the schools disperse and the fish forage independently on plankton in the water column above the reef (Waikiki Aquarium 1999a; WPRFMC 2001a). Juveniles are found individually or in small aggregations in tidal pools or along shallow shoreline areas (Waikiki Aquarium 1999a; Randall and Randall 2001). Hawaiian flagtails can tolerate a wide range of temperatures and salinities, and can be found in freshwater, brackish water, or salt water (Waikiki Aquarium 1999a; Benson and Fitzsimons 2002).

Life History—The Hawaiian flagtail is eyryhaline throughout its entire life cycle (Benson and Fitzsimons 2002). Spawning for all species of flagtails occurs in marine or estuarine habitats (Benson and Fitzsimons 2002). Overall, information on the life history and habitat requirements of this family is lacking (WPRFMC 2001; Benson and Fitzsimons 2002).

Common Prey Species—The Hawaiian flagtail feeds on fishes, invertebrates, and insects (Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, **and D-24**; **Table 4-6**)

- Eggs/Larvae—The water column from the shoreline to the outer limits of the EEZ to a depth of 100 m.
- Adult/Juveniles—All bottom habitat and the adjacent water column from 0 to 27 m.

- **Kyphosidae** (Rudderfishes or Sea Chubs)

Status—Three species of the family Kyphosidae (grey sea chub [*Kyphosus bigibbus*], blue sea chub [*K. cinerascens*], and brassy chub [*K. vaigiensis*]) are found in the Hawaiian archipelago (Randall 1998), are managed as part of the CHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (NMFS 2004d). Currently, no data are available to determine if rudderfish of the CHCRT are approaching an overfished situation (NMFS 2004c). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Rudderfish are found in the Atlantic, Indian, and Pacific Oceans (Froese and Pauly 2005). In the Indo-Pacific, this family is found throughout the tropical and subtropical waters from Easter Island westward to the Red Sea (WPRFMC 2001a).

Habitat Preference—Rudderfish, or sea chubs, occur near shore over rocky bottoms or associated with coral reefs along exposed coasts (WPRFMC 2001a; Froese and Pauly 2005). Adults are usually found swimming several meters above the bottom. Eggs, larvae, and juveniles are found in the upper layer of pelagic waters. Juveniles are often found far out at sea associated with floating debris or seaweed (Myers 1999; WPRFMC 2001a; Froese and Pauly 2005).

The grey sea chub is found in tropical waters, from 35°N to 28°S, typically associated with reefs (Froese and Pauly 2005). This species is abundant around exposed seaward reefs of isolated high islands (Myers 1999).

The blue sea chub and the brassy chub occur in tropical waters from 30°N to 30°S at depths from 1 to 24 m (Froese and Pauly 2005). These species can be found associated with hard algal coated bottoms of exposed, surf-swept outer reef flats, lagoon reefs, and seaward reefs (Myers 1999).

Life History—Information is lacking on the spawning and migration of rudderfish (WPRFMC 2001a). Eggs and larvae are both subject to advection by ocean currents (WPRFMC 2001a). Adults spawn in large numbers in pelagic waters (Froese and Pauly 2005).

Common Prey Species—Most species of the subfamilies Girellinae and Kyphosinae are omnivorus, feeding mainly on seagrass, algae, *Sargassum*, and benthic invertebrates (Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae/Juvenile—The water column from the shoreline to the outer boundary of the EEZ to a depth of 100 m.
- Adult—All rocky and coral bottom habitat and the adjacent water column from 0 to 47 m.

♦ **Labridae** (Wrasses)

Status—Nine of the forty-three labrid species found in the Hawaiian archipelago are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (WPRFMC 2001a). In addition, the remaining thirty-four wrasse species have EFH designated under the PHCRT (NMFS 2004e). Fourteen species of wrasse are endemic to Hawai‘i (Randall 1996). Currently, no data are available to determine if labrids of the CHCRT are approaching an overfished situation (NMFS 2004c). In the Hawaiian archipelago, labrids make up a small percentage of the aquarium and commercial fish trade (WPRFMC 2001a). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Wrasses are found in shallow tropical and temperate seas of the Atlantic, Indian, and Pacific Oceans (Froese and Pauly 2005). This species is distributed throughout the shallow-water areas of the western Pacific (WPRFMC 2001a).

Habitat Preference—Labrids prefer shallow waters closely associated with coral reefs (WPRFMC 2001a). They inhabit steep outer reef slopes, channel slopes, and lagoon reefs. Wrasses can be found in virtually every habitat on tropical reefs, including rubble, sand, algae, seaweeds, rocks, flats, tidepools, crevices, caves, fringing reefs, and patch reefs (Allen and Steene 1987; WPRFMC 2001a). Most wrasses are found in relatively calm waters between about 3 and 20 m; however, some species occur at depths greater than 200 m (Allen and Steene 1987; WPRFMC 2001a) (e.g., cross seamount near Hawai‘i) (Chave and Mundy 1994). Adults roam the coral reefs during the day keeping close to coral or rocky cover (Froese and Pauly 2005). At night, they may rest in caves or under coral ledges, bury themselves in the sand, or lie motionless on the bottom (WPRFMC 2001a; Froese and Pauly 2005). Labrid eggs and larvae are pelagic and are routinely found in the open ocean (WPRFMC 2001a). Juveniles, like adults, inhabit a wide range of habitats from shallow lagoons to deep reef slopes (WPRFMC 2001a).

Life History—Wrasses are pelagic spawners and schooling behavior is usually associated with reproduction. In tropical waters, spawning occurs year-round along the outer edge of the patch reef or along the outer slope of more extensive reefs. Many labrids migrate to prominent coral or rock outcrops to spawn. Wrasses may spawn in large aggregations or in pairs depending on the maturity of the individuals (WPRFMC 2001a). Labrids exhibit two types of spawning behaviour: (1) aggregate spawning of large groups of a dozen to several hundred initial-phase males and females and (2) pair spawning of a terminal-phase male and an initial-phase female (WPRFMC 2001a).

Common Prey Species—Most labrids are carnivores, preying on benthic invertebrates (mollusks, crustaceans, polychaetes, sea urchins, brittle stars, tunicates, and forminiferans), fish, and fish eggs; some are planktivores (copepods, fish eggs, larval fish, and invertebrates), corallivores (live coral polyps), and cleaners, removing ectoparasites from larger fish (WPRFMC 2001a; Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figure D-19**; **Table 4-6**)

- Eggs/Larvae/Juvenile/Adult—The water column and all bottom habitats extending from the shoreline to the outer boundary of the EEZ to a depth of 100 m.

- **Mullidae** (Goatfishes)

Status—Eight of the thirteen species in the family Mullidae found in the Hawaiian archipelago are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (WPRFMC 2001). In addition, the remaining five species of goatfish have EFH designated under the PHCRT (NMFS 2004e). There are 10 native, one introduced (yellow-banded goatfish: *Upeneus vittatus*), and two endemic species (whitesaddle goatfish: *Parupeneus porphyreus* and yellowbarbel goatfish: *P. chrysonemus*) of goatfishes known from Hawaiian waters (WPRFMC 2001a). Currently, no data are available to determine if goatfishes of the CHCRT are approaching an overfished situation (NMFS 2004c). A number of goatfish are commercially important in the western Pacific and most of the catch is marketed fresh (Randall 2001b). None of these are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Goatfish are found in tropical and subtropical regions of the Atlantic, Indian, and Pacific Oceans (Froese and Pauly 2005). The majority of species in this family can be found in the Indo-West Pacific region (Allen and Steene 1987).

Habitat Preference—Generally, goatfish are found over sandy areas in shallow waters adjacent to reefs at depths of about 10 m (Allen and Steene 1987; WPRFMC 2001). However, some species have been reported as deep as 140 m (WPRFMC 2001a). Goatfish eggs and larvae are pelagic and adults and juveniles are found in demersal habitats associated with coral reefs, rocks, sand, mud, crevices, and ledges (WPRFMC 2001a).

Life History—Goatfish are commonly found schooling and may spawn either in groups or pairs (WPRFMC 2001a). Mullids spawn in pelagic waters with aggregations of 300 to 400 individuals being common for certain species (Allen and Steene 1987). Spawning aggregations are found near channels with heavy tidal flow (WPRFMC 2001a).

Common Prey Species—Goatfish use their chin barbells to probe the sand or holes in the reef for benthic invertebrates such as crabs, shrimps, isopods, amphipods, ostracods, stomatopods, planktonic crab megalops larvae and copepods, gastropods, and foraminiferans; some species consume small fish (WPRFMC 2001a; Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—The water column extending from the shoreline to the outer boundary of the EEZ to a depth of 100 m.
- Juvenile/Adult—All rocky/coral and sand-bottom habitat and the adjacent water column from 0 to 100 m.

- **Mugilidae** (Mullets)

Status—Three species of the family Mugilidae, two natives (Engel's mullet [*Moolgarda engeli*] and false mullet [*Neomyxus leuciscus*]) and one introduced form (striped mullet [*Mugil cephalus*]), are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if mullets of the CHCRT are approaching an overfished situation (NMFS 2004c). Several species of mullets are of moderate to major importance to fisheries in the western Pacific and small-scale, subsistence fisheries are probably also relatively large (Harrison and Senou 1999). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—The family Mugilidae can be found in all tropical and temperate seas but are most speciose in the Indo-West Pacific region (Harrison and Senou 1999; Foese and Pauly 2005).

The striped mullet is found in the coastal waters of the tropical and subtropical zones of all seas (Froese and Pauly 2005).

The Engel's mullet is found in the Indo-Pacific region from East Africa to the Marquesan and Tuamoto Islands and north to the Yaeyamas (Froese and Pauly 2005).

The false mullet is found in the Pacific Ocean around southern Japan and the Mariana, and Bonin Islands east to the Hawaiian, Line, and Ducie Islands (Froeses and Pauly 2005).

Habitat Preference—Most species are capable of tolerating a wide range of salt water concentrations and inhabit marine waters, brackish water lagoons, estuaries, and freshwater (Harrison and Senou 1999). Some species more typically inhabit brackish waters. Mullets are generally found feeding over reefs or sandy bottoms at depths around 20 m (Harrison and Senou 1999; WPRFMC 2001a).

The striped mullet is a coastal species that often enters estuaries and rivers (Froese and Pauly 2005). This species generally aggregates over sandy or muddy bottoms in shallow water (WPRFMC 2001a; Froese and Pauly 2005). The striped mullet is found in subtropical waters between 42°N and 42°S at depths from 0 to 120 m in water temperatures between 8° and 24°C (Froese and Pauly 2005).

The Engel's mullet is found in tropical waters from 25°N to 24°S usually associated with coral reefs. Adults usually inhabit sandy to muddy areas of reef flats and shallow lagoons while juveniles are generally found in tide pools (Froese and Pauly 2005).

The false mullet is found in tropical waters between 30°N and 30°S at depths from 0 to 4 m. This species inhabits sandy shores, tide pools, and rocky surge areas. The false mullet tends to move inshore to surface waters at night (Froese and Pauly 2005).

Life History—Information is lacking concerning the spawning and migration of these species (WPRFMC 2001a). It is presumed that the eggs and larvae are dispersed by advection (WPRFMC 2001a). The acute-jawed mullet is a schooling species. The striped mullet spawns from July to October (Froese and Pauly 2005).

Common Prey Species—Mullets feed on fine algae, diatoms, and detritus of bottom sediments (Randal 1996).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—The water column from the shoreline to the outer limits of the EEZ to a depth of 100 m.
- Juvenile/Adult—All sand and mud bottoms and the adjacent water column from 0 to 27 m.

- **Muraenidae** (Moray Eels)

Status—Three of the thirty-eight members of the family Muraenidae found in the Hawaiian archipelago are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (WPRFMC 2001a). The remaining thirty-five moray eels, excluding the dragon moray (*Enchelycore paradilis*) which is an aquarium taxa, have EFH designated under the PHCRT (NMFS 2004e). One species, Steindachner's moray (*Gymnothorax steindachneri*), is endemic to Hawai'i (WPRFMC 2001a). Currently, no data are available to determine if moray eels of the CHCRT are approaching an overfished situation (NMFS 2004b). Although there is no commercial fishery for morays, most are taken as incidental catch, sold in fish markets and readily eaten in the western Pacific (Bohlke et al. 1999). These species are also targets of the aquarium trade. None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Moray eels are found worldwide in tropical and subtropical waters (Froese and Pauly 2005).

The yellowmargin moray eel (*G. flavimarginatus*) ranges throughout the Indo-Pacific from the Red Sea and South Africa eastward to the Tuamoto and Austral Islands, north to the Ryukyu and Hawaiian Islands and south to New Caledonia (Froese and Pauly 2005).

The giant moray (*G. javanicus*) is found in the Indo-Pacific from the Red Sea and East Africa to the Marquesas and Oeno Atoll (Pitcairn Group), north to the Ryukyu and Hawaiian Islands, south to New Caledonia and the Austral Islands; throughout Micronesia (Froese and Pauly 2005).

The undulated moray (*G. undulatus*) is distributed throughout the Indo-Pacific from the Red Sea and East Africa, including Walter Shoal, to French Polynesia, north to southern Japan and the Hawaiian Islands, south to the southern Great Barrier Reef (Froese and Pauly 2005).

Habitat Preference—Most species of moray eels are benthic and can be found in shallow waters around rocks or reefs. Some species are associated with sand or mud bottoms and morays have been caught as deep as 500 m. (Bohlke et al. 1999). Moray eel juveniles and adults lurk in holes and crevices during the day and emerge at night to search the reef for food (Waikiki Aquarium 1999b). Moray eggs are pelagic and the leptocephalic larvae are epipelagic (WPRFMC 2001a; Froese and Pauly 2005).

The yellow-edged moray inhabits tropical waters between 30°N and 24°S at depths from 1 to 150 m. This species can be found along drop-offs and in coral or rocky areas of reef flats and protected shorelines to seaward reefs (Froese and Pauly 2005).

The giant moray inhabits tropical waters from 30°N to 25°S at depths from 0 to 50 m. This species is usually found in lagoons and along seaward reefs (Froese and Pauly 2005).

The undulated moray inhabits tropical waters from 32°N to 28°S at depths from 0 to 30 m. This species is common on reef flats among rocks, rubble, or debris and in lagoons and seaward reefs to depths greater than 26 m (Froese and Pauly 2005).

Life History—Information is lacking on the life history of this family (WPRFMC 2001a). Migration has been observed in some species of morays but most tropical species remain in their home territories or congregate in small groups in certain areas (Debelius 2002).

Common Prey Species—Moray eels mainly feed on crustaceans, cephalopods, and small fishes (Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—The water column from the shoreline to the outer boundary of the EEZ to a depth of 100 m.
- Juvenile/Adult—All rocky coral areas and the adjacent water column and the adjacent water column from 0 to 100 m.

♦ **Octopodidae** (Octopuses)

Status—Two of the species of the family Octopodidae, the day squid (*Octopus cyanea*) and the night squid (*O. ornatus*), are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (WPRFMC 2001). In addition, the remaining six species of octopuses found in the study area have designated EFH under the PHCRT (NMFS 2004d). Currently, no data are available to determine if octopuses of the CHCRT are approaching an overfished situation (NMFS 2004b). These species are primarily harvested for human consumption but are also used as bait in other fisheries (Norman 1998). Octopuses are a component of the incidental catch of the lobster-trap fishery in the NWHI (WPRFMC 2001a). None of the species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Members of the family Octopodidae occur in all the oceans of the world from the equator to polar latitudes (Norman 1998; Waikki Aquarium 1998d).

The day squid and the night squid are found widely throughout the shallow waters of the Indo-West Pacific from Hawai‘i in the east to the east African coast in the west. These species have been reported as far north as Japan and as far south as New South Wales, Australia (Norman 1998).

Habitat Preference—Reef-associated octopuses are bottom-dwelling species that usually occupy holes and crevices or coral areas. These species are found from the shallowest part of the reef down to approximately 50 m (WPRFMC 2001a). Octopuses occur on a wide range of substrates including coral and rock reefs, seagrass beds, sand, and mud. Octopus eggs are demersal and typically attached in clusters within the rocky depths of the reef (WPRFMC 2001a).

The day squid and night squid are found from intertidal reefs, shallow reef flats and reef slopes to depths of at least 25 m and are associated with both live and dead corals. As the name implies the day squid is more active throughout the day with peak activities at dusk and dawn (Norman 1998). The night squid is nocturnal, resting by day and foraging at night (Waikiki Aquarium 1998d).

Life History—Life history information is lacking for these species of octopus (Norman 1998; Waikki Aquarium 1998d; WPRFMC 2001a).

Common Prey Species—Octopuses feed on fishes, isopods, stomatopods, eels, and crabs (Wood 2005)

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Juvenile/Adult—EFH for the adult, juvenile, and demersal egg phases are defined as all coral, rocky, and sand-bottom areas from 0 to 100 m.
- Larvae—The water column extending from the shoreline to the outer boundary of the EEZ to a depth of 100 m.

♦ **Polynemidae** (Threadfin)

Status—One species, the sixfeeler threadfin (*Polydactylus sexfilis)*, of the family Polynemidae is managed as part of the CHCRT by the WPRFMC and has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004d). Currently, no data are available to determine if the sixfeeler threadfin of the CHCRT is approaching an overfished situation (NMFS 2004b). This species is highly valued as foodfish in Hawai‘i (WPRFMC 2001a). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—The sixfeeler threadfin is found throughout the tropical waters of the Atlantic and Indo-Pacific Oceans from 30°N to 0°N (WPRFMC 2001a; Froese and Pauly 2005). In the Indo-Pacific this species ranges from India to the Hawaiian, Marquesan, and Pitcairn Islands, north to the Yaeyama and Bonin Island, and throughout Micronesia (Myers 1999).

Habitat Preference—Adult sixfeeler threadfin are found near reef areas and inhabits turbid waters along sandy shorelines and over sandy lagoon bottoms usually associated with high-energy surf zones (Meyers 1999; Feltes 2001; WPRFMC 2001a). This species is most common at depths from 20 to 50 m (Feltes 2001). Sixfeeler threadfin eggs and larvae are pelagic but after larval metamorphisis they enter nearshore habitats such as surf zones, reefs, and stream entrances (WPRFMC 2001a). Juvenile sixfeeler threadfin are found from the shoreline breaker to 100 m depth (WPRFMC 2001a). In Kane‘ohe Bay, adults can be found on reef faces, in depths of the inner bay and in shallow (2 to 4 m) areas with muddy sand bottoms (WPRFMC 2001a).

Life History—Spawning occurs close to shore for three to six days per month and is associated with the lunar cycle (Meyers 1999; WPRFMC 2001a). In Hawai‘i, the sixfeeler threadfin spawns from June

to September, with a peak in July and August (WPRFMC 2001a). Spawning may occur year round in tropical locations (WPRFMC 2001). Both eggs and larvae are subject to advection by ocean currents (WPRFMC 2001a).

Common Prey Species—Threadfins mainly feed on benthic invertebrates such as penaeid and caridean shrimps, and fish (Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—The water column extending from the shoreline to the outer boundary of the EEZ to a depth of 100 m.
- Juvenile/Adult—All rocky/coral and sand-bottom habitat and the adjacent water column from 0 to 100 m.

♦ **Priacanthidae** (Bigeyes)

Status—One of the two species of the family Priacanthidae is managed as part of the CHCRT by the WPRFMC (2001a) and is found in the Hawaiian Islands OPAREA (Randall 1998). The glasseye (*Heteropriacanthus cruentatus*) has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if the glasseye is approaching an overfished situation (NMFS 2004c). Priacanthids are excellent foodfish but are not important in most fishery areas (Starnes 1999). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Priacanthids can be found in the tropical and subtropical waters of the Atlantic, Indian, and Pacific Oceans (Froese and Pauly 2005).

The glasseye is located circumtropically north to Ryukyu, Bonin, and Hawaiian Islands, and south to Lord Howe and Easter Island (Myers 1999).

Habitat Preference—Bigeyes are typically epibenthic and are usually associated with rock formations or coral reefs. This family prefers shaded overhangs, caves, and crevices near the reef during the daytime (WPRFMC 2001a). Ocassionally, bigeyes may be associated with more open areas at depths of 5 to 400 m (Starnes 1999). Eggs, larvae, and early juvenile stages are pelagic (Froese and Pauly 2005).

The glasseye is a subtropical species that ranges from 33°N to 32°S at depths from 3 to 300 m (Froese and Pauly 2005). This species is commonly associated with lagoons or seaward reefs below the surge zone, generally around islands (Myers 1999; Froese and Pauly 2005). Glasseyes are found singly or in small groups under or near ledges during the day forming larger groups at dusk to forage. Juveniles of this species are pelagic (Froese and Pauly 2005).

Life History—Spawning has not been observed for this species (WPRFMC 2001a). Daily migrations usually occur above and away from the reef in search of food (Myers 1999).

Common Prey Species—Glasseyes are nocturnal zooplanktivores feeding on the larvae of crabs, fishes, crustaceans, polychaete worms and cephalopods, and soft-bodied invertebrates (WPRFMC 2001a; Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—The water column extending from the shoreline to the outer boundary of the EEZ to a depth of 100 m.
- Juvenile/Adult—All rocky/coral and sand-bottom habitat and the adjacent water column from 0 to 100 m.

- **Scaridae** (Parrotfishes)

Status—One species, the stareye parrotfish (*Catolomus carolinus*), and one genus, *Scarus* spp., of the family Scaridae is managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (WPRFMC 2001a). In addition, the remaining five species of parrotfishes found in the study area have EFH designated under the PHCRT (WPRFMC 2001a). Three of these species are endemic to the Hawaiian Islands: yellowbar parrotfish (*C. zonarchus*), spectacled parrotfish *(Chlorurus perspicillatus),* and regal parrotfish *(Scarus dubius*) (WPRFMC 2001a). Currently, no data are available to determine if parrotfishes of the CHCRT are approaching an overfished situation (NMFS 2004c). Parrotfish are not a major commercial catch but they are an important food-fish and are frequently found in fish markets (Westneat 2001; Froese and Pauly 2005). There are no species of parrotfish found in the study area listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Parrotfish are mainly a tropical species occurring in the Atlantic, Indian, and Pacific Oceans (Froese and Pauly 2005). The majority of these species are found inhabiting the coral reefs of the Indian and western Pacific Oceans (WPRFMC 2001a).

Habitat Preference—Parrotfish are commonly found around coral reefs, and are usually most abundant in shallow waters to a depth of 30 m (Bellwood 2001). This family occupies a variety of coral reef habitats including seagrass beds, coral-rich areas, sand patches, rubble or pavement fields, lagoons, reef flats, and upper reef slopes (Myers 1999). Parrotfish sleep under ledges or wedged against coral or rock at night (Myers 1999).

Life History—Parrotfish spawn in pairs and groups with group spawning frequently occurring on reef slopes associated with high current speeds. Pair spawning has been observed at the reef crest or reef slope during peak or falling tides. Parrotfish may migrate into lagoons or to the outer reef slope in order to spawn. Some parrotfish are diandric, forming schools and spawning groups often after migration to specific sites, while others are monandric and are strongly site attached and practice haremic, pair spawning. The eggs and larvae of these species are pelagic and both are subject to dispersal by ocean currents (WPRFMC 2001a).

Common Prey Species—Parrotfish are herbivorous and scrape algae from dead coral substrates (Froese and Pauly 2005).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—The water column from the shoreline to the outer limit of the EEZ to a depth of 100 m.
- Juvenile/Adult—All bottom habitat and the adjacent water column from 0 to 100 m.

- **Sphyraenidae** (Barracudas)

Status—Two species (Heller's barracuda [*Sphyraena helleri*] and the great barracuda [*S. barracuda])* of the family Sphyraenidae are managed as part of the CHCRT by the WPRFMC and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if barracudas of the CHCRT are approaching an overfished situation (NMFS 2004c). These two species of barracuda are not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Barracudas can be found in tropical and subtropical waters in the Atlantic, Indian, and Pacific Oceans (Froese and Pauly 2005). Heller's barracuda and the great barracuda are the only two species positively recorded from Hawaiian waters (WPRFMC 2001).

Heller's barracuda can be found from southern Japan south to the Coral Sea and east to French Polynesia. This species is common around the oceanic islands of the Pacific (Froese and Pauly 2005).

The great barracuda is common in the Indo-Pacific from the Red Sea and east coast of Africa to the Hawaiian, Marquesan, and Tuamoto Islands (Froese and Pauly 2005).

Habitat Preference—Barracudas are both pelagic and demersal fish, and inhabit shallow coastal waters such as bays, estuaries, or the vicinity of coral reefs. This species may also be found at the surface of open oceans down to depths greater than 100 m (Senou 2001). Barracudas may be found within lagoons and mangrove areas, over coral reefs or sand or mud bottoms, or off of deep outer reef slopes. Eggs and larvae for these species are pelagic (WPRFMC 2001a).

Heller's barracuda is a subtropical species found from 30°N to 25°S at depths from 15 to 60 m (Froese and Pauly 2005). This species occurs in lagoons and over seaward reefs (Myers 1999).

The great barracuda is a subtropical species found from 30°N to 30°S at depths from 0 to 100 m. Adults occur from murky inner harbors to open seas, usually at or near the surface (Froese and Pauly 2005). Juveniles occur among mangroves and in shallow sheltered inner reefs (WPRFMC 2001a).

Life History—Barracuda migrate in very large numbers to specific spawning areas at reef edges or in deeper water. Eggs and juveniles may be carried long distances by ocean currents (WPRFMC 2001a). Heller's barracuda can be found in large school during the day, whereas, the great barracuda is diurnal and solitary (Froese and Pauly 2005).

Common Prey Species—Barracudas are piscivorous feeding on a variety of fishes including, but not limited to jacks, groupers, snappers, small tunas, mullets, herrings, and anchovies (Bester 2005).

EFH Designations—(WPRFMC 2001a; **Figure D-19**; **Table 4-6**)

- Eggs/Larvae/Juvenile/Adult—The water column from the shoreline to the outer boundary of the EEZ to a depth of 100 m.

4.2.5.2.2 Aquarium species/taxa

Fish species harvested for aquarium trade are managed as part of the CHCRT by the WPRFMC (2001a) and have EFH designated within the boundaries of the study area (NMFS 2004e). All aquarium taxa are managed as a unit, and EFH designation for the life stages of each species are identical. The EFH designations for all species of aquarium taxa can be found below and will therefore not be listed for individual species. Within the jurisdictional waters of the WPRFMC, Hawai'i is the main site where commercial collection and sale of coral reef fishes and invertebrates for the aquarium trade is occurring (WPRFMC 2001). As a result, the aquarium MUS complex is based primarily on those species known from Hawaiian waters. The species found within the Aquarium Species/Taxa category do not represent a taxonomically related group, however, from an ecological standpoint, these species are generally associated with shallow coral areas (WPRFMC 2001a).

EFH Designations—(WPRFMC 2001a; **Figures D-19**, **D-20**, **D-21**, **D-22**, **D-23**, and **D-24**; **Table 4-6**)

- Eggs/Larvae—All waters from 0 to 100 m from the shoreline to the limits of the EEZ.
- Juvenile/Adult—All coral, rubble, or other hardbottom features and the adjacent water column from 0 to 100 m.

♦ **Acanthuridae** (Surgeonfishes)

A complete summary of the family Acanthuridae including EFH designations is provided earlier in the CHCRT section 4.2.5.2.1.

- ***Zebrasoma flavescens*** (Yellow tang)

  Status—The yellow tang is managed as part of the CHCRT by the WPRFMC and has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if the yellow tang is approaching an overfished situation (NMFS 2004b). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

  Distribution—The yellow tang can be found in the Pacific Ocean associated with Ryukyu, Mariana, Marshall, Marcus, Wake, and Hawaiian Islands (Froese and Pauly 2005).

  Habitat Preference—Yellow tangs inhabit coral-rich areas of lagoons and seaward reefs from below the surge to approximately 46 m. This species can be found in tropical waters from 30°N to 15°N in water temperatures ranging from 24° to 28°C at depths between 2 and 46 m (Froese and Pauly 2005).

  Life History—The yellow tang may spawn in groups or pairs (Myers 1999).

  Common Prey Species—The yellow tang is herbivorous, generally feeding on filamentous algae growing exposed on basalt and dead coral heads (Froese and Pauly 2005).

- ***Ctenochaetus strigosus*** (Yellow-eyed surgeonfish)

  Status—The yellow-eyed surgeonfish is managed as part of the CHCRT by the WPRFMC and has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if the yellow-eyed surgeonfish is approaching an overfished situation (NMFS 2004c). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

  Distribution—The yellow-eyed surgeonfish can be found in the Indo-Pacific region from east Africa to the Hawaiian, Marquesan, and Ducie Islands. Its range is bounded to the north by the Bonin Islands and to the south by the Great Barrier Reef and New Caledonia (Myers 1999).

  Habitat Preference—The yellow-eyed surgeonfish inhabits coral-rich areas of lagoons and seaward reefs. This species can be found in tropical waters from 30°N to 30°S in water temperatures ranging from 21° to 27°C at depths between 1 and 113 m (Froese and Pauly 2005).

  Life History—The yellow-eyed surgeonfish has been observed spawning in pairs (Myers 1999).

  Common Prey Species—The yellow-eyed surgeonfish feeds mainly on detritus (Froese and Pauly 2005).

- ***Acanthurus achilles*** (Achilles tang)

  Status—The achilles tang is managed as part of the CHCRT by the WPRFMC and has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if the achilles tang is approaching an overfished situation (NMFS 2004c). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

  Distribution—The achilles tang can be found distributed throughout the tropical Indo-Pacific from the western Caroline Islands, Parece Vela, and the Torres Strait east to the Hawaiian, Marquesan, and Ducie Islands. This species ranges as far north as the Marcus Islands and south to New Caledonia (Myers 1999).

Habitat Preference—The achilles tang inhabits clear seaward reefs from the surge zone to a depth of 4 m (Myers 1999). This species can be found in tropical waters from 28°N to 26°S in water temperatures ranging from 26° to 28°C at depths between 0 and 10 m (Froese and Pauly 2005).

Life History—Information is lacking on the life history of the achilles tang (WPRFMC 2001a).

Common Prey Species—The achilles tang feeds on filamentous and small fleshy algae (Froese and Pauly 2005).

- **Zanclidae** (Moorish Idol)

Status—The Moorish idol (*Zanclus cornutus*), the sole member of this monotypic family, is an aquarium taxa that is managed in the Hawaiian archipelago as part of the CHCRT by the WPRFMC (2001a) and has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if the Moorish idol is approaching an overfished situation (NMFS 2004c). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—The Moorish idol can be found distributed throughout the Indo-pan-Pacific from the Gulf of Aden and eastern Africa east to Mexico. This species ranges as far north as southern Japan and the Hawaiian Islands and south to Lord Howe, the Kermadecs, Rapa, and Ducie Islands (Myers 1999).

Habitat Preference—The Moorish idol inhabits areas of hard substrates from turbid inner harbors and reef flats to clear seaward reefs as deep as 182 m (Myers 1999; WPRFMC 2001a). This species can be found in tropical waters from 30°N to 35°S in water temperatures ranging from 24° to 28°C at depths between 3 and 182 m (Froese and Pauly 2005).

Life History—The Moorish idol is usually found in small groups, but may occur in schools numbering over 100 individuals (Myers 1999; WPRFMC 2001a).

Common Prey Species—The Moorish idol feeds on small encrusting animals (sponges) and occasionally on benthic crustaceans and algae (Randall 1996; Froese and Pauly 2005).

- **Pomacanthidae** (Angelfish)

Status—Aquarium species in the family Pomacanthidae are managed in the Hawaiian archipelago as part of the CHCRT by the WPRFMC (2001a). Six angelfish species occur in Hawai‘i and have EFH designated within the boundaries of the study area (NMFS 2004e). Four of these species are endemic: Fisher’s angelfish (*Centropyge fisheri*), Potter’s angelfish (*C. potteri*), bandit angelfish (*Desmoholacantus arcuatus*), and masked angelfish (*Genicanthus personatus*) (WPRFMC 2001a). The masked angelfish is highly valued for the aquarium trade (WPRFMC 2001a). Currently, no data are available to determine if angelfishes of the CHCRT are approaching an overfished situation (NMFS 2004c). Although harvested as food-fish, the primary value of angelfish is through the ornamental marine aquarium trade, where they are the second most-frequently exported fish by number and highest in total value of all families of aquarium fishes in trade (Pyle 2001a). These species are not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Angelfish are circumtropical with the greatest numbers of species distributed throughout the Indo-Pacific (Myers 1999).

Habitat Preference—Angelfish require suitable shelter in the form of boulders, caves, and coral crevices and occur from 2 to 30 m depth (WPRFMC 2001a). A few species have been known to occur at depths greater than 100 m (WPRFMC 2001a).

Life History—Angelfish spawn in pairs, typically around sunset (Myers 1999).

Common Prey Species—Most large angelfish (e.g., *Pomacanthus* spp.) feed primarily on sponges whereas small species (e.g., *Centropyge* spp.) feed on benthic algae and detritus (Randall 1996). All species take small amounts of soft-bodied invertebrates (tunicates), zooantharians, gorgonians, fish and invertrebrate eggs, hydroids, algae, and seagrasses (Myers 1999; WPRFMC 2001a). The masked angelfish is zooplanktivores, but may consume algae, copepods, diatoms, fish eggs, and sponge spicules (WPRFMC 2001a).

- **Muraenidae** (Moray Eels)

Status—The dragon moray (*Enchelycore pardalis*) is the only aquarium species in the family Muraenidae that is managed as a part of the CHCRT by the WPRFMC and has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if the dragon moray eel of the CHCRT is approaching an overfished situation (NMFS 2004c). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—The dragon moray can be found from Reunion Island in the east to the Hawaiian, Line and Society Islands in the west and ranges from southern Japan and southern Korea in the north to New Caledonia in the south (Froese and Pauly 2005). This species is more common around NWHI than in the MHI (WPRFMC 2001a).

Habitat Preference—The dragon moray is found in tropical waters and typically inhabits coral and rocky reefs at depths from 8 to 60 m (Froese and Pauly 2005).

Life History—Information is lacking on the life history of the dragon moray (WPRFMC 2001a).

Common Prey Species—The dragon moray is an opportunistic piscivore, feeding on sponges, invertebrates, and algae (Froese and Pauly 2005).

- **Cirrhitidae** (Hawkfishes)

Status—The longnose hawkfish (*Oxycirrhites typus*) is the sole species of aquarium taxa in the family Cirrhitidae that is managed in the Hawaiian archipelago as part of the CHCRT by the WPRFMC (2001a) and has EFH designated within the boundaries of the study area (NMFS 2004e). However, the remaining five species of hawkfishes found in the study area have designated EFH under the PHCRT (NMFS 2004e). Currently, no data are available to determine if hawkfishes of the CHCRT are approaching an overfished situation (NMFS 2004c). Some hawkfishes are occasionally used as food and are valued aquarium fishes (Randall 2001c). These species found are not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Hawkfishes can be found from the tropical western and eastern Atlantic, Indian, and Pacific Oceans (Froese and Pauly 2005).

The longnose hawkfish can be found from the Red Sea in the west to Panama in the east and from southern Japan and Hawai‘i in the north to New Caledonia in the south (Myers 1999).

Habitat Preference—Cirritids are bottom-dwelling species associated with coral reefs, rocky substrate, or rubble in the surge zone (Randall 2001c). Hawkfishes typically can be found around seaward reefs, lagoons, channels, rocky shorelines, and submarines terraces. Some are found on heads of small branching corals (Randall 2001c; WPRFMC 2001a). Both the egg and larval stages for most hawkfishes are pelagic with the larval stage being prolonged allowing for the potential of wide dispersal (WPRFMC 2001a).

The longnose hawkfish can be found perched on the branches of black corals and gorgonian sea fans of steep outer reef slopes exposed to strong currents (Myers 1999; WPRFMC 2001; Allen et al.

2003). The longnose hawkfish also lays demersal eggs, unlike many other Cirrhitids (Froese and Pauly 2005).

Life History—Spawning occurs throughout the year in tropical waters and only during warmer months in temperate areas. These species usually spawn at dusk or during early nighttime (Myers 1999).

Common Prey Species—Hawkfish feed on small crustaceans (primarily zooplankton and crabs), sea urchins, brittle stars, and fish (Randall 1996; Froese and Pauly 2005).

- **Chaetodontidae** (Butterflyfishes)

Status—Three aquarium species in the family Chaetodontidae are managed in the Hawaiian archipelago as part of the CHCRT by the WPRFMC (2001a) and have EFH designated within the boundaries of the study area (NMFS 2004e). These species include the threadfin butterflyfish (*Chaetodon auriga*), the raccoon butterflyfish (*C. lunula*), and the saddled butterflyfish (*C. ephippium*). In addition, the remaining twenty-one species of butterflyfishes found in the study area have EFH designated under the PHCRT (NMFS 2004e). Four of these species are endemic to Hawai‘i: bluestripe butterflyfish (*Chaetodon fremblii*), milletseed butterflyfish (*C. miliaris*), multiband butterflyfish (*C. multicinctus*), and Tinker's butterflyfish (*C. tinkeri*) (WPRFMC 2001a). Currently, no data are available to determine if butterflyfishes of the CHCRT are approaching an overfished situation (NMFS 2004c). Although harvested as food-fish, the primary value of the butterflyfish is through the ornamental marine aquarium trade, where they are the third most-frequently exported fish by number and second highest in total value of all families of aquarium fishes in trade (Pyle 2001b). None of the three aquarium species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Chaetodontids can be found in the tropical to temperate waters of the Atlantic, Indian, and Pacific Oceans but are most abundant in the Indo-West Pacific region (Froese and Pauly 2005).

The threadfin butterflyfish can be found from the in the western Red Sea and off the east coast of Africa to the Hawaiian, Marquesan, and Ducie Islands in the west. This species ranges from southern Japan in the north to Lord Howe and Rapa Islands in the south (Froese and Pauly 2005).

The raccoon butterflyfish can be found in the Indo-Pacific from the east coast of Africa in the west to the Hawaiian, Marquesan, and Ducie Islands in the east. This species ranges from southern Japan south to Lord Howe and Rapa Islands (Froese and Pauly 2005).

The saddled butterflyfish can be found distributed throughout the tropical Indo-Pacific from the Cocos-Keeling Islands in the west to the Hawaiian, Marquesan and Tuamoto Islands in the east. This species ranges as far north as the southern Japan and south to Rowley Shoals and New South Wales, Australia (Froese and Pauly 2005).

Habitat Preference—Butterflyfish are diurnal species that are generally found near coral reefs (Froese and Pauly 2005). Juveniles tend to occupy shallower, more sheltered habitats than adults. Butterflyfish eggs are planktonic (WPRFMC 2001a).

The threadfin butterflyfish can be found in a variety of habitats including mixed sand, rubble, and coral (WPRFMC 2001). This species inhabits tropical waters at depths between 1 and 35 m (Froese and Pauly 2005) and may be found on seaward reefs at depths greater than 30 m (Myers 1999). The threadfin butterflyfish ranges from 30°N to 20°S at depths between 1 and 35 m (Froese and Pauly 2005).

The raccoon butterflyfish inhabits shallow reef flats of lagoons and seaward reefs to depths of over 30 m (Froese and Pauly 2005). This species is common in exposed rocky areas of high vertical relief (Myers 1999). The raccoon butterflyfish can be found in tropical waters from 30°N to 32°S at depths

between 0 and 30 m (Froese and Pauly 2005). Juveniles prefer rocks of inner reef flats and tide pools (Froese and Pauly 2005). This is the only nocturnally active butterflyfish, spending its days hovering inactively in aggregations between boulders (Myers 1999).

The saddled butterflyfish inhabits lagoons and seaward reefs to a depth of 30 m and prefers areas of rich coral growth and clear water (Myers 1999). This species can be found in tropical waters from 30°N to 30°S at depths between 0 and 30 m (Froese and Pauly 2005).

Life History—The threadfin butterflyfish may be found singly or in pairs and forms aggregations that roam long distances in search of food (Froese and Pauly 2005). Information is lacking about the spawning and migration of the racoon and saddled butterflyfishes (Myers 1999; WPRFMC 2001a; Froese and Pauly 2005).

Common Prey Species—The threadfin butterflyfish feeds mainly by tearing pieces from polychaetes, sea anemones, coral polyps, and algae (Froese and Pauly 2005). Adult raccoon butterflyfish feed mainly on nudibranchs, tubeworm tentacles, and other benthic invertebrates but may also feed on algae and coral polyps (Froese and Pauly 2005). The saddled butterflyfish feeds on filamentous algae, small invertebrates, coral polyps, and fish eggs (Froese and Pauly 2005).

- **Pomacentridae** (Damselfishes)

Status—Aquarium species in the family Pomacentridae are managed in the Hawaiian archipelago as part of the CHCRT by the WPRFMC (2001a). Seventeen damselfish species occur in Hawai‘i, of which six are endemic: Hawaiian sergeant (*Abudefduf abdominalis*), chocolate-dip chromis (*Chromis hanui*), oval chromis (*C. ovalis*), threespot chromis (*C.verater*), Hawaiian dascyllus (*Dascyllus albisella*), and rock damselfish (*Plectoglyphidodon sindonis*) (WPRFMC 2001a). All of these species have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if damselfishes of the CHCRT are approaching an overfished situation (NMFS 2004c). Damselfish’s most important commercial use is as aquarium fishes (Allen 2001). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Damselfish can be found in all tropical seas but are most abundant in the Indo-West Pacific region (Froese and Pauly 2005).

Habitat Preference—Damselfish typically occur in shallow water or coral or rock substrata associated with shelter (Froese and Pauly 2005). Damselfish eggs are demersal and laid in nests which are guarded by the male (WPRFMC 2001a). Upon hatching, the larval stage is planktonic (WPRFMC 2001a).

Life History—Spawning for damselfish typically occurs in the morning (Myers 1999) throughout most of the year in tropical waters (Allen 2001). In many species, spawning exhibits lunar periodicity (Myers 1999).

Common Prey Species—Damselfish may be planktivores (e.g., *Chromis* spp., *Dascyllus* spp.,—zooplankton), omnivores (e.g., *Abudefduf* spp.—benthic algae, small invertebrates, zooplankton); or herbivores (e.g., *Stegastes* spp., *Plectroglyphidodon* spp.—algal mats), except for blue-eye damselfish (*P. johnstonianus*) which feed on coral polyps (Myers 1999).

- **Scorpaenidae** (Scorpionfishes)

Status—Twenty-five species of the family Scorpaenidae are managed as aquarium taxa in the Hawaiian archipelago as part of the CHCRT by the WPRFMC (2001) and have EFH designated within the boundaries of the study area (NMFS 2004e). Three of these species are endemic: Hawaiian lionfish (*Dendrochirus barberi*), Hawaiian turkeyfish (*Pterois sphex*), and titan scorpionfish (*Scorpaenopsis cacopsis*) (WPRFMC 2001a). Currently, no data are available to determine if

scorpionfishes of CHCRT are approaching an overfished situation (NMFS 2004c). Most species in the western central Pacific are small and dangerous to handle and do not form the basis of large fisheries (Poss 1999a). These species are not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Scorpaenids can be found in all tropical and temperate seas (Froese and Pauly 2005).

Habitat Preference—Turkeyfishes and lionfishes may be found swimming well above the bottom but smaller, more cryptic species of the subfamily Scorpaeninae are typically found on the bottom usually associated with rubble areas in shallow water. Scorpaenids are commonly found in shallow waters but may be found at depths greater than 50 m (WPRFMC 2001a). The eggs are pelagic and larvae of these species are planktonic (Froese and Pauly 2005).

Life History—Most scorpaenids are ovoviparous, producing between a few hundred and a few thousand eggs, although, some species are viviparous (Poss 1999a).

Common Prey Species—Scorpaenids feed on shrimps, crabs, and other crustaceans (Froese and Pauly 2005).

- **Sabellidae** (Feather-duster Worms)

Status—The family Sabellidae is managed as aquarium taxa in the Hawaiian archipelago as part of the CHCRT by the WPRFMC (2001a) and have EFH designated within the boundaries of the study area (NMFS 2004e). This family has no species found in the study area listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Feather-duster worms are common throughout the world in shallow water (Waikiki Aquarium 1998e).

Habitat Preference—In the western Pacific, feather-duster worms are common on reef flats and in quiet bays and harbors (e.g., Kane‘ohe Bay, O‘ahu) (Hoover 1998) where they are associated with hard surfaces to which they attach (Waikiki Aquarium 1998e). They are occasionally found in clear water, usually at depths greater than 30 m (WPRFMC 2001a).

Life History—Information is lacking on the life history of feather-duster worms (WPRFMC 2001a).

Common Prey Species—Feather-duster worms feed on plankton and organic detritus (Waikiki Aquarium 1998e).

4.2.5.3 Potentially Harvested Coral Reef Taxa

The PHCRT are managed as part of the CRE FMP by the WPRFMC (2001a). Taxa included under PHCRT consist of thousands of coral reef associated species, families, or subfamilies that encompass fish, invertebrate, and sessile benthos MUS (WPRFMC 2001a). These MUS are limited to those families/species known or believed to occur in association with coral reefs during some phase of their life cycle (WPRFMC 2001a). Since little information is available about life histories and habitats of this biota beyond general taxonomic and distributional descriptions, WPRFMC (2001a) has adopted a precautionary approach in designating EFH for PHCRT. EFH for all life stages of PHCRT is designated as the water column and bottom habitat from the shoreline to the outer boundary of the EEZ to a depth of 100 m (WPRFMC 2001a; **Figure D-25**).

In addition to EFH, the WPRFMC also identified HAPC which are specific areas within EFH that are essential to the life cycle of important coral reef species. HAPC for all life stages of the PHCRT includes all hardbottom substrate between 0 and 100 m depth in the study area. Over 47 HAPC have been identified for the MHI and Nihoa of the NWHI chain, of which nine sites occur within the inshore sections of the study area: six on O‘ahu and three on the main island of Hawai‘i (WPRFMC 2001a; Moncada et al. 2004; Jokiel and Friedlander n.d.; **Figure D-18**; **Table D-1**).

A complete list of the PHCRT and habitat requirements of all life stages occurring in the study area can be found in **Tables 4-1** and **4-6**, respectively. All other CRE MUS that are marine plants, invertebrates, and fish not listed in the CHCRT or as MUS are included in the PHCRT. Descriptions of these taxa will be presented only in the CHCRT section. Descriptions of the individual families, subfamilies, or species comprising the fish, invertebrate, and sessile benthos are described in the following paragraphs.

Fish Management Unit Species

- **Sphyrnidae** (Hammerhead Sharks)

  Status—Two species of hammerhead sharks, the scalloped hammerhead (*Sphyrna lewini*) and the smooth hammerhead (*S. zygaena*), are managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). Of the nine different species of hammerheads, only the scalloped hammerhead has been positively recorded from along the tropical coasts of the MHI and NWHI (Randall 1996). The smoothed hammerhead is a significant element in the offshore longline catch (Taylor 1993). Both species have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if these hammerheads of the PHCRT are approaching an overfished situation (NMFS 2004c). Hammerhead sharks are generally caught in low numbers as part of longline fishery (NMFS 2001) and are readily available to inshore artisanal and small commercial fisheries (Compagno 1998). Both hammerhead species are listed on the IUCN Red List of threatened species as near threatened (Kotas 2000; Simpfendorfer 2000b). In addition, both species are afforded protected under the *Shark Finning Prohibition Act* (NMFS 2002b).

  Distribution—Hammerheads are wide-ranging, coastal-pelagic, and semi-oceanic sharks that inhabit tropical and warm temperate waters over continental and insular shelves (Compagno 1984, 1998).

  Habitat Preference—Hammerhead sharks are found in a wide variety of coral reef habitats (Hennemann 2001). They are very active swimmers occurring in pairs, schools, or solitary, and range from the surface, surfline, and intertidal region down at least 275 m depth (Compagno 1984). Juveniles often occur in schools frequently inhabiting inshore areas such as bays, seagrass beds, and lagoon flats before moving into deeper waters as adults (WPRFMC 2001a). Adults (e.g., scalloped hammerhead) can be found in shallow inshore areas during mating or birthing events (Compagno 1984).

  Life History—Hammerhead sharks (e.g., smooth hammerhead) make long seasonal, north-south migrations to warmer waters in the winter and cooler waters in the summer (Hennemann 2001). They are viviparous, having a gestation period of about 12 months (WPRFMC 2001a). The scalloped hammerhead produces an offspring of 15 to 31 pups per liter and utilizes shallow, turbid coastal waters (e.g., Kane‘ohe Bay, Waimea Bay, Honolulu Harbor, Pearl Harbor, and Keehi Lagoon on O‘ahu and Hilo Bay on Hawai‘i) as a nursery areas (Compagno 1984; Taylor 1993; WPRFMC 2001a). The southern part of Kane‘ohe Bay is a major breeding and pupping ground for this species (WPRFMC 2001a). The smooth hammerhead has a gestation period of about eight months with a litter size of 29 to 32 pups (Hennemann 2001).

  Common Prey Species—Hammerhead sharks feed on a wide variety of organisms including eels, halfbeaks, lizardfish, jacks, goatfish, damselfish, wrasses, butterflyfish, surgeonfish, blacktip reef sharks, squids, octopuses, mantis shrimp, crabs, and lobsters (Compagno 1984; Taylor 1993; Randall 1996).

- **Dasyatididae, Myliobatidae, and Mobulidae** (Whiptail Stingrays, Eagle Rays, and Manta Rays)

  Status—Six species of rays (three stingrays of the genus *Dasyatis*, the spotted eagle ray [*Aetobatis narinari*], manta ray [*Manta birostris*], and the Japanese devil ray [*Mobula japanica*]) occur in the Hawaiian archipelago (Randall 1996), are managed as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if rays of the PHCRT are approaching an overfished

situation (NMFS 2004c). The white-spotted eagle ray and the Japanese devil ray are taken as a by-catch, while the manta ray is neither a fisheries nor a by-catch species (Cavanagh et al. 2003). Eagle rays and devil rays are attractive and desirable as captives in large aquaria and oceanaria (Compagno and Last 1999a, 1999b). Both the spotted eagle ray and the manta ray are listed on the IUCN Red List of threatened species as data deficient (Ishihara 2000; Ishihara et al. 2002), whereas the Japanese devil ray is listed as near threatened (White 2003).

Distribution—Stingrays range throughout the Indo-Pacific region, while the spotted eagle, manta, and devil rays are circumglobal occurring in tropical and subtropical seas and warm temperate and tropical oceans (G. Nelson 1994; Myers 1999; Hennemann 2001).

Habitat Preference—Habitat preferences for most rays include sand and mud bottoms of continental shelves with a few species occurring on coral reefs (Myers 1999). Juveniles inhabit a variety of habitats from shallow clear lagoons to outer reef slopes, and nursery areas in seagrass beds, mangroves, and shallow sand flats (WPRFMC 2001a). Adults utilize shallow clear lagoons to outer reef slopes at depths ranging from the shoreline out to a depth of 100 m (Myers 1999) or deeper (e.g., eagle rays: 527 m, sting rays: 480 m) (Compagno and Last 1999a; Last and Compagno 1999).

Life History—Stingrays are viviparous (Last and Compagno 1999), whereas eagle, manta, and devil rays are ovoviviparous (WPRFMC 2001a; White 2003). Stingrays produce a litter with two to six young with a 12-month gestation period (Last and Compagno 1999). The spotted eagle ray produces an average of four pups per liter after a gestation period of about 12 months (Bester n.d.), while both the manta and devil rays may give birth to one pup during a breeding season (White 2003; Passarelli and Piercy n.d.). During the winter, manta rays migrate to warmer areas, deeper waters, or disperse offshore (Passarelli and Piercy n.d.). Some species of eagle rays breed in shallow bays and lagoons (Compagno and Last 1999a).

Common Prey Species—Stingrays feed on sand-dwelling and reef-dwelling invertebrates and fish, whereas the spotted eagle ray feed mainly on hard-shelled mollusks and crustaceans and the manta and devil rays consume zooplankton and small fishes (Randall 1996; Hennemann 2001; WPRFMC 2001a).

- **Serranidae** (Groupers)

Status—Three species of groupers occur in the Hawaiian archipelago (Randall 1996). The endemic Hawaiian grouper (*Epinephelus quernus*), which is native to the Hawaiian Islands and Johnston Atoll, is managed as part of BMUS by the WPRFMC (1998). The other native giant grouper (*E. lanceolatus*) and introduced peacock grouper (*Cephalopholis argus*) are managed as part of the PHCRT by the WPRFMC (2001a) and have EFH designated within the boundaries of the study area (NMFS 2004e). Currently, no data are available to determine if the giant and peacock groupers of the PHCRT are approaching an overfished situation (NMFS 2004c). Groupers are most highly prized food fishes and are actively caught by commercial and sport fishermen (Heemstra and Randall 1999). Two of the groupers are listed on the IUCN Red List of threatened species: Hawaiian grouper as near threatened (Cornish 2004) and the giant grouper as vulnerable (Sadovy 1996)

Distribution—Groupers have a worldwide distribution occurring in tropical and semitropical seas of the Indo-Pacific region (G. Nelson 1994; Debelius 2002). Their wide geographic distribution is thought to be due to the relatively long pelagic phase as larvae (Allen et al. 2003).

Habitat Preference—Serranids inhabit a wide variety of habitats (Myers 1999). Larvae tend to be more abundant over the continental shelf than oceanic waters, avoiding surface waters during the day, are evenly distributed vertically in the surface water column at night; and may be influenced by oceanic currents (Leis et al. 1987; Rivera et al. 2004). Juveniles are found in shallow-water reef areas (seagrass beds and tide pools) and estuarine habitats (WPRFMC 2001a). Adults utilize shallow coastal coral reef areas to deep slope rocky habitats from the shoreline to a depth of at least 400 m (Heemstra and Randall 1993). The Hawaiian grouper is found at depths of 20 to 380 m on rocky

bottom substrate (WPRFMC 1999), the giant grouper is a solitary inhabitant of lagoon and seaward reefs at depths of a few to at least 50 m, and the introduced peacock grouper occurs in areas of rich coral growth in clear water lagoons and seaward reefs at depths ranging from 1 to 40 m (Myers 1999). Regardless of size, groupers are typically ambush predators, hiding in crevices and among coral and rocks (WPRFMC 2001a).

Life History—Spawning in groupers is typically seasonal (e.g., Hawaiian Grouper: January through June, peaking in April and again in June) (Cornish 2004) and synchronized by lunar phase (Grimes 1987) with some species of groupers migrating several kilometers to spawn (Heemstra and Randall 1993). Groupers tend to spawn in predictable, dense aggregations (some species spawn in pairs) with individual males spawning multiple times during the breeding season (Myers 1999; Rivera et al. 2004). Most species of groupers are solitary fishes with a limited home range (Heemstra and Randall 1993).

Common Prey Species—Groupers prey upon brachyuran crabs, fishes, shrimps, galatheid crabs, octopus, stomatopods, fishes, and ophiuroids (Heemstra and Randall 1993; Randall 1996).

- **Lethrinidae** (Emperor Fishes)

Status—Emperor fishes occur in the Hawaiian archipelago and are managed as part of the PHCRT by the WPRFMC (2001a). The only Hawaiian representative is the bigeye emperor (*Monotaxis grandoculis*) (Randall 1996) which has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Emperors are commonly taken by bottom handline fishing and are of moderate to significant importance in commercial, recreational, and artisanal fisheries throughout the tropical Pacific (WPRFMC 1996). Currently, no data are available to determine if the bigeye emperor of the PHCRT is approaching an overfished situation (NMFS 2004c). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Emperor fishes are widely distributed over the Indo-Pacific in tropical and subtropical waters with a few species ranging into warm-temperate waters (Debelius 2002).

Habitat Preference—Little is known about the biology of the emperor fish (WPRFMC 2001a). Emperors are known to occur in the deeper waters of coral reefs and adjacent sandy coastal areas from 0 to 350 m (WPRFMC 2001a). Some lethrinid species are found inhabiting coastal waters, including coral and rocky reefs, sand flats, seagrass beds, and mangrove swamps (Debelius 2002). Most species occur either singly or in schools and feed primarily at night on or near reefs (Myers 1999). The bigeye emperor is relatively common over sandy patches and channels of both lagoon and seaward reefs from depths of one to at least 100 m (Myers 1999; Debelius 2001).

Life History—Spawning behavior of lethrinid species is poorly documented (WPRFMC 1998). Based on available data, spawning occurs throughout the year and is preceded by localized migrations during crepuscular periods (Carpenter 2001). Peak spawning events occur on or near the new moon. Spawning occurs near the surface as well as near the bottom of reef slopes (WPRFMC 2001a).

Common Prey Species—The bigeye emperor feeds mainly on hermit crabs, sea and heart urchins, and mollusks (Randall 1996).

- **Chlopsidae, Congridae, and Ophichthidae** (False Moray Eels, Conger Eels, Garden Eels, and Snake Eels)

Status—Twenty-two species of eels occur in the Hawaiian archipelago (Randall 1996), are managed as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if eels of the PHCRT are approaching an overfished situation (NMFS 2004c). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Eels are distributed worldwide in tropical and temperate seas (Allen and Steene 1987).

Habitat Preference—Both juvenile and adult eels inhabit cryptic locations in the framework of coral reefs (e.g., false moray) or softbottom habitats (e.g., snake and conger/garden eels) (Myers 1999). Habitats vary between the different families. False moray eels are secretive indwellers of coral heads, seaward reefs, and seagrass beds at depths of 0 to 56 m. Conger and garden eels tend to be solitary or exist in large colonies on sand patches/flats or slopes away from reefs at depths of 7 to 53 m with strong currents. Snake eels are indwellers that stay buried in the sand or mud with a few occasionally emerging to traverse sand, rubble, or seagrass habitats at depths of 16 to 68 m (Myers 1999; Smith 1999; Debelius 2002; Allen et al. 2003).

Life History—Most eel species are known to migrate to spawn (WPRFMC 2001a). Individual spawning characteristics vary among the different families. False moray eels are known to migrate off the reef to spawn (Myers 1999). Snake eels appear to be nocturnal with some species also coming to the surface to spawn (Myers 1999). Group spawning of eels has also been documented with large numbers of adults congregating at the water surface at night (WPRFMC 2001a).

Common Prey Species—False moray eels feed on crustaceans, whereas conger and garden eels are planktivores and snake eels feed on small fish and crustaceans (Allen and Steene 1987; WPRFMC 2001a; Debelius 2002).

- **Apogonidae** (Cardinalfishes)

Status—Ten cardinalfish species occur in the Hawaiian archipelago (Randall 1996), are managed as PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if cardinalfish of the PHCRT are approaching an overfished situation (NMFS 2004c). Generally, not important economically, a few species are seen in the aquarium trade or as tuna bait (Allen 1999). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Apogonids are a very large family of small reef fishes that are distributed in shallow coastal waters of the Atlantic, Pacific, and Indian Oceans (Debelius 2002).

Habitat Preference—Cardinalfish are found in water depths ranging from 1 to 80 m and are typically nocturnal, remaining hidden under coral reef ledges, holes, flats, and rubble even among the spines of sea urchins (*Diadema* spp.) or crown-of-thorns starfish (*Acanthaster* spp.) during the day, then emerging at night to feed on the reef (Allen 1999; Debelius 2002). Although typically solitary, in pairs or loose clusters, a few species form dense aggregations immediately above mounds of branching corals (Allen et al. 2003). Members of the genera *Apogonichthys* spp. and *Foa* spp. are typically secretive, cryptic inhabitants of seagrasses, algal beds or rubble of sheltered reefs and reef flats (WPRFMC 2001a).

Life History—Apogonid species display a variety of different spawning patterns including year-round, spring and fall peaks and in conjunction with phases of the moon (WPRFMC 2001a). Courtship and spawning in cardinalfishes are always paired rather than group activities (Debelius 2002). Cardinalfish are also among the few marine fishes with oral brooding, with the male carrying the eggs in his mouth until they hatch (Allen et al. 2003).

Common Prey Species—Cardinalfish prey mainly on large zooplankton with some species eating primarily small benthic crustaceans (Randall 1996; WPRFMC 2001a).

- **Blenniidae** (Blennies)

Status—Fourteen species of blennies occur in the Hawaiian archipelago (Randall 1996), are managed as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to

determine if blennies of the PHCRT are approaching an overfished situation (NMFS 2004c). Blennies have very little commercial importance due to their small size (Springer 2001). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Blennies have a worldwide distribution occurring in tropical and temperate seas. The Indo-Pacific population consists of two subfamilies: sabretooth (Salariinae) and combtooth (Blenniinae) blennies based on dentition and diet (Myers 1999).

Habitat Preference—Blennies are bottom-dwelling fishes that tend to shelter in small holes in the rocky, oyster, or coral reefs or sand substrate in tidepools (Springer 2001; Debelius 2002). This group exhibits complex color patterns that enable them to be well camouflaged to the surrounding habitat (WPRFMC 2001a). Most of the combtooth blennies are sedentary inhabitants of rocky shorelines, reef flats, or shallow seaward reefs from one to 30 m depths (Myers 1999). Some combtooth blennies (e.g., *Istiblennius* spp. and *Entomacrodus* spp.), called rockskippers, inhabit tidal zones where they are able to leap between tide pools. Others in the genus *Escenius* spp. generally occupy coral-rich areas (Allen et al. 2003). Sabretooth blennies (e.g., *Plagiotremus* spp. and *Omobranchus* spp.) utilize empty worm tubes or shells when they are not actively swimming above the seafloor, mimicking (e.g., bluestreak cleaner wrasse, *Labroides dimidiatus*, or pursuing other fishes (Allen et al. 2003).

Life History—The reproductive biology of blennies has been studied extensively. Although there are many variations, most are demersal territorial fishes that deposit adhesive eggs in or near a shelter hole that are guarded by the male (Randall 1996). Spawning occurs throughout the year with a peak from January to April (WPRFMC 2001a).

Common Prey Species—Sabretooth blennies feed on scales, skin or mucus of larger fish and combtooth blennies feed primarily on benthic algae, although a few also feed on coral polyps (e.g., leopard blenny, *Exalias brevis*) (Randall 1996; WPRFMC 2001a).

- **Pinguipedidae** (Sandperches)

Status—Two sandperch species occur in the Hawaiian archipelago (Randall 1996), are managed as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if sandperch of the PHCRT are approaching an overfished situation (NMFS 2004c). A few species of sandperch are large enough to be of commercial importance as food, but only of limited value (Randall 2001d). Neither of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Only species of the genus, *Parapercis,* occur in the Indo-Pacific region (Myers 1999).

Habitat Preference—Species of the genus, *Parapercis*, typically occur on sandy bottoms near rubble, rock, or coral reefs, where they can be found resting using well-separated pectoral fins (WPRFMC 2001a). Adults are found at depths ranging from 10 to 50 m (e.g., redspotted sandperch, *P. schauinslandii*) (Randall 1996) with some species occurring in deeper waters (100 to 300 m) (Myers 1999).

Life History—Sandperch live in small harems with a single dominant, territorial male (Allen et al. 2003). Some sandperch are unisexual (Randall 2001d). Courtship and spawning occur just before sunset year round (Myers 1999). There is no evidence of spawning migrations (WPRFMC 2001a).

Common Prey Species—Sandperch feed on benthic crustaceans and small fishes (Randall 1996).

- **Bothidae, Pleuronectidae, and Soleidae** (Flounders and Soles)

Status—Seventeen flatfish species occur in the Hawaiian archipelago and are managed as part of the PHCRT by the WPRFMC (2001a). Thirteen left-eyed flounders including two common shallow-

water species, two tropical right-eyed flounders of the subfamily Samaridae, and two soles of the native genus *Aseraggodes* spp. (Randall 1996) have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Although flatfish are among the world's important food fishes, there are currently no data available to determine if flatfish of the PHCRT are approaching an overfished situation (NMFS 2004c). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Flatfish are distributed on tropical and temperate continental shelves worldwide. Some species are associated with coral reefs in the Indo-Pacific (Myers 1999).

Habitat Preference—Habitats for most flatfish consist of softbottoms such as sand, mud, silt, or gravel that are often associated with coral reefs (Myers 1999). Some species occur directly on the reef or within the reef framework (WPRFMC 2001a). Juveniles and adults are often found in lagoons, caves, flats, and reefs (WPRFMC 2001a). Flatfishes exhibit adaptive camouflage to closely match the surrounding bottom habitat (Allen et al. 2003). Some flatfishes are found in water deeper than 100 m (e.g., panther flounder, [*Bothus pantheinus*]), with some species being common in shallower habitats (flowery flounder, [*B. mancus*]: 1 to 73 m) (Myers 1999). Eggs of the flounder and sole are pelagic. As larvae metamorphose into juveniles and adults they become demersal (WPRFMC 2001a).

Life History—Information on the reproductive process and the extent of spawning aggregations are lacking on these Indo-Pacific species (WPRFMC 2001a).

Common Prey Species—Flatfish prey upon small fishes and crustaceans (Randall 1996; WPRFMC 2001a).

- **Ostraciidae** (Trunkfishes)

Status—Six trunkfish species occur in the Hawaiian archipelago (Randall 1996), are managed as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if trunkfish of the PHCRT are approaching an overfished situation (NMFS 2004c). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Trunkfish, also known as boxfish, are distributed in marine and tropical waters in the Pacific, Indian, and Atlantic Oceans (G. Nelson 1994; Randall 1996; Myers 1999).

Habitat Preference—Ostraciids are solitary, slow-swimming, diurnal predators that inhabit a variety of sand and rubble bottom areas (e.g., subtidal reef flats, lagoons, bays, channels, seaward reefs) covered with moderate to heavy algae or coral growth (Myers 1999; Matsuura 2001a). These fish have been reported at depths from one to 100 m (Matsuura 2001a). Postlarvae and juveniles are commonly collected in grassbeds and other shallow areas (WPRFMC 2001a).

Life History—Trunkfish are sexually dimorphic. The species of trunkfish studied to date are haremic with males defending a large territory with non-territorial females and subordinate males. Trunkfish spawning occurs in pairs at dusk, usually above a structure (WPRFMC 2001a).

Common Prey Species—Trunkfish feed on a wide variety of small sessile invertebrates, especially didemnid tunicates and sponges, but also polychaetes, algae, mollusks, and copepods (Randall 1996; WPRFMC 2001a).

- **Tetradontidae and Diodontidae** (Pufferfishes and Porcupinefishes)

Status—Fourteen pufferfish and three porcupinefish species are managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). Nine of the pufferfish and all three porcupinefish have been reported from the Hawaiian Island's inshore waters (Randall 1996) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently,

no data are available to determine if pufferfish or porcupinefish of the PHCRT are approaching an overfished situation (NMFS 2004c). Some porcupinefish are inflated, dried, and sold as curios (Leis 2001). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Pufferfish and porcupinefish are distributed worldwide throughout tropical and temperate waters including brackish and some freshwater habitats (Waikiki Aquarium 1999c; Matsuura 2001b).

Habitat Preference—Both families have reef-associated and pelagic species utilizing bottom types of sand, rubble, silt, coral, or rock in estuarine, mangrove, lagoon, and coral reef (e.g., reef flats, seaward reefs, and patch reefs) habitats from the shoreline to 100 m (Myers 1999; WPRFMC 2001a). Pufferfish feed in the quiet shallow waters of the reef during the day and rest in caves or crevices at night. Porcupinefish also occur close to the reef in quiet waters during the day, often in caves or under ledges, but emerge at night to feed (Waikiki Aquarium 1999c). Most puffers are solitary but a few form small aggregations (WPRFMC 2001a). Larval forms are pelagic occurring from 0 to 100 m (WPRFMC 2001a).

Life History—Most information on pufferfish reproduction has been collected in temperate locations, however, some assumptions can be made about tropical species (WPRFMC 2001a). All species lay demersal adhesive eggs, although the courtship often occurs near the surface (Myers 1999). At least one genus (*Canthigaster* spp.), is haremic with males spawning at mid-morning with a different female each day. Females then deposit the eggs in tufts of algae (Myers 1999). Porcupinefish may spawn pelagic or demersal eggs depending on species. As observed in one species, the spiny balloonfish (*Diodon holcanthus*) spawning takes place at the surface near dawn or dusk as pairs or groups of males with a single female. In Hawai‘i, porcupinefish have a peak spawning in late spring with some spawning also occurring from January to September (WPRFMC 2001a).

Common Prey Species—Puffers feed on a wide variety of algae and benthic invertebrates including fleshy, calcareous, or coralline algae and detritus, sponges, mollusks, tunicates, corals, zoanthid anemones, crabs, hermit crabs, tube worms, sea urchins, brittle stars, starfishes, hydroids, bryozoans, and foraminifera (WPRFMC 2001a). Porcupinefish consume hard tests of sea urchins, shells of mollusks and hermit crabs, and exoskeletons of crabs (Randall 1996).

- **Echineididae** (Remoras)

Status—Three remora species (sharpsucker {*Echeneis naucrates*], common remora [*Remora remora*], and white suckerfish [*Remorina albescens*]) occur in the Hawaiian archipelago (Randall 1996), are managed as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (NMFS 2004e). Currently, no data are available to determine if remoras of the PHCRT are approaching an overfished situation (NMFS 2004c). Remoras are not considered to be of any commercial importance (Collette 1999). None of these three species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Remoras are circumglobal in their distribution and are found throughout the Pacific, Indian, and Atlantic Oceans (G. Nelson 1994).

Habitat Preference—Remoras occur in coastal and pelagic waters either as free swimming species, host specific species (large reef-associated inhabitants: sharks, rays, large bony fishes, sea turtles, or marine mammals), or utilize a variety of hosts (e.g., ships, drivers, etc.) (Myers 1999; Debelius 2001). Species associated with coral reef dwellers are found near reefs down to 50 m (Allen et al. 2003). Eggs of the sharpsucker and common remora are pelagic (Leis and Trnski 1989).

Life History—Information is lacking on the spawning techniques and/or locations of remoras (WPRFMC 2001a).

Common Prey Species—Remoras pick parasites and diseased tissues from their hosts and make short forays from their capture host to feed on zooplankton (copepods and isopods) or zoobenthos such as small crustaceans, detritus, and small fish (Moyle and Cech 2000; WPRFMC 2001).

- **Malacanthidae** (Tilefishes)

Status—One tilefish species is managed in Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). The flagtail tilefish (*Malacanthus brevirostris*) has been reported as occurring in Hawai‘i (Randall 1996) and has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if the flagtail tilefish of the PHCRT is approaching an overfished situation (NMFS 2004c). Tilefishes are very high quality food fishes with several species being commercially important (Dooley 1999). The flagtail tilefish is not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Tilefishes are distributed worldwide in tropical and temperate seas (WPRFMC 2001a). The flagtail tilefish ranges from the Red Sea to Panama, north to south Japan and Hawaiian Islands, south to north New Zealand and Lord Howe and Austral Islands, and throughout Micronesia (Myers 1999).

Habitat Preference—Tilefish usually occur singly or in pairs on outer slope reefs (Myers 1999). They can be found in depths ranging from 6 to 115 m in mud, sand, rubble or talus areas of barren seaward slopes (WPRFMC 2001a). Tilefish frequently build mounds under rocks in the sand or excavate burrows when facing a potential threat (Debelius 2002). The flagtail tilefish is an uncommon inhabitant of barren, open areas of sand and rubble on outer reef slopes at depths of 14 to 45 m (Myers 1999; Allen et al. 2003).

Life History—Few accounts of spawning are known, but it appears that adult pairs of tilefish make a short spawning ascent releasing gametes into the water column (Leis and Trnski 1989).

Common Prey Species—Tilefish feed on benthic invertebrates and plankton (WPRFMC 2001a).

- **Caracanthidae** (Coral Crouchers)

Status—One coral croucher or orbicular velvetfish species is managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). The Hawaiian orbicular velvetfish (*Caracanthus typicus*) has been reported as occurring in Hawai‘i (Randall 1996) and has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if the Hawaiian orbicular velvetfish of the PHCRT is approaching an overfished situation (NMFS 2004c). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Coral crouchers are distributed in the Pacific and Indian Oceans and represented by a single species, the Hawaiian orbicular velvetfish, in the Hawaiian Islands (G. Nelson 1994; Froese and Pauly 2005).

Habitat Preference—Coral crouchers inhabit branches of certain *Stylophora* spp., *Pocillopora* spp., and *Acropora* spp. corals at depths from 3 to 15 m where they tightly wedge themselves into the coral branched when disturbed (Myers 1999). Other than their close association with corals, little is known of their biology (Poss 1999b).

Life History—Information is lacking on the life history of the coral croucher (WPRFMC 2001a).

Common Prey Species—Coral crouchers feed on alpheid shrimps and other small crustaceans (WPRFMC 2001a).

- **Grammistidae** (Soapfishes)

  Status—Five species of soapfish occur in the Hawaiian archipelago (Randall 1996), are managed as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if soapfish of the PHCRT are approaching an overfished situation (NMFS 2004c). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

  Distribution—Soapfishes are distributed in the Atlantic, Pacific, and Indian Oceans and are represented by two genera (*Liopropoma* spp. and *Pseudogramma* spp.) in Hawai'i of the Indo-Pacific region (WPRFMC 2001a).

  Habitat Preference—Soapfishes are small, grouper-like, secretive fishes that occur on reef flats, shallow lagoons, outer reef slopes, and wave-washed seaward reefs (WPRFMC 2001a). They often hide in small caves, under ledges or in holes at depths up to 150 m (Myers 1999). *Liopropoma* spp. has pelagic eggs, whereas *Pseudogramma* spp. has large demersal eggs (WPRFMC 2001a).

  Life History—The soapfish, like the grouper, are generally unisex. All species are solitary and territorial. *Liopropoma* has pelagic eggs, whereas *Pseudogramma* has large demersal eggs (WPRFMC 2001a).

  Common Prey Species—Soapfishes prey upon fishes, crustaceans, and a variety of invertebrates (WPRFMC 2001a).

- **Aulostomidae** (Trumpetfishes)

  Status—A single trumpetfish species, the Chinese trumpetfish (*Aulostomus chinensis*), is managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). This species has been reported as occurring in Hawai'i (Randall 1996) and has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if the trumpetfish of the PHCRT is approaching an overfished situation (NMFS 2004c). Trumpetfish have no commercial importance, but are occasionally taken as by-catch in artisanal fisheries (Fritzsche and Thiesfeld 1999a). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

  Distribution—Trumpetfishes are distributed in the tropical Atlantic and Indo-Pacific regions occurring in Hawai'i, Micronesia, and American Soma (G. Nelson 1994; WPRFMC 2001a).

  Habitat Preference—Trumpetfishes occur in virtually all reef habitats except areas of heavy surge to a depth of 122 m (Myers 1999). These fishes are solitary ambush predators which hover vertically among branches of corals and seagrasses, hide within schools of surgeonfishes, or use the body of a large parrotfish as cover to approach unsuspecting prey (Waikiki Aquarium 1999c).

  Life History—Spawning of trumpetfishes has been reported to occur at dusk when individual males and females ascend to a depth of 5 to 8 m to release gametes before returning to the bottom (WPRFMC 2001a).

  Common Prey Species—Trumpetfishes feed mainly on small fishes and shrimps (Randall 1996; Myers 1999; WPRFMC 2001a).

- **Fistularidae** (Cornetfishes)

  Status—A single cornetfish species, the reef cornetfish (*Fistularia commersonnii*), is managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). This species has been reported as occurring in Hawai'i (Randall 1996) and has EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if the cornetfish of the PHCRT is approaching an overfished situation (NMFS 2004c). Although not

important in commercial fisheries, cornetfish are frequently taken in trawls and by various types of artisanal gear and may appear in local food markets (Fritzsche and Thiesfeld 1999b). This species is not listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—The cornetfishes are distributed in the tropical Atlantic, Pacific, and Indian Oceans and is represented by a shallow-water and deepwater species in the Indo-Pacific region (G. Nelson 1994; WPRFMC 2001a).

Habitat Preference—The shallow-water cornetfish species occur in virtually all reef habitats except in areas of heavy surge to a depth of 122 m (Myers 1999; Allen et al. 2003). It is usually seen in relatively open sandy areas within schools of similarly sized individuals (WPRFMC 2001a) and occasionally occurs in mid-water, above steep dropoffs (Myers 1999).

Life History—Cornetfish eggs are large, pelagic, and subject to advection by ocean currents (WPRFMC 2001a).

Life History—Information is lacking on the life history of cornetfishes (WPRFMC 2001a).

Common Prey Species—Cornetfishes feed on small fishes, including the lionfish (*Pterois miles*), crustaceans, and squids (Randall 1996; Myers 1999; WPRFMC 2001a).

- **Clupeidae** (Herrings and Sardines)

Status—Four clupeid species are managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001). Two species of introduced sardines (Marquesan [*Sardinella marquesensis*] and goldspot [*Herkotsichthys quadrimaculatus*]) and two species of round herrings (redeye [*Etrumeus teres*] and delicate [*Spratelloides delicatulus*]) have been reported as occurring in Hawai‘i (Randall 1996) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if sardines and round herrings of the PHCRT are approaching an overfished situation (NMFS 2004c). In Hawai‘i, the goldspot sardine is an important food and baitfish in many areas (Myers 1999). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Clupeids are distributed worldwide in freshwater and marine systems and are represented by four genera in Hawai‘i and the Indo-Pacific region (J. Nelson 1994; Myers 1999).

Habitat Preference—Both the sardine and round herring species occur in coastal water habitats over sand, mud, rock, and coral reefs from the surface down to 20 m (WPRFMC 2001a). Round herrings occur in large schools near the surface in relatively clear coastal waters, lagoons, and along reef margins during feeding. Sardines school near mangroves and above sandy shallows of coastal bays and lagoons during the day moving into deeper water at night to feed (Myers 1999).

Life History—Tropical round herrings and sardines spawn throughout the year (Myers 1999). The goldspot sardine is known to migrate to tidal creeks to spawn from Novemebr to April (WPRFMC 2001a).

Common Prey Species—Sardines and round herrings feed on plankton, mainly crustaceans and their larvae (G. Nelson 1994; Randall 1996; Myers 1999).

- **Engraulidae** (Anchovies)

Status—Two anchovy species are managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). Both species (endemic Hawaiian anchovy [*Encrasicholina purpurea*] and oceanic or buccaneer anchovy [*E. punctifer*]) have been reported as occurring in Hawai‘i (Randall 1996) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if anchovies of the PHCRT are approaching an

overfished situation (NMFS 2004c). Anchovies are commercially important being utilized as live bait for pole and line tuna fisheries (Myers 1999; Wongratana et al. 1999). Neither of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Anchovies are distributed in the Atlantic, Indian, and Pacific Oceans and represented by one genus (*Enchasicholina* spp.) in Hawai‘i and the Indo-Pacific region (J. Nelson 1994; Myers 1999).

Habitat Preference—Anchovies typically inhabit estuaries and turbid coastal waters, but some occur over inner protected reefs, and at least one species, the oceanic or buccaneer anchovy is found in large atoll lagoons or deep, clear bays (WPRFMC 2001a). Juvenile and adult anchovies are planktivores utilizing the surface waters over sand, mud, rock, or coral reef habitats (Myers 1999).

Life History—Anchovies are serial spawners that produce and disperse large quantities of eggs. While most anchovy species inhabit and spawn in coastal waters, some enter brackish water or freshwater to feed or spawn (Munroe 2002).

Common Prey Species—Anchovies feed on planktonic organisms (Randall 1996; Myers 1999).

- **Gobiidae** (Gobies)

Status—Thirty-one species of gobies occur in the Hawaiian archipelago (Randall 1996), are managed as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Five species of gobies are endemic in Hawaiian waters (WPRFMC 2001a). Currently, no data are available to determine if gobies of the PHCRT are approaching an overfished situation (NMFS 2004c). Most gobies have no commercial or recreational importance other than food for larger fishes (Larson and Murdy 2001). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Gobies are distributed worldwide in temperate and tropical seas represented by 212 genera and 1,000 species in the Indo-Pacific region (WPRFMC 2001a; Allen et al. 2003).

Habitat Preference—Gobies occur in a variety of habitats such as rocky shorelines, coral reefs, reef flats, shallow seaward reefs, sand flats, and seagrass beds (Myers 1999). The majority of gobies utilize the coral reef habitat where they exhibit high diversity and abundance, but may occur in adjacent coastal and estuarine waters (Larson and Murdy 2001). Many gobies also occupy a wide variety of substrata ranging from mud, rock, or coral at depths from one to 48 m (Debelius 2002). Certain species live in close association with other marine organisms such as sponges, gorgonians, or snapping shrimps. Different genera of gobies (e.g., *Bryaninops* spp*., Pleurosicya* spp.) live within or occur in groups hovering above the branches of various coral species (*Porites cylindrica, P. lutea, Acropora* spp., and *Cirrhipathes anguina*) (WPRFMC 2001a). Some species (e.g., Hawaiian shrimp goby, *Psilogobius mainlandi*) have a symbiotic relationship with aplheid prawns in which the gobies occupy and/or share a burrow (Randall 1996; WPRFMC 2001a). The gobies, either singly or in pairs, act as sentinels for the snapping shrimp (*Alpheus* spp.) who maintains the burrow (WPRFMC 2001a).

Life History—Gobies appear to spawn promiscuously with many individuals loosely organized into a social hierarchy or with individuals maintaining small contiguous territories (WPRFMC 2001a). Pairing and apparent monogamy have also been documented for a number of gobies (Debelius 2002). Female gobies lay in a small mass of eggs in burrows, on the underside of rocks or shells, or in cavities within the body of sponges (Larson and Murdy 2001a). Males guard the nesting site and eggs, which are attached to the substrate at one end by a tuft of adhesive filaments (WPRFMC 2001a).

Common Prey Species—Gobies feed on tiny crustaceans including shrimps and copepods as well as worms, sponges, and mollusks (Allen et al. 2003).

- **Lutjanidae** (Snappers)

  Status—Eleven snapper species occur in the Hawaiian archipelago (Randall 1996) and are managed as part of the BMUS and the PHCRT by the WPRFMC (1998, 2001a). Nine of these species have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if snappers of the PHCRT are approaching an overfished situation (NMFS 2004c). Snappers are important to tropical and subtropical commercial artisanal fisheries where they are caught with handlines, traps, a variety of nets, and trawls (Anderson and Allen 2001). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

  Distribution—Snappers occur in the subtropical and tropical waters of the Atlantic, Indian, and Pacific Oceans and are represented by five genera in Hawai'i and the Indo-Pacific region (J. Nelson 1994; Randall 1996; Myers 1999).

  Habitat Preference—Snappers are slow growing, long-lived fish that inhabit shallow coastal coral reef areas to deep (0 to 400 m) slope rocky habitats (Allen et al. 2003). Snapper larvae tend to be more abundant over the continental shelf than in oceanic waters, are absent from surface waters during the day, and undergo nighttime vertical migrations (Leis 1987). Juveniles utilize a wide variety of shallow-water reef and estuarine habitats, whereas adults primarily utilize shallow to deep reef and rocky substrate (WPRFMC 2001a). Some snapper species exhibit higher densities on the upcurrent side versus the downcurrent side of islands, banks, and atolls probably due to the increased availability of allochthonous planktonic prey (Moffitt 1993).

  Life History—Snappers may be batch or serial spawners, spawning multiple times over the course of the spawning season (spring and summer with peak activity occurring in November and December). Certain snappers may also exhibit a shorter, more well-defined spawning period July to September), or have a protracted spawning period (June through December peaking in August) (Allen 1985; Parrish 1987; Moffitt 1993). They form large aggregations near areas of prominent relief for spawning with lunar periodicity coinciding with new/full moon events (Grimes 1987).

  Common Prey Species—Most species of snappers feed heavily on crustaceans (crabs), with some eating primarily small fishes, cephalopods, and gastropods while others are zooplanktivorous (Parrish 1987; Randall 1996; Allen et al. 2003).

- **Monacanthidae** (Filefishes)

  Status—Eight filefish species occur in the Hawaiian archipelago (Randall 1996), are managed as as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if filefishes of the PHCRT are approaching an overfished situation (NMFS 2004c). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

  Distribution—Filefishes occur in tropical and temperate waters of the Atlantic, Indian, and Pacific Oceans (J. Nelson 1994). Three filefish species are endemic to Hawai'i (WPRFMC 2001a).

  Habitat Preference—Filefishes are found in lagoons, shallow coral and rocky reefs, seaward reefs with steeply sloping areas, and seagrass beds in depths ranging from 10 m to over 220 m (Myers 1999; Hutchins 2001). Adults are solitary or occur in pairs, while some juvenile species forming schools (Debelius 2001).

  Life History—Information is lacking on the reproduction of most filefish species (Debelius 2002). Some species are sexually dimorphic (WPRFMC 2001a) and lay demersal eggs in nests near the base of dead corals that may be guarded by at least one of the parents (Myers 1999).

Common Prey Species—Filefishes feed on a wide variety of sessile marine organisms including algae, seagrasses, hydrozoans, branching gorgonians, colonial anemones, tunicates, sea urchins, sponges, mollusks, and bryozoans as well as ingesting detritus (Randall 1996; Myers 1999).

- **Antennariidae** (Frogfishes)

Status—Six frogfish species occur in the Hawaiian archipelago (Randall 1996), are managed as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if frogfishes of the PHCRT are approaching an overfished situation (NMFS 2004c). Besides their value in the aquarium trade, frogfishes have no significant economic interest in the Pacific (Pietsch 1998). None of these species found are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Frogfishes occur in all subtropical and tropical waters of the Indo-Pacific region and occasionally in temperate waters (J. Nelson 1994). The Hawaiian freckled frogfish (*Antennarius drombus*) is endemic in Hawaiian waters (Randall 1996; WPRFMC 2001a).

Habitat Preference—Frogfishes are found in estuaries and turbid coastal waters, but are rare on most coral reefs, occurring in low numbers (WPRFMC 2001a). Habitats include the bottoms of seagrass beds, algae, sponges, rocks or corals, from tidepools to lagoons and seaward reefs (Waikiki Aquarium 1999d).

Life History—Frogfish spawn in pairs following a quick rush to the surface. Female frogfishes lay thousands of tiny eggs within large, raft-shaped gelatinous masses at three to four day intervals (Myers 1999).

Common Prey Species—Frogfishes prey upon fishes or crustaceans (Randall 1996).

- **Syngnathidae** (Pipefishes and Seahorses)

Status—Eight pipefish and seahorse species occur in the Hawaiian archipelago (Randall 1996), are managed as part of the PHCRT by the WPRFMC (2001a), and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). The redstripe pipefish (*Dunckerocampus baldwini*) is endemic in Hawai‘i (Randall 1996; WPRFMC 2001a). Currently, no data are available to determine if pipefishes or seahorses of the PHCRT are approaching an overfished situation (NMFS 2004c). Some species regularly appear in the trade for traditional medicine, curios, and aquaria (Paulus 1999). The spiny seahorse (*Hippocampus histrix*) and Fisher's seahorse (*H. fisheri*) have been listed as data deficient and the common seahorse (*H. kuda*) as vulnerable on the IUCN Red List of threatened species (Project Seahorse 2002a, 2002b, 2003; Lourie et al. 2004).

Distribution—Pipefish and seahorses are circumtropical and temperate in their distribution occurring in the Atlantic, Indian, and Pacific Oceans in marine, brackish, and freshwaters (J. Nelson 1994).

Habitat Preference—Syngnathids are small, inconspicuous bottom dwellers that occur in a wide variety of shallow habitats from estuaries and shallow sheltered reefs to seaward reef slopes (WPRFMC 2001a). Habitats include seagrasses, floating weeds, algae, corals, mud bottoms, sand, rubble, or mixed reef substrate from tidepools to lagoons and seaward reefs (Myers 1999). Demersal syngnathid populations occur in pairs or singly at depths ranging from a few centimeters to more than 400 m, although they are generally limited to water shallower than 50 m (Allen et al. 2003). Juveniles are occasionally found in the open sea in association with floating debris (WPRFMC 2001a).

Life History—Spawning by pipefish and seahorses involves the female depositing her eggs into a ventral pouch on the male, which carries the egg until hatching at intervals of three to four days (WPRFMC 2001a). Breeding populations occur throughout the salinity range from fresh to hypersaline waters (Dawson 1985).

Common Prey Species—Pipefish and seahorses feed upon small free-living crustaceans such as copepods (Dawson 1985; Randall 1996).

Invertebrate Management Unit Species

- **Gastropods** (Sea Snails and Sea Slugs)

Status—Gastropods consisting of sea snails (prosobranchs) and sea slugs (opisthobranchs) are managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). About 572 gastropod species representing 66 prosobranch and 33 opisthobranch families have been reported as occurring in Hawai'i (Hoover 1998) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). At least 116 species of Hawaiian gastropods are known to be endemic (Kay 1979). Various species of prosobranchs (e.g., turbans, tops, cowries, cones, and miter shells) are highly prized among collectors and currently utilized in the shellcraft industries (Hoover 1998; Poutiers 1998a). None of these species found are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Gastropods are found worldwide in tropical, subtropical, and temperate waters of marine and freshwater ecosystems (Kay 1995).

Habitat Preference—Gastropods inhabit all bottom econiches of coral reef ecosystems including the surfaces of sediments, rocks, dead coral heads, living corals, and seaweed thalloms (Sorokin 1995). The prosobranch are the most numerous of the gastropods and occupy a variety of reef habitats including soft sediments, rocky and stony littoral/sublittoral areas, reef flat rocks, outer slope rocks, lagoons of barrier reefs, trenchs of rocks at the reef-flat edge, reef flats, and patch reefs (Sorokin 1995). Nudibranchs, the largest of the sea slugs, are predatory opisthobranchs inhabiting the surface of soft corals (alcyonaceans and gorgonaceans), hydroids, and sponges which they utilized as prey (Russo 1994; Colin and Arneson 1995).

Life History—Sea snails generally have separate sexes, whereas sea slugs are unisexual. Fertilization may be external or internal in sea snails. Sea snail species that undergo internal fertilization produce eggs that may be enclosed in protective layers of gelatinous mucus or corneous capsules. Sea slugs deposit eggs in ribbon-like clusters, whereas sea snail embryos hatch as free-swimming planktonic larvae or as crawling young (Poutiers 1998a).

Common Prey Species—Depending upon the species, sea snails feed on a wide variety of benthic organisms such as turf or fleshy algae, hydroids, sponges, heart and sea urchins, echinoderms, mollusks, sea stars, worms (polychaetes), scleractinian hard corals, small crustaceans, and sleeping fish as well as detritus. Different species of sea slugs consume hydroids, small crustraceans, soft corals, red and blue-green algae, sponges, tunicates, broyozoans, and other sea slugs (Colin and Arneson 1995; Sorokin 1995; Hoover 1998).

- **Bivalves** (Oysters and Clams)

Status—Oysters and clams are managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). At least 171 bivalve species including 83 endemics have been reported as occurring in Hawai'i (Eldredge and Evenhuis 2003) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). The black-lipped pearl oyster (*Pinctada margartifera*) occurs in the Hawaiian archipelago, but is uncommon in near-shore waters and has been illegal to harvest for 60 years (Hoover 1998). Several oysters and clams from North America and Japan have been introduced successfully to Hawai'i and occur in limited numbers in shallow sheltered areas such as Pearl Harbor, Maunalua Bay, and Kane'ohe Bay, O'ahu (Hoover 1998). Different species of bivalves have been locally collected for subsistence purposes and utilized as decorative items in the shellcraft industry (ark and pen shells) or introduced for aquaculture (oysters) (Poutiers 1998b). Currently, the season is closed and collection of clams, oysters, and other shellfish

is prohibited in Hawai‘i’s state waters (Hoover 1998; HDAR 2003b). None of these species found are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Bivalves are found in all tropical and temperate seas of the world (Briggs 1974) with the overall biodiversity of the malacological fauna being the greatest in the western central Pacific (Poutiers (1998b).

Habitat Preference—Bivalves comprise 10 to 30% of the coral reef malacofauna utilizing rocky hard substrates for sessile and boring species and softbottom areas for vagile species (Sorokin 1995). Sessile bivalves inhabit reef areas such as rocky surfaces of reef-flats, dead coral heads, patch reefs, walls of trenches and channels, and on coarse sands and rubble substrates on flat and littoral areas (Sorokin 1995). Boring bivalves are extremely widespread in areas of the rocky flat and in areas of profuse coral growth hidden in coral colonies (Sorokin 1995). The sandy bottom of channels crossing the reef-flat and its outer slopes as well as on silty coral sands in the lagoons of barrier reefs are inhabited mainly by vagile bivalves (Sorokin 1995). The black-lipped pearl oyster occurs in lagoons, bays, and sheltered reef areas to around 40 m depth, but is most abundant just below the low-water (Sims 1993).

Life History—In the majority of bivalves, sexes are separate. Fertilization is external, giving rise to free-swimming larvae followed by a metamorphosis leading to a benthonic mode of life (Poutiers 1998b). Some species may be unisexual with fertilization occuring in the pallial cavity with protection of eggs or larvae in a brooding chamber. If the planktonic larval stage is reduced or totally absent, young hatch directly as benthic organisms (Poutiers 1998b).

- **Cephalopods** (Squids and Octopuses)

Status—Cephalopods are managed in the Hawaiian archipelago as PHCRT by the WPRFMC (2001a). Seven octopus species and more than a dozen squids and cuttle-lie fishes (including one endemic cuttle-like fish (*Euprymna scolopes*), one possibly extirpated bigfin reef squid (*Sepioteuthis lessoniana*), most of which are pelagic, have been reported as occurring in Hawai‘i (Kay 1979; Hoover 1998; WPRFMC 2001a; Eldredge and Evenhuis 2003). All have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if cephalopods of the PHCRT are approaching an overfished situation (NMFS 2004c). Cephalopods are of considerable ecological and commercial fisheries importance in the Pacific where they are harvested for food items in the subsistence fishery (Dunning et al. 1998). Octopuses are a component of the incidental catch of the lobster-trap fishery in the NWHI (WPRFMC 2001a). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Cephalopods are found in all tropical and temperate seas of the world (Roper et al. 1984).

Habitat Preference—Cephalopods occur over a wide variety of habitats including holes and crevices in rocky or coral areas. Octopuses burrow in the sand and are found around seagrass beds, whereas squid are associated with nearby reef areas over sandy, muddy, and rocky bottoms (Dunning 1998; Norman 1998; Reid 1998). Their range of depth extends from the surface to over 5,000 m (Roper et al. 1984). Some species (e.g., squids) exhibit diurnal vertical migration, moving upward to feed during the night and dispersing into the deeper water during the day (Dunning 1998). Eggs are encapsulated in gelatinous finger-like strings (squids) or attached to each other (octopuses) adhering to various substrates (e.g. rockes, shells, seagrass) (Dunning 1998; Norman 1998; Reid 1998).

Life History—Cephalopods have separate sexes and reproduction occurs through copulation (Colin and Arneson 1995). Spawning varies between the various groups of cephalopods. Squids migrate in aggregations biannually to spawn in response to temperature changes (Dunning 1998; Reid 1998). Octopuses lay eggs which are tended by the female until hatching (Norman 1998; Waikiki Aquarium 1998d).

Common Prey Species—Cephalopods exhibit a wide range of feeding habits and food preferences. Free-swimming squids prey upon fish, crustaceans (shrimp), and other squids, and octopuses mostly prey on shrimp, and occasionally crabs (Kay 1979; Hoover 1998; Waikiki Aquarium 1998f; WPRFMC 2001a).

- **Ascidians** (Tunicates)

Status—Tunicates are managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). At least 70 species have been reported as occurring in Hawai‘i (Eldredge and Evenhuis 2003) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Ascidians are of economic importance for bio-prospecting and are problematic as marine fouling organisms by clogging cooling water intakes and interfering with boat operations (WPRFMC 2001a).

Distribution—Ascidians are common worldwide and are important inhabitants of the shallow water tropical Pacific (Colin and Arneson 1995; WPRFMC 2001a).

Habitat Preference—Solitary (sea squirts) and colonial (clusters) tunicates are important components of the reef cryptofauna ranging from high-light and high-energy environments to protected deeper water areas (Russo 1994; Sorokin 1995; WPRFMC 2001a). Ascidians attach to inert surfaces such as dead corals, stones, shells, pilings, ship bottoms and less durable surfaces of seaweeds, mangrove roots, sand, and mud, or grow epizoically on other sessile organisms (e.g., soft corals, sponges, other tunicates) (Colin and Arneson 1995). Solitary forms colonize new surfaces in disturbed areas, whereas colonial types are more suited for growth on the outer reef slopes (WPRFMC 2001a). Larval and adult tunicates occur from intertidal areas to 120 m depth or greater (WPRFMC 2001a).

Life History—Both sexual and asexual reproduction occurs in ascidians and is highly variable, both by family and genera. Egg production is year-round (WPRFMC 2001a). Solitary forms release both unfertilized eggs and sperm into the water, whereas the colonial forms are ovoviviparous, releasing only larvae (Colin and Arneson 1995). The release of certain chemicals by tunicates may trigger various processes, such as spawning, larval attraction, etc. (WPRFMC 2001a). Solitary and colonial ascidians are unisexual but may also reproduce asexually by budding (WPRFMC 2001a).

Common Prey Species—Ascidians filter-feed non-selectively on phytoplankton and other suspended food particles and nutrients (WPRFMC 2001a).

- **Bryozoans** (Moss Animals)

Status—Bryozoans are managed in the Hawaiian archipelago as part of the PHCRT (WPRFMC 2001a). At least 168 species have been reported as occurring in Hawai‘i (Eldredge and Evenhuis 2004a) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Surveys conducted in Kane‘ohe Bay reported 57 species of bryozoans (45 cheilostomes, 13 cyclostomes, and one ctenostome) of which 23% are considered endemic (WPRFMC 2001a). Bryozoans are of economic importance for bio-prospecting and as marine fouling organisms which interfere with boat operations and clog industrial water intakes and conduits (Hoover 1998; WPRFMC 2001a). Another type of brachiopod (*Lingula reevii*) inhabits a solitary sandbar in Kane‘ohe Bay, O‘ahu and has been designated as a species of concern by NMFS (2004f).

Distribution—Bryozoans are inhabitants of tropical Pacific reefs ranging from Hawai‘i to the Indian Ocean (Colin and Arneson 1995).

Habitat Preference—Though widepsread on tropical reefs, bryozoans are often not recognized due to the fact that they occur in mixed associations with algae, hydroids, sponges, and tunicates on older portions of coral reefs (WPRFMC 2001a). These benthic sessile organisms occur from the intertidal zone to abyssal depths with the majority occurring in shallower clear waters ranging from 20 to 80 m

(WPRFMC 2001a). Forming encrusting, erect branching, or foliose colonies, bryozoans attach to rocks, corals, shells, other animals, mangrove roots, and algae or grow on shaded surfaces on the undersides of coral heads, rock ledges, rubble, and fill cavities within the reef structure (Sorokin 1995). Encrusting forms would be associated with intertidal areas (fringing and patch reefs, barrier reef coral-algal flat breaker zone) or other sites subject to strong waves (ocean slope bench), whereas the erect branching or foliose types would be confined to deeper, more stable habits not subject to strong ocean surges (Sorokin 1995; WPRFMC 2001a). The pelagic larvae exhibit a positive phototropic reaction, but become negatively phototropic before metamorphosis, settling in dark places on the reef. This may be dependent upon day length and temperature (WPRFMC 2001a). Thermal boundaries of 27°C may provide a filtering mechanism that determines the distribution of bryozoan larvae (WPRFMC 2001a).

Life History—Most marine bryozoans are unisexual releasing sperm and eggs into the water or brooding eggs in a cavity until fertilized (WPRFMC 2001a). Larvae take approximately two weeks from fertilization to development (WPRFMC 2001a).

Common Prey Species—Bryozoans are suspension-feeders that capture plankton such as diatoms, detritus, bacteria, silicoflagellates, peridinians, coccolithophores, algal cysts, and flagellates (WPRFMC 2001a).

- **Crustaceans** (Mantis Shrimps, Lobsters, Crabs, and Shrimps)

Status—Crustaceans of the orders Stomatopoda (mantis shrimp) and Decapoda (penaeid, stenopodidean, and caridean shrimps, astacidean/palinurid lobsters, and hermit/true crabs) are managed in the Hawaiian archipelago as part of the CMUS and the PHCRT by the WPRFMC (1998, 2001a). Over 600 crustacean species (20 stomatopods and 652 decapods) have been reported as occurring in Hawai‘i (Eldredge and Evenhuis 2003) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Currently, no data are available to determine if crustaceans of the PHCRT are approaching an overfished situation (NMFS 2004c). Stomatopods are of little economic importance due to their limited use in subsistence fisheries and ornamental trade. However, decapods are very important in commercial, recreational, and artisanal fisheries with limited use in the ornamental trade (except shrimp) throughout the tropical Pacific (WPRFMC 2001a). In the Hawaiian Islands, spiny/slipper lobsters and crabs (e.g., Kona) have many restrictions regarding harvest (Hoover 1998; Waikiki Aquarium 1998a; 1998b; HDAR 2003b). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Crustaceans occur in all tropical and temperate seas of the world and are the most abundant and diverse groups of the coral reef vagile and sedentary benthic organisms in waters of the Pacific tropical and subtropical islands (Eldredge 1995; Sorokin 1995).

Habitat Preference—Crustaceans occur over a wide variety of coral reef habitats and associated environments. Mantis shrimp inhabit cavities of coral and rock or smooth-walled burrows on sandy bottoms (Manning 1998). Penaeid, caridean, and stenopodidean shrimps utilize pockets of corals and are found among rubble, or buried in sand on reef flats and in seagrass beds (Chan 1998a). The spiny, slipper, and coral lobsters use subtidal holes or crevices of rocky and coralline bottoms (Chan 1998b). True and hermit crabs can be found in mud or sandy bottoms in high littoral sands, crevices or burrows among subtidal rocks and coral heads, or on the surfaces of marine plants and other invertebrates (Ng 1998). The depth distribution of these different reef crustaceans varies from the intertidal and subtidal zones to over 100 m (mantis shrimp: 5 to 70 m, coral associated shrimps: 3 to 15 m, lobsters: 20 to 50 m, true crabs: 0 to 115 m, and hermit crabs: 0 to 305 m) (Hoover 1998; WPRFMC 2001a). Some crustaceans also provide symbiotic or commensal associations with other marine organisms (Colin and Arneson 1995).

Life History—Information is available on the spawning seasons and reproductive capability of most crustaceans in the subtropical and tropical regions of the Pacific (WPRFMC 2001a). In decapods, for example, the spiny lobster spawns continuously throughout the year with individual females spawning

four times per year (Pitcher 1993). Other lobster species may have more defined spawning seasons (WPRFMC 2001a). Eggs are carried on the pleopods of the female in the stomatopods prior to being deposited at the bottom of their burrows where they are constantly aerated (Hoover 1998). Other decapod eggs are also carried on the female's pleopods except for penaeid shrimp that shed their eggs directly into the water (WPRFMC 2001a).

Common Prey Species—Crustaceans are typically carnivorous or omnivorous predators or scavengers preying upon mollusks, other crustaceans and small fish. Some taxa feed on ectoparasites, whereas others are filter feeders (Hoover 1998; WPRFMC 2001a).

- **Echinoderms** (Sea Cucumbers and Sea Urchins)

Status—Echinoderms, including sea cucumbers (holothuriods), sea urchins (echinoids), brittle stars and basket stars (ophuiroids), sea stars (asteroids), and feather stars/sea lilies (crinoids), are managed in the Hawaiian archipelago as part of the PHCRT (WPRFMC 2001a). More than 300 echinoderm species (over 58 holothuroids, 84 echinoids, 61 ophuiroids, 90 asteriods, and 16 crinoids) have been reported as occurring in Hawai'i (Hoover 1998; Eldredge and Evenhuis 2003) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Echinoderms have some economic importance, particularly the holothurians or sea cucumbers which are prized as beche-de-mer or trepang (dried body wall) and some species of sea urchins whose gonads are edible (Conand 1998). Of negative economic importance are the species, such as the crown-of-thorns starfish (*Acanthaster planci*), that can devastate coral reefs (Pawson 1995). In Hawai'i, this species infested reefs off southern Moloka'i in 1969 but did not cause extensive damage to living coral polyps (*Pocillopora meandrina*) (Gulko 1998; Hoover 1998). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—The phyllum Echinodermata is exclusively marine and distributed throughout all oceans, at all latitudes, and depths from the intertidal zone down to the abyssal plains (Colin and Arneson 1995). Echinoderm fauna are widely distributed across several localities of the Indo-Pacific region with few taxa being endemic (Pawson 1995), except for Hawai'i where at least 48% of the population is considered endemic (Eldredge and Evenhuis 2003).

Habitat Preference—Echinoderms form dense monospecific populations in shallow reef zones and play important roles in trophodynamics and nutrient regeneration. They occupy all the trophic niches, as filters (ophiuroids [brittle stars], crinoids [feathered stars]), detritus and sediment eaters (holothurians, ophiuroids), phytophages (sea urchins), and predators (sea stars, and in part, sea urchins and ophiuroids) from the intertidal regions to depths of about 2,000 m (Colin and Anderson 1995). The coral reef habitat and associated environments inhabited by echinoderms include sandy bottoms of lagoons, coral sand, and reef-flats rocks (sea urchins); hardbottom biotopes of reef flats, sublittoral and patch reefs, outer reef slope, and cryptofaunal habitats (sea stars); under stones in trenches on reef flats or on seagrasses (brittle stars); weak current areas in reef-flats and outer slope trenches and caves (feathered stars); and coral slopes (passages), inner/outer lagoons, inner/outer reef-flats covered with sand and rubble (sea cucumbers) (Sorokin 1995; Conand 1998; Miskelly 2002). Most echinoderms (e.g., brittle stars and feathered stars) are nocturnal, hiding in the daytime and feeding at nighttime (Sorokin 1995). They also have formed commensal relationships with small reef organisms (e.g., shrimps and fishes) (Colin and Arneson 1995).

Life History—The majority of echinoderms have separate sexes, but unisexual forms occur among the sea stars, sea cucumbers, and brittle stars. Many species of echinoderms are broadcast spawners (e.g., sea cucumbers, sea stars) (Waikiki Aquarium 1998g, 1998h). These species have external fertilization producing planktonic larvae; but some brood their eggs, never releasing free-swimming larvae (Colin and Arneson 1995).

Commom Prey Species—Many echinoderms are either scavengers or predators on sessile organisms such as algae, stony corals, sponges, clams, and oysters. Some species, however; filter food particles from sand, mud or water (Hoover 1998).

- **Annelids** (Segmented Worms)

Status—Segmented worms or polychaetes are managed in the Hawaiian archipelago as part of the PHCRT (WPRFMC 2001a). At least 295 polychaetes with over 70 endemic species have been reported as occurring in Hawai‘i (Eldredge and Evenhuis 2003) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Polychaetes are important food resources of reef fishes and invertebrates with some species being indicators of environmental perturbation and reef condition (Bailey-Brock 1995).

Distribution—Polychaetes are primarily marine worms that are extremely abundant and widespread in tropical and temperate oceans with brackish and freshwater forms living in streams and estuaries of tropical regions (Colin and Arneson 1995). Islands in the tropical central and western Pacific region have species-rich polychaete communities that are mostly cryptic, endolithic, or infanual (Bailey-Brock 1995).
Habitat Preference—Benthic coral reef polychaetes are associated with hard or softbottom materials or live among marine vegetation (Bailey-Brock 1995). The polychaetes occupying all these econiches in the coral reef biotopes are classified into two groups: free-living (free-swimming) errant and sedentary (tube-dwelling) segmented worms (Sorokin 1995). Specific types of coral reef habitats frequently colonized by these polychaetes at depths to 15 m include rocky intertidal areas (e.g., tide pools and shallow sand-filled depressions associated with lava rocks, basalt, and limestone benches), mud and sand at the sediment-water interface, reef flats, sandy tops of patch reefs, sandy cays, seagrasses, mangroves, and fleshy or thalloid algae (Bailey-Brock 1995; Sorokin 1995; Hoover 1998). In addition to coral reefs, polychaetes also colonize vessel hulls, docks, and harbor walls, as well as floating slippers, glass floats, and debris (Bailey-Brock 1995). Polychaetes stabilize sand on reef flats by their tube-building activities, bore into coral rock contributing to the erosion of reef materials, or are commensals of sponges, mollusks, holothurians, and hydroids (Sorokin 1995).

Life History—Most polychaetes have separate sexes, although some are unisexual and a few change sex. Fertilization of eggs takes place in the water column for species, which release their gametes into the water. Other species mate and lay encapsulated eggs in the female, while a few retain their fertilized eggs in the body of the female (Colin and Arneson 1995). Some species swarm in water during their breeding season, others spawn during the first lunar cycle, and some undergo asexual breeding by simple division of the body into several pieces (Sorokin 1995).

Common Prey Species—Polychaetes are raptorial predators, omnivorous scavengers, filter or suspension feeders of sand, sediment, and water, deposit feeders, and selective deposit feeders (Bailey-Brock 1995; Hoover 1998).

Sessile Benthos Management Unit Species

- **Algae** (Seaweeds)

Status—Algae (belonging to the blue-green, green, brown, and red algal groups) are managed in the Hawaiian archipelago as as part of the PHCRT by the WPRFMC (2001a). Over 850 algal species have been reported from the NWHI (196 species) (WPRFMC 2001a) and the MHI (636 species) (Abbott 1999; Eldredge and Evenhuis 2003; Abbott and Huisman 2004) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Algae are classified as EFH because they are direct contributors to the well-being and protection of fish species, both as a source of food and protection to larvae and small fish species (WPRFMC 2001a). Several species are harvested for commercial and subsistence use in the MHI, including *Gracilaria parvispora, Codium edule, Asparagopsis taxiformis,* and *Ulva fasciata* (Green 1997). None of these species are listed on the IUCN Red List of threatened species (IUCN 2004).

Distribution—Algae are found worldwide along most shorelines and shallow water environments. In the Indo-Pacific they have a discontinuous distribution and a low level of endemicity (South 1993).

Habitat Preference—Seaweeds are prominent organisms in the shallow water photic zone ranging from the spray zone well above the high tide level to depths as great as 268 m (South 1993; Russo 1994). From the intertidal to shallow subtidal zones, they occur on soft and/or hard substrata within a variety of marine benthic habitats such as flat reefs, sheltered bays and coves, and rocky wave-exposed areas along the shore or on the edge of the reef (Truno 1998). Habitat distribution of the most abundant common algal forms include the blue-green algae (cyanobacteria) on sandy bottoms of lagoons; green and brown algae in shallow, calm fringing reefs; colonies of large brown algae and tufts of red algae on the barrier reef coral boomies; encrusting calcified algae and belts of brown algae on outer reef flats; and red algae and crustose coralline algae on the outer reef slope (WPRFMC 2001a). Coralline algae are of primary importance in constructing algal ridges that are characteristic of exposed Indo-Pacific reefs preventing oceanic waves from eroding coastal areas (WPRFMC 2001a).

Life History—Both sexual and asexual reproduction occurs in the algae with predominance of one or the other being linked to the type of algae and the predominant geographical and environmental conditions affecting the algal populations (WPRFMC 2001a). Unicellular algae reproduce asexually, while the multicellular algal forms have asexual or sexual life cycles of varying complexity (South 1993).

Common Prey Species—Although algae do not utilize prey species, marine macroalgal forms contribute significantly to organism interrelationships in reef ecosystems. This is accomplished either by the production of chemical or structural by-products on which other organisms depend, by providing protective micro-habitats for other species of algae or marine invertebrates, or by offering surfaces promoting the settlement and growth of other algal species or the larvae of some herbivorous invertebrates (WPRFMC 2001a).

- **Porifera** (Sponges)

Status—Sponges are managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). At least 122 sponges including 24 endemic species have been reported as occurring in Hawai‘i (Eldredge and Evenhuis 2003) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Within the study area, sponges are common under stones or rubble and on docks, pilings or mangrove roots in protected locations such as Pearl Harbor, Honolulu Harbor, and the quiet backwater areas of Kane‘ohe Bay, O‘ahu. They also blanket the walls and caves and crevices along Hawai‘i’s (main island) volcanic shore (Hoover 1998).

Distribution—Poriferans represent a significant component of all tropical, temperate, and polar marine benthic communities (Kelley-Borges and Valentine 1995) with the sponge fauna of the broad Indo-West Pacific region being the most diverse in the world (Briggs 1974). Within Oceania, sponge faunas are divided into four broad groups: (1) regionally endemic sponges that are habitat- or locality-specific (e.g., patch-reefs within nutrient-rich bays or caves); (2) regionally endemic sponges occurring within a single island group; (3) species that are found in “super-regions” (e.g., Hawai‘i alone); and (4) species that occur throughout the Indo-West Pacific Region (Kelley-Borges and Valentine 1995).

Habitat Preference—Sponge diversity is greatest on coral reefs where they occur at various depths in caves and vertical areas not colonized by hard coral (WPRFMC 2001a). They are also abundant in seagrass beds, mangroves, and other environments at depths from 0.6 to 15 m (Colin and Arneson 1995; Hoover 1998). Within the reef benthic community, the shallow biotopes are dominated by demosponges and to a lesser degree by calcareous ones, while the deeper shadowed zones of the outer reef slopes, caves, and tunnels are colonized mainly by sclerosponge species (Sorokin 1995). On the reef-flat and on upper zones of the reef slope, the spongal fauna consists mostly of phototropic and boring species. The more abundant and varied spongal communities inhabit the middle depths of the outer slope, especially the buttress zone and the upper part of the fore-reef (Sorokin 1995). Sponges also provide homes for a huge variety of animals including shrimp, crabs, barnacles, worms, brittle stars, holothurians, and other sponges (Colin and Arneson 1995).

Life History—Reproduction among sponges is highly variable and includes sexual (viviparous and oviparous), asexual (budding, fragmentation, and gemmules), or unisexual reproduction (Colin and Arneson 1995). Mass spawning and release of sperm is triggered by lunar and diurnal periodicity (WPRFMC 2001a).

Common Prey Species—Sponges are living filters feeding on organic particles and ingesting plankton and bacteria (Hoover 1998; WPRFMC 2001a).

- **Corals** (Hydrozoans)

Status—Hydrozoans consisting of sea fans and feather hydroids are managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). Eighty-five hydrozoan species have been reported as occurring in Hawaiʻi (Eldredge and Evenhuis 2003) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Within the study area, hydroids are an important component of marine fouling assemblages and have been reported from artificial habitats (e.g., pillings, floats, etc.) or from disturbed areas such as Kaneʻohe Bay, Oʻahu (Cooke 1977).

Distribution—Hydroids are the most common and conspicuous invertebrates found in shallow tropical waters (Collin and Arneson 1995). Distribution of hydrozoan species in the Hawaiian archipelago consist solely of the family Solanderidae which ranges from western Africa through the central Indo-Pacific with its northerly limit being Japan and Hawaiʻi (Gulko 1998; WPRFMC 2001a).

Habitat Preference—Hydrozoans are colonial, polyp-like animals that occur in cryptic habitats or occur as epizotic on other organisms (Colin and Arneson 1995; Gulko 1998). Similar in appearance to gorgonians and other sea fans, *Solanderia* spp. exhibits branching, ramose or encrusting forms that are commonly found in exposed areas on wave swept shallow outer reefs, caves, or overhanging environments at depth ranges from shallow outer reefs to 100 m (Colin and Arneson 1995).

Life History—Most hydroids have both sexes, but their life cycle is highly variable, complex and poorly understood (Colin and Arneson 1995). Generally, attached colonial hydroids develop an asexual polyp (gonozooid) stage (male or female medusa) and a free-living, medusa stage which reproduce by asexual division or budding (WPRFMC 2001a).

Common Prey Species—The feeding polyp (gastrozoid) of the hydroid captures and ingest small zooplankters (Gulko 1998; WPRFMC 2001a).

- **Corals** (Scleractinian Anthozoans)

Status—Stony corals are managed in the Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). At least 126 scleractinian species (72 shallow-water and 54 deep-water forms) have been reported as occurring in Hawaiʻi (Eldredge and Evenhuis 2003) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Within the study area, coral collecting is banned in Hawaiian state waters under regulations that prohibit the collection or damaging of any live stony corals including reef or mushroom corals and harvesting or breaking of live rock to which marine live of any type is visibly attached (Hoover 1998; HDAR 2003b). This statute also prohibits the sale of all native Hawaiian coral species (regardless of origin) including the following hermatypic forms: cauliflower or rose coral (*Pocillopora meandrina*), lace coral (*P. damicornis*), antler coral (*P. eydouxi*), rice coral (*Montipora capitata*), lobe coral (*Porites lobata*), finger coral (*P. compressa*), and mushroom or razor coral (*Fungia scuteria*), and ahermatypic types: orange or cup coral (*Tubastraea coccinea*) (Gulko 1998; HDAR 2003b). In addition, the Hawaiian reef coral (*M. dilatata*) which has been reported from Kaneʻohe Bay, Oʻahu in the MHI, and Midway Atoll and Maro Reef in the NWHI, is listed as a species of concern by NMFS (2004f).

Distribution—The communities of scleractinian reef-building (hermatypic) and non-reef building (ahermatypic) corals grow in tropical and subtropical seas globally (Veron 1995) with the Pacific

Ocean containing the most diverse coral fauna in the world (Colin and Arneson 1995). In Hawai'i, the genera *Porites* spp., *Montipora* spp., and *Pavona* spp. dominate the reef scleractinians (Maragos 1977; WPRFMC 2001a).

Habitat Preference—Stony corals have polyps which manifests themselves into attached colonial forms that may be branching, tabulate, massive, or encrusting. Stony corals may also be solitary, free-living (e.g., mushroom corals, Fungiidae) forms (WPRFMC 2001a) that extend to a maximum depth of 60 m (Hodgson 1998). The hermatypic coral fauna are found in shallow surf zones and submerged areas of reef flats, lagoon patch-reef zones, patch reefs, and upper outer reef slopes (Sorokin 1995). A typical Hawaiian zonation reef pattern would include: reef flat—0 to 2 m, cauliflower coral; reef bench—2 to 10 m, lobe coral; reef slope—10 to 30 m, finger coral; and rubble—30 to 40 m, lobe and finger coral rubble (Gulko 1998; Tissot 2005). Mushroom corals inhabit shallow water reef areas unsuitable for permanently attached corals such as bottom of pits and channels with sand or rubble in turbulent zones of reef flats, reef edge, and moat on outer slopes (Sorokin 1995; WPRFMC 2001a). Ahermatypic corals (e.g., orange cup coral) colonize areas of low scleractinian coral or algal occurrence including poorly illuminated or even dark biotopes in caves and trenches in shallow water, and in deep, steep-reef zones below 40 m (Sorokin 1995; Gulko 1998; WPRFMC 2001a).

Life History—Hermatypic corals reproduce by both sexual (external fertilization and development and brooded planulae, bisexual, unisexual) and asexual (brooded planulae, polyp-balls, polyp bail-out, fission, fragmentation, and re-cementation) development (Veron 2000; WPRFMC 2001a). Corals may be free spawners (12 month maturation cycle) or brooders (several cycles per year) depending upon their geographic distribution (WPRFMC 2001a). Spawning follows a lunar periodicity beginning on the 15th to 24th night of the lunar cycle (Colin and Arneson 1995). Mushroom corals are asexual (fragmentation or natural regeneration through fracture) or sexual (dioecious or unisexual) (Veron 2000). Ahermatypic corals are dioecious with fertilization being internal and larvae being brooded (WPRFMC 2001a). They also may be free-spawners (Harrison and Wallace 1990). Currents play a major role in transport and abundance of coral eggs and larvae, often concentrating them into a dense mass and dispersing them into the ocean flow (WPRFMC 2001a).

Common Prey Species—The majority of reef-building corals and all ahermatypic corals feed on small planktonic organisms or dissolved organic matter (DOM) (Gulko 1998). Mushroom corals feed heterotrophically through prey capture of zooplankters and autrotrophically through nutrient exchange with zooxanthellae (WPRFMC 2001a).

- **Corals** (Non-Scleractinian Anthozoans)

Status—Non-scleractinian anthozoans are managed in Hawaiian archipelago as part of the PHCRT by the WPRFMC (2001a). At least 140 non-scleractinian anthozoan species (40 anemones and 100 octocorals) have been reported as occurring in Hawai'i (Eldredge and Evenhuis 2003) and have EFH designated within the boundaries of the study area (WPRFMC 2001a; NMFS 2004e). Collecting of sea anemones is discouraged and importation into Hawai'i is illegal (Hoover 1998).

Distribution—The communities of non-scleractinian corals are distributed in shallow tropical and subtropical habitats worldwide (Veron 1995). However, little is known about the zoogeography of individual hexacoral and octocoral species across the tropical Pacific due to improper identification of specimens (Colin and Arneson 1995).

Habitat Preference—Members of the non-scleractinian anthozoans (hexacorals and octocorals) exist only as polyps, either solitary or as colonies. Hexacorals consist of anemones and zooanthids (Colin and Arneson 1995). Anemones have solitary polyps that are attached to hard substrate by their basal disc, burrowed into soft substrate, or attached as symbionts to sessile and moblie reef organisms (e.g., fish or shrimps) (Colin and Arneson 1995). Some species of anemones also exhibit mimicry, appearing like their background or other reef entities (e.g., hard coral or algae) (WPRFMC 2001a). In addition, many anemones can form large colonies of related individuals (Waikiki Aquarium 1998i). Zooanthids have species that are either colonial or solitary, often forming large monospecific patch or

belt associations on biotopes of reef flats (Colin and Arneson 1995). They usually colonize rock bottom substrates in reef-crest and reef-edge zones (*Palythoa* spp.), rubble areas and dead corals (*Zoanthus* spp., *Isaurus* spp.), and even living colonies of acroporids corals (*Zoanthus* spp.) (Walsh and Bowers 1977; Sorokin 1995; Waikiki Aquarium 1998j).

Octocorals consist of soft corals and gorgonian corals (Colin and Arneson 1995). Soft corals occur as large, lobed colonial forms intertidally with high light intensity or as smaller colonies on roofs and caves (WPRFMC 2001a). Gorgonians, which take the form of fans, whips, or brushy shrub-like colonies, inhabit well-illuminated zones of the reef as well as deeper dark biotopes, caves or channels in strong currents (Collin and Arneson 1995; Sorokin 1995). Two endemic octocorals, the blue octocoral (*Anthelia edmondsoni*) and the bicolor sea fan (*Acabaria bicolor*) along with the introduced snowflake coral (*Carijoa riisei*), occur in the study area (Hoover 1998; Gulko 1998). The blue octocoral forms light blue to purple patches on both hard and soft surfaces in shallow water habitats such as bays, harbors, and the leeward side of islands, particularly, O‘ahu (Russo 1994; Hoover 1998). Producing tiny colonies, the bicolor sea fan, the only native shallow-water bicolor gorgonian coral typically grows in rocky crevices in surgy or current-swept locations as shallow as 1.8 m but usually deeper to 427 m (Hoover 1998). Introduced to Hawai‘i in 1972, the snowflake coral forms dense colonies in cavities along vertical walls or on the ceilings of caves and overhangs where current is strong, under docks where plankton is plentiful, on shipwrecks, and in the same areas as black coral (*Antipathes* spp.) down to 50 m (Russo 1994; Hoover 1998).

Life History—Hexacorals and octocorals utilize both asexual (pedal laceration, longitudinal or transverse fission, budding, arising as new polyps) and sexual (dioecious, external/internal fertilization giving rise to brooded planulae, clonal propagation) reproductive strategies (WPRFMC 2001a). Spawning in anemones is synchronized with a full moon or low tide, whereas zooanthids exhibit seasonal free spawning or spawning synchronous with mass spawning of stony coral (WPRFMC 2001a). Sexual reproduction in zooanthids is thought to allow for dispersal and colonization over large distances (WPRFMC 2001a). Broadcast spawning occurs in both soft and gorgonian corals (WPRFMC 2001a).

Common Prey Species—Anemones are polyphagous opportunists feeding on plankton born crustacea, fish worms, algal fragments, gastropods, echinoderms, small fish, DOM, nutrients produced by algae (zooxanthellae), and possibly the excrement from associated symbiotic fishes (Gulko 1998; Waikiki Aquarium 1998i; WPRFMC 2001a). Zooanthids ingest a variety of live and dead crustacea and fish portions, as well as DOM (WPRFMC 2001a). Octocorals feed heterotrophically through zooplankton capture and autotrophically through nutrient exchange with zooxanthellae, digestion of zooxanthellae, and absorption of DOM (WPRFMC 2001a).

4.3 FISHERIES RESOURCES

Fishery resources have a long history of harvest in the Hawaiian Islands and are currently utilized by commercial, traditional, and recreational groups (Simonds 2003). Rich fishery resources are found from nearshore coastal reefs to open ocean waters and deep-sea formations. Fisheries participants of the Hawaiian Islands are diverse comprising individual anglers, small-scale artisinal fishing, commercial fishing communities, and large industrial interests, operating in various locations, utilizing a variety of gears and methods, and targeting a wide array of available fishery resources. As with most coastal and island populations of the world, fish and fishing constitute an important socio-economic element of life in the Hawaiian Islands. Fishery products harvested in adjacent waters are exported worldwide and used locally as an integral part of the island’s American, Asian, and traditional Hawaiian cultures. Fishery management, research, and harvesting therefore are endeavors undertaken in earnest in Hawai‘i for beneficial reasons (NMFS 2001; WPRFMC 2005a).

4.3.1 Introduction

Geographic and oceanographic elements provide the Hawaiian Islands with the basis for its rich fishery resources. Its tropical location supports thriving coral reef ecosystems and numerous islands and

seamounts support ample bottom habitat for sessile communities and the fishes associated with them. Currents of the surrounding Pacific Ocean provide sufficient supplies of nutrients and planktonic food sources to support pelagic and coastal fish assemblages (McGowan and Williams 1973; McGowan and Hayward 1978; McGowan and Walker 1979, 1985; Landry et al. 2001). See sections 2.3 through 2.6 for detailed descriptions of the oceanographic and biological environment of the study area.

The year-to-year occurrence and distribution of fishery activities is related to the occurrence and distribution of economically and socially desired fishery resources in conjunction with the ability of fishermen to locate and harvest these resources. The activities of marine fisheries are ultimately part of a dynamic and ever-changing system. For most commercial, traditional, and recreational fishing endeavors, successful fishing stems from the ability to anticipate the occurrence of target species at a given place and time. In turn, the distribution and abundance of fishery species in the study area depend greatly on the physical and biological factors associated with the region such as: salinity, temperature, dissolved oxygen, food/prey availability, habitat quality, reproductive/life cycles, seasonal movements, population dynamics, and juvenile recruitment success, among others (Helfman et al. 1997). The process of fishing often involves constant searching: the greatest portion of most fishing efforts is spent on travel to and discovery of locations that provide acceptable levels of return for the time and energy expended on the harvest. Complicating matters is the continuous flow of change that the distribution and abundance of fishery resources experience in response to changing seasons, food sources, and life history stages, including responses to fishing pressure from the fisheries themselves (Waite et al. 1994; Helfman et al. 1997).

In the never ending search for a profitable catch, successful fishermen “read the signs” and make educated guesses based on experience and knowledge about where and when to best fish. Over time, certain areas become known as productive fishing grounds. The recent availability of technologies such as sonar, radar, and GPS systems, as well as detailed bottom topography maps and access to real-time meteorologic/oceanographic information greatly aid in the ability of fishermen to discover, pinpoint, and navigate to target fishery resources (SeaWeb 2002).

4.3.1.1 Fisheries Problems

Continuous variations are natural and expected in marine fishery stocks, yet it has become evident that human activities have had, sometimes severe, effects on long-term patterns of fish distribution and abundance. Primary among these human activities are excessive fishing, habitat alteration, and water quality degradation (Saila and Pratt 1973; Malakoff 1997; Williams 1998). Coastal habitat alteration, use, and destruction can severely affect estuarine and nearshore fisheries, threatening their ultimate viability as a resource and their existence (local extinction). Destructive and damaging offshore activities, including dragging fishing nets and dredges on the seafloor, can impact benthic species and communities and diminish the ability of the seafloor habitat to adequately support fishery resources. Excessive harvesting of fishery resources can deplete a stock beyond the point of sustainability: the fishery population no longer replaces itself above the overall rate of loss. Lastly, water quality degradation can affect the individual health of fishery resources and therefore reduce their ability to thrive and exist in their environment. Water quality degradation can also negatively affect the safety of the harvested fishery resources for consumption by ocean predators and humans (Lazaroff 2001).

Over the past two centuries and especially within the last 50 years, the overall intensity of fishery effort (commercial and recreational) has been increasing. High demand for commercial fishery products and increases in recreational fishing activities have resulted in increased fishing pressure on available resources, causing a decrease in fishery landings (Waite et al. 1994; Parker and Dixon 1998). While improvements in fishing gear, technology, and methods continue, overall catch rates are decreasing in relation to the level of effort expended fishing (Waite et al. 1994). In short, world fish stocks are declining. One clear illustration of this statement is the fact that fisheries are “fishing down the food chain.” In other words, as fishery landings diminish and commercial stocks dwindle, species that were once considered commercially undesirable have been added to the list of commercially targeted species. Although they may be less attractive to consumers and previously were discarded as by-catch, these species are presently available in harvestable numbers and are marketed to an often unsuspecting public (Caddy et

al. 1998; Pauly et al. 1998). Because many numbers associated with U.S. fishing regulations are presented in English units, both metric and English have been provided in this section. Also, NMFS provides fisheries data in pounds and therefore, both pounds and metric tons will be provided.

4.3.1.2 Fisheries Management

Wise management and an involved fishing community have become crucial to protecting fishery industries and maintaining fishery resources in a harvestable condition. At the federal level, laws, EOs, proclamations, and regulations have been created to aid in the conservation of fishery resources. One of the mandates of the SFA was the creation of a number of interstate management agencies, called FMCs, to oversee the condition of fishery stocks occurring in the U.S. EEZ (3 to 200 NM from shore). The FMCs use FMPs to set forth management objectives for specific fishery resources and formulate strategies for the best way to achieve those objectives. The NMFS participates in fishery management efforts by providing technical support and fisheries data and analysis.

The WPRFMC is one of eight FMCs in the U.S. and is responsible for managing fisheries in the 1.5 million NM^2 of the Pacific Ocean that are under U.S. jurisdiction. This is the largest management area of any of the FMCs of the U.S., covering almost half of all U.S. EEZ waters. The U.S. territories, possessions, and states in the Pacific that are at the root of this expansive management area include: the Territories of American Samoa and Guam; the U.S. Pacific atoll/island possessions of Jarvis, Johnston, Wake, Howland, Baker, Kingman Reef, Palmyra, and Midway; the CNMI; and the State of Hawai‘i (including the NWHI; Simonds 2003).

The WPRFMC focuses their management efforts on the major fisheries that occur in federal waters. These fisheries have been grouped by the council into five major categories and five related FMPs have been developed to set forth respective management regulations, provisions, and policies for them. The latest FMP covers the coral reef ecosystems of the western Pacific and was approved in 2002. Follow-up amendments are produced periodically for each FMP as necessary to adjust or add regulations based on new information, data, or changing conditions. In addition, the council produces summary reports, individual documents of specific fishery interests, and reports on environmental impact assessments. They also produce analytical products (such as stock assessments and regulatory impact reviews) related to the fisheries and fishery resources. In coordination with NMFS and state agencies, the council works to monitor fishery landings, levels of fishery effort, and geographical distribution of fishery effort (Simonds 2003).

The State of Hawai‘i manages and regulates fishery resources in waters that are under state jurisdiction (from shore to 3 NM [5 km]) through the HDAR. The HDAR deals with commercial and recreational issues, as well as those concerning habitat and biological conservation, preservation, and sustainable use. The HDAR works with the WPRFMC to coordinate management of shared resources. Portions of the Hawaiian Islands OPAREA boundaries are within state waters and fall under the fishery management jurisdiction of HDAR (2005b).

The NMFS plays a dual, sometimes conflicting role. As an agency within the U.S. Department of Commerce, NMFS is tasked with supporting, encouraging, and expanding fishery efforts to assist in strengthening and stabilizing the economy of the nation. As a science based organization, NMFS often works to conserve, preserve, and protect marine species, communities, and habitats. A large part of this second role can be seen as an aspect of the first: proper management of available resources allows for the reasonable, long-term harvest/use of those resources. Also, because fishery activities operate in a dynamic environment populated with a multitude of non-fishery related elements (i.e., non-target species and habitats), NMFS acts to limit destructive, harmful, and wasteful interactions with those elements. To carry out these roles, NMFS conducts research; collects, analyzes, and interprets data; communicates with involved parties; develops strategies and sets policy; reports to and advises the legislative, executive, and judicial branches of the federal government; and works with state and local agencies (NMFS 2005b).

4.3.1.3 Traditional Fisheries

Both the act and the products of fishing represent an important cultural link for indigenous Hawaiians to their Polynesian Islander heritage. Many of the Pacific Islander populations have depended on fishery resources from the earliest times of their histories and have developed traditions and beliefs that are intertwined with all aspects of the marine environment. Because their lives and societies relied to a large degree on local marine resources for survival and existence, many of their traditions and beliefs deal with sustainable management of these fishery resources. The re-authorized and updated version of the SFA, known as the MSFCMA, recognizes and states the importance of this connection they have with the sea. Several federal programs work to ensure access to and assist in the interaction with marine fishery resources (Simonds 2003). Participation in traditional fishing activities is of high priority to indigenous peoples in protecting their rights and in maintaining their cultural identities.

4.3.2 Commercial Fisheries

Commercial fisheries activity is divided into five major groups: (1) pelagics; (2) bottomfish and seamount groundfish; (3) crustaceans; (4) precious corals; and (5) coral reef ecosystems. Each of these major fisheries is in turn divided into sub-groups depending on species targeted and on methods and gears used in the fishery (**Table 4-7**). Locations of fishing grounds sometimes also define a portion of a major fishery. The fisheries of Hawai‘i operate in most of the Hawaiian Islands OPAREA (mostly for pelagics and bottom groundfish) from shore and state waters to and beyond the boundaries of the U.S. EEZ off the MHI and the NWHI (**Table 4-8**). Below is a descriptive list of the primary fishing gears used in these fisheries:

- Longline gear: are lines that are deployed horizontally in the water to which hooks are attached. Longlines in the EEZ are strictly surface and mid-water pelagic lines that may be hauled manually, electrically, or hydraulically. Longline gear is used to catch a variety of pelagic fishes including tunas, swordfishes, and sharks. Bottom longlines may be used in state waters.
- Troll gear: can consist of up to six or more lines running from hydraulic spools and/or outrigger poles from which they are spread and pulled in the water while the boat travels forward. Trolling gear is used to target various pelagic fishes including swordfish, billfishes, dolphinfish, tunas, and sometimes sharks.
- Hook-and-line gear: includes handline and pole-and-line gears that are used to target tuna and swordfish and other pelagic and bottom groundfish in the study area.
- Purse/beach seine: are long panels of netting used to encircle a school of fish at the surface, while the bottom of the net is cinched closed. Purse seines targeting tuna are not generally used in the study area but sometimes operate near and beyond the outer boundaries of the U.S. EEZ.
- Barrier net: is a small mesh net used to capture reef and coastal pelagic fishes.
- Trap gear: is generally constructed of plastic in the study area. They are usually distributed in shallow water to target spiny and slipper lobsters. Some metal fish traps are used in state waters in coral reef areas.
- SCUBA/Dive gear: consists of a self-contained underwater breathing apparatus system and is used to collect black corals, lobsters, and other coral reef resources. Accessory fishing gear is sometimes used, such as snares, spear guns, and nets. Some divers may use “hookah” systems, which consist of a long air hose, connected to a gas-run air compressor on the deck of a boat.
- Submersibles: are underwater vehicles that are either manned or unmanned and are fitted with robotic arms or other appendages that are used to selectively collect precious corals at great depths.

Hawai‘i’s commercial fisheries grossed $52.4 million in 2003 and averaged $60.1 million from 1994 to 2003 (2003 is the most recent year for which data is available; NMFS 2004a; **Table 4-9**). The actual economic value to the region is far greater than this, in terms of jobs, goods, and services associated with these fisheries. It is also important to note that in the Hawaiian Islands, it is often difficult to distinguish recreational fishing from commercial fishing since many recreational anglers end up selling all or part of their daily catch to markets, restaurants, or at personal street side stands. These anglers do not register

Table 4-7. Gears and target species for Hawai'i's five major fisheries (target species are not associated with gear types as displayed in this table).

Pelagics		Bottomfish and Seamount Groundfish		Crustaceans		Precious Corals		Coral Reef Ecosystems	
Gears	**Target Species**	**Gears**	**Target Species**	**Gears**	**Target Species**	**Gears**	**Target Species**	**Gears**	**Target Species**
Longlines Handlines Pole-and-line Trolling	Swordfish Albacore tuna Yellowfin tuna Skipjack tuna Bigeye tuna Kawakawa Pelagic Sharks Moonfish (opah) Marlin (billfishes) Sailfish Dolphinfish Wahoo Pomfret	Handline (hook, line, and reel)	Snappers Groupers Jacks Armorhead[1]	Traps[2]	Spiny lobsters (2 spp.) Slipper lobsters (3 spp.)	Tangle net dredge[3] Hand harvest via SCUBA Manned submersible Un-manned submersible	Pink corals (3 spp.) Gold corals (3 spp.) Bamboo corals (2 spp.) Black corals (3 spp.)	Hand harvest Hook-and-line Spears Various nets and traps	Wide variety of coral reef and lagoon species (invertebrate[4] and fish corals) as well as some large and small pelagic fishes found in lagoons and near reef margins

[1] the seamount groundfish fishery, which had targeted these species has been suspended due to depleted stocks
[2] historically nets, snares, and hand harvest were used
[3] no longer allowed
[4] does not include coral species

Source: WPRFMC 1979, 1982; NMFS, 2001; WPRFMC 2001, 2002, 2005a, 2005b

Table 4-8. General areas fished in Hawai‘i’s five major fisheries.

Pelagics	Bottomfish and Seamount Groundfish	Crustaceans
Longlining: Offshore portions of EEZ around Hawai‘i (25-200 NM) and beyond (high seas)	Slopes, banks, and seamounts between 90-370 m ; Primarily NWHI & Hawai‘i state waters; Some MHI	Primarily NWHI & MHI state waters (0-180 m)
Trolling, handlining, & pole-and-line fishing: Hawai‘i state waters and most of EEZ		
Precious Corals	**Coral Reef Ecosystems**	
Pink, gold, & bamboo corals: At 400-1500 m depths, primarily NWHI; some at Makapuu off Oahu	Primarily Hawai‘i state waters; shore to 3 NM	
Black corals: At 30-100 m depths, primarily MHI state waters between Maui and Lāna‘i; some federal waters between Maui and Lāna‘i		

Source: WPRFMC 1979, 1982; NMFS, 2001; WPRFMC 2001, 2002 2005a, 2005b

Table 4-9. Landings and dollar value of Hawai‘i’s fisheries from 1994 through 2003.

Year	Metric Tons	Pounds	Dollars
1994	12,288	27,090,000	$62,451,000
1995	13,559	29,892,000	$59,847,000
1996	14,456	31,870,000	$64,288,000
1997	16,587	36,568,000	$68,693,000
1998	16,523	36,426,030	$62,064,800
1999	16,741	36,906,840	$64,556,518
2000	14,756	32,531,330	$68,447,404
2001	10,828	23,870,471	$54,561,446
2002	10,814	23,840,620	$52,113,310
2003	10,685	23,555,793	$52,433,417
Average:	***13,724***	***30,255,108***	***$60,945,590***
Total:	**137,236**	**302,551,084**	**$609,455,895**

Source: NMFS 2004a

as "commercial" fishers and their landings are not generally reported directly (Simonds 2003). Of the commercial fisheries in the Hawaiian archipelago, the pelagic fishery is the largest and most important (by effort and dollar value) that occurs in the waters of the Hawaiian Islands OPAREA. This is followed in importance by the bottomfish fishery. The coral reef ecosystem, precious coral, and crustacean fisheries are comparatively small and minimal in the waters of the Hawaiian Islands OPAREA .

4.3.2.1 Pelagic Fisheries

The pelagic fishery is dominant among the major fisheries of the Hawaiian Islands OPAREA. Approximately 22 million pounds (lbs) (9,700 metric tons [mt]) were landed in 2002, comprising nearly 91% of all marine fishery landings in Hawai'i for that year (Simonds 2003). Pelagic fishing is directed at open ocean fishes found primarily in the mid and upper water column using a variety of hook-and-line gears, most commonly longline (down to 300 m) (Simmonds 2003; Itano 2004). Target species include swordfish and tunas primarily but may include species such as other billfishes, pelagic sharks, and other small fishes such as dolphinfish, wahoo, moonfish, and pomfret. See the EFH descriptions in section 4.2.2 for more information on individual target species. Drift gill nets and fishing by foreign nations are no longer allowed within the U.S. EEZ (Simonds 2003). Landings of tunas have steadily increased since the 1990's, while those of sharks and swordfish have dramatically increased until 2000 when regulations were introduced that limited that harvest of these fishes (NMFS 2001; **Figures 4-1** and **4-2**).

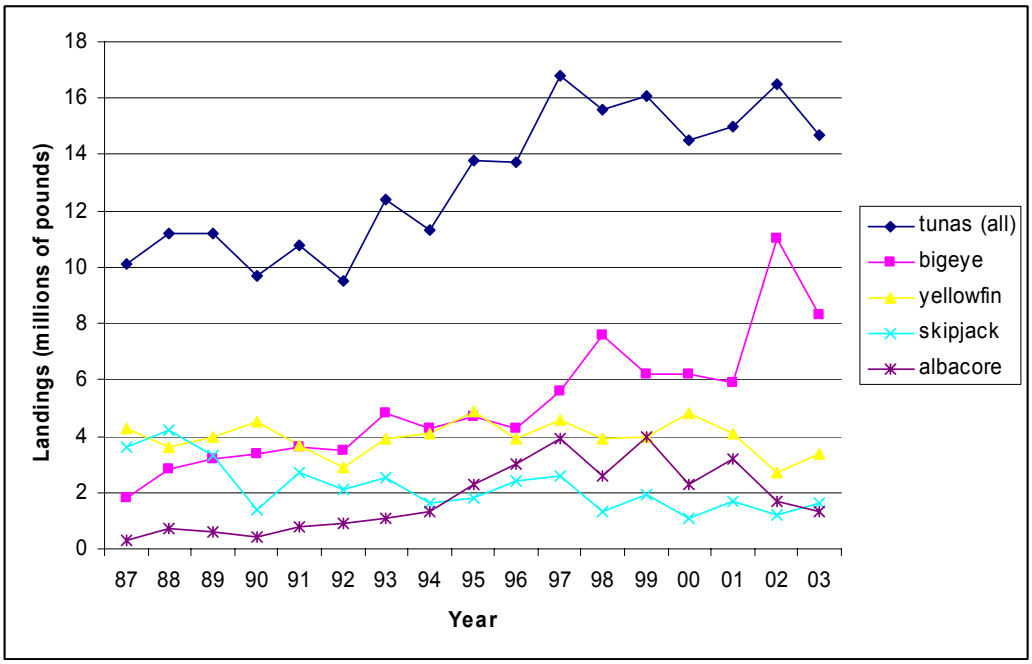

Figure 4-1. Pelagic fishery landings in millions of pounds for tunas between the years 1987 through 2003 (WPRFMC 2004c).

Vessels range in size from small wooden boats with outboard engines (mostly for handlining and trolling) to large steel hull vessels of up to 33 m (in the longline fisheries) with the larger vessels able to stay out for several days at a time (Boggs and Ito 1993; Simonds 2003). Fishing occurs essentially year-round in the study area and may take place during the night as well as during the day depending on the species targeted (WPRFMC 1986b; NMFS 2001; WPRFMC, 2002, 2004c). The indefinite line between purely commercial activities and subsistence/recreational activities occurs mostly with the smaller vessels using handlining and trolling methods in which part of the catch is kept, part is sold, and the activity itself is sometimes done for sport (Boggs and Ito 1993; Simonds 2003).

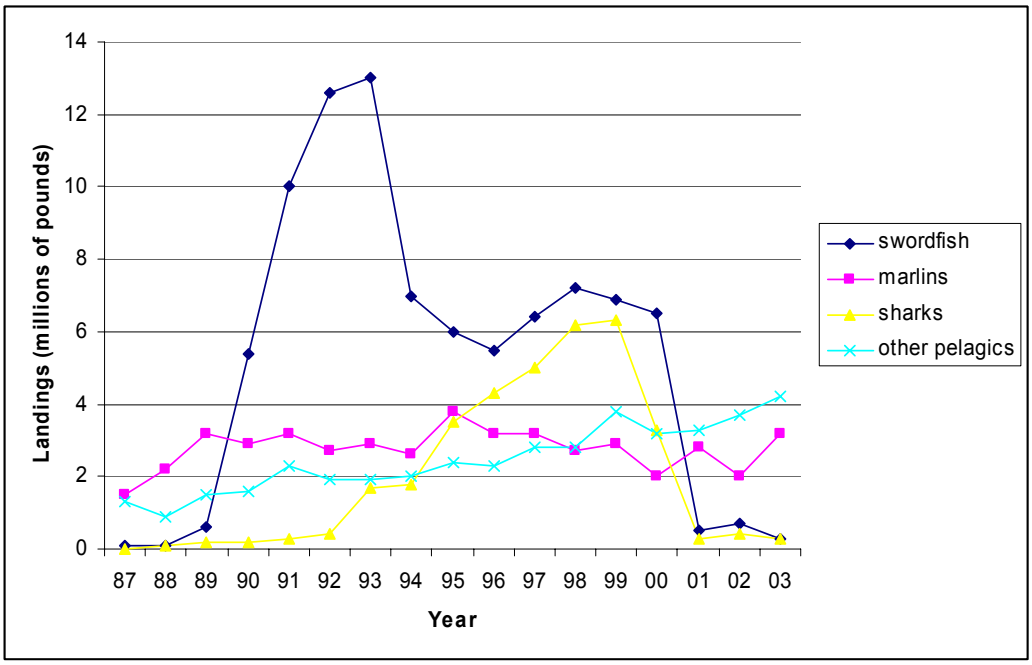

Figure 4-2. Pelagic fishery landings in millions of pounds for swordfish, marlins, sharks, and other pelagic fishes (dolphinfish, wahoo, moonfish, pomfret, etc.) between the years 1987 through 2003 (WPRFMC 2004c).

4.3.2.1.1 Longline fishery

History of Fishery—Hawaiian longlining techniques were originally imported from Japan in the early part of the twentieth century (circa 1917). By mid-century, the fishery was using wooden sampan boats converted from the slightly older pole-and-line fishery. The larger vessels (12 to 19 m) employ high-powered diesel engines. Longlining was second only to pole-and-line fishing in the 1930s. Landings decreased steadily after the late 1950s and have increased dramatically since the early 1990s (Boggs and Ito 1993; NMFS 2001; WPRFMC 2002; Simonds 2003). Longlining is the largest of the pelagic fisheries and is currently the predominant fishery in the Hawaiian Islands OPAREA. Longline landings represent 74% of all pelagic fisheries (from averaged values of yearly landings 1987 to 2001; WPRFMC 2004c).

Target Species—Longline fisheries actively target either swordfish or large tunas, primarily yellowfin and bigeye. Switching between these fisheries is variable by vessel and may potentially change daily, monthly, seasonally, or following long-term trends. Commercially valuable species caught incidentally are kept as well and may include other tunas, billfishes, pelagic sharks, dolphinfish, wahoo, moonfish, and pomfret. From a management and fishery activity perspective, the WPRFMC states that “for most species of tuna and billfish (swordfish and marlins) it is reasonable to assume a single, ocean-wide stock in the Pacific where a mingling of fish takes place gradually through the fishes’ whole lifespan.” Factors that affect any longline fishing activity may potentially impact any given stock of the respective species (Boggs and Ito 1993; NMFS 2001; WPRFMC 2002; Simonds 2003). The following list indicates the landings percentage each species represents in the longline fisheries (average landing values for 1991 to 1998) (NMFS 2001):

Target:		**Incidental:**	
Yellowfin and Bigeye tunas:	22%	Albacore tuna:	11%
Swordfish:	15%	Pelagic sharks:	29%
		Billfishes (marlins and sailfish):	9%
		Dolphinfish:	1%
		Wahoo:	1%
		Moonfish:	2%

Location of Fishery—Includes the entire EEZ and beyond, beginning 50 NM from shore around the islands of Maui, Molokaʻi, Lānaʻi, Kahoʻolawe, and Hawaiʻi and beginning 75 NM from shore around the islands of Kauaʻi and Oʻahu (**Figure 4-2**). These boundaries shift seasonally (see Current Regulations below). FADs and weather buoys are sometimes more heavily targeted as are seamounts, upwelling areas, and current convergence zones (WPRFMC 1986b; Boggs and Ito 1993; NMFS 2001). Vessels targeting particular species such as tunas or swordfish follow the seasonal migrations of those fishes through the study area, and while the distribution of pelagic species extends, shifts, and contracts throughout the year, the entire study area remains within their distribution (NMFS 2001).

Current Regulations—The areas within 50 NM from shore around the islands of Maui, Molokaʻi, Lānaʻi, Kahoʻolawe, and Hawaiʻi and within 75 NM from shore around the islands of Kauaʻi and Oʻahu are off-limits to longline fishing. The boundaries of this longline exclusion area shift seasonally from October to January, when fishing is permitted from 25 NM and outward off the windward coasts of the all Hawaiian Islands except Oahu where fishing is prohibited from 50 NM to shore (NMFS 2001; WPRFMC 2002).

Gear—"Regular" longlines are used from near the surface down to 150 m depths and "deep-set" longlines are fished down to 300 m (1,000 ft) depths. Vessels averaging in size from 20 to 50 m (66 to 164 ft) set monofilament lines that can be up to 100 km (62 miles [mi]) long and have up to 2,000 hooks. Deployment and retrieval of sets may take up to 24 hours and fishing occurs day and night, depending on species targeted. Average fishing time for hooks in a set is 12 hours (PIFSC 2005). Sets targeting tunas are usually deeper and occur during the day. Swordfish sets are fished at night and are set shallower in the water. Fishing trips can last from 2 to 45 days. Fluorescent light sticks are often used in addition to or in place of bait (NMFS 2001; WPRFMC 2002, 2005b).

Season—Fishing occurs year round. Landings fluctuate slightly by season and species targeted, but some vessels switch target species when seasonal abundances change. Fishery effort targeting tunas (yellowfin, bigeye, and albacore) around the Hawaiian Islands is consistent throughout the year with the areas located southeast of the island of Hawaiʻi and west of Niʻihau being slightly less intense year round (NMFS 2001). Swordfish effort is slightly greater during the first half of the year (January through June) to the north of the MHI and lowest year round to the southwest of the island of Hawaiʻi and west of Niʻihau (NMFS 2001).

Landings—Longline landings peaked in the 1990s but have declined since 2000. During 2002 and 2003, approximately 28 million lbs (12,700 mt) and 17 million lbs (7,700 mt) were landed respectively (WPRFMC 2004c; **Figure 4-3**).

4.3.2.1.2 Handline fishery

History of Fishery—Some handline fishing, called palu-ahi, has roots in traditional Hawaiian culture. Nighttime fishing, called ika shibi, has roots to Japanese techniques introduced to the Hawaiian Islands around the 1920s. Fishing activity and landings were primarily based around the island of Hawaiʻi until the early 1970s. Since then, the activity has spread to the other Hawaiian Islands and landings increased dramatically in the 1980s but have since been in decline. A significant portion of handline fishing is conducted by a recreational/subsistence sector that is difficult to distinguish clearly from the commercial sector (Boggs and Ito 1993; NMFS 2001; Simonds 2003). Handline fishing accounts for 9% of all pelagic landings in the Hawaiian Islands from averaged values of yearly landings 1987 to 2001 (WPRFMC 2004c).

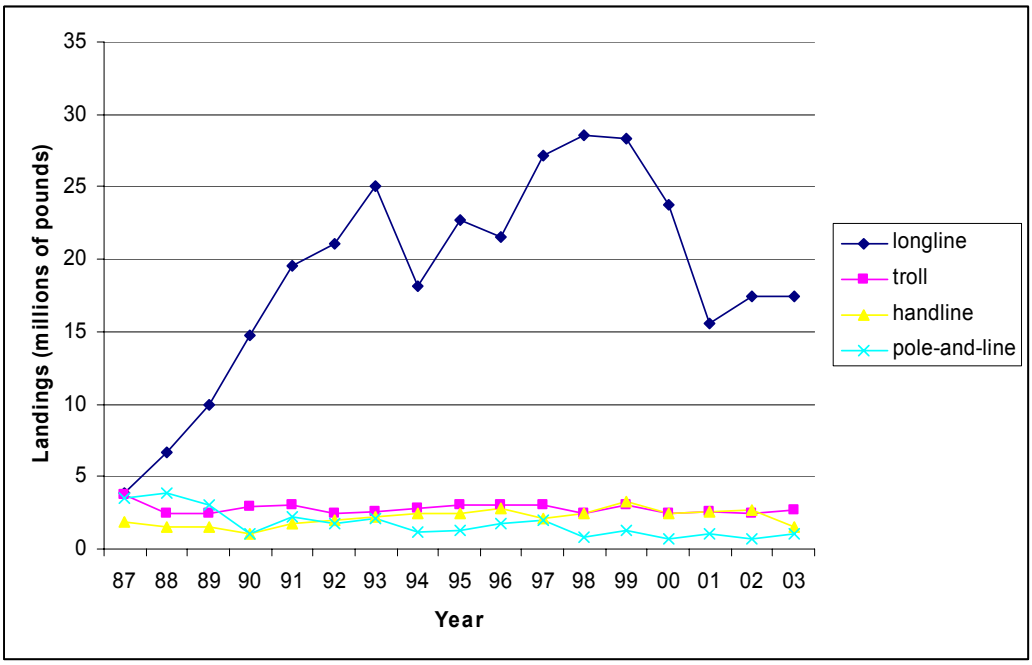

Figure 4-3. Pelagic fishery landings in millions of pounds by method between the years 1987 through 2003 (WPRFMC 2004a).

Target Species—Target species of handline fisheries are yellowfin and bigeye tunas with the yellowfin predominating the catches. Incidental pelagic fishes (species other than yellowfin and bigeye) landed account for less than ten percent of the catch (NMFS 2001; WPRFMC 2004c, 2005b). Other tuna species landed include skipjack and albacore.

Location of Fishery—Handline fishing for pelagic species occurs within the U.S. EEZ beyond 20 NM off shore, primarily at seamounts, FADs, and weather buoys (Simonds 2003). Fishing also occurs anywhere large tunas are expected or found (depending on migrations and oceanographic conditions such as currents and up-wellings; NMFS 2001; WPRFMC 2002; **Figure 4-4**). A nearshore component of the handline fishery operates in state waters a few miles from shore (WPRFMC 2005b).

Current Regulations—No regulations currently affect the distribution or activity of handline fisheries around the MHIs.

Gear—There are two distinct methods/fisheries employed in the pelagic handline fisheries: palu-ahi and ika-shibi. Palu-ahi, the predominant handline method in the Hawaiian Islands, is a daytime fishery for large tuna species such as yellowfin, bigeye, and larger albacore. This method also referred to as “drop-stone” fishing, uses a line with a hook attached to a sinker weight. Fresh mackerel scad is used as bait on the hook and a bag of chum bait is suspended above the hook. The chum is released from the bag when the hook reaches the desired fishing depth, which depending on location and target species is either 20 to 30 m (66 to 100 ft) or 120 to 140 m (394 to 460 ft). The other fishing method, called ika-shibi, is a nighttime endeavor that also targets large species of tunas. Squid are attracted to the vessel at the surface with night-lights where they are caught and used to bait a lead weighted hook. Variations and crossover of techniques are used by both of these methods. The night handline fishery may also use mackerel scad as bait while using the night-light to attract squid to use as chum (NMFS 2001; WPRFMC 2002, 2005b; Simonds 2003; Itano 2004).

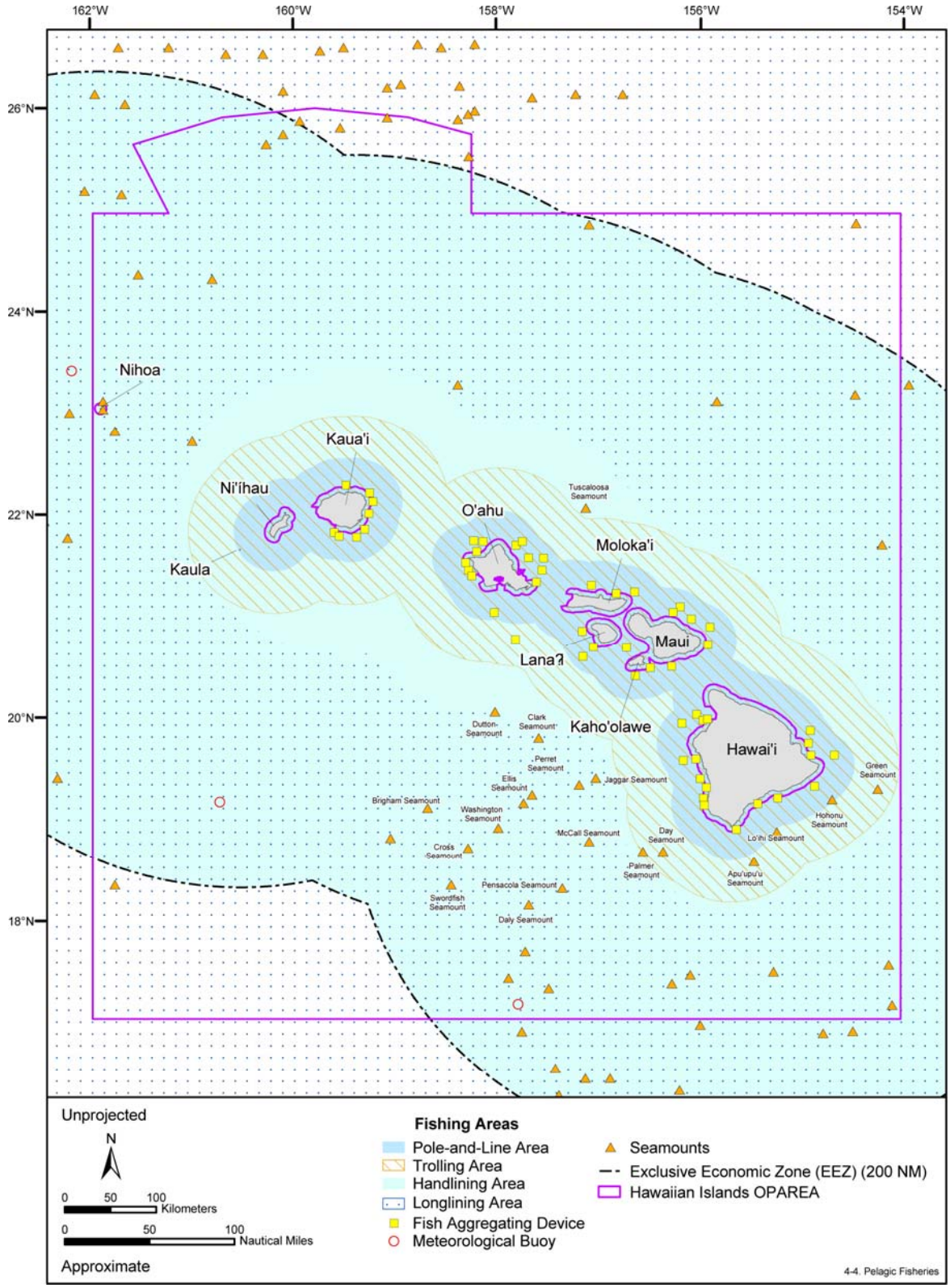

Figure 4-4. Pelagic fisheries fishing areas of the Hawaiian Islands OPAREA including longlines, handlines, trolling, and pole-and-line (aku boat). Fishing areas represent potential fishing activity based on fishery descriptions and regulated zones. Source information: Boggs and Ito 1993; NMFS 2001; WPRFMC 2002, 2005b.

Both methods may use a sea anchor, or drogue (a parachute type of anchor deployed in the water), to maintain position while fishing. Offshore trips may last 1 to 5 days. Vessels range in size from 7 to 17 m (23 to 56 ft). When fishing seamounts, FADs, and weather buoys, fishing with trolling gear may also be used (WPRFMC 2005b).

Season—Handlining occurs year round, but the ika-shibi method is employed for roughly only five months of the year. Fishermen have been known to alternate methods throughout the year (NMFS 2001; WPRFMC 2002, 2005b).

Landings—Landings have been variable since 1987 (**Figures 4-1** and **4-2**). A peak occurred in 1999 at about 3.3 million lbs (1,500 mt) and landings have declined to about 1.4 million lbs (635 mt) in 2003 (WPRFMC 2004c; **Figure 4-3**).

4.3.2.1.3 Troll fishery

History of Fishery—The history of troll fishing in Hawai‘i has not been well documented, however, trolling has been a traditional Polynesian fishing method for centuries (Boggs and Ito 1993). The troll fishery in Hawai‘i is largely recreational but may be broken down into several components: (1) a recreational-subsistence sector which is poorly differentiated from a part-time commercial sector; (2) a charter sector which is recreational for its patrons but commercial for the operators who sell the catch; (3) a part-time commercial sector; and (4) a full-time commercial sector (Boggs and Ito 1993; Witherell 2003). Troll fishing accounts for 11% of pelagic landings in the Hawaiian Islands from averaged values of yearly landings 1987 to 2001 (WPRFMC 2004c).

Target Species—Trolling targets a variety of pelagic species and may be more opportunistic than specific on any given outing. Species landed and kept as commercially valuable include large yellowfin tuna, dolphinfish, and wahoo as well as other tunas, such as albacore, bigeye, and skipjack, and billfishes like the various marlins (blue and striped) and very infrequently swordfish (NMFS 2001; WPRFMC 2002, 2004c, 2005b).

Location of Fishery—Troll fishing occurs off every Hawaiian island within roughly 20 NM from shore (Boggs and Ito 1993; **Figure 4-4**). Trolling may also occur near FADs and weather buoys and other fisheries may employ trolling gear while traveling to fishing sites and between sets (NMFS 2001; WPRFMC 2002, 2005b). Trolling often targets oceanographic conditions such as converging currents and upwellings.

Gear—Trolling is carried out by towing hooks with lures or bait behind a moving vessel. Up to six lines can be trailed behind the vessel with the use of out riggers. Boats may travel at various speeds but are usually slow and may follow zigzag or circling paths. Vessels range from 5 to 13 m (16 to 43 ft) in size (NFMS 2001; WPRFMC 2002, 2005b).

Season—Trolling activity occurs year round though activity may be limited by weather during the fall and winter season (NMFS 2001; WPRFMC 2002, 2005b).

Landings—Landings recorded by trolling have been steady from 1987 through 2003. Nearly 2.7 million lbs (1,200 mt) were landed in 2003 (WPRFMC 2004c; **Figure 4-3**).

4.3.2.1.4 Pole-and-line fishery

History of Fishery—Okinawan fishermen introduced pole-and-line fishing to the Hawaiian Islands around 1900. It is also known as the “bait boat” fishery or “aku” boat fishery. The pole-and-line fishery was one of the predominant fisheries of the islands until around 1987 when the longline fishery increased dramatically. Pole-and-line fishing continued as a leading fishery until 1989 when its emphasis declined. Currently, landings are the lowest of the pelagic fisheries accounting for about 7% of the total pelagic landings (Boggs and Ito 1993; NMFS 2001; WPRFMC 2002, 2004b; Simonds 2003).

Target Species—Pole-and-line fishing is the most specific of the pelagic fisheries, targeting primarily skipjack and occasionally juvenile yellowfin tuna (NMFS 2001; WPRFMC 2002, 2004c, 2005b).

Location of Fishery—Fishing occurs around all of the major Hawaiian Islands out to 20 NM (37 km) from shore (NMFS 2001; WPRFMC 2002, 2005b; **Figure 4-4**).

Gear—Fishing poles of fiberglass or bamboo are used to fish surface waters with a barbless leather lure. Vessels range 12 to 30 m (39 to 9 ft) in size. Live bait is used to attract the tunas to the boat (NMFS 2001; WPRFMC 2002, 2005b). The number of vessels active in the fishery is currently small (around three in 2003; Simonds 2003).

Season—Fishing occurs year round though may be limited by weather in the fall and winter season (NMFS 2001; WPRFMC 2002, 2005b).

Landings—Landings have decreased since 1997 and reached a low of 700,000 lbs (318 mt) in 2002, increasing slightly to 1 million lbs (455 mt) in 2003 (WPRFMC 2004c; **Figure 4-3**).

4.3.2.2 Bottomfish Fisheries

The commercial bottomfish stocks in the Hawaiian Islands are divided into two fisheries: seamount groundfish and deep-slope bottomfish. The seamount fishery targets alfonsin and armorhead and is located around Southeast Hancock Seamount, 1,400 NM northwest of Hawaiʻi. This fishery was closed indefinitely in 1986 due to overfishing (WPRFMC 2004b). For this reason, the deep-slope bottomfish fishery will be the focus of this discussion. The deep-slope bottomfish fishery is characterized by the target species and location of fishing activity.

History of Fishery—Species associated with bottom fishing have been harvested for subsistence since ancient times and commercially for at least 90 years (PIFSC 2005). Native Hawaiians harvested the same bottomfish species sought after today with gear and techniques changing very little over time (Simonds 2003). As a fishery, bottom fishing has declined since the 1950s and does not currently represent a major fishery in Federal waters (WPRFMC 1986a; Simonds 2003; WPRFMC 2002, 2005a).

Target Species—The species of deep-slope bottomfish targeted around the MHI are pink snapper, grey snapper/jobfish, longtail red snapper, shorttail red snapper, and seabass. Pink snapper is the most important of these, followed by both grey snapper/jobfish and longtail red snapper then lastly by shorttail red snapper and seabass (WPRFMC 1986a, 2002, 2004b).

Location of Fishery—Fishing occurs around the slopes primarily around the NWHI and to a lesser degree around the MHI. 80% of these MHI fishing locations primarily occur in Hawaiian state waters within 3 NM from shore where reef slopes drop off (WPRFMC 2002; 2005a). Other fishing banks that occur beyond 3 NM from shore include Middle Bank, most of Penguin Bank, and bottomfish habitat at 200 m around the Maui-Lānaʻi-Molokaʻi complex as well as off the north shore of Maui at 90 to 370 m depths (WPRFMC 2002, 2005a, 2004b). Favored banks are located around Moloakʻi, Maui, Lānaʻi, and Kauaʻi, accounting for about two thirds of the MHI landings (WPRFMC 2005a; **Figure 4-5**).

Current Regulations—The use of destructive fishing methods is prohibited. This includes the use of explosives, poisons, trawl nets, and bottom-set gillnets. The bottomfish fishery of the Hawaiian archipelago is divided into three zones with two of them (Hoomla and the Mau zones) located in the NWHI. While the fishing zones located in the NWHI have limited entry programs there are no such restrictions in the EEZ around the MHI. Vessels fishing in MHI state waters must be registered (WPRFMC 2002).

Gear—Bottom fishing uses gears that are similar to handlines: weighted and baited lines are lowered and raised with electric, hydraulic, or hand-powered reels. Vessels size and trip length vary considerably with larger commercial vessels (greater than 10 m in length) able to conduct trips of about 10 days. Smaller vessels (less than 10 m) are generally restricted to the MHI and trips of 1 to 3 days (WPRFMC 2004b).

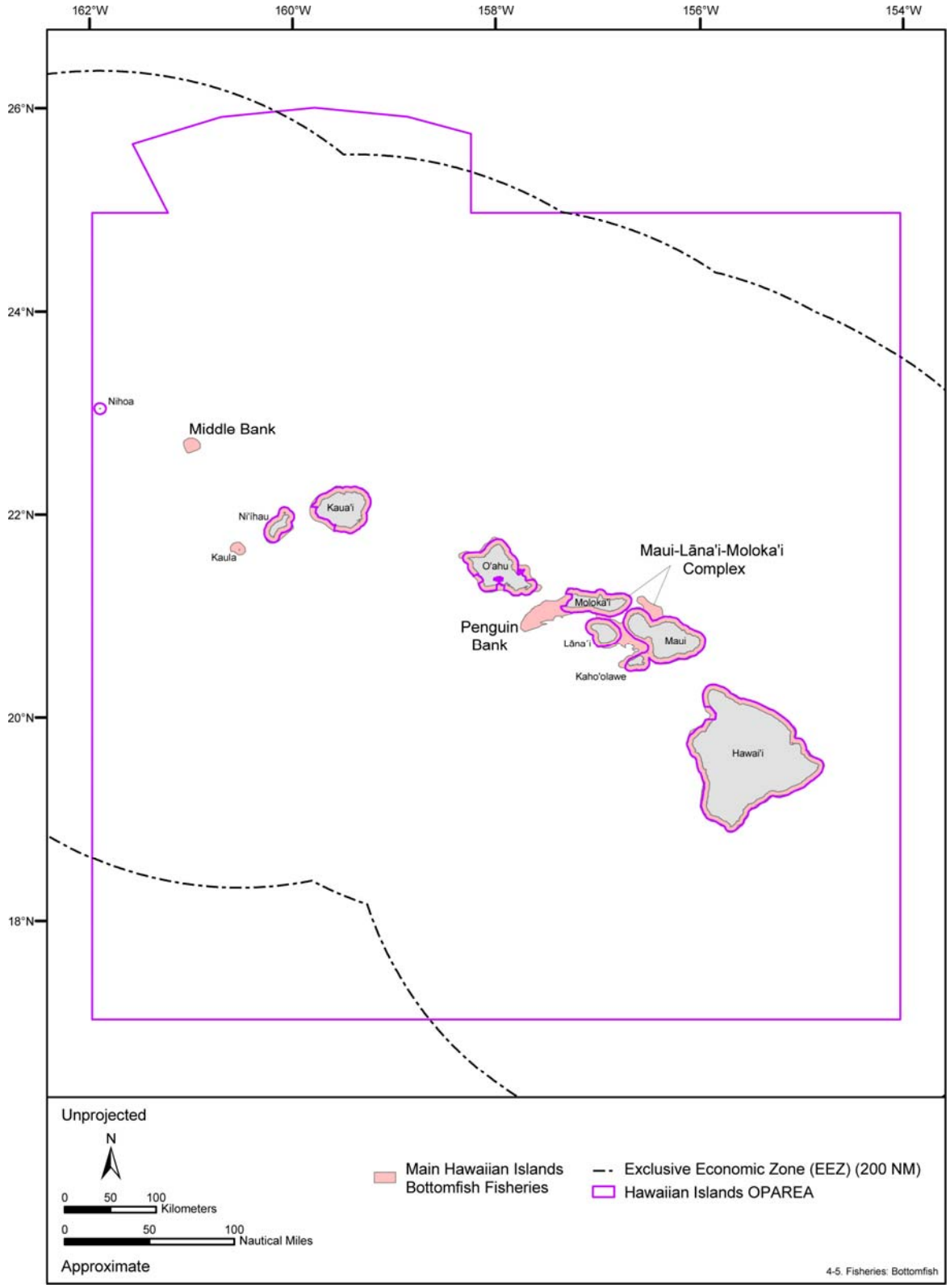

Figure 4-5. Bottomfish fisheries fishing areas of the Hawaiian Islands OPAREA. Fishing areas represent potential fishing activity based on fishery descriptions and regulated zones. Source information: WPRFMC 1986a, 2002; Simonds 2003; WPRFMC 2005a. Source data. WPRFMC 2005a.

Season—Fishing occurs year round, however alternating between target species transpires due to seasonal availability and seasonal market demands (e.g., traditional holiday associated species), as well as changes in weather conditions. Grounds located on the windward (north) side of the MHI are fished less in the winter season (October through January; WPRFMC 2002; WPRFMC 2005a).

Landings—Landings have fluctuated since 1983, peaking at around 66,000 lbs (30 mt) in 1996 and declining to about 42,000 lbs (19 mt) in 2003 (WPRFMC 2004b). Stocks of bottomfishes around the MHI are currently stressed (WPRFMC 2004b). While seabass and pink snapper still represent the largest portion of bottomfish landings, but have experienced sudden declines since 2000. There has been an overall decline in landings of bottomfish species since 2000, though the longtail red snapper showed a slight increase (**Figure 4-6**).

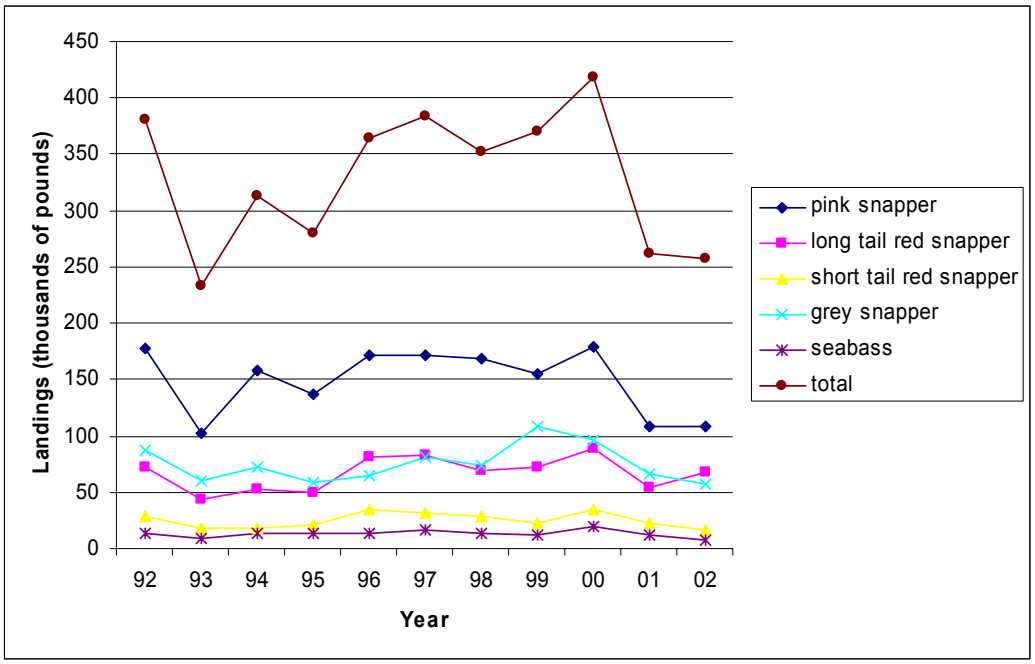

Figure 4-6. Bottomfish fishery landings in millions of pounds for pink snapper, grey snapper/jobfish, longtail red snapper, shorttail red snapper, and seabass between the years 1987 through 2003 (WPRFMC 2004b).

4.3.2.3 Crustacean Fisheries

The crustacean fishery of the Hawaiian Islands OPAREA is primarily directed at spiny lobsters and slipper lobsters using traps. These lobster species live on shallow reefs and banks with broken uneven bottoms and crevices. In the MHI, these crustacean fishery habitats are restricted to nearshore areas. The crustacean fishery is primarily focused around the NWHI where the lobster habitat is much more abundant. Both spiny and slipper lobsters can be found in the same fishing areas, although in slightly different habitat types. Both species are often caught at the same locations and so are not distinguished as distinct fisheries. Very little fishing activity occurs in waters greater than 3 NM from shore around the MHI. In state waters of the MHI, the recreational catch of lobster is much more prominent (WPRFMC 2002; WPRFMC 2005a)

History of Fishery—Lobster has been a traditional food for centuries in Hawaii. In the early 1900s it had become a substantial fishery, landing approximately 131,000 lbs (59 mt) in 1901 (Simonds 2003). Lobsters were caught with nets, snares, and by hand. Nearshore lobster resources had become depleted by mid-century around the populous Hawaiian Islands. The relocation of several commercial vessels to

NWHI during the late 1970s helped develop the crustacean fishery in this area (WPRFMC 1981, 1982, 2002; Simonds 2003).

Target Species—The two lobster species that are the primarily targeted are the red spiny lobster and the common slipper lobster. Also harvested are the ridgeback slipper lobster, Chinese slipper lobster, and the green spiny lobster (WPRFMC 1981, 2002; Simonds 2003).

Location of Fishery— Lobsters are caught primarily in state waters around the MHI where shallow reefs and rocky bottoms provide crevices and small caves for shelter during the day. Only a very small portion of potential lobster habitat occurs within the boundary of the Hawaiian Islands OPAREA. These are located in the shore regions of the OPAREA at Kaua‘i, O‘ahu, Moloka‘i, and Hawai‘i (WPRFMC 2002; Simonds 2003; **Figure 4-7**).

Current Regulations—There are no current regulations of the crustacean fishery around the MHI that affect the distribution or activity of the fishery in the EEZ (WPRFMC 2002). Regulations do specify types and dimensions of traps used in the EEZ (see Gear below). State regulations do apply to recreational and commercial harvest of lobsters in state waters (see Season below).

Gear—Commercial fishing for lobsters involves the use of plastic, dome-shaped traps. Vessels are generally either Pacific crab vessels or Hawaiian-based longline vessels that also fish lobster traps. Traps are fished in groups that are strung together and set by sunset in depths 20 to 70 m (66 to 230 ft) and are retrieved the following day (WPRFMC 2002; Simonds 2003).

Season—Activity is spotty throughout the year around the MHI and is seasonal at the NWHI, never extending beyond September (WPRFMC 2002). Lobsters are not allowed to be taken in Hawaiian state waters from May through August (HDAR n.d.).

Landings—There are no statistics available for crustacean landings harvested from the EEZ around the MHI.

4.3.2.4 Precious Corals Fisheries

Fisheries for precious corals involve the harvest of branching, bush-like corals that are non-reef forming. While they may grow in groups or dense patches, they do not form the calcium carbonate skeletal structures associated with hermatipic (reef building) corals. The precious corals are harvested for their aesthetic qualities and are cleaned and shaped by jewelers and craftsmen to be sold as decoration and jewelry. This fishery is divided into two groups: one being the deeper water fishery for pink, gold, and bamboo corals (400 to 1,500 m [1300 to 5000 ft]); the other is a shallow water fishery for black corals (30 to 100 m [98 to 328 ft]) (WPRFMC 2002; Simonds 2003)

4.3.2.4.1 Pink, gold, and bamboo corals

History of Fishery—Japanese fishermen seeking coral to harvest discovered a pink coral bed at the Milwaukee Banks beyond the NWHI. Foreign harvesters collected coral with tangle-net dredges around the NWHI through 1985. A high level of illegal fishing and poaching by foreign vessels occurred during the 1980s. Researchers discovered a pink coral bed off Makapuu, O‘ahu in 1966. This bed was harvested by tangle-net dredges until the 1970s when more selective harvest methods such as manned and unmanned submersibles were developed. The fishery for the deep-water precious corals has been variable depending on market factors, the cost of operating submersibles, and the condition of harvest beds (WPRFMC 1979, 2002; Simonds 2003).

Target Species—The deep-water species consist of pink (three species: *Corallium secundum, C. regale, C. lacuense*), gold (three species: *Gerardia* spp*., Callogorgia gilberti, Narella* spp.), and bamboo (two species: *Lepidisis olapa, Acenella* spp.) corals. Gold and bamboo corals were originally harvested incidentally with pink coral and are currently kept as commercially valuable during harvest activity. They

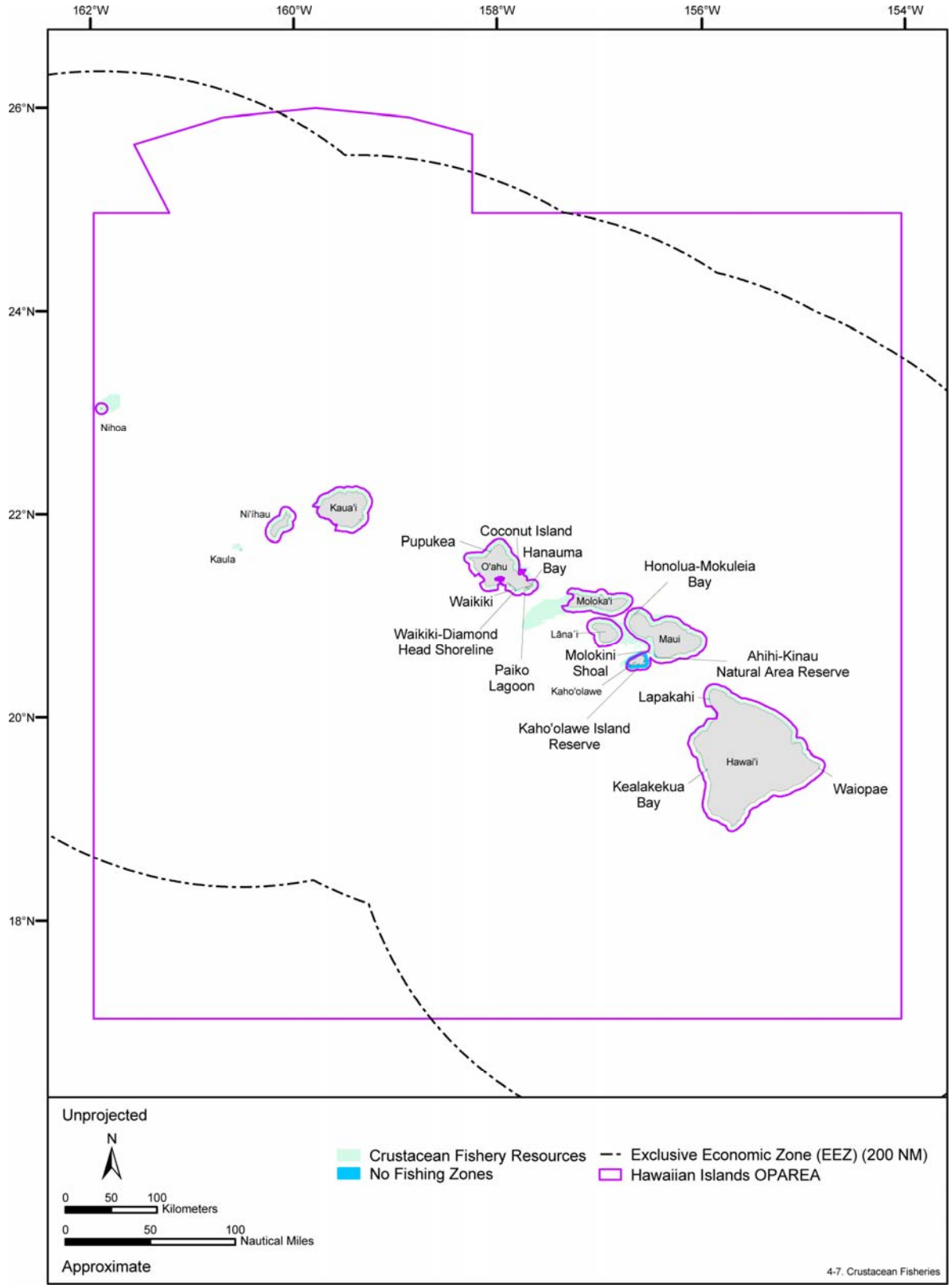

Figure 4-7. Crustacean fisheries fishing areas of the Hawaiian Islands OPAREA. Fishing areas represent potential fishing activity based on fishery descriptions and regulated zones. Source information: WPRFMC 1981, 2002 Simonds 2003. Source data: HDAR 2005.

are still harvested with selective harvest methods, but the pink corals are the primary deepwater target species (i.e., beds of pink corals are sought and all three species of pink corals are harvested if all are present) (WPRFMC 1979, 2002).

Location of Fishery—Fishery activity occurs at a small number of deep-water coral beds around the Hawaiian Islands. The primary harvest location is at the Makapuu bed off O‘ahu. Some very minimal activity occurs elsewhere (not specified due to confidentiality laws) in the U.S. EEZ (WPRFMC 1979; WPRFMC 2002). **Figure 4-8** displays the precious coral fisheries harvest areas in the Hawaiian Islands OPAREA.

Current Regulations—Non-selective harvest methods have been prohibited. This limits deepwater harvest of precious corals to manned or un-manned submersibles. The harvest of gold corals at the Makapuu bed was suspended in 2002 (WPRFMC 2002).

Gear—Harvest of deep-water corals is performed strictly with submersibles, manned or un-manned. The use of manned vehicles for the selective harvest of precious corals requires large/technical support vessels. Both manned and un-manned submersibles have high operating costs. Some participants in the fishery cross over from industries that utilize the vehicles for other purposes and vice versa (WPRFMC 1979, 2002).

Season—No seasonal information is available, but activity is expected to be year round depending on weather conditions (i.e., expect less activity during the fall-winter season on the windward side of the islands). Change in activity is more dependent on market factors—supply, demand, and value (WPRFMC 1979, 2002).

Landings—Statistics are not available for landings within last ten years.

4.3.2.4.2 Black Corals

History of Fishery—Collection and use of black corals (as charms or medicines) has its roots in traditional Hawaiian culture (Simonds 2003). Commercial harvests of black corals developed in the 1950s with the advent of SCUBA and sport diving. Participation in the commercial black coral harvest has remained limited since the 1950s. As with the deep-water corals, the fishery activity has fluctuated with market factors and cost of harvesting. In the 1970s and 1990s, state and federal regulations were created to protect the black coral resources of the Hawaiian Islands from over-harvest (WPRFMC 1979, 2002).

Target Species—There are three species of black corals: *Antipathes dichotoma, A. grandis,* and *A. ulex* (WPRFMC 1979, 2002).

Location of Fishery—The primary harvest sites for black coral are in the Au‘au Channel at depths of 30 to 100 m (**Figure 4-8**). Most of the harvest activity occurs in state waters, within 3 NM from shore although a small amount of harvesting does occur in Federal waters (WPRFMC 1979, 2002).

Current Regulations—Regulations on black coral harvest do not currently affect the distribution or activity of the fishery. Regulations deal with allowable sizes of harvested specimens (WPRFMC 2002). Destructive fishing methods are not allowed.

Gear—Black corals are harvested by hand by divers employing either SCUBA or hookah (surface supplied air) systems (WPRFMC 2002).

Season—Harvesting can occur year round, yet fluctuations may occur in relation to demand and supply levels in workshops and on the market (WPRFMC 1979, 2002).

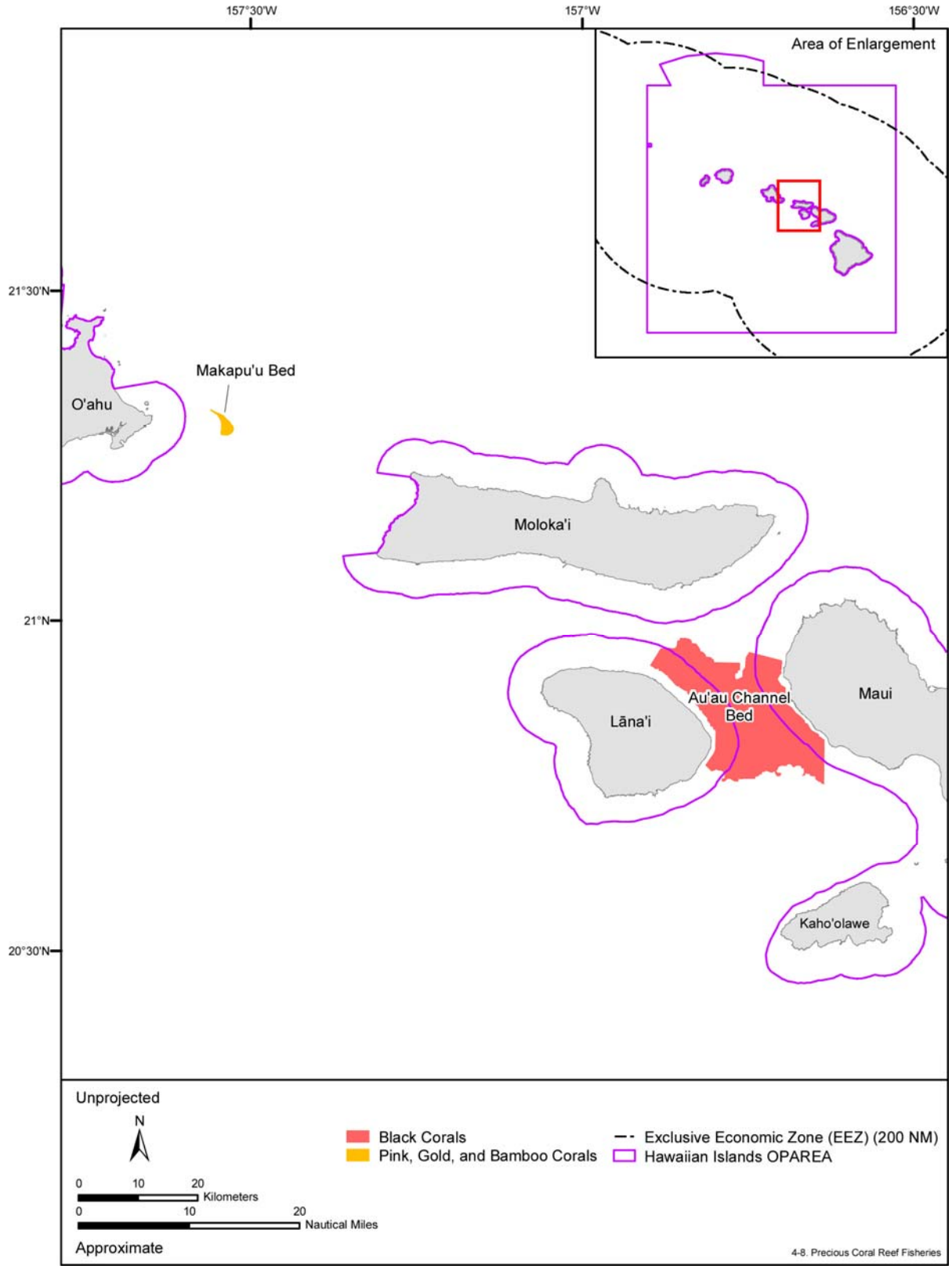

Figure 4-8. Precious coral fisheries fishing areas of the Hawaiian Islands OPAREA. Fishing areas represent potential fishing activity based on fishery descriptions and regulated zones. Source information: WPRFMC 1979, 2002; Simonds 2003. Source data: WPRFMC 1979.

Landings—Between 1990 and 1997, the average landings of the black coral harvest was about 3,000 lbs (1.4 mt). During this period, the greatest harvest occurred in 1995 at 6,000 lbs (2.7 mt) and the lowest in 1993 at about 800 lbs (0.4 mt) (Simonds 2003). While landings decreased after the peak of 1995, they increased dramatically beginning in 2000 with 158,000 lbs (7 mt) estimated to have been landed in 2001 (WPRFMC 2002).

4.3.2.5 Coral Reef Ecosystem Fisheries

The CRE fishery, while not representing a new element of fishery activity, does represent a new way of approaching the management of marine resources in an "ecosystem based management" style. The species managed under the CRE fisheries management plan are all considered part of an interconnected system. The harvested resources include fishes and invertebrates, including corals and algae. A variety of gears and methods may be implemented and targeted species are utilized in both food (consumptive) and ornamental markets. The greatest activity is associated with proximity to the more populated areas of the Hawaiian Islands. As with other major fisheries of the Hawaiian archipelago, especially the trolling fishery, coral reef resource fisheries have a weak distinction between commercial, recreational, and subsistence activities. The commercial sector can be subdivided according to the use of the resource. In addition to selling harvested resources for consumptive uses (food), commercial sectors also include the ornamental trade (aquariums) and natural product sales (pharmaceuticals, etc.). Currently, almost all coral reef ecosystem fishery activity occurs in state waters.

History of Fishery—The Polynesians that explored and settled the islands of the Pacific Ocean region utilized available reef resources as their primary source of protein. As part of this reliance on reef fisheries, they developed knowledge, attitudes, and behaviors that allowed continued long-term use of the available resources and supported the ongoing existence of their populations and respective cultures. The resources themselves as well as the act of the harvest, the products of the harvest, and the cultural rules regarding the harvests were and are integral parts of the island societies. As part of their Polynesians heritage, Hawaiians have had an ongoing relationship with marine and reef resources for centuries (WPRFMC 2001a).

The commercial fishery began with the arrival of British and American whalers to the islands in the early 1800s and was conducted primarily by indigenous Hawaiian Islanders. By the 1900s, Americans, Asians, and Europeans had displaced the Hawaiians as the principal operators of commercial fisheries (WPRFMC 2001a).

Many of the current fisheries, harvesting a spectrum of reef species, are extensions of hundreds of years of fishery activity. Rapid population expansion, disruption of culture and attitudes, as well as the introduction of new fishing methods and gears has altered the use patterns of reef resources in the Hawaiian Islands since the 1800s and more severely since the start of the 1900s. In addition, increased pressures from non-fishery activities and periodic natural stresses on reefs have impacted reef ecosystems. Current CRE resource managers have reached similar conclusions that the historic Polynesians did hundreds and thousands of years ago: that reef ecosystems resources require proper monitoring and management to maintain their productivity and ensure their continued existence and use (WPRFMC 2001a).

Target Species—Several hundred species of organisms are harvested from CREs. These include fishes, invertebrates, and seaweeds (algae). In addition to crustaceans and mollusks, the invertebrate harvest includes taking corals along with their rocky skeletal structures referred to as "live rock" by the aquarium trade. Fishes and invertebrates, in addition to being caught for food, are also collected as "ornamentals" for the aquarium trade. Four species of seaweeds (marine algae) are harvested as well (HDAR n.d.). Some of the species not currently harvested are considered potentially harvestable within one of the commercial sectors (food, ornamental, pharmaceutical/natural, mariculture). The following is a list of the primary family and taxa groups involved in the reef fisheries that occur in the U.S. EEZ (WPRFMC 2001a):

- Surgeonfishes
- Triggerfishes
- Jacks/Trevallies
- Coastal Sharks
- Soldierfishes/Squirrelfishes
- Flagtails
- Rudderfishes
- Wrasses
- Goatfishes
- Mullets
- Moray Eels
- Threadfins
- Bigeyes
- Parrotfishes
- Tunas
- Barracudas
- Crustaceans
- Octopuses

See **Table 4-1** in Section 4.1.1 for a more detailed list of species included in these families and taxa groups. Additional reef species are harvested from the nearshore/coastal reef regions of the Hawaiian Islands OPAREA.

Location of Fishery—The coral reef ecosystem fisheries occur in waters of 182 m (600 ft) or less (**Figure 4-9**). The lower limit of most reef building (hermatypic) corals is around 49 m (160 ft). The majority of coral reef fisheries around the Hawaiian Islands occur in state waters. Coral reef fishing activity is replaced by the bottomfish fishery beyond depths of 100 m (328 ft) (described in Section 4.3.2.2 above).

The coral reef fisheries that occur within the bounds of the Hawaiian Islands OPAREA represent a small portion of the overall activity that occurs around the MHI. Only 880 km^2 (547 square miles [mi^2]) of the total 2,530 km^2 (1,572 mi^2) of coral reefs around the MHI are located in federal waters (greater than 3 NM from shore). Within the nearshore regions of the Hawaiian Islands OPAREA (state waters), coral reef resources occur in four locations: Kihalo Bay on the Island of Hawaii, separate portions of the southwest shore of Kauai (near Barking sands and near Prince Kuhio Park), around Mokapu Peninsula on O‘ahu, and between Mamala Bay and Pearl Harbor on O‘ahu.

Current Regulations—The region off the north shore of Kaho‘olawe is off limits to fishing, as is the area around the Coconut Island—Hawai‘i Marine Laboratory Refuge in Kailua Bay on O‘ahu. Various reef species have seasonal restrictions

Gear—A wide variety of gear types are used to harvest coral reef resources. The primary commercial gears are fish traps, crab nets, surround nets, and gill nets. Also used are hook-and-line, spearguns, mid-water handlines, beach seine-nets, barrier nets, and to a very small degree, cast nets (WPRFMC 2001a).

Season—Fishing occurs year round. Various reef species have seasonal restrictions (WPRFMC 2001a; HDAR n.d., 2004b).

Landings—Landings of coral reef resources in Hawai‘i was 1.4 million lbs (635 mt) in 1999, including resources harvested for both consumptive and ornamental markets (WPRFMC 2001a).

4.3.2.6 Summary of Commercial Fisheries

Comparatively, commercial fishing in the waters of the Hawaiian Islands OPAREA may be lower than any other coastal region of the U.S. with some of the smaller fisheries appearing nearly insignificant. Fishery activity, however, in relation to the population size and total area of the islands is significant. A key characteristic of Hawaiian fisheries is that the distinction between commercial, traditional, and purely recreational activity is extremely difficult to assess at any given time. This is especially true of reef fisheries and trolling.

Pelagic fisheries, specifically longline fisheries, are the most significant by far in the Hawaiian Islands OPAREA. They constitute the majority of vessel activity and account for the bulk of fishery landings and overall market value. Some of the other fisheries of the Hawaiian Islands represent a relatively small

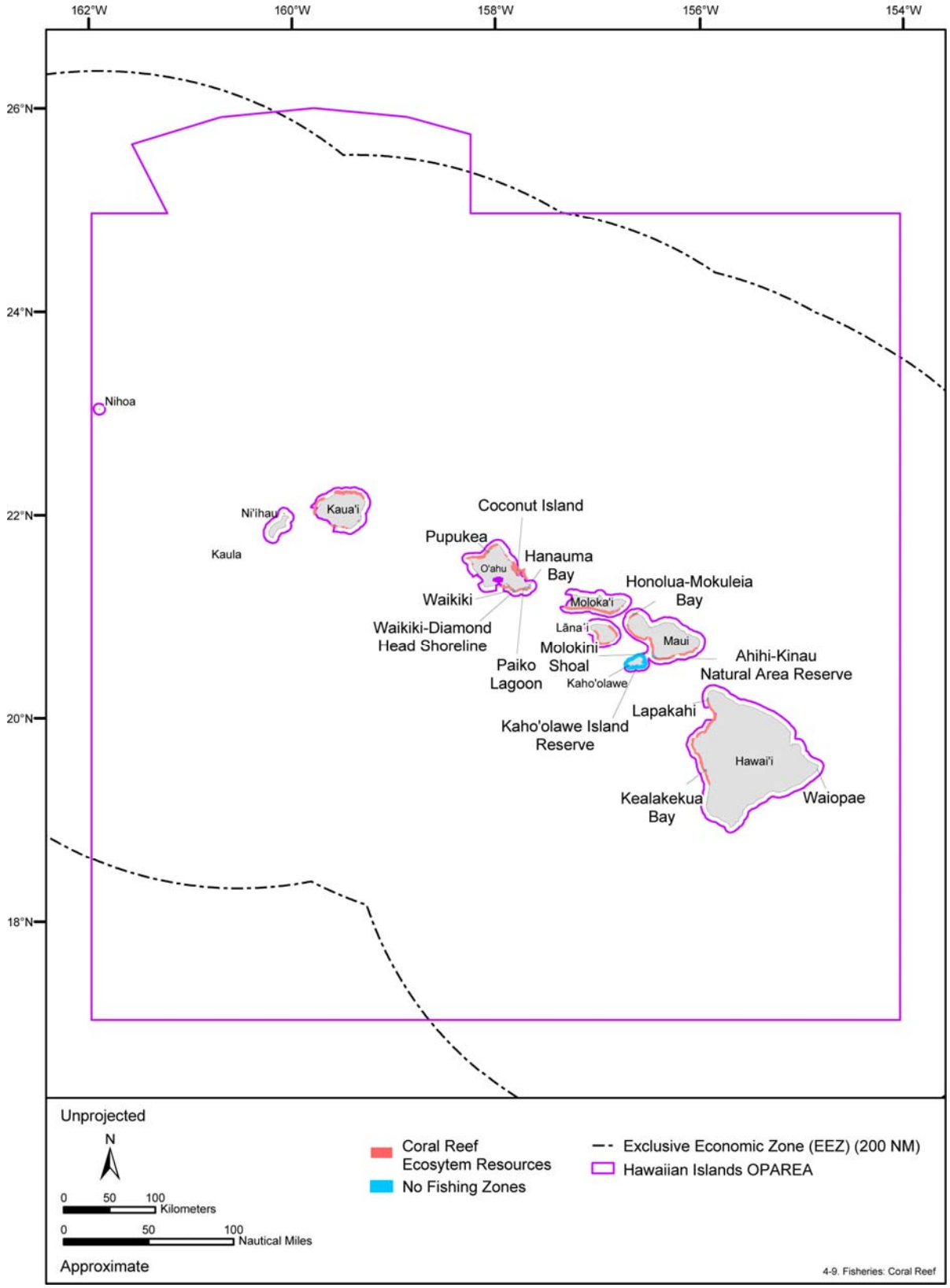

Figure 4-9. Coral reef ecosystem (CRE) fisheries fishing areas of the Hawaiian Islands OPAREA. Fishing areas represent potential fishing activity based on fishery descriptions and regulated zones. Source information: WPRFMC 2001a. Source data: HDAR 2005.

portion of total commercial fishery effort in comparison. The pelagic fisheries, however, are spread over a large oceanic area, covering almost all parts of the Hawaiian Islands OPAREA except for the restricted zones around the MHI. In contrast, the coral reef ecosystems represent the most concentrated areas of fishery effort.

Fishing generally occurs year round but the seasonal shift of the north-east trade winds and change in ocean conditions during the fall-winter months (October through February) limits fishing activity to the north of the MHI especially for smaller fishing vessels. Seasonal shifts in target species does not generally affect the overall level of fishing because fishermen alternate target species and may switch their fishing methods (between the fisheries described above). Market factors, management regulations, and target stock strength influence fishing patterns.

4.3.2.7 Ports

Fishery vessels operate out of various locations around the six MHI. Proximity to population centers is one of the principal factors affecting where these departure and unloading locations (WPRFMC 2002). **Table 4-10** shows the total commercial landings at each of the six islands and their relative proportion of the total commercial catch for 1998. O‘ahu by far sees the greatest amount of fishing activity with Honolulu Harbor and Kewalo Basin being the center of departure and unloading. **Table 4-11** lists the major landing areas for each of main Hawaiian Islands showing pounds landed in 1998 and its statewide ranking. The use of different harbor and unloading docks changes throughout the year in response to sea conditions (WPRFMC 2002).

Table 4-10. Commercial fishery landings by main Hawaiian Islands for 1998 (data from HDAR and compiled by Southwest Fisheries Science Center-NMFS as seen in WPRFMC 2002).

Island	Pounds Landed	Percent of Total
Hawai‘i	3,362,372	12.36%
Kaua‘i	803,897	2.95%
Lāna‘i	23,725	0.09%
Maui	706,903	2.60%
Moloka‘i	42,685	0.16%
O‘ahu	22,274,538	81.85%
Total:	27,214,120	

Table 4-11. Commercial fishery landing areas by island showing their landings in pounds and statewide ranking for 1998 (data from HDAR source data compiled by NMFS Southwest Fisheries Science Center as seen in WPRFMC 2002).

Landing Area	Landing (lbs)	State-wide Rank
Hawai‘i		
Honokohau, Kailua, Kailua-Kona	1,295,350	5
Hilo, Papa‘ikou, Waiakea, Wailoa	727,802	7
Pohoiki, Kalapana, Kapoho Point, Puna	400,342	10
Keahou, Kahalu‘u	228,730	13

Table 4-11. Commercial fishery landing areas by island showing their landings in pounds and statewide ranking for 1998 (data from HDAR source data compiled by NMFS Southwest Fisheries Science Center as seen in WPRFMC 2002) (continued).

Landing Area	Landing (lbs)	State-wide Rank
Hawai‘i (continued)		
Kona	131,751	19
Other	131,712	20
Honaunau	116,601	23
Kawaihae, Puako	104,046	24
Punalu‘u	69,804	27
Kealakekua, Ke‘ei, Napo‘opo‘o	56,882	30
Miloli‘i	45,028	35
South Point	37,300	37
Na‘alehu, Ka Lae, Kaulana, Ka‘alu‘alu	10,635	47
Kau Desert	3,407	53
Ho‘okena, Kohala	1,711	57
Mahukona	406	68
Upolu	370	69
Pahoa	250	72
Honoka‘a	245	73
Hawai‘i Total	3,362,372	4
Kaua‘i		
Port Allen	289,965	12
Nawiliwili, Niumalu	206,872	14
Kekaha, Kiki a Ola, Mana	130,011	21
Kapa‘a, Wailua	49,990	33
Other	37,002	38
‘Anini, Kalihiwai, Moloa‘a	27,625	41
Lihu‘e, Ahukuni	26,067	42
Kukui‘ula, Makahu‘ena Pt.	12,249	45
Hanama‘ulu	11,026	46
Hanalei, Wainiha	9,825	49
Koloa	3,022	54
Anahola	148	76
Waimea	69	77
Ha‘ena	26	80
Kaua‘i Total	803,897	6
Lāna‘i		
Manele Beach	19,625	44
Other	4,100	52
Lāna‘i Total	23,725	43
Maui		
Maliko, Ha‘iku, Pa‘uwela	32,390	39
Hana	9,535	50
Honokowai, Ka‘anapali	4,506	51
Makena, Keone‘oi‘o	1,556	60
Nahiku, Ke‘anae, Peahi	269	71
Honolua	31	79

Table 4-11. Commercial fishery landing areas by island showing their landings in pounds and statewide ranking for 1998 (data from HDAR source data compiled by NMFS Southwest Fisheries Science Center as seen in WPRFMC 2002) (continued).

Landing Area	Landing (lbs)	State-wide Rank
Maui (continued)		
Olowalu	6	81
Maui Total	706,903	8
O‘ahu		
Kewalo Basin	10,957,172	2
Honolulu, Ke‘ehi, Sand Island	9,746,154	3
Waianae, Pokai Bay	627,887	9
Hale‘iwa	326,579	11
Campbell Park, Pearl Harbor, Hickam, Other	173,402	15
Nanakuli	124,485	22
Kaneohe, Mikiola	103,515	25
Koko Head, Hawai‘i Kai, Maunalua Bay, Portlock	93,746	26
Kane‘ohe Bay	60,145	29
He‘eia, He‘eia Kea	48,271	34
Awa Wai, Diamond Head, Waikiki	2,814	55
Kailua Bay	2,783	56
Pearl City, Waipio, Waipahu	1,649	58
Hau‘ula, La‘ie, Punalu‘u	1,577	59
Kahana Bay	1,099	61
Ewa	921	62
Kahuku	628	64
Honouliuli, Hoaeae	613	65
Waiahole	457	67
Waimanalo	277	70
Kahalu‘u	185	74
Waikane	179	75
O‘ahu Total	22,274,538	1
Molokai		
Kaunakakai	31,120	40
Other	10,255	48
Kamalo Harbor	756	63
Halawa	495	66
Puko‘o Harbor	59	78
Moloka‘i Total	42,685	36

4.3.3 Recreational Fisheries

Fishes are considered an important socio-economic resource in the Hawaiian Islands, and this includes recreational uses. In addition to being important to local residents, they draw visitors from the mainland U.S. and from around the world. Recreational fishing is a serious industry in itself and an integral part of local economies, extending its financial impact into related goods and services markets (Wilson 2001). Purely recreational anglers are not looking to generate revenue but some do sell their catch to cover the expenses of their fishing activities. This type of fishing is referred to as “expense fishing” in Hawai‘i. Subsistence fishing and traditional fishing are similar to recreational fishing in that they are not directly

profit driven endeavors (WPRFMC 2001a; 2002; Simonds 2003). Subsistence fishing often provides an alternative to other sources of food or provides food in addition to the fisherman's existing supplies.

Distinguishing between fisheries is often difficult. Traditional and subsistence fishing utilize many of the same fishing methods as recreational fishing. Commercial fishermen also fish recreationally on and between commercial fishing trips. Furthermore, recreational trolling, handlining, and reef fishing often use similar techniques and gears as those of commercial fisheries (NMFS 2001; WPRFMC 2001; WPRFMC 2002; WPRFMC 2005a; WPRFMC 2005b).

4.3.3.1 Background, Target Species, Gears, and Fishing Areas

In Hawaii, chartered fishing trips, usually with trolling gear, are considered commercial in the sense that the fishing trip itself is a business transaction, though the activity of the fishing is recreational in nature. Management of fishery resources used by the recreational sector has been light in the past but declines in certain fishery resources have spurred an increase in regulatory and monitoring efforts. Catch and release programs have been gaining influence recently, however Hawaiians and Polynesians in general have a strong connection with fishery resources and utilizing their catch is part of the entire fishing experience (Akau'ola 2001). Other regulations involve restrictions in fishing areas and seasons for some species, such as lobsters in their reproductive stages (NMFS 2001; WPRFMC 2001a, 2002, 2005a; HDAR n.d.).

Advanced fishing technologies and gear types have made finding and catching fish easier in recent decades. Recreational fisherman may use a variety of gears with trolling and rod-and-reel gear being the most common. Blue water trolling is one of the most popular recreational fishing activities, especially for visitors to the Hawaiian Islands. This troll fishing occurs mostly on the calm leeward sides of the big island of Hawai'i, O'ahu, and Maui and is represented by a large charter boat fleet. The pelagic sport fishes targeted include dolphinfish, wahoo, skipjack tuna, yellowfin tuna, swordfish, marlin, trevally, and small jacks. A variety of hand gears, traps, and nets are also common among "recreational" fishermen catching coral reef resources. Targeted reef species include goatfish, surgeonfish, soldierfish, parrotfish, spiny lobster, crabs, and grouper (Maragos 2000).

Recreational fishing occurs at many of the same types of locations as the commercial sector, but is generally concentrated closer to shore and at coral reefs and on reef slopes. Fishing also is commonly concentrated around the network of FADs and near the island slopes and banks (NMFS 2001; WPRFMC 2001a, 2002).

4.3.3.2 Socioeconomics

Anglers contribute about $138 million a year to the Hawaiian economy (Wilson 2001). Fishing occurs generally year round but is noticeably reduced during the fall-winter season on the windward side of the islands (north and east). Charter fishing trips cost from $700 to $500 depending on location. In a survey of over 500 small boat operators (small being less than 9 to 12 m [30 to 40 ft]), about one third considered themselves recreational anglers and another third as expense fishers with the remaining third being commercially oriented (Hamilton and Huffman 1997). Since the 1990s the Hawaiian Islands have experienced an upward trend of personal recreational boat owners, reaching about 14,000 in 1999.

The most common fish caught by recreational anglers using private or rental boats in 2002 was skipjack tuna, followed by yellowfin tuna, dolphinfish, and wahoo (HDAR 2003a). Marine recreational survey records show that in 2003 about 440,000 individuals took about 2.4 million trips catching a total of 12.5 million fish (NFMS 2004b). The number of fishing trips remained above 50,000 per two-month survey period in 2001, peaking during the July-August period at 150,000 trips (HDAR 2003a). The average number of private boat trips in 2003 increased to about 60,000. The greatest number of trips was slightly less than 140,000 in the November-December survey period (HDAR 2004). The level of activity fishing from shore (no boats) is nearly an order of magnitude greater, averaging at about 200,000 fishing trips per two-month period and peaking at over 500,000 during the July-August period in 2001 (HDAR 2003a).

The greatest numbers of fish caught at nearshore/coral reef ecosystems were iridescent cardinal fish, mackerel scad, bigeye scad, and yellowstripe goatfish (NFMS 2004b).

4.3.3.3 Tournaments

A wide variety of fishing tournaments take place in the Hawaiian Islands every year. These range from small locally organized tournaments to the internationally famous Hawaiian International Billfish Tournament. Each tournament has its own set of rules, which include time limits and geographical boundaries. The maximum distance typically traveled by offshore tournament participants is no more than 75 NM (139 km) from the tournament host site. Tournaments have one to several designated starting locations and usually have a single weigh-in/check-in station afterwards. The sites fished by anglers within the tournament zones are dependent on several factors, including the species targeted, tournament rules, and weather. Among the different tournaments, the level of participation varies between individual events, seasons, and years. Although most tournaments are annual events, the list of scheduled tournaments is not static. Existing tournaments may be cancelled due to a lack of participation or support or new tournaments may be organized. The exact dates and weigh-in locations of annual tournaments will vary slightly year to year.

Table 4-12 provides a list of fishing tournaments and the month in which they usually occur. Around 50 events may occur in a year at various locations around the islands; however, they are usually concentrated around population centers on Oʻahu and Hawaiʻi. Tournaments occur year round with most taking place in the summer months of June and July. The average number per year is around 30 major tournaments on Oʻahu, Hawaiʻi, Maui, Kauaʻi, and Lānaʻi combined. The trend of yearly tournaments has shown an overall decrease since 1999 with just over 30 scheduled in both 2004 and 2005 (Sportfish Hawaii 2004, 2005).

Table 4-12. Compilation of Fishing Tournaments held in Hawaiʻi between 2001 and 2004 (Sportfish Hawaii 2004, 2005).

Month	Tournament Name	Location
January	Keiki Fishing Tournament	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu/ Waikiki Yacht Club, Ala Wai Yacht Harbor, Oʻahu
February	President's Day Fishing Tournament	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu
March	Offshore Fishing Tournament	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu
March	St. Patrick's Day Fishing Tournament	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu
March	IGFA Int'l Tournament of Champions	Honokohau Harbor, Kailua-Kona, Main Island of Hawaiʻi
April	Annual KBC Pure Jackpot Tournament	Keehi Boat Club, Honolulu, Oʻahu
April	KBC Pure Jackpot	Keehi Boat Club, Honolulu, Oʻahu
April	Senoritas Jackpot Fishing Tournament	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu
May	Memorial Day Tournament	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu
May	Ko'olina Overnighter	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu
June	King Kam Tournament	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu
June	Ahi Fever Fishing Tournament	Pokai Bay Waianae Boat Harbor, Waianae, Oʻahu
June	Goodwill Fishing Tournament	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu
June	Hana Paʻa Fishing Tournament	Haleiwa Boat Harbor, Haleiwa, Oʻahu
June	Kona Classic Fishing Tournament	Honokohau Harbor, Kailua-Kona, Main Island of Hawaiʻi
June	Pearl Harbor Fishing Tournament	Pearl Harbor, Oʻahu
June	Akule Overnighter	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu
July	Independence Day Tournament	Hawaiʻi Yacht Club, Ala Wai Yacht Harbor, Oʻahu
July	Annual Firecracker Open Marlin Tournament	Honokohau Harbor, Kailua-Kona, Main Island of Hawaiʻi
July	Annual Skins Marlin Derby	Honokohau Harbor, Kailua-Kona, Main Island of Hawaiʻi

Table 4-12. Compilation of Fishing Tournaments held in Hawai‘i between 2001 and 2004 (Sportfish Hawaii 2004, 2005) (continued).

Month	Tournament Name	Location
July	Annual World Cup Blue Marlin Championship	Worldwide
July	Rock N Reel Hawaiian Open	Honokohau Harbor, Kailua-Kona, Main Island of Hawai‘i
July	Annual KBC Pure Jackpot Team Challenge	Keehi Boat Club, Honolulu, O‘ahu
July	World Billfish Challenge Light Tackle	Honokohau Harbor, Kailua-Kona, Main Island of Hawai‘i
July	Billfish Foundation Hawai‘i Shootout	Honokohau Harbor, Kailua-Kona, Main Island of Hawai‘i
July	World Billfish Challenge Heavy Tackle	Honokohau Harbor, Kailua-Kona, Main Island of Hawai‘i
July	HIBT Pro-Am	Honokohau Harbor, Kailua-Kona, Main Island of Hawai‘i
July	Hickam Outdoor Recreation Tournament	Hickam Harbor, Hickam Air Force Base, O‘ahu
July	Hooters Tournament	Honolulu
August	Hawai‘i International Billfish Tournament	Honokohau Harbor, Kailua-Kona, Main Island of Hawai‘i
August	Bob Goodman Memorial Tournament	Hawai‘i Yacht Club, Ala Wai Yacht Harbor, O‘ahu
August	Kaneohe Yacht Club Open Tournament	Kane‘ohe Yacht Club, Kane‘ohe Bay, O‘ahu
August	Cockeyed Mayor's Fishing Tournament	Hawai‘i Yacht Club, Ala Wai Yacht Harbor, O‘ahu
August	World Billfish Challenge Ko Olina	Ko Olina Harbor, West O‘ahu
August	Annual Big Island Invitational Marlin Tournament	Honokohau Harbor, Kailua-Kona, Main Island of Hawai‘i
September	KBC Na Wahine O Keehi Fishing Tournament	Keehi Boat Club, Honolulu, O‘ahu
September	Hoolea Jackpot Fishing Tournament	Hawai‘i Yacht Club, Ala Wai Yacht Harbor, O‘ahu/ Waikiki Yacht Club, Ala Wai Yacht Harbor, O‘ahu
September	KBC Annual Open Jackpot Fishing Tournament	Keehi Boat Club, Honolulu, O‘ahu
September	Wahine Tournament	Hawai‘i Yacht Club, Ala Wai Yacht Harbor, O‘ahu
September	Okoe Bay Rendezvous	Honokohau Harbor, Kailua-Kona, Main Island of Hawai‘i
October	Do or Die Fishing Tournament	Waikiki Yacht Club, Ala Wai Yacht Harbor, O‘ahu
October	Lahaina Jackpot	Lahaina Yacht Club, Lahaina
October	LYC Wahine Tournament	Lahaina Yacht Club, Lahaina
November	Maui Jim Championship	Honokohau Harbor, Kailua-Kona, Main Island of Hawai‘i
November	Tri-Club Shootout Tournament	Hawai‘i Yacht Club, Ala Wai Yacht Harbor, O‘ahu/ Waikiki Yacht Club, Ala Wai Yacht Harbor, O‘ahu/ Kane‘ohe Yacht Club, Kane‘ohe Bay, O‘ahu
November	Apples and Oranges Tournament	Hawai‘i Yacht Club, Ala Wai Yacht Harbor, O‘ahu/ Waikiki Yacht Club, Ala Wai Yacht Harbor, O‘ahu
November	Aloha Relief Fishing Tournament for Shorecasters - Benefits Red Cross	O‘ahu

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5.0 ADDITIONAL CONSIDERATIONS

5.1 MARITIME BOUNDARIES: U.S. TERRITORIAL WATERS, CONTIGUOUS ZONE, AND EXCLUSIVE ECONOMIC ZONE

Maritime boundaries are critical elements that affect the planning of activities in the marine environment (GDAIS 2003). They delimit the extent of a nation's sovereignty, exclusive rights, jurisdiction, and control over the ocean areas off its coast. Maritime boundaries may include a 12 NM territorial sea, an 18 to 24 NM contiguous zone, a 200 NM EEZ, and a nation's continental shelf (**Figure 5-1**). Since maritime boundaries are delimited, rather than demarcated, there is generally no physical evidence of the boundary. As a result, there can often be confusion, disagreement, and conflicting versions of marine boundaries between distinct nations and/or territories (NOAA 2005a).

Although the U.S. and other nations historically used 3 NM as their seaward territorial limit, some American states (e.g., Texas and the Gulf Coast of Florida) and territories (e.g., Puerto Rico) have historical seaward boundaries of 3 marine leagues or 9 NM. These territorial limits were measured from the baseline of each nation or state. The U.S. has traditionally used the "rule of the tidemark" as the baseline from which to measure the width of its territorial waters. This baseline coincides with the mean lower low water (MLLW)/tide line found along the shore and is often termed the "normal" baseline (Kapoor and Kerr 1986; Prescott 1987; **Figure 5-1**). At the mouths of bays, rivers, or other areas where the coastline is not continuous, a straight baseline is drawn over the coastal feature. Rather than use the normal baseline, an increasing number of countries use either the straight baseline or archipelagic baseline system from which to measure their territorial waters (Kapoor and Kerr 1986; Prescott 1987).

The 3 NM limit was the standard until the latter half of the twentieth century when the extent of U.S. territorial waters was redefined. In 1945, President Truman issued Presidential Proclamation No. 2667 (also known as the Truman Proclamation) claiming jurisdiction and control over all the natural resources of the seabed and subsoil of the entire continental shelf adjacent to the coasts of the U.S. The Truman Proclamation did not include jurisdiction or control over the waters overlaying the U.S. continental shelf. In 1953, the Truman Proclamation was nullified and replaced by the Outer Continental Shelf (OCS) Act. The OCS Act placed the subsoil and seabed of the OCS under U.S. jurisdiction. Section 1331 of this act defines the OCS as "…all submerged lands lying seaward and outside of the area of lands beneath navigable waters as defined in section 1301 of this title…" (DOALOS 2004). Like the Truman Proclamation, the OCS Act did not give the U.S. authority over the waters above the continental shelf seabed, leaving them open to navigation and fishing (**Table 5-1**).

In 1976, the U.S. followed the trend established by the United Nations (U.N.) by drafting a federal resource law known as the FCMA. The FCMA established a 200 NM fishery conservation zone extending outward from the U.S. baseline. The 200 NM zone was designed to protect and conserve the fisheries of the U.S and its territories. With the official enactment of the FCMA in 1977, the U.S. formally claimed the 200 NM fishery conservation zone in which it exercised exclusive fishery management authority, except in cases where a country was situated within 400 NM (**Table 5-1**). In the Gulf of Mexico, for instance, Cuba and Mexico are located less than 400 NM away from the U.S. fishery conservation zone boundary. Pending the establishment of permanent maritime boundaries by treaty or agreement with these nations, the FCMA sets forth fishery limits based on a median line drawn equidistantly between two nations where a 200 NM limit is not possible (DoS 1977).

By the early 1980s, it was evident that the U.S. needed to control more than fisheries outside of its territorial waters. In 1983, President Reagan recognized the necessity of protecting, controlling, and developing the ocean area adjacent to the territorial waters of the U.S. by issuing Presidential Proclamation No. 5030 (**Table 5-1**). This proclamation established an EEZ that extended 200 NM from the U.S. baseline and included all areas adjoining the territorial waters of the U.S. and its territories, except where another country is less than 400 NM from the U.S. The establishment of the EEZ gave the U.S. sovereign rights over the natural resources within the 200 NM zone, but it did not affect the lawful use of this zone by other nations for navigation or overflight (DOALOS 2004; **Table 5-2**). Sovereign rights include the rights to explore, exploit, conserve, and manage natural resources.

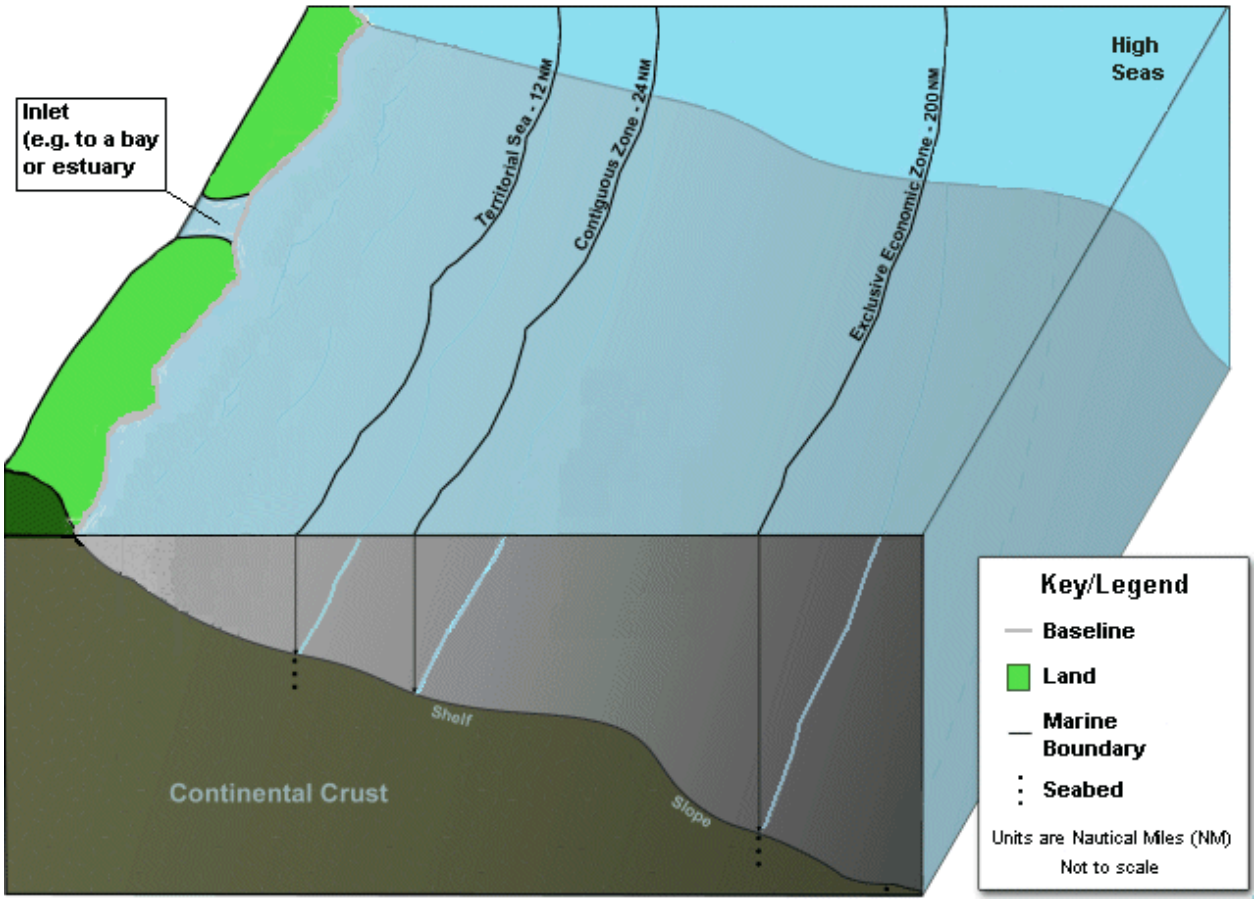

Figure 5-1. A generic three-dimensional representation of the U.S. maritime boundaries. The baseline is defined as the mean low water/tide line along the coast or a straight line drawn across coastal bays or other inlets. Adapted from NOAA (2005a).

The U.S. EEZ covers approximately 7.8 million km^2 of ocean space, half of which is found in the central and western Pacific Ocean around U.S. possessions such as the Hawaiian Islands, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands. Overlapping boundaries with other nations exist in 25 situations. International maritime boundaries are those agreed upon by one or more countries to resolve these overlapping claim issues. In cases where a nation's 200 NM EEZ overlaps with that of another country, both countries' EEZs are deemed to end at what is called the "median line," an imaginary line that is equidistant from the baseline of each country. Around the Hawaiian Islands the U.S. EEZ does not overlap with the maritime boundaries of any other nation (Maragos 2000).

The U.N. Law of the Sea Treaty, created in 1982 and entered into force in 1994, delimited the international maritime sovereignties of coastal nations as 12 NM for territorial seas, 18 to 24 NM for a contiguous zone, and 200 NM for an EEZ (54 FR 777). While the U.S. has not yet signed the Law of the Sea Treaty, it does recognize and abide by many of its rules. For instance, in 1988, Presidential Proclamation No. 5928 extended the seaward territorial limit of the U.S. to 12 NM from the baseline (**Table 5-1**). This expansion of federal territorial waters from 3 NM (or in some cases 9 NM) to 12 NM provided the U.S. with jurisdiction and supreme power over this area (**Table 5-2**). The seabed and its resources, the biota found in the water column, and the airspace above the territorial seas, as well as the use of surface waters, are all under the jurisdiction of the U.S. Although the territorial waters of the U.S. extend 12 NM seaward from its baseline, the part of the territorial sea closest to shore (3 to 9 NM) remains under the primary jurisdiction of each coastal state.

Table 5-1. Timeline detailing the establishment of U.S. jurisdiction and maritime boundaries in the Hawaiian Islands OPAREA by treaty, legislation, and presidential proclamation.

- **From Antiquity to the Early Twentieth Century:** nations individually established seaward boundaries of 3 to 9 NM under the "cannon shot" concept.
- **1945–Truman Presidential Proclamation No. 2667 on the Continental Shelf:** for the purpose of conserving and utilizing natural resources, the U.S. claimed jurisdiction and control of the subsoil and seabed of the continental shelf contiguous to its coast. The waters overlying the continental shelf were not affected.
- **1945–Truman Presidential Proclamation No. 2668 on Coastal Fisheries:** conservation zones were established in areas of the high seas contiguous to U.S. coasts for the purpose of protecting coastal fishery resources.
- **1953–Outer Continental Shelf Act:** the subsoil and seabed of the OCS was declared to be under U.S. jurisdiction, control, and power. The waters overlying the OCS were not affected by this act, so fishing and navigation were unrestricted. This act nullified Presidential Proclamation No. 2667 (67 Stat. 462, 43 U.S.C. 1331 et seq.).
- **1958–U.N. Convention on the Law of the Sea I:** the U.N. convened the first international conference on maritime boundaries.
- **1960–U.N. Convention on the Law of the Sea II:** the second U.N. conference convened on international maritime boundaries.
- **1973–U.N. Convention on the Law of the Sea III:** the third U.N. conference convened on international maritime boundaries.
- **1976–Fishery Conservation and Management Act:** this legislation established a fishery conservation zone extending 200 NM from the U.S. baseline, except in several areas such as the Caribbean Sea, where to the west, south, and east of Puerto Rico and the U.S. Virgin Islands, the limit of the fishery conservation zone was determined by geodetic or straight lines connecting points of latitude and longitude that were delineated in the act.
- **1977–Fishery Conservation and Management Act:** the fishery conservation zone, established by the 1976 FCMA, went into effect.
- **1982–U.N. Convention on the Law of the Sea Treaty:** an international treaty developed by the U.N. but not yet ratified by the U.S. The U.N. Convention on the Law of the Sea lays down a comprehensive regime of law and order in the world's oceans and seas by establishing rules governing all uses of the oceans and their resources. Most nations, including the U.S., adhere to its guidelines for maritime boundaries, including territorial seas, contiguous zones, and EEZs.
- **1983–Reagan Presidential Proclamation No. 5030 on the EEZ:** an EEZ was formally established to facilitate wise development and use of the oceans consistent with international law as well as to recognize the zone adjacent to a nation's territorial seas where a nation may assert certain sovereign rights over natural resources. Establishment of the U.S. EEZ advanced the development of ocean resources and promoted protection of the marine environment but did not affect other lawful uses of the zone, including navigation and overflight. This proclamation set the EEZ at 200 NM from the baselines of the U.S. and its territories, except where nations are less than 400 NM apart. In such cases, equidistant lines delineated the EEZ boundary. The EEZ boundaries coincided with those established by the 1976 Fishery Conservation and Management Act. This proclamation did not affect existing U.S. policies concerning the continental shelf, marine mammals, or fisheries. Jurisdiction and sovereign rights will be exercised in accordance with rules of international law.
- **1988–Reagan Presidential Proclamation No. 5928 on the Territorial Sea:** the seaward extent of the U.S. territorial sea was extended to 12 NM from the baseline of the nation and its territories by this proclamation. The territorial sea is the zone over which the U.S. exercises supreme sovereignty and jurisdiction from the airspace over the sea to the seabed and its soil. This extension of the territorial sea advanced national security and other interests of the U.S. This proclamation did not extend or alter existing federal or state laws (jurisdiction, rights, legal interests, or obligations).
- **1994–U.N. Convention on the Law of the Sea:** the U.N. entered into force the 1982 Law of the Sea Treaty. It has yet to be ratified by the U.S.
- **1999–Clinton Presidential Proclamation No. 7219 on the Contiguous Zone:** the contiguous zone of the U.S. was established 24 NM from the nation's baseline by this proclamation. The contiguous zone is the area where the U.S. exercises the control necessary to prevent and punish infringement of its fiscal, customs, immigration, or sanitary laws and regulations within its territorial sea. Establishment of the U.S. contiguous zone advanced the law enforcement and public health interests of the nation. This proclamation did not change existing federal or states law and did not alter the rights of the U.S. in the EEZ.

Sources: DoS (1977), U.S. President (1988), de Blij and Muller (1999), DOALOS (2004), and Rosenberg (2005).

Table 5-2. The maritime boundaries of the U.S. and their seaward and jurisdictional extents.

Maritime Boundary	Seaward Extent	Jurisdictional Extent
State Waters	3 to 9 NM from U.S. baseline (depending on state or territory's historical maritime boundary)	State or territory jurisdiction over the air, sea, and seabed
Territorial Waters	12 NM from U.S. baseline	Federal jurisdiction over the air, sea, and seabed
Contiguous Zone	24 NM from U.S. baseline	Power to prevent and punish for infringement of fiscal, customs, immigration, and sanitary laws
Exclusive Economic Zone	200 NM from U.S. baseline	Sovereign rights over all natural resources and jurisdiction to protect the marine environment

Source: DOALOS (2004)

U.S. control over the waters adjacent to its shores was further solidified in 1999 when President Clinton's Presidential Proclamation No. 7219 extended U.S. federal jurisdiction by the additional 12 NM maximum allowed by international law. This 24 NM contiguous zone is measured from the U.S. baseline and, as its name implies, is an area contiguous or next to a nation's territorial waters that provides an added area of limited jurisdiction. The U.S. makes no territorial claims within its contiguous zone, but it does, however, claim the right to exercise the control necessary to prevent infringement of its fiscal, customs, immigration, or sanitary laws/regulations and to punish infringement of these laws/regulations committed within the zone (DOALOS 2004). The establishment of the U.S. contiguous zone additionally advances both the law enforcement and public health interests of the U.S. (**Table 5-1**).

5.1.1 Maritime Boundaries in the Hawaiian Islands OPAREA

The Hawaiian Islands OPAREA is predominantly located within the U.S. EEZ (**Figure 5-2**). Portions of the Hawaiian Islands OPAREA that stretch beyond the U.S. EEZ and into the "high seas" (international waters outside the jurisdiction of any single nation) include the northeast and southwest corners as well as the northeast section of the KUKU OPAREA. Off the Hawaiian Islands, the U.S. EEZ does not abut the EEZ of any other nation. As a result, Navy activities conducted in OPAREA waters beyond the U.S. EEZ are not subject to the jurisdiction of other nations.

Several warning areas, restricted areas, and other Navy training areas lie within or adjacent to the U.S. territorial waters, including W-186, W-187, W-188, W-189, R3101, R3107, BSURE, Barking Sands PMRF, SESEF, HATS, SWTR, and nearshore waters of the Echo and Uniform OPAREAs. The warning areas south of the Hawaiian Islands all lie beyond the U.S. contiguous zone, except for a large section of W-196 and a small portion of W-194. Warning area W-190 is also situated beyond the U.S. contiguous zone.

5.1.2 U.S. Maritime Boundary Effects on Federal Legislation and Executive Orders

According to the presidential proclamations and treaties that extended or established the maritime boundaries of the U.S. (territorial seas, contiguous zone, and EEZ), existing federal or state laws or any associated jurisdiction, rights, legal interests, or obligations were not extended or altered in any way. The following federal legislation and EOs have associated maritime zone or boundary limitations.

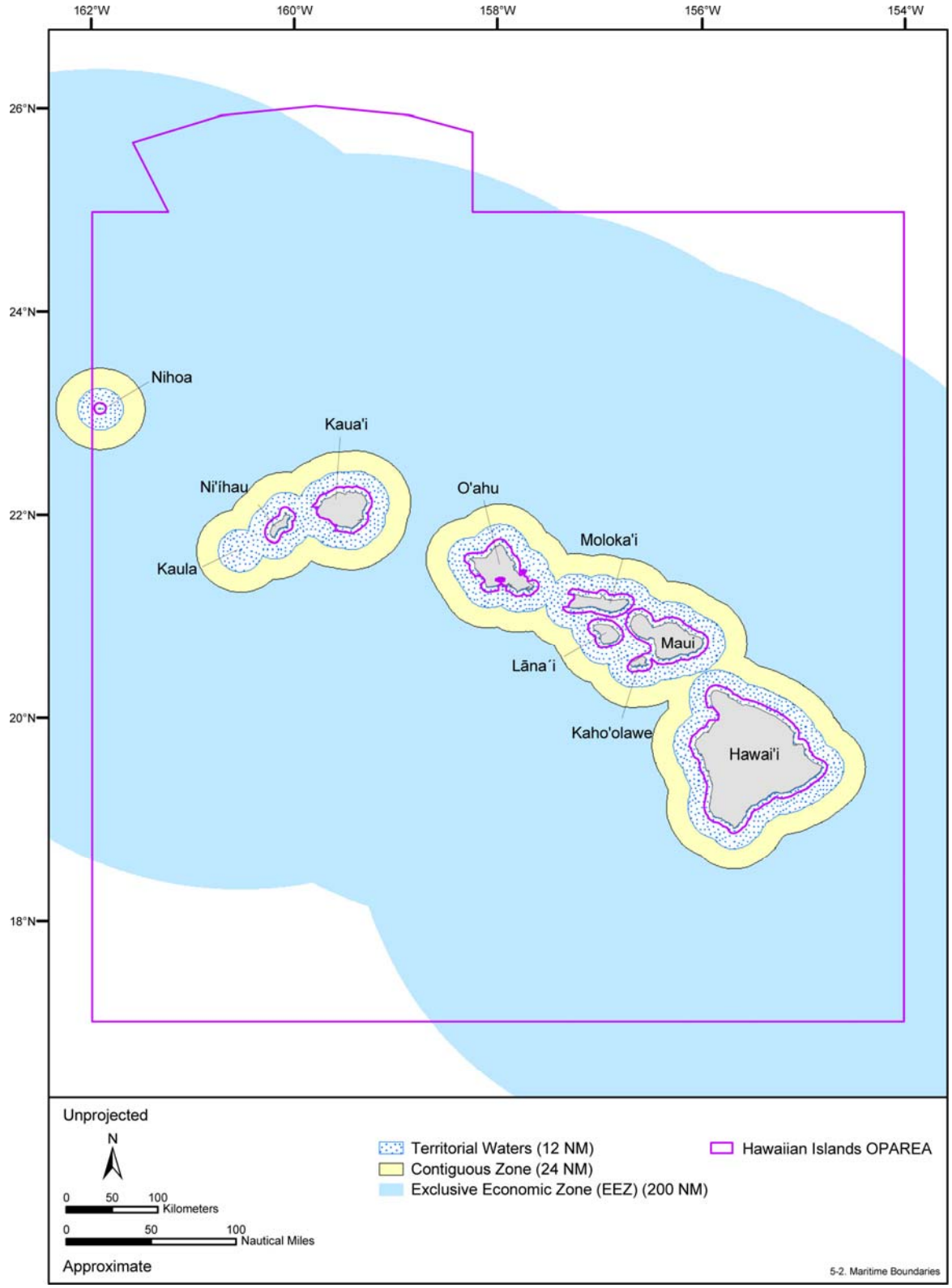

Figure 5-2. Proximity of the Hawaiian Islands OPAREA to the U.S. maritime boundaries. The territorial waters (12 NM), contiguous zone (24 NM), and exclusive economic zone (EEZ) (200 NM) are each measured outward from the baseline (usually mean low-tide line) along the shore. Source data: GDAIS (2004).

The maritime boundary associations detailed in the legislation or orders relevant to the Hawaiian Islands OPAREA are listed below (see Section 1.3 for a full description of the legislation and their applications).

- The MMPA protects, conserves, and manages marine mammals in waters under the jurisdiction of the U.S., which are defined by the MMPA as the U.S. territorial seas, EEZ, and the eastern special areas between the U.S. and Russia. The act further regulates 'takes' of marine mammals on the global commons (i.e., the high seas or Antarctica) by vessels or persons under U.S. jurisdiction.

- The ESA regulates the protection, conservation, or management of endangered species in the U.S. territorial land and seas as well as on the high seas.

- The MSFCMA, as amended by the SFA, claims sovereign rights over fish and fishery management in the U.S. EEZ (except for highly migratory species [HMS]). The U.S. cooperates with nations or international organizations involved in fisheries for the HMS in order to conserve and promote optimum yields of the species in their entire range in and beyond the U.S. EEZ.

- The NEPA establishes a CEQ and a national policy that will encourage productive harmony between humans and their environment. It also promotes efforts that will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man. Jurisdiction of this act includes the territorial lands and waters of the U.S. to the limit of the territorial seas.

- The MPRSA regulates the dumping of materials in the ocean. It is applicable to material transported by any U.S. person, vessel, aircraft, or agency from any location in the world and by any person outside the U.S. intending to dump materials in U.S. territorial seas and the contiguous zone.

- EO 12114 extends environmental impact evaluation requirements for U.S. federal agencies beyond the territorial seas and contiguous zone to include the environments of other nations and the global commons outside the jurisdiction of any nation.

- The MPPRCA prevents pollution of the marine environment by any vessel with U.S. registry or under U.S. authority and all vessels in the U.S. territorial waters or EEZ.

5.2 COMMERCIALLY NAVIGABLE WATERWAYS

Commercially navigable waterways are those waters that are presently used to transport interstate or foreign commerce. A determination of navigability, once made, applies laterally over the entire surface of the water body and is not extinguished by later actions or events that impede or destroy navigable capacity (33 CFR 329.4). There are more than 40,000 km of commercially navigable waterways under the U.S. transportation system. Navigable waterways encircle each of the MHI and lead into and out of a number of the state's ports and commercial harbors. Transoceanic shipping lanes extend offshore from the region (primarily from O‘ahu and Kaua‘i) in several directions: north towards Alaska; northeast towards Washington, Oregon, and California; east towards the Panama Canal; southwest towards Guam and Wake Island; and northwest towards Japan and Okinawa (**Figure 5-3**).

The Hawaiian Islands serve as a major port for international shipping. In 1987, over 82.7 billion kg of freight worth over $124 billion were moved between ports in the U.S. southwest, Alaska, the Far East, and the Hawaiian Islands. Of this, approximately 20.3 billion kg were handled through Hawaiian ports. This shipping activity involved 21,325 vessel arrivals and departures from Hawaiian ports (ONR 2001). The Hawai‘i Department of Transportation, Harbors Division administers the statewide commercial harbor system, which consists of nine commercial harbors. These harbors include Honolulu Harbor, Barbers Point Harbor, and Kewalo Basin on O‘ahu; Port Allen and Nawiliwili Harbors on Kaua‘i; Kahului Harbor on Maui; Hilo and Kawaihae Harbors on Hawai‘i; and Kaunakakai Harbor on Moloka‘i. Honolulu Harbor is the state's primary harbor and hub of the commercial harbor system. Essentially all of the overseas waterborne traffic that travels to and from the Hawaiian Islands utilizes this harbor. It is also the focal point for inter-island cargo transportation (Hawai‘i Department of Transportation 2004).

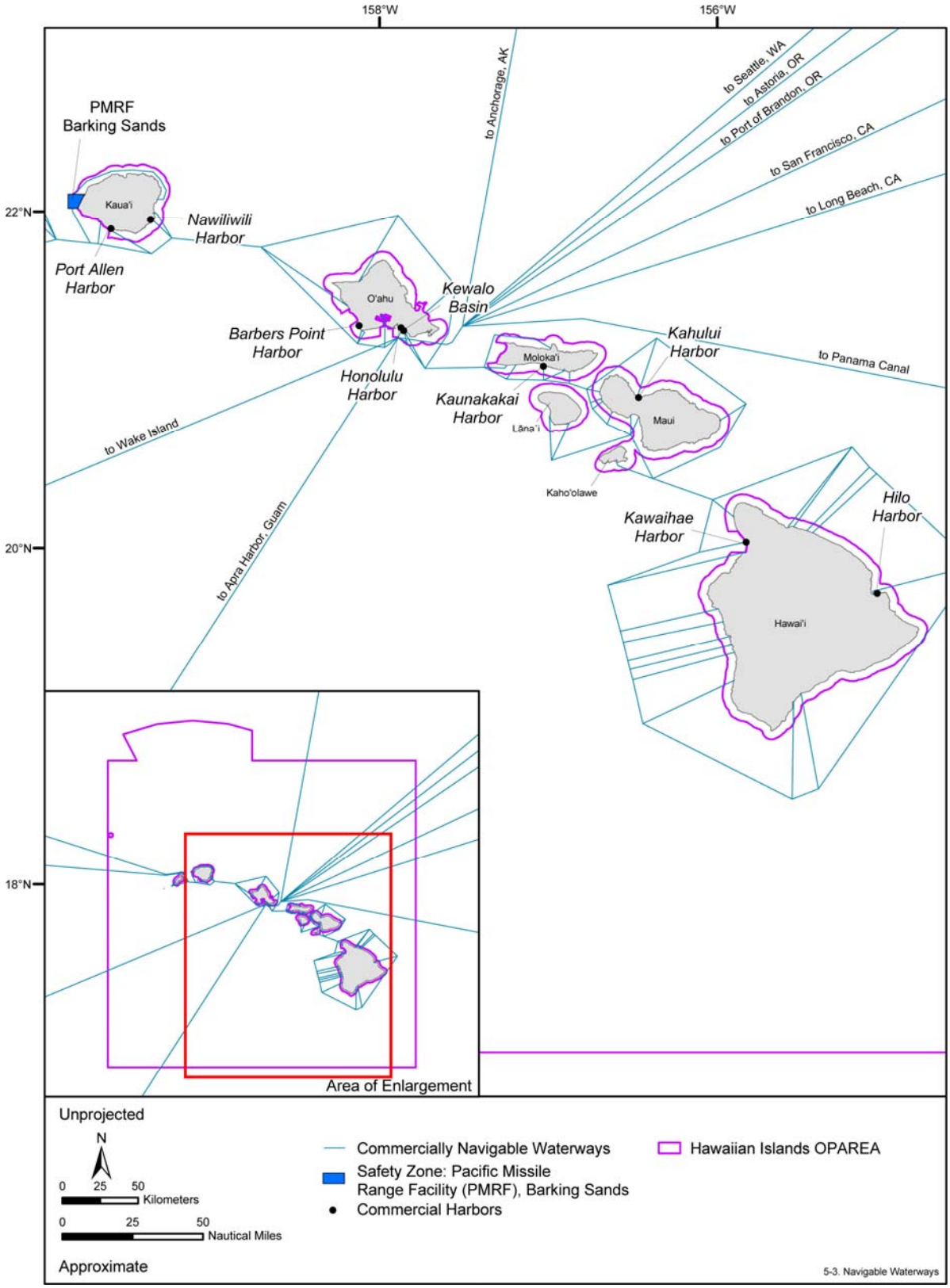

Figure 5-3. Commercially navigable waterways, safety zones, and commercial harbors in the Hawaiian Islands OPAREA and vicinity. Source data: DoT (2002), HDLNR (2002), and 33 CFR 165.1406.

Vessel traffic in the vicinity of major U.S. ports and harbors is often governed by a system of Traffic Separation Schemes. A Traffic Separation Scheme is an internationally recognized routing designation created by the USCG that separates opposing flows of vessel traffic into lanes, including a zone between lanes where traffic is to be avoided. These schemes, which are delineated by a series of geographic (latitude/longitude) coordinates, allow for safe navigation into and out of major ports. Vessels are not required to use designated Traffic Separation Schemes, but failure to use one, if available, would be a major factor for determining liability in the event of a collision (CERES 2003). Although several ports in the Pacific region have Traffic Separation Schemes (e.g., Vancouver, Seattle, San Francisco, Los Angeles/Long Beach), they are not present in any of the nine major Hawaiian ports (33 CFR 167).

5.3 MARINE MANAGED AREAS

MPAs, as defined in EO 13158, are "any area of the marine environment that has been reserved by federal, state, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein." Section 5 of EO 13158 stipulates, "Each Federal agency whose actions affect the natural or cultural resources that are protected by MPAs shall identify such actions. To the extent permitted by law and to the maximum extent practicable, each federal agency, in taking such actions, shall avoid harm to the natural and cultural resources that are protected by an MPA." EO 13158 also calls for the preparation of annual reports by federal agencies describing the actions they have taken over the previous year to implement the order. EO 13158 proposes the development of a national system of MPAs and provides a formal but vague definition of an MPA. As such, the National MPA Center is developing an MPA classification system providing definitions and qualifications for the various terms within the EO.

The new MPA definition will be narrower and will have stricter criteria. The new classification system is designed to objectively define MPAs by six fundamental characteristics: primary conservation goal, level of protection, permanence of protection, constancy of protection, scale of protection, and allowed extractive activities (NMPAC 2004a). The intent of MPAs is to be an effective conservation tool for sustaining ocean ecosystems (Agardy 1999; NRC 2000).

Many areas of the U.S. marine environment receive some level of management protection. The NOAA and the Department of the Interior (DoI) are documenting all marine sites and the National MPA Center is compiling a comprehensive inventory of all federal, state, tribal, and local sites that meet certain criteria of either a MMA or an MPA. MMAs are similar to MPAs in that they have a conservation or management purpose, defined boundaries, and some legal authority to protect resources. MMAs encompass a wider range of management intents, including areas of protection for geological, cultural, or recreational resources that might not be included under the definition provided in EO 13158 for MPAs. MMAs may also include areas that are managed for reasons other than conservation (e.g., security zones, shellfish closures, sewage discharge areas, and pipeline and cable corridors).

To date, federal sites have been added to the national MMA Inventory with an initial subset of data being collected; full data sets are at various stages of completion for some sites. The data are in the process of being reviewed and updated by each responsible agency. Data collection was to have been completed by 2004 with the Inventory being finalized in 2005. Once the MMA Inventory is complete, the MPA Classification System will be applied and official MPA designations will be made. Only sites in the MPA list are subject to the ‘avoid harm’ stipulation stated in EO 13158 (NOAA 2004).

There are 10 federal and 61 state MMAs in the Hawaiian Islands OPAREA and vicinity (**Table 5-3**). Federal MMAs located in the OPAREA and vicinity include two sites managed under the National Marine Sanctuaries Program (NMSP), three National Park (NP) System sites, three NWR, and two NMFS-managed threatened/endangered species protected areas. There are 61 state MMAs in the area of interest including 11 Marine Life Conservation Districts (MLCD), 19 Fisheries Management Areas (FMA), nine Fisheries Replenishment Areas (FRA), two wildlife sanctuaries, two natural area reserves, and 18 Bottomfish Restricted Fishing Areas (BRFA) (**Figure 5-4**).

Table 5-3. Federal and state marine managed areas (MMAs) located in the Hawaiian Islands OPAREA and vicinity. For the actual locations of these MMAs, refer to Figure 5-4.

Federal MMAs

1. Hawaiian Islands Humpback Whale NMS
2. Kalaupapa NHP
3. Kaloko-Honokohau NHP
4. *U.S.S. Arizona* Memorial
5. Kilauea NWR
6. Pearl Harbor NWR
7. Kakahaia NWR
8. Longline Protected Species Zone
9. Lobster Closed Areas
10. Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve

State MMAs

11. Pupukea MLCD
12. Waikiki MLCD
13. Hanauma Bay MLCD
14. Honolua-Mokuleai Bay MLCD
15. Manele-Hulopoe MLCD
16. Molokini Shoal MLCD
17. Lapakahi MLCD
18. Waialea Bay MLCD
19. Old Kona Airport MLCD
20. Kealakekua Bay MLCD
21. Waiopae MLCD
22. Waimea Bay FMA
23. Port Allen FMA
24. Nawiliwili Harbor FMA
25. Hanamaulu Bay FMA
26. Waialua Bay FMA
27. Pokai Bay FMA
28. Honolulu Harbor FMA
29. Waikiki-Diamond Head Shoreline FMA
30. Heeia Kea Wharf FMA
31. Kaunakakai Harbor FMA
32. Manele Harbor FMA
33. Kahului Harbor FMA
34. Kawaihae Harbor FMA
35. Puako Bay and Puako Reef FMA

State MMAs (cont.)

36. Kiholo Bay FMA
37. Kona Coast FMA
38. Kailua Bay FMA
39. Keauhou Bay FMA
40. Hilo Harbor FMA
41. North Kohala FRA
42. Puako-Anaehoomalu FRA
43. Kaupulehu FRA
44. Kaloko-Honokohau FRA
45. Kailua-Keauhou FRA
46. Red Hill FRA
47. Napoopoo-Honaunau FRA
48. Hookena FRA
49. Milolii FRA
50. Coconut Island - Hawaii Marine Laboratory Refuge
51. Paiko Lagoon Wildlife Sanctuary
52. Kahoʻolawe Island Reserve
53. Ahihi-Kinau Natural Area Reserve
54. Makawana Point to Pauwela Point BRFA
55. Kaupo to Kaapahu Bay BRFA
56. Kalohi/Pailolo Channels BRFA
57. Ilio Point to Panalaia Point BRFA
58. Niʻihau BRFA
59. Makahuena Point to S. Kawai Point BRFA
60. Hanalei-Kilauea Point BRFA
61. Kaena Point to Makua BRFA
62. Kaneohe Bay BRFA
63. Barbers Point BRFA
64. Maunalua Bay BRFA
65. Makapuu Point BRFA
66. Palemano Point to Alika BRFA
67. Hakalau to Onomea Bay BRFA
68. Leleiwi Point to Kaloli Point BRFA
69. Ka Lae BRFA
70. Penguin Bank, Pinnacle BRFA
71. Penguin Bank, Third Finger BRFA

NMS = National Marine Sanctuary
NHP = National Historical Park
NWR = National Wildlife Refuge
MLCD = Marine Life Conservation District
FMA = Fisheries Management Area
FRA = Fisheries Replenishment Area
BRFA = Bottomfish Restricted Fishing Area

5.3.1 National Marine Sanctuaries Program

There are 14 NMSP sites included in the MMA Inventory: 13 NMS and one CRE Reserve, which is being proposed as the fourteenth NMS under EO 13178 (U.S. Office of the President 2000). Designated and managed by the NOAA, these 14 sites protect over 390,000 km^2 of coastal and ocean habitat. Comprehensive management plans have been written for each NMS to guide their activities and programs, set priorities, and enforce relevant regulations. More information on both existing and proposed NMS can be found at the NOAA's NMSP website (http://www.sanctuaries.noaa.gov). Two NMSP sites are located within the Hawaiian Islands OPAREA and vicinity: the HIHWNMS and the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve (NWHICRER) (**Figure 5-4**).

The shallow, warm waters surrounding the MHI constitute one of the world's most important humpback whale habitats. Scientists estimate that two-thirds of the entire North Pacific humpback whale population migrates to Hawaiian waters each winter to engage in breeding, calving, and nursing activities (HIHWNMS 2004). Due to the importance of Hawaiian coastal waters to humpback whales, the NOAA designated five separate areas abutting six of the state's major islands as the HIHWNMS. Created in 1992, the HIHWNMS includes relatively shallow nearshore areas built up from the sea floor by the development of the Hawaiian Islands chain, protecting over 3,600 km^2 of humpback whale habitat in the Hawaiian archipelago (NOS 2003). The HIHWNMS encompasses waters along the north shore of Kaua‘i, the north and south coasts of O‘ahu, the four-island area of Maui County (Maui, Moloka‘i, Lāna‘i, and Kaho‘olawe), and the northwest portion of Hawai‘i.

The goals of the HIHWNMS are to: (1) protect humpback whales and their calving grounds; (2) educate and interpret for the public the relationship of humpback whales to the Hawaiian Islands marine environment; (3) manage human uses of the sanctuary consistent with the designation and the NMSA; and (4) provide for the identification of marine resources and ecosystems of national significance for possible inclusion in the sanctuary. Sanctuary regulations protect humpback whales and their calving habitats by prohibiting vessel approaches within 100 yards (yd), low aircraft overflights, discharge of wastes into sanctuary waters, and alteration of the sea floor, all of which have the potential to harm either humpback whales or their preferred habitat (NOS 2003; HIHWNMS 2004).

The NWHICRER spans 340,000 km^2 of ocean habitat in the NWHI, making it the second largest MPA in the world. It extends 2,200 km across the central North Pacific Ocean from Nihoa to Midway and Kure Atolls. While U.S. waters contain only 3% of the world's coral reefs, approximately 70% of the coral reefs found in U.S. waters are located in the NWHI. The 14,000 km^2 of coral reefs located within the NWHICRER are some of the most pristine and spectacular marine environments on Earth. This vast area supports a dynamic reef ecosystem that is home to more than 7,000 marine species, of which approximately one quarter are endemic to the Hawaiian Islands chain. This diverse ecosystem is home to a number of coral, fish, bird, marine mammal, and sea turtle species including the endangered Hawaiian monk seal, the threatened green turtle, and the endangered leatherback and hawksbill turtles. In addition, this area has great cultural significance to Native Hawaiians as well as linkages to early Polynesian culture (NOAA 2005b).

5.3.2 National Park System Sites

The NPS administers all areas that are protected and managed under the U.S. National Park System. The NPS Organic Act of 1916 established the NPS with "the fundamental purpose to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment for the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (NPS 2003).

The NPS is composed of 388 areas covering more than 340,000 km^2 in 49 states, the District of Columbia, American Samoa, Guam, Puerto Rico, Saipan, and the USVI (DoI 2005). The system includes NPs, monuments, seashores, memorials, preserves, historical parks, historical sites, recreational areas, and many other similarly named areas that are distinguished for their historic or prehistoric importance,

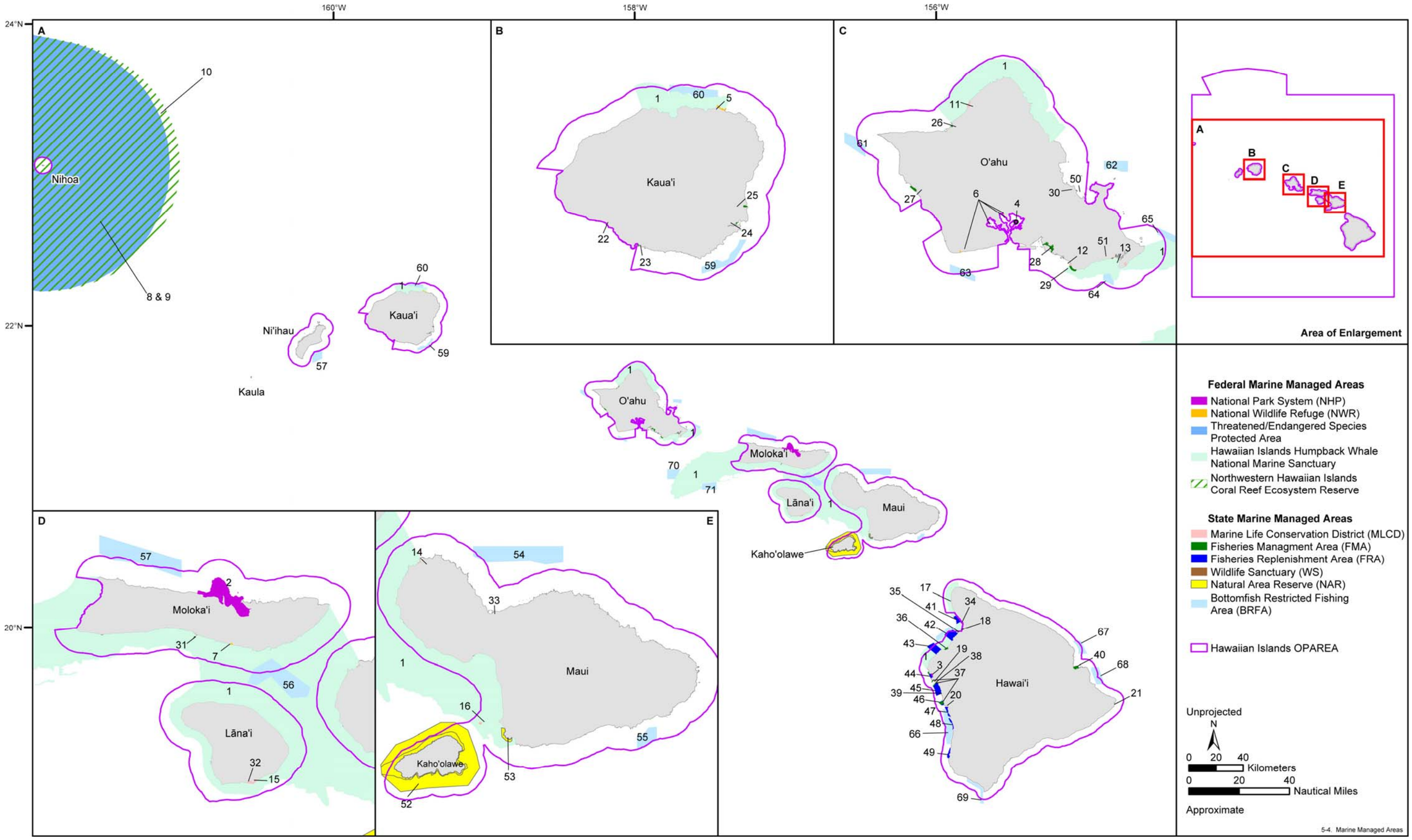

Figure 5-4. Locations of federal and state marine managed areas (MMAs) in the Hawaiian Islands OPAREA and vicinity. Numbers listed within figure correspond to Table 5-3. Source data: HDLNR (2003) and NOAA (2005b).

scientific interest, or superior recreational assets. Two national historical parks (NHP) and one memorial are located in the Hawaiian Islands OPAREA and vicinity. These include Kalaupapa NHP on Molokaʻi, Kaloko-Honokohau NHP on Hawaiʻi, and the *U.S.S. Arizona* Memorial on Oʻahu (**Figure 5-4**).

Kalaupapa NHP is located on the north shore of Molokaʻi and contains the Kalaupapa Peninsula, adjacent cliffs and valleys, offshore islands, and submerged lands and waters out to 0.4 km from shore. Established in 1980, this park is the physical setting of two tragic events in Hawaiian history: (1) the removal of indigenous peoples in 1865 and 1895 and (2) the forced isolation of individuals stricken with Hansen's disease (leprosy) from 1866 until 1969. Native Hawaiians inhabited the Kalaupapa Peninsula and valleys for hundreds of years prior to the establishment of the isolation settlement in 1866. Evidence of this occupation is relatively undisturbed and represents one of the richest archeological preserves in the state. Several areas within the park provide rare native habitat for threatened and endangered Hawaiian plants and animals. Endangered Hawaiian monk seals have been known to give birth on Kalaupapa's beaches. These marine mammals require solitude and the physical isolation of Kalaupapa NHP provides an ideal habitat to support these births and subsequent care (NPS 2005a).

Kaloko-Honokohau NHP, located near Kailua-Kona on the west coast of Hawaiʻi, is a 470 ha park that was established in 1978 for the preservation, protection, and interpretation of traditional native Hawaiian activities and culture. Situated at the base of Hualalai Volcano, it is the site of an ancient Hawaiian settlement that encompasses portions of four different ahupuaʻa, or traditional sea-to-mountain land divisions. Resources housed within the park include fishponds, house site platforms, petroglyphs, stone slides, and religious sites. Hiking, fishing, swimming, snorkeling, scuba diving, and kayaking are all popular activities that can be performed within the confines of Kaloko-Honokohau NHP (NPS 2005b).

Located in Pearl Harbor on the island of Oʻahu, the *U.S.S. Arizona* Memorial is the final resting place for many of the ship's 1,177 crewmen who lost their lives during the Japanese attack on 7 December 1941. The 56 m long memorial structure spans the mid-portion of the sunken battleship and consists of three main sections: the entry and assembly rooms, a central area designed for ceremonies and general observation, and the shrine room where the names of those killed on the *U.S.S. Arizona* are engraved on the marble wall. Completed in 1961 and dedicated in 1962, the *U.S.S. Arizona* Memorial grew out of wartime desire to establish some sort of memorial at Pearl Harbor to honor all those who died in the attack (NPS 2005c).

5.3.3 National Wildlife Refuges

The USFWS, which oversees the National Wildlife Refuge System (NWRS), also protects a significant amount of marine habitat within U.S. waters. The NWRS is comprised of 544 established NWR, of which approximately 140 to 150 contain marine and estuarine habitat. These MMAs provide important habitat for a number of threatened and endangered mammals, plants, birds, and reptiles. The NWRS also contains about 10,500 km^2 of coral reefs and adjacent ocean habitat. There are four NWR in the Hawaiian Islands OPAREA and vicinity that are currently designated as federal MMAs: Kilauea Point NWR on Kauaʻi, Pearl Harbor NWR on Oʻahu, Kakahaia NWR on Molokaʻi, and the Hawaiian Islands NWR, which encompasses Nihoa and several other remote islands in the NWHI chain (**Figure 5-4**).

Kilauea Point NWR was established in 1985 after its transfer from the USCG. It consists of 82 ha of protected land on the northernmost tip of Kauaʻi, and is one of the few Hawaiian refuges open to the public. Protected marine species encountered at the refuge include humpback whales, Hawaiian monk seals, spinner dolphins, green turtles, and Laysan albatrosses. The refuge's seaside rocky cliffs have been a premier seabird nesting area for thousands of years, providing protected coastal nesting and roosting habitat for seven species of native Hawaiian seabirds. The most prominent feature of Kilauea Point NWR is the Kilauea Lighthouse, which was built in 1913 as a navigational aid for commercial shipping between the Hawaiian Islands and the Orient. For 62 years its gigantic lens guided ships and boats safely along the rugged north shore of Kauaʻi (USFWS 2005a).

Managed under a cooperative agreement with the Navy, Pearl Harbor NWR was established in 1976 as mitigation for construction of the Honolulu International Airport Reef Runway. This refuge, located in

southern O‘ahu, is composed of three units: the 15 ha Honouliuli Unit (bordering West Loch), the 10 ha Waiawa Unit (bordering Middle Loch), and the 15 ha Kalaeloa Unit (located on the leeward side of the island). Kalaeloa, the newest unit, was formerly part of Barbers Point Naval Air Station, but was transferred to the USFWS in 2001. The Kalaeloa Unit protects the largest native remnant stand of the endangered *Achyranthes* plant. The Honouliuli and Waiawa Units are freshwater wetlands that are extensively managed for endangered waterbirds, migratory shorebirds, and waterfowl (USFWS 2005b).

Established in 1977, Kakahaia NWR is situated on the southern shore of Moloka‘i. This 18 ha refuge contains a 6 ha pond and a man-made 3 ha impoundment. The spring-fed pond, originally used as an artificial fish pond, lies on a narrow plain just above sea level at the foot of the island’s volcanic hills. Twelve species of birds, including the endangered Hawaiian stilt, use this area. Wildlife observation and environmental education activities conducted in the refuge require a special use permit (USFWS 2005c).

The Hawaiian Islands NWR is also located in the vicinity of the Hawaiian Islands OPAREA but is not depicted on **Figure 5-4**. This is due to a lack of geographic data available for this federal MMA. The Hawaiian Islands NWR is a chain of eight islands, reefs, and atolls extending about 1,300 km northwest from the MHI (from Nihoa in the east to Pearl and Hermes Reef in the west). It supports four endangered and endemic birds, 14 million seabirds, endangered Hawaiian monk seals, threatened green turtles, and eight endangered plant species. Several thousand species of inshore tropical fish, algae, coral, and other marine organisms inhabit the more than 100,000 ha of marine habitat found in and around the refuge. Except for field stations on Tern and Laysan Islands, these remote islands are not inhabited by humans and are protected by the USFWS. Scientific research is limited and closely scrutinized to minimize unnecessary disturbance; entry is by special use permit only (NMPAC 2005a; USFWS 2005d).

5.3.4 Threatened/Endangered Species Critical Habitats and Protected Areas

One of the many responsibilities of the NMFS is to promote the recovery of federally protected species. To satisfy this responsibility, the NMFS uses its authority to designate critical habitats and protected areas for threatened and endangered species. There are two threatened/endangered species protected areas and one critical habitat located in the Hawaiian Islands OPAREA (**Figure 5-4**). However, the Hawaiian monk seal critical habitat, which is located in 10 areas around the NWHI (including Nihoa), is not currently included in the federal MMA Inventory, as it does not have additional federal regulations beyond its designation as a critical habitat.

The Longline Protected Species Zone is located in the NWHI and stretches 92.6 km offshore from the following points: Nihoa, Necker Island, French Frigate Shoals, Gardner Pinnacles, Maro Reef, Laysan Island, Lisianski Island, Pearl and Hermes Reef, Midway Islands, and Kure Island. Established in 1991 by the WPRFMC, this area encompasses the Hawaiian monk seal critical habitat area outside of territorial waters. Inside the protected species zone, longline fishing is prohibited. Species protected by this MMA include Hawaiian monk seals, sea turtles, seabirds, and juvenile swordfish (NMPAC 2005b).

The Lobster Closed Areas were designated in 1983 under the authority of the MSFCMA (NMPAC 2005c) and also encircle the NWHI, encompassing the same ocean area as the Longline Protected Species Zone. These areas are closed to all types of lobster fishing year round in order to protect the endangered Hawaiian monk seal.

5.3.5 Fisheries Management Zones

An additional responsibility of the NMFS includes rebuilding and maintaining sustainable fisheries. To satisfy this responsibility, the NMFS uses fisheries management zones as one of several tools to conserve fish stocks and fish habitat. Fisheries management zones are areas that are closed, at least partially, to fishing activities. The NMFS has the authority to restrict or even prohibit the use of specific fishing gear types in areas where they are aiming to better protect habitats, fish stocks, or species assemblages and/or to promote the recovery of threatened and endangered species such as marine mammals, sea turtles, or seabirds. There are no federally designated fisheries management zones in the

Hawaiian Islands OPAREA, although a year-round closure established to protect precious corals is located just west of the map extent.

This fisheries management zone, known as WestPac Bed, was established by the NMFS in 1983 under the authority of the MSFCMA and the Western Pacific Precious Corals FMP. Under 50 CFR 660.87, it is illegal to fish for corals on the WestPac Bed. The WestPac Bed closure, located west of Nihoa, includes all waters within a 2 NM radius of 23°18'N, 162°35'W.

5.3.6 State Marine Managed Areas

In 1967, Hanauma Bay MLCD on Oʻahu was designated as the first MMA in the Hawaiian Islands. Since then, the Hawaiʻi Department of Land and Natural Resources (DLNR) has established a number of state-level MMAs tailored to address various human impacts and uses at each site. Fishing activities (including vessel anchoring) are highly regulated at most of these sites (HDLNR 2005; **Figure 5-4**).

MLCDs are designed to conserve and replenish marine resources by allowing only limited fishing and other consumptive uses. They provide fish and other aquatic life with a protected area in which to grow and reproduce, and are home to a great variety of species. MLCDs are often popular sites for snorkeling, diving, and underwater photography. At present, there are 11 MLCDs statewide with additional sites under consideration. MLCDs are established by the Hawaiʻi DLNR as authorized by Chapter 190 of the Hawaiʻi Revised Statutes. Suggestions for areas to be included in the system may come from the state legislature or the general public. The HDAR, a branch of the DLNR, conducts surveys of marine ecosystems throughout the state and may recommend MLCD status for areas that appear promising (NMPAC 2004b).

The HDAR has also established a network of FMAs in the Hawaiian Islands. One of the most prominent FMAs in the MHI is the Waikiki-Diamond Head Shoreline FMA, which is closed to fishing for the calendar year 2005. Since its inception in 1978, this area has been closed to fishing during alternate (odd-numbered) years to help restore fish populations. Only hook-and-line, throw net, hand net, spear fishing, and hand harvesting methods are permitted in this FMA during "open" periods (HDAR 2005).

In 1998, the Hawaiʻi State Legislature enacted Act 306, which attempted to improve management of fish resources by declaring a minimum of 30% of the west Hawaiʻi coastline as FRAs, where fish collecting is prohibited. The same year, the West Hawaiʻi Fisheries Council proposed the location and size of nine FRAs along the west coast. In April 1999, a public hearing was held on the management plan developed by the council. It was one of the largest ever held in the state of Hawaiʻi on a natural resource issue, resulting in overwhelming public support for FRAs. The nine established FRAs were officially closed to aquarium collecting on 1 January 2000 (HCRI 2002).

As implied by their name, BRFA are restricted areas where bottomfishing is prohibited. Under Hawaiian state law, it is unlawful to capture or possess bottomfish while drifting or anchored within a BRFA, except in the case of an emergency. BRFAs comprise 20% of important habitat for spawning onaga and ehu, two of the most highly valued commercial fish species found in Hawaiian waters. The Hawaiʻi DLNR is charged with selecting appropriate areas and distributing them statewide, using input from local bottomfish fishermen. Other fishing activities, such trolling or handlining for pelagic species, are permitted within the boundaries of a BRFA (HDAR 2002).

5.5 SCUBA DIVING SITES

Numerous diving sites are located along the MHI (**Figure 5-5**). Diving opportunities in the Hawaiian Islands are ubiquitous with year-round warm waters and abundant and diverse marine life. The suitability of a site for diving is based upon accessibility and water conditions of a particular site. This is determined by marine weather conditions and coastal geography. Hawaiian shores are subjected to harsh wind, wave, and water conditions. For diving, currents are of the greatest concern. Some diving areas, particularly those on the leeward coasts, are almost always free of any noticeable currents; in other areas currents may prevent diving throughout the majority of the year (Wallin 1991). Wind direction is also a

factor in day-to-day diving conditions. Usually (80% of the time), trade winds from the northeast yield calm waters on leeward coastlines; thus, areas off of leeward coasts make the best year-round dive sites. In the winter months (November to April), the trade winds diminish and are replaced by southerly Kona winds. Kona winds bring high surf that makes leeward coasts unsuitable for diving. In the summer months, some island landmasses can shield the north shores from wind, making the north coastline waters calm and popular diving areas in the summertime (Wallin 1991).

The Hawaiian Islands are one of the world's most popular diving destinations because of an abundant and diverse array of marine life, a multitude of professional dive charter boats, clear visibility, unique shipwreck dive sites, coral reef ecosystems, and year-round warm air and water temperatures. Each Hawaiian Island has its own personality and characteristics, and they each offer unique dive sites; due to Hawai'i's geographical isolation, they also offer an abundance of endemic marine life.

The Hawaiian Islands offer both natural and artificial marine habitats. The Islands offer a plethora of natural habitats including vertical walls, coral reef ecosystems, lava tubes, arches, boulders, tunnels, lava fingers, rocky outcroppings, caves, pinnacles, and channels with tunnels. The most notable underwater features are CREs and vertical walls or drop-offs. Vertical walls are well-defined ledges that run parallel to the shore and are located anywhere from near the shore to approximately 300 m; they create interesting topography that feature steep walls that are cut by ravines, caves, and grottos (Wallin 1991). In addition, there are numerous artificial habitats available within the Hawaiian Islands including FADs, artificial reefs, and sunken wrecks of ships, boats, and planes (Wallin 1991). These natural and artificial marine habitats attract abundant marine life including whitetip reef sharks, eagle rays, turtles, octopus, lobsters, shellfish, moray eels, tiger cowries, trumpet snail shells, textile cones, porcupine fish, parrot fish, yellowfin tuna, openwater jack, large schools of convict tangs and juvenile mullets, and a wide variety of tropical fish (Hawaii Scuba Diving n.d.). Each island offers a unique array of marine life, bottom depths, terrain, and underwater visibility. The exact number of dive sites in the waters of the Hawaiian Islands OPAREA is not known. Many of them are shown in **Figure 5-5** and the most popular sites are described in detail for each island.

O'ahu—O'ahu dive sites offer offshore lava formations, grottoes, plane wrecks, and shipwrecks that bring many large schools of fish, sharks, and green sea turtles. Hanauma Bay provides a safe haven from the surf and swell and supplies O'ahu with many of its dive sites (Sawyer 2005). The main sites stretch from the southeast point west of Waikiki and along the Waianea coast (Sawyer 2005); Hanauma Bay regularly has over 10,000 visitors daily. There are over 43 dive sites in O'ahu (Hawaii Scuba Diving n.d.). The more popular dive sites are detailed in the following description.

Sharks Cove on the North Shore ranges from 4.5 to 18 m in depth. Numerous arches, open-ended lava tubes, shallow caverns, and large boulders interspersed with sand and lava formations characterize Sharks Cove. Sharks Cove boasts the "Elevator". The "Elevator" is a hole 3 m in diameter that allows a descent to 6 m and exits through one of three different tubes. One tube allows divers to come up into an enclosed dry chamber (Hawaii Scuba Diving n.d.).

Makaha Caverns and Land of Oz on the West Shore are both very popular dive sites. They are both superb shallow water dives with tubes and archways. It is very common for divers to see eels, lobster, turtles, octopus and dolphins (Hawaii Scuba Diving n.d.).

The wreck of the Mahi is also located on the West Shore; this is the most popular dive in O'ahu (Sawyer 2005). The Mahi originally sunk in 1982 as an artificial reef; it is located ½ mile offshore. Although originally sunk facing shoreward, it now lies upright on a sand bottom facing seaward. In 1982, Hurricane Iwa repositioned the ship 180 degrees to its present bearing. Conditions vary from 15 to 30 m of visibility with light to seasonally heavy surge. This is a successful artificial reef; it supports a large array of marine life including spotted eagle rays, whitetip reef sharks, large yellow head moray, snowflake coral, red and yellow encrusting sponge, hydroids, spiny puffer fish, large schools of fish, trumpetfish, and humpback whales and whale sharks in season (Hawaii Scuba Diving n.d.).

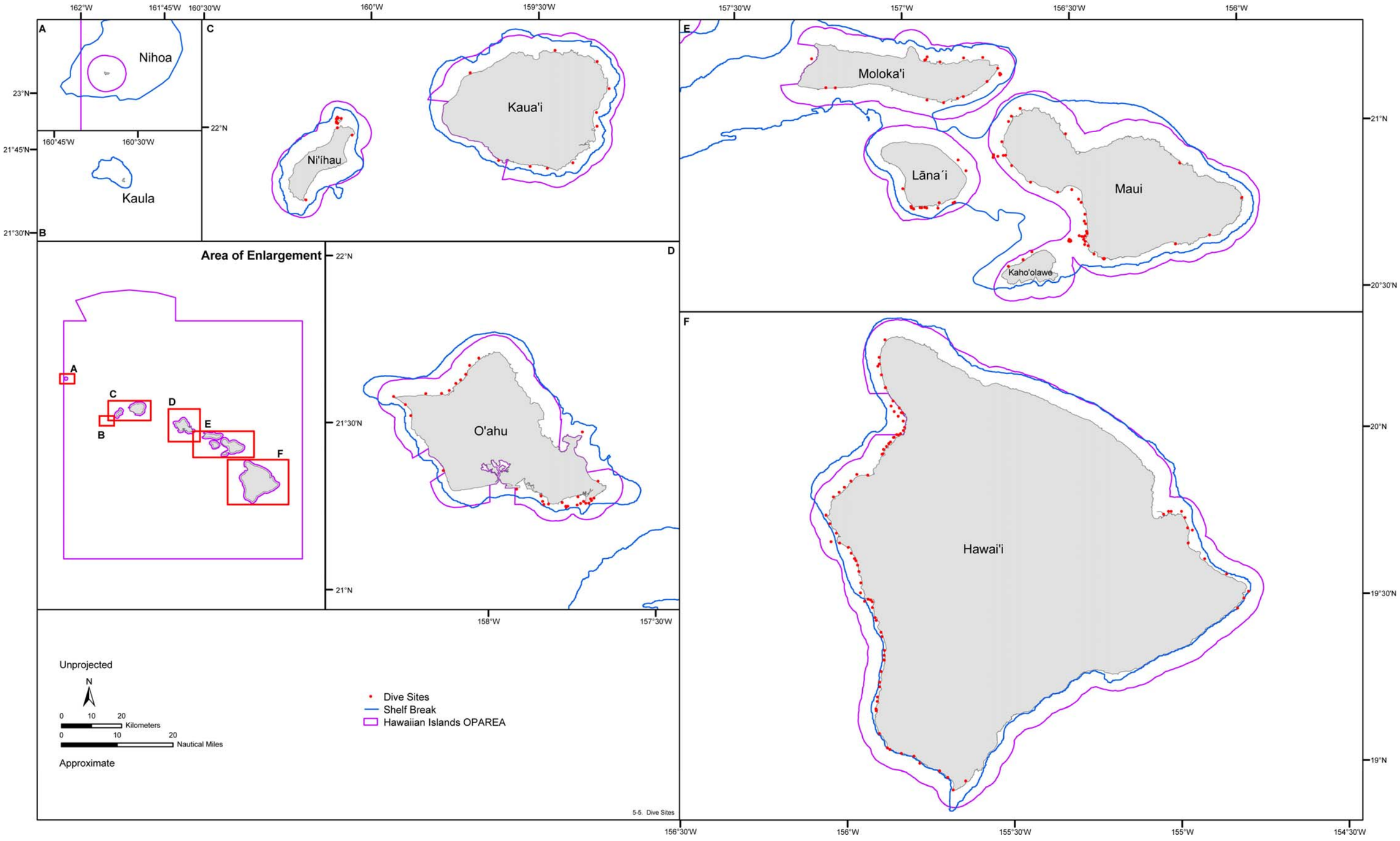

Figure 5-5. Locations of scuba diving sites in the Hawaiian Islands OPAREA and vicinity. Source data: NOS (2001). Source maps (scanned): Severns and Fiene-Severns (2002).

The wreck of YO-257 is one of the south shores more popular boat dives. The YO-257 was a Navy yard oiler built in the 1940s. It was sunk as an artificial reef off Waikiki in 1989. The ship rests upright in 100 feet of water with the main deck at about 30 m. It was prepared for diving with many large access holes cut through the structure. Visibility is normally ≥30 m. In 1996, a new ship, the San Pedro, was sunk within 50 yards of the YO-257 as an additional dive attraction (Hawaii Scuba Diving n.d.).

Another popular south shore dive site is the wreck of the Corsair. During a training mission in 1946, the pilot of the plane ran out of fuel and abandoned the aircraft where it settled intact in 33 m of water. The white sand bottom reflects light giving these waters an almost constant visibility of over 30 m. Encrusting orange sponge and a large antler coral have established themselves over much of the aircraft. Large schools of tropical fish, green sea turtles, reef sharks, and eagle rays also visit this artificial reef for shelter and to seek food (Hawaii Scuba Diving n.d.).

Maui—Maui offers the most diverse dive sites of all the MHIs. Most of Maui's dive sites are located off the west coast. It is common to see humpback whales during their birthing season along with abundant sea turtles, sharks, and huge numbers of fish (Sawyer 2005). The famous Molokini Crater is located along the south shore. There are over 45 dive sites associated with Maui (Hawaii Scuba Diving n.d.); the more popular dive sites are detailed in the following descriptions.

Black Rock on the Northwest shore is a lava rock formation that supports a wide variety of fish, turtles, moray eels, and even the occasional eagle ray. This rock extends about 15 m above the ocean and drops to depths of 11 m (Hawaii Scuba Diving n.d.).

Hidden Pinnacle is another popular dive site located off the Southwest shore; due to the location it can only be reached under calm ocean conditions. The pinnacle rises from the ocean floor at 37 m to the surface. Leathery octocoral and sponges cover the pinnacle and schools of pyramid butterfly fish and other plankton feeders feed in the water column. Pelagic encounters are also a possibility at this dive site (Hawaii Scuba Diving n.d.).

Molokini Crater is located three miles off the southwestern shore and is a State Marine Life Conservation District (Hawaii Scuba Diving n.d.). It has been a marine preserve for almost 25 years; thus, it has a wide variety of marine life and has become one of the world's top dive sites. Molokini is a submerged half-crater with a surrounding reef rich in coral and fish life (Severns and Severns 2002). It is a microcosm of all the southern Hawaiian island reefs with habitats ranging from shallow sand bottoms to deep walls (Severns and Severns 2002). Molokini has at least 12 dive sites associated with it (Hawaii Scuba Diving n.d.). Inside Crater and Enenue are the more popular of the sites (Sawyer 2005). Inside Crater is an excellent spot for snorkeling and diving because near the inside crater wall the bottom is at 9 m with some coral formations extending to as shallow as 3 m. Vast schools of butterfly fish, trumpetfish, octopus, and other marine life can be found at all depths (Hawaii Scuba Diving n.d.). Enenue is at the base of the crater wall where it levels off into a shelf at 15 m before dropping off into a sand channel reaching depths over 40 m. Schools of fish are common in the shallows and the rare boarfish can be seen at depth (Hawaii Scuba Diving n.d.).

Kaho‘olawe—Kaho‘olawe was formed by a group of six volcanoes and as a result has many volcanic caverns for diving (Hawaii Scuba Diving n.d.). The island was once a part of Maui but separated when sea level rose and flooded the valleys between the landmasses. These underwater valleys are shallower than the surrounding ocean and provide shelter for an abundance of marine life, including the humpback whales that migrate to Hawaiian waters during winter months to give birth to their calves (Hawaii Scuba Diving n.d.). Kaho‘olawe was previously used as a target for aerial bombing and for ship to shore bombardment activities by the Navy (Severns and Severns 2002). In 1993, the island was returned to the Hawaiian people and habitat restoration efforts are underway (Severns and Severns 2002). The region is now called the Kaho‘olawe Island Reserve. Puu Koae and The Tubes are two of the most popular dive sites (Hawaii Scuba Diving n.d.).

Hawai‘i—In Hawai‘i there are excellent dive sites stretched all along the coast but the majority of diving occurs off the leeward coast where conditions tend to be glassy with visibility over 30 m. Lava tubes,

tunnels, caverns, and arches provide excellent nearshore diving, and more pelagic dives offer marine life such as manta rays, bottlenose and spotted dolphins, pilot whales, pygmy killer whales, and whale sharks (Hawaii Scuba Diving n.d.). Diving on the Hilo side of the island tends to be mostly beach dives. On the western shore, there are many dive sites around Kailua-Kona where a variety of marine life inhabits the nearshore clear waters (Sawyer 2005). From January through March, pods of humpback whales come to give birth off these shores; in addition, pilot whales, huge aggregations of dolphins, and whitetip sharks are frequently seen (Sawyer 2005). There are over 42 dive sites associated with Hawaiʻi (Hawaii Scuba Diving n.d.); some popular dive sites include Turtle Pinnacle, Pinetrees, Suck-Em-Up Caverns, Milemarker 4, open water offshore, Wreck of the Naked Lady, Puako, Ledges, and Garden Eel Cove where manta rays come in at night to feed on krill (Sawyer 2005).

The most popular dive site in Hawaiʻi is Place of Refuge, south of Kona at Honaunau Bay and just north of the National Historic Park, Puʻuhonua Oʻ Honaunau (Place of Refuge) (Hawaii Scuba Diving n.d.). This area is an ancient Hawaiian fishing/religious ceremonial area. There is an abundance of colorful reef marine life with excellent water clarity. The endangered Green sea turtle is frequently seen; and recently, the Hawaiian Monk Seal has been found near the center bay reef (Monk Seals are being released along the Kona Coast—transplanted from the NWHI in hopes of saving this endangered species) (Hawaii Scuba Diving n.d.).

Kauaʻi—Kauaʻi is known for its rugged and pristine diving. During the winter months large swells make the north shore generally inaccessible for diving but during summer months and on calm days the north shore has some excellent locations such as Keʻe Lagoon, Tunnels Reef, and Blue Bluffs (Hawaii Scuba Diving n.d.). On the south shore, most of the diving is centered around Poipu Beach, where green sea turtles are abundant and accessibility continues throughout the year (Sawyer 2005). The south shore's most popular spots include Fishbowl, General Store, Sheraton Caverns, Koloa Landing, Fast Lanes, Turtle Bluffs, and Icebox (Sawyer 2005). There are over 18 dive sites associated with Kauaʻi (Hawaii Scuba Diving n.d.).

Niʻihau—Niʻihau is considered the holy grail of diving in the Hawaiian Islands (Sawyer 2005); the island is located 27 km off the southwestern coast of Kauaʻi. It features gigantic sea arches and harbors unique marine-life including the endangered monk seal, eagle rays, blacktip sharks, large pelagic fish, and rare species of fish like morwongs (Sawyer 2005). Niʻihau is generally recommended for intermediate to advanced divers. There are approximately 7 dive sites associated with Niʻihau (Hawaii Scuba Diving n.d.). The most popular sites include Niʻihau Arches, Lehua Gardens, Keyhole, Vertical Awareness, and Pyramid Point; these are all offshore dive sites that can only be reached via boat.

Kaʻula—Kaʻula is a small, isolated islet 37 km to the west-southwest of the southern end of Niʻihau**.** Kaʻula volcano is uninhabited and was previously used as a target for aerial bombing and contains many unexploded bombs; fishermen frequently visit its shores. Kaʻula Rock is a recommended destination for the serious diver. However, there are no documented dive sites associated with this island (Resture 2004).

Nihoa—Nihoa is also known as Moku Manu; it is the largest volcanic island in the NWHI chain with an area of about 69 ha of land. It is inhabited by insects, monk seals, two species of endemic land birds (i.e., a finch and a millerbird), and numerous seabirds (terns, boobies, petrels, shearwaters, albatrosses, tropic birds, and frigate birds). Access is controlled by the USFWS and landing is prohibited, except for scientific study and cultural purposes (Parks 2005). Diving on Nihoa is only allowed by permit.

Lānaʻi—The dive sites around Lānaʻi are best known for their lava formations. The lava formations feature archways, ridges, tunnels, pinnacles and caverns with porous lava ceilings. Most diving takes place off the south and west coasts (Hawaii Scuba Diving n.d.). There are approximately 13 dive sites associated with Lānaʻi. The world-famous dive sites located off the coasts of Lānaʻi include the lava domes of First and Second Cathedral, Pyramids (harbors an abundant number of pyramid butterflyfish surrounding the top of the pinnacle), and Fish Rock where menpachi, pipefish, viper moray, large cowries, and whitetip sharks are common (Sawyer 2005).

Moloka‘i—The entire south side of Moloka‘i is the longest barrier reef in Hawaii. This natural sanctuary offers some of the best diving in the Hawaiian Islands, but it is seldom visited by divers due to high winds and large swells. The pristine waters surrounding the island are teaming with marine life including several species of rare fish and coral. The sites off of Mokuhooniki Islet are the most frequently dived. Since it was used for bombing practice, military debris is common including the F4U Corsair. In late summer and early fall, scalloped hammerheads gather by the hundreds off of Mokuhooniki. There are 6 dive sites documented for Moloka‘i (Hawaii Scuba Diving n.d.).

5.5 NORTH PACIFIC ACOUSTIC LABORATORY SOUND SOURCE

The Acoustic Thermometry of Ocean Climate (ATOC) program of the Scripps Institute of Oceanography, in conjunction with the Applied Physics Laboratory of the University of Washington, was one of the first large-scale acoustic thermometry studies. Acoustic thermometry studies utilize sound transmissions from an underwater projector to determine long-term trends in ocean temperature for the study of global warming. The North Pacific Acoustic Laboratory (NPAL) takes advantage of the acoustic network installed by the ATOC Program, as well as instrumentation developed for that network and data previously obtained using it. Existing network components include two low-frequency (75 Hz) broadband acoustic sources installed on the Pioneer seamount off central California and north of Kaua‘i, 15 Navy SOSUS arrays instrumented to receive the source transmissions, and two autonomous vertical line arrays (VLA) installed near and Kaua‘i and Kiritimati Island. The NPAL project is supported by funding from the Office of Naval Research (ONR), as was ATOC; ONR (2001) provides further information on the NPAL.

The Kaua‘i sound projector is a stationary sound source located approximately 14.7 km north of Kaua‘i (22º20.94 N, 159º43.18 W) at a depth of 807 m (**Figure 5-6**). The projector is 2.1 m high by 0.9 m wide, with a weight of 2,268 kg, and is contained within a galvanized steel tripod frame (ONR 2001). The seabed cable is approximately 51.5 km long, with a diameter of 3.18 cm. It runs along the 75 to 100 m isobaths and connects to the seashore interface at a depth of approximately 25 m in an area of coral rubble that lies within the SWTR of the PMRF Barking Sands (ONR 2001). The projector produces a low-frequency sound having a center frequency of 75 Hz (bandwidth: 57.5 to 92.5 Hz) and a source level of 195 dB re: 1 μPa-m with 260 watts of transmitted power (DoD 1999). The typical transmission schedule consists of six 20-minute transmissions within a 24-hr period (i.e., a 20 min transmission every 4 hrs), with the signal projections occurring every fourth day (NPAL 2004). Transmission is expected to continue through 2006 (NPAL 2004).

5.6 WHALE WATCHING AND SWIM WITH WILD DOLPHIN TOURS

5.6.1 Whale Watching Tours

Commercial whale watching comprises the fastest growing sector of the Hawaiian Islands’ ocean industry; it is valued at more than 9.3 million dollars (NOAA 2002; Markrich 2004). An estimated 300,000 people participate in whale watch tours in the Hawaiian Islands each year. This number is steadily increasing as popularity continues to grow (Markrich 2004). Whale watching tours target humpback whales that migrate to Hawaiian waters each winter and spring to breed. Most tours operate from December to April when humpback whales are present (DoN 2002); the peak whale watching season is in February and March (Deakos personal communication). Whale watch vessels are usually less than 30 m long and include outboard motor boats, power and sailing catamarans, and some zodiac inflatable boats (NMFS 1991; ARPA 1995). However, several large dinner cruise vessels also offer whale watching tours on some of the islands (Markrich 2004). Whale watching tours run several times a day during the season and typically last two hours (Utech 2000). Many tours incorporate sightseeing and recreational activities, such as snorkeling and diving, as part of the whale watch trips (Markrich 2004).

Over 52 vessels offer humpback whale watch trips from Maui, Kaua‘i, O‘ahu, Moloka‘i, and Hawai‘i (Utech 2000). The majority of these operate from Maui, the island with the longest and strongest history of commercial whale watching in the Hawaiian Islands (Utech 2000). Humpback whales tend to congregate in shallow, coastal waters around the MHI; therefore, tour boats do not have to go far offshore to locate

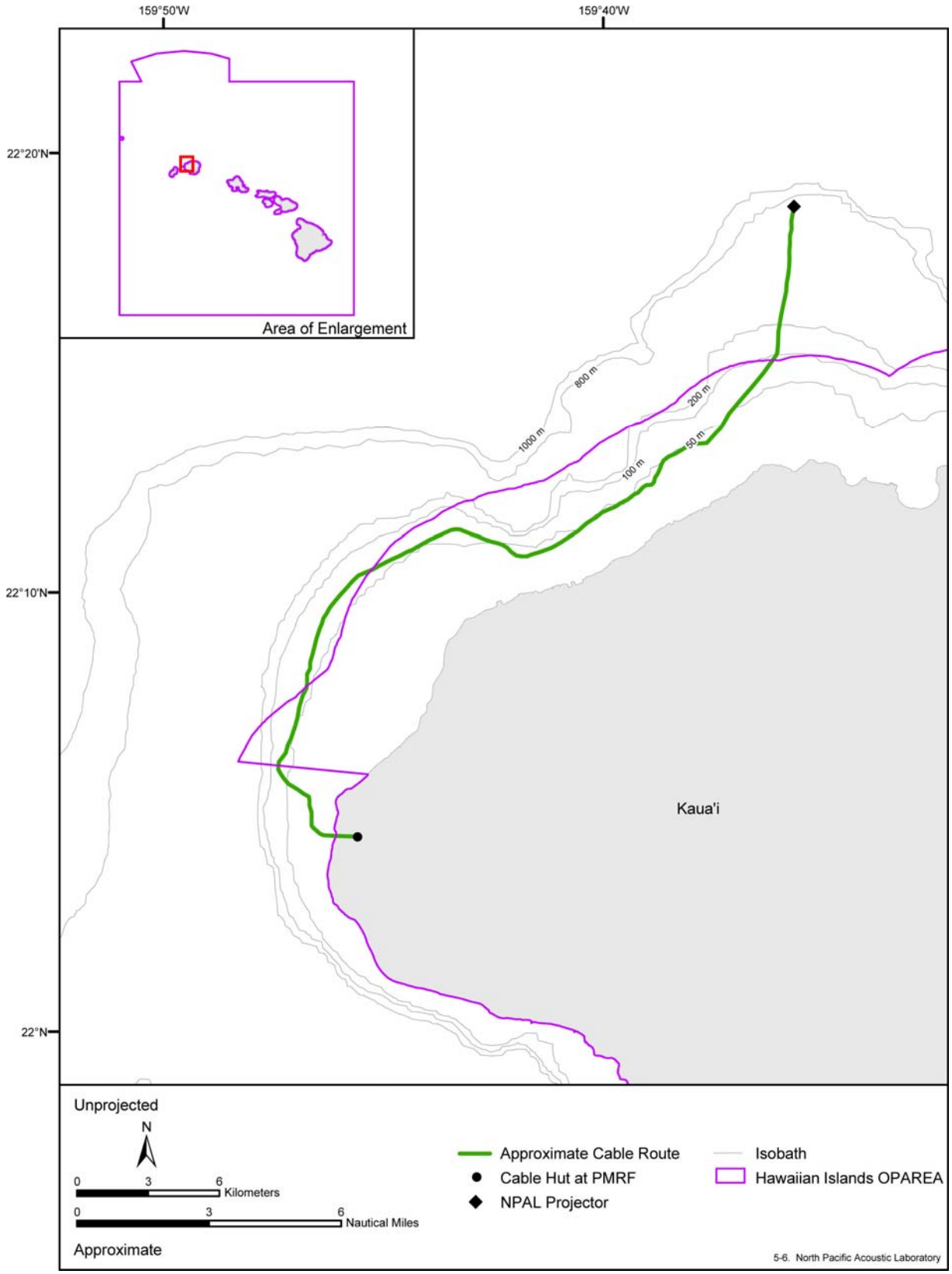

Figure 5-6. Location of the North Pacific Acoustic Laboratory's sound source and cable route in the Hawaiian Islands OPAREA and vicinity. Source map (scanned): ONR (2001).

whales (Smultea 1994; Viezbicke personal communication). Most whale watch boats are able to locate whales within 2 to 3 km from shore and often stay within the HIHWNMS waters (Vann personal communication).

Whale watch boats from Maui tend to stay within the waters between Maui, Kahoʻolawe, and Lānaʻi where humpback whales are concentrated (Vann personal communication). Tours depart from Lahaina, Maʻalaea, Kihei boat ramp, Mala Wharf, and Kaʻanapali Beach (Utech 2000; Markrich 2004; Deakos personal communication). Most whale watching takes place in a wide area offshore of Lahaina, Kihei, Kaʻanapali Beach, Honokowai, Molokini Beach, Kamaʻole Beach, and in La Perouse, Maʻalaea, and Napili Bays (Aki et al. 1994; Deakos personal communication; Smultea personal communication; **Figure 5-7**). Whale watch tours from Kauaʻi depart from Port Allen, Hanalei, and Kikiaola Small Boat Harbor and primarily encounter humpback whales on the west side of the island along the Na Pali coast (**Figure 5-7**). On Hawaiʻi, tours depart from Kailua-Kona Pier, Honokohau Harbor, Kawaihae Harbor, Keauhou Bay, Anaehoomalu Bay and several resorts on the Kohala coast. The main area for viewing humpback whales is along the west side of the island (Utech 2000; Markrich 2004; Viezbicke personal communication; **Figure 5-7**). Whale watching on Oʻahu is becoming increasingly popular. Large dinner boats in Honolulu Harbor dominate the industry, but smaller vessels also run whale watch tours from Kewalo Basin, Kaneʻohe Bay, Haleʻiwa, and Waiʻanae Boat Harbor (Utech 2000; Markrich 2004; Deakos personal communication; **Figure 5-7**). Whale watching tours in Molokaʻi depart from Kaunakakai Harbor and are mostly operated by sportfishing charters (World Wide Fishing Guide 2005; Molokaifishing 2005).

5.6.2 Swim with Wild Dolphin Tours

Particular bays in the Hawaiian Islands are critical resting areas for spinner dolphins (see Section 3.1 for more information) (**Figure 5-7**). Since at least 1979, locals have swum with spinner dolphins in some of those locations (Samuels et al. 2003). More recently, year-round commercial swim with wild dolphin tours have become extremely popular with tourists (Driscoll-Lind and Östman-Lind 1999a). On Hawaiʻi, commercial tour operators target known spinner dolphin resting areas, specifically, Kealakeʻkua, Kauhako (also known as Hoʻokena Bay), and Honaunau Bays south of Kailua-Kona (e.g., Courbis 2004; Östman-Lind et al. 2004). Most of the swimming in Kealakeʻakua Bay takes place near the Captain Cook Monument (Courbis 2004). To a lesser degree, spinner dolphins and swimmers visit Makako Bay on Hawaiʻi (Östman-Lind et al. 2004). Tourists also swim with spinner dolphins at Makua Beach off the leeward (western) side of Oʻahu (Psarakos and Marten 1999; Lammers 2004), and Hulopoe Bay at Lānaʻi (Driscoll-Lind and Östman-Lind 1999b). Dolphin swimming takes place in Kilauea Bay on the northeast coast of Kauaʻi (Jefferson personal communication) and also also occurs in La Perouse Bay on the south side of Maui (Kubota 1999; **Figure 5-7**).

Human disturbance is highest during the mid-morning hours, at the time when most spinner dolphins are in the process of locating and settling into a resting area (Courbis 2004; Östman-Lind et al. 2004). Most of the human activity in Kealakeʻkua Bay is boat-based (motorboats or kayaks), although, people swim out from shore to swim with dolphins resting in Kauhako Bay (Östman-Lind et al. 2004).

While spinner dolphins are the primary target, pantropical spotted dolphins (that sometimes associate with spinners) are also sometimes part of the encounter (e.g., Östman-Lind et al. 2004). Opportunistic swim encounters with other cetacean species such as pilot whales, other blackfish, and even Blainville's beaked whales have been documented off Hawaiʻi (Baird personal communication; Choquette personal communication; Driscoll-Lind personal communication). Noteworthy is a well-publicized incident in which a short-finned pilot whale grabbed a lady in her thigh and pulled her down 12 m before releasing her (Shane et al. 1993).

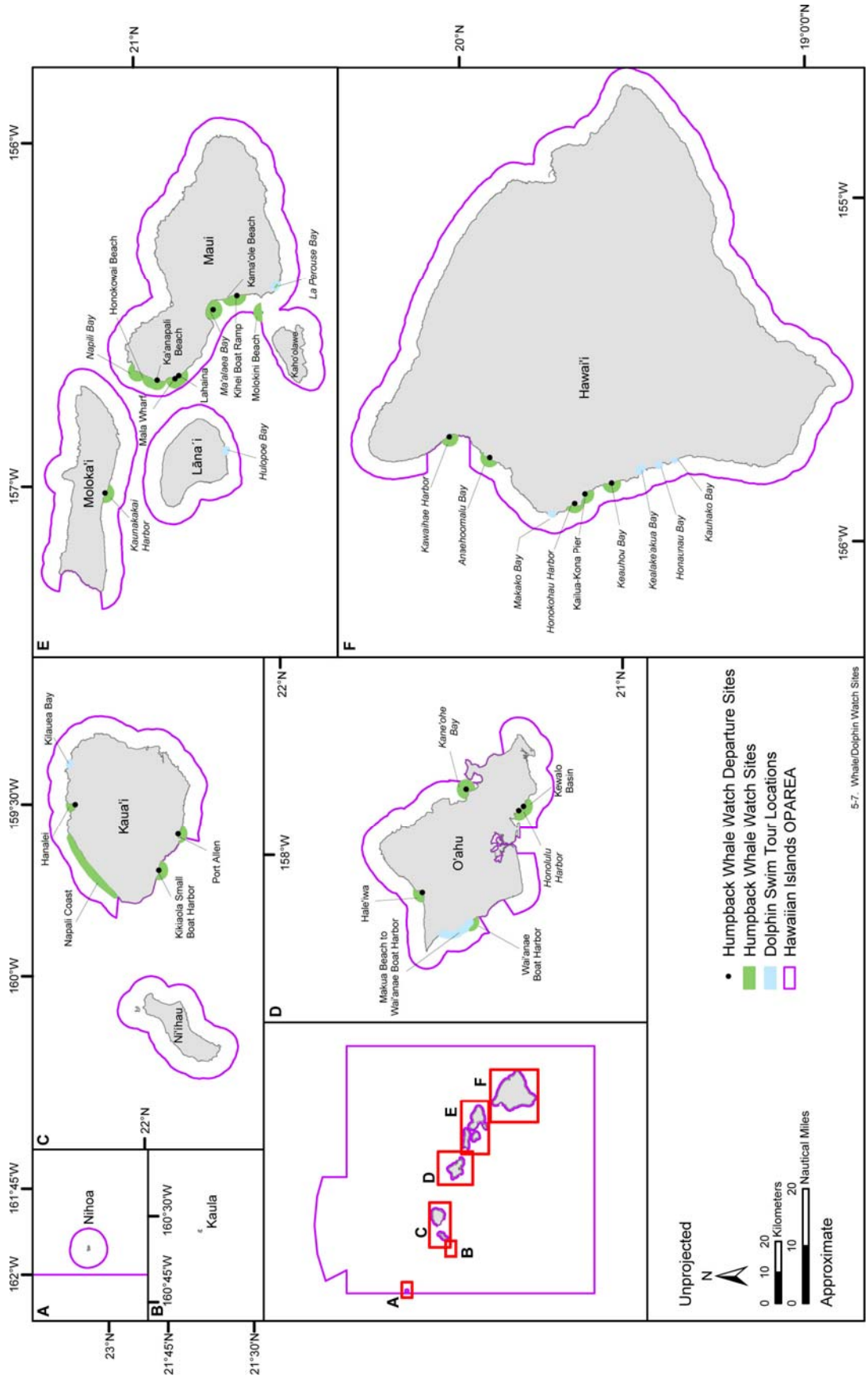

Figure 5-7. Location of humpback whale and spinner dolphin tourism sites including main whale watch tour departure points, whale watch encounter sites, and dolphin swim locations. Source data: Aki et al. 1994, Driscoll-Lind and Östman-Lind 1999b, Kubota 1999, Psarakos and Marten 1999, Utech 2000, Courbis 2004, Lammers 2004, Markrich 2004, Östman-Lind et al. 2004, Deakos personal communication, Molokaifishing 2005, Smultea personal communication, Viezbicke personal communication, World Wide Fishing Guide 2005.

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6.0 RECOMMENDATIONS

The following recommendations, conceived of by the MRA authors, are designed to improve our understanding of the marine resources in the waters off the Hawaiian Islands, especially those resources that may be potentially affected by Navy operations. Each recommendation is assigned a priority value of 1, 2, or 3; 1 is the highest priority while 3 is the lowest. The priority designations are relative to each other and in no way refer to a recommendation's overall value. The relative cost of each recommendation is labeled low, moderate, or high. Low-cost recommendations may be completed at a cost of several hundred to a few thousand dollars. Moderate-cost projects could range from thousands to tens of thousands of dollars, while high-cost research initiatives range from tens of thousands to over one hundred thousand dollars.

The recommendations are grouped into those related to the production and evaluation of the MRA and those needed to adequately complete environmental documentation for the study area of the Hawaiian Islands OPAREA MRA.

6.1 MARINE RESOURCE ASSESSMENTS

- Revise the Hawaiian Islands OPAREA MRA once every five years. The MRA would need a full revision of the text, data, GIS maps, and other informational components so that newly available datasets and published literature can be incorporated. The Navy needs the best (i.e., most recent, most complete, and most accurate) available information to evaluate future actions and consider adjustments to training exercises or operations in order to mitigate any potential impacts to protected marine resources. Periodic updates would be of moderate cost relative to the initial MRA. Cost: Moderate. Priority: 1.

- Subject the Hawaiian Islands OPAREA MRA to peer review. Peer review by regulatory agencies (e.g., NMFS and USFWS), the general scientific community, and potential government users (e.g., USMC) would increase the effectiveness of this MRA. Biologists from universities and agencies (**Table 6-1**) could evaluate the collection, synthesis, and interpretation of data (including data completeness) and provide suggestions for improvements to the MRA. Cost: Low. Priority: 1.

Table 6-1. Suggested expert reviewers for the Hawaiian Islands OPAREA MRA.

Name	Affiliation	Expertise
Pierre Flament , Ph.D.	University of Hawai'i at Manoa	Oceanography
Robert J. (Rob) Toonen, Ph.D.	Hawai'i Institute of Marine Biology	Coral reefs
Robert A. Kinzie III, Ph.D.	Hawai'i Institute of Marine Biology	Coral reefs
Robin Baird, Ph.D.	Cascadia Research Collective	Cetaceans
Joseph Mobley, Ph.D.	University of Hawai'i	Cetaceans
Jay Barlow, Ph.D.	NMFS-SWFSC	Cetaceans
Karin Forney, Ph.D.	NMFS-SWFSC	Cetaceans
Jan Őstman-Lind, Ph.D.	Kula Nai'a Wild Dolphin Research Foundation	Spinner dolphins
George A. Antonelis, Ph.D.	NMFS-PIFSC	Monk seals
Allen Tom	Hawaiian Islands Humpback Whale NMS	Marine protected areas; Marine mammals; Whale-watching
Joseph Uravitch	National Marine Protected Areas Center	Marine Protected Areas
Peter Dutton, Ph.D.	NMFS-SWFSC	Sea turtles
Jeffrey Seminoff, Ph.D.	NMFS-SWFSC	Sea turtles
George Balazs	NMFS-PIFSC	Sea turtles
Jeffrey Polovina, Ph.D.	NMFS-PIFSC	Sea turtles
James D. Parrish, Ph.D.	Hawai'i Cooperative Fishery Research Unit	Fisheries
Beth Flint	U.S. Fish and Wildlife Service	Birds

- Obtain marine mammal and sea turtle datasets for the Hawaiian Islands OPAREA MRA that may not have been available for inclusion in this assessment. While all available comprehensive data have been included (**Table A-1**), acquiring the following datasets may ensure more complete data coverage:

  - Global beaked whale sightings database (contact: Glenn Mitchell, NUWC)
  - NMFS ship strike database (contact: Greg Silber, Ph.D., NMFS-Silver Spring)
  - Boat-based cetacean sighting data from whale watching tours for island of Hawai‘i (contact: Dan McSweeney)
  - Land-based cetacean survey data for island of Hawai‘i (contact: Chris Gabrielle, Hawai‘i Marine Mammal Research Consortium)
  - Spinner dolphin data for island of Hawai‘i (contact: Jan Östman-Lind, Ph.D., Kula Nai‘a Wild Dolphin Research Foundation)
  - Cetacean survey data for O‘ahu (contact: Marc Lammers, Oceanwide Science Institute)
  - HIHWNMS data (contact: Tom Allen)
  - Any available SPLASH data (contact: HIHWNMS or NMFS-SWFSC)
  - Aerial survey data for O‘ahu from Maldini (2003) dissertation (POC: Joseph Mobley, Ph.D., University of Hawai‘i)

6.2 ENVIRONMENTAL DOCUMENTATION

- Support restoration of several endemic habitats in one effort. This effort can restore some of the invasive mangrove habitats to endemic mudflat, seagrass, and anchialine pool habitats. Cost: Moderate. Priority: 1.

- Fund research for a survey of deep-sea coral, precious coral, hydrothermal vent, and methane hydrate distribution. This survey can be done through mapping deep sea floor habitat and could be combined with other research efforts on a research cruise. Cost: High. Priority: 2.

- Fund research to understand the value of deep slope terrace/vertical wall habitat including studies of habitat distribution, zonation, and associated biota interactions. Cost: Moderate. Priority: 1.

- Fund dedicated marine mammal and sea turtle aerial and/or shipboard surveys in sections of the Hawaiian Islands OPAREA designated as areas of no survey effort (**Figures 6-1a** and **6-1b**). While it is essential to continue surveying in previously studied areas to account for seasonal and inter-annual variation in distribution and abundance of protected species stocks, it is also critical to gather data for areas where survey effort has not taken place (or has occurred at lower levels). By focusing attention on these areas, a more complete picture of marine mammal and sea turtle distributions may emerge. Given the high-profile status of these protected species, it would be beneficial to learn as much as possible about them, especially their distribution. Additionally, further funding by the Navy will provide the NMFS-SWFSC and NMFS-PIFSC the means to provide greater focus on data collection and thereby greatly improve the ability to estimate species densities within the region. Surveys should include:

  - Year-round shipboard surveys in regions of the OPAREA where gaps in survey effort occur; specifically, the northeast and southwest portions of the OPAREA (**Figures 6-1a** and **6-1b**). Due to the distance of these regions from shore, shipboard surveys would be the most feasible survey method. Priority should be given to portions of the OPAREA located closest to shore and within the U.S. EEZ. Cost: High. Priority: 1.

  - Year-round aerial or boat based surveys of the waters surrounding Nihoa. Nihoa is the only island in the OPAREA that lies within the area of no survey effort (**Figures 6-1a** and **6-1b**). There is not much information on the abundance and distribution of marine mammals and sea turtles around this island. Aerial or shipboard surveys could shed more light on the seasonal or year-round occurrence patterns of these animals at Nihoa. Cost: Moderate to High. Priority: 1.

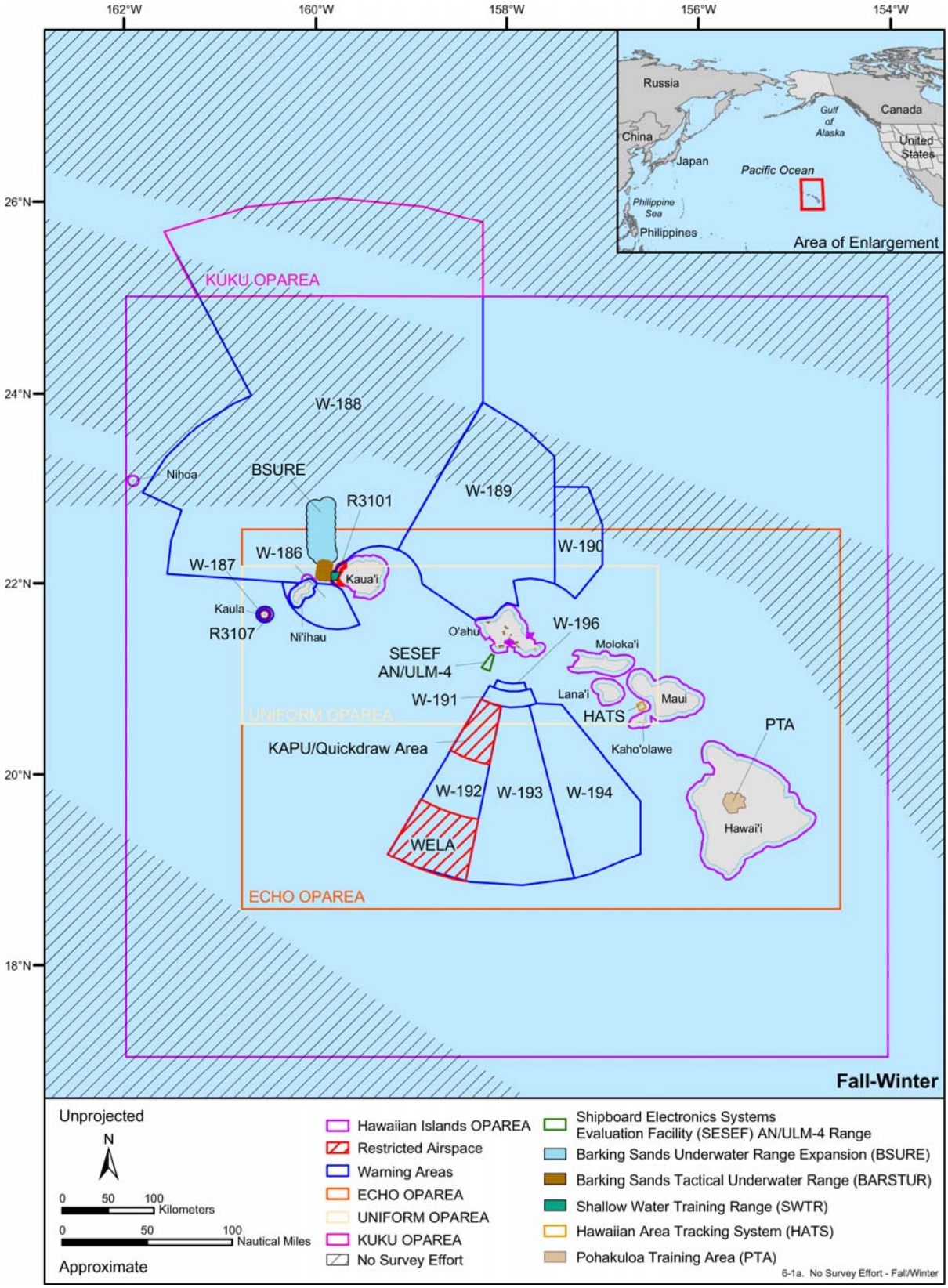

Figure 6-1a. Areas of no survey effort in the Hawaiian Islands OPAREA during fall/winter (October through February). Source data: Marine Mammal Research Consultants, Ltd. (2004), NMFS-SWFSC (2004a), Cetos Research Organization (2005a, 2005b), and CRC (2005).

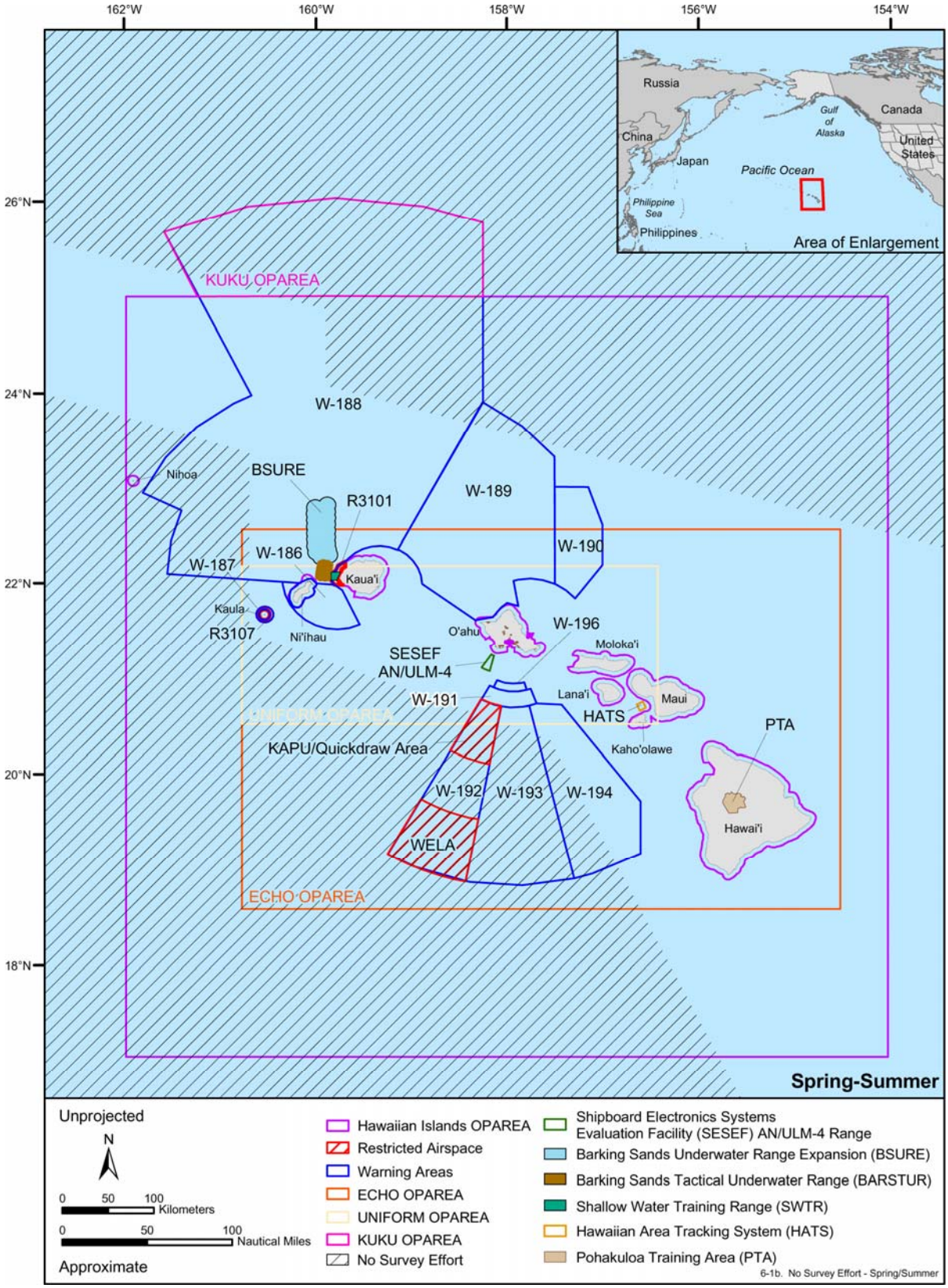

Figure 6-1b. Areas of no survey effort in the Hawaiian Islands OPAREA during spring/summer (March through September). Source data: Marine Mammal Research Consultants, Ltd. (2004), NMFS-SWFSC (2004a, 2004b, 2005), and CRC (2005).

- NMFS-SWFSC shipboard surveys of offshore waters during the humpback whale calving season (November through April). Numerous aerial and small-boat based surveys have occurred over the nearshore waters of the MHI during the calving season, but not much is known regarding the distribution of humpbacks that may be singing in deeper waters. Shipboard surveys could also help to elucidate a migratory corridor north of the Hawaiian Islands used by humpbacks when transiting to or departing from the calving grounds. Cost: High. Priority: 1.

- Aerial and boat based surveys around the island of Ni'ihau that focus on marine mammal, sea turtle, and seabird occurrence. Cost: High. Priority: 1.

➢ Support the utilization of satellite-tracking technology to monitor the movements of species of special interest. Several species of endangered cetaceans and sea turtles occur in the Hawaiian Islands OPAREA and vicinity, yet comparatively little is known about their movements. Knowledge of their potential movements would greatly aid our understanding of their behavior and ecology. Given the endangered status of certain whales, sea turtles, and other protected species, such studies are tremendously important. Satellite-tracking programs are expensive, precluding the study of more than a few individuals. While insights on an individual's behaviors or movements may be gained, questions at the population level may go unanswered. Cost: Moderate. Priority: 2.

➢ Support the marine mammal and sea turtle stranding networks, particularly with mapping and analysis of their collected data. Stranding network data could be utilized to determine the species diversity in the area, collect life history information on diet and reproduction, assist with stock determination, and assess impacts of human activities. At the present, nearly all of the marine mammal and sea turtle stranding records for the Hawaiian Islands are only available as general locations. Converting these general location descriptions into actual latitude/longitude coordinates would increase the GIS utility of the data tremendously. Cost: Low. Priority: 3.

➢ Conduct small boat-based, SCUBA/snorkel, or land-based surveys for sea turtles in the six portions of the OPAREA that run up to the shoreline. Sea turtle locations can be documented in the water through the use of hand-held waterproof GPS units. Monthly or quarterly surveys could help to elucidate the distribution patterns of sea turtles throughout these nearshore areas and also help to determine which species and life stages are found there seasonally and which are found there year round. Cost: Moderate. Priority: 2.

➢ Conduct benthic habitat mapping and a coral reef ecosystem survey of Kaula Island and Kaula Bank. Cost: High. Priority: 1.

➢ Update EFH identifications/descriptions/maps and HAPC as revised, redesignated, or additional amendments (i.e., Amendment 8 to the Bottomfish and Groundfish FMP, Pelagic Squid Fishery Management under FMP Pelagic Fisheries of the Western Pacific Region, Precious Corals Draft EIS) and/or plans (i.e., Archipelago Fisheries Ecosystem Plans) become available from the FMCs and/or NMFS. Cost: Low. Priority: 1.

➢ Support the development of a database containing all the Hawai'i Islands OPAREA EFH data and information, which would provide user-friendly access to all the EFH data and maps. Cost: Low to Moderate. Priority: 1.

➢ Support the development of a custom GIS-based application designed to provide functionally to the use of EFH data and use the EFH database proposed in the above recommendation as its base. This custom, stand-alone application would not require the purchase of any additional software or hardware and would allow for easy use of the EFH data in many different environments. Cost: Moderate. Priority: 2.

- Continue to conduct acoustic surveys for marine mammals by towing passive acoustic arrays behind research ships. Acoustic surveys have been conducted in conjunction with some sighting surveys and are particularly useful for vocal, deep-diving species such as sperm whales, which spend less time at the surface and are often missed during visual sighting surveys. Acoustic equipment and ship costs make this program potentially expensive. Cost: Moderate to High. Priority: 1.

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8.0 GLOSSARY

`a`ā—stony, rough lava

Abiotic—nonliving

Abundant—an indication of the plentifulness of a species at a particular place and time; an abundant species is more plentiful than an occasional or rare species

Abyssal plain—flat, sediment-covered part of the ocean floor between the continental rise and the mid-ocean ridge at a depth greater than 4,000 to 5,000 m

Abyssal zone—flat, sediment-covered part of the ocean floor between the continental rise and the mid-ocean ridge at a depth between 4, 000 and 7, 000 m

Acoustic thermometry—method for obtaining information about the temperature field in the ocean from precise measurements of the travel time of sound pulses transmitted through the ocean

Adult—developmental stage characterized by sexual or physical (full size and strength) maturity

Advection—refers to horizontal or vertical flow of seawater as current

Aerobic—life or biological processes that can occur only in the presence of oxygen

Aggregation—group of animals that forms when individuals are attracted to an environmental resource to which each responds independently; the term does not imply any social organization

Ahermatypic coral—non-reef building types of coral that lack symbiotic zooxanthallae and are not restricted by depth, temperature, or light penetration; may be solitary or colonial

Algae—a number of primarily aquatic, photosynthetic groups (taxa) of plants and plant-liked protists ranging in size from single cells to large, multicellular forms (i.e., giant kelp) that have no seeds, roots, stems, flowers or leaf systems

Algal cyst—resting stages of aquatic algae (e.g., dinoflagellates) which form enduring outer walls which may survive burial

Alkalic—rocks which contain above average amounts of sodium and/or potassium for the group of rocks for which it belongs. For example, the basalts of the capping stage of Hawaiian volcanoes are alkalic

Allochthonous—material that has originated elsewhere, non-native

Alpha Male—the dominant male

Amphidromic point—a nodal or no-tide point in the ocean or sea around which the crest of the tide wave rotates during one tide period

Amphipods—an order of laterally compressed (shrimp-like) crustaceans with thoracic gills, no carapace, and similar body segments. An important component of zooplankton and benthic invertebrate communities

Anaerobic—life or biological processes that occur in the absence of oxygen

Anchialine pools—land-locked, marine or brackish pools of water located along rocky coasts and connected to the sea via underground caves, tunnels, or fissures

Anemone—a cnidarian of the Class Anthozoa that possess a flexible cylindrical body and a central mouth surrounded by tentacles

Annelids—invertebrate animals of the Phylum Annelida in which the body is typically made up of a series of rings or segments covered by a soft cuticle and lacking jointed appendages (e.g., marine worms)

Anthozoan—a class of the coelenterates in which the medusiod stage is absent and the polyp (hydroid) stage is better developed than in other coelenterates; may be solitary or colonial and sedentary (e.g., sea anemones, corals, alcyonarians, sea fans, sea pens, sea pansies, sea feathers)

Anthropogenic—describing a phenomenon or condition created, directly or indirectly, as a result of human activity

Anticyclonic—clockwise circulation in the Northern Hemisphere and counterclockwise circulation in the Southern Hemisphere; in oceanography, synonymous with warm-core ring

Archipelago—group of islands more or less adjacent to each other and arranged in groups covering portions of the sea

Artificial habitat—a human-made, estuarine/marine habitat (sunken ships, artificial reefs: rubble, concrete igloos, FADs) created in navigable waters of the U.S. or in waters overlying the continental shelf to attract aquatic life.

Artificial reef—a human-made, marine habitat (sunken ships, concrete igloos, rubble) created in the navigable waters of the U.S. or in waters overlying the continental shelf to attract aquatic life

Artisanal fishing—fisheries involving skilled but non-industrialized operators; typically a small-scale, decentralized operation

Ascidians—sea squirts; taxonomic class of globular or cylindrical animals that inhabit shallow and deep water, attach themselves to substrates (rocks, pilings, the bottom of ships, and coral reefs), and may be solitary or colonial

Assemblage—the populations of various species from a larger taxon characteristically associated with a particular environment that can be used as an indicator of the environment

Astacidean lobsters—group of clawed lobsters that have first pair of legs modified as modified massive chelipedes (pincers)

Asthenosphere—region in the upper mantle of the earth's interior, characterized by low-density, semiplastic (or partially molten) rock material chemically similar to the lithosphere.

Atoll—an organic reef that surrounds a lagoon and is bordered by open sea, often with low sand islands

Audiogram—a hearing sensitivity curve drawn as a function of frequency and sound pressure level; describes the hearing ability of an animal

Authigenic—formed or generated in place. Said of rocks or minerals formed at the spot where they are now found

Autonomous vertical line arrays—used to receive underwater acoustic transmissions in acoustic thermometry studies that utilize sound transmissions to determine long-term trends in ocean temperature for the study of global warming

Autotrophically—capable of synthesizing complex organic substances from simple inorganic substrates; including both chemoautotrophic and photoautotrophic organisms

Back-arc—referring to the region behind the island arc (the concave side of the arc)

Baleen—the interleaved, hard, fibrous plates made of keratin (protein in fingernails and hair) that hang side by side in rows from the roof of the mouth of mysticete whales; baleen takes the place of teeth and serves to filter the whale's food from the water

Bandwidth—the difference between the highest and lowest frequencies; measured in Hertz (Hz)

Bank—an elevation of the sea floor located on a continental (or island) shelf and over which the depth of water is relatively shallow (20 to 200m) but sufficient for surface navigation

Barrier reef—an offshore coral reef running parallel to the shore separated from the shore by a lagoon or channel

Basalt—the most common type of solidified lava, an inner layer of worldwide extent underlying ocean and granitic continents

Baseline—the line from which maritime boundaries (EEZ, contiguous zone, territorial waters) are measured; in the U.S., the baseline is the low tide line except at the mouths of inland water bodies (bays) where a closing line (straight line) is drawn

Basking—an activity performed by pinnipeds and sea turtles while on land in which they expose themselves to pleasant warmth

Batch spawning—releasing gametes into the sea for external fertilization and development

Bathymetry—the topography of the ocean floor; study and mapping of the ocean depths

Beaked whales—members of the Family Ziphiidae, includes the Genus *Ziphius*, *Mesoplodon*, *Indopacetus*, *Berardius*

Benthic—organisms living on or near the ocean floor; the term is used irrespective of whether the sea is shallow or deep

Benthonic—of or relating to or happening on the bottom under a body of water

Benthopelagic—the ecological zone from the seabed to 100 m above the seabed

Benthos—organisms that live in, on, or are attached to the ocean bottom substrate

Billfish—giant warm-water fish of tropical and subtropical seas having a prolonged and rounded toothless upper jaw of the Family Xiphidae

Biomass—the amount of living matter per unit of water surface or water volume

Bioprospecting—search for commercially valuable biochemical and genetic resources in plants, animals, and microorganisms for use in food production, development of new drugs, and other biotechnology applications

Biotic—pertaining to life or living organisms

Birds of conservation concern—candidate, proposed, and recently delisted bird species recognized by the USFWS as in highest need of conservation

Bivalve—group of marine or freshwater mollusk that consist of a soft body protected by two hinging shells (e.g., clams and oysters)

Blow—air exhaled through the blowhole of a cetacean mixed with surrounding water that is displaced by the exhalation

Blowhole—the nostrils or nasal openings on top of the head of a cetacean

Blubber—a specialized layer of fat found between the skin and underlying muscle of many marine mammals; it is used primarily for insulation and energy storage

Bottlenose dolphin—the former common name for *Tursiops truncatus,* now called the common bottlenose dolphin

Brittlestar—starfishlike echinoderm belonging to Class Ophiuroidea that has 5 to 8 elongate, slender, cylindrical arms distinctly radiating from a flat central disc

Brooded planulae—brooding of planula larva within the polyp of corals; form of asexual reproduction

Brown algae—division of algae (Phaeophycophyta) consisting of large macroscopic forms occurring widespread in marine habitats attached either to rocks, stones or coarser algae (kelp); commonly found relatively shallow water in the intertidal and subtidal zones along the coast, in estuaries, and muddy bottoms of salt marshes

Bryozoan (ectoprocta)—phylum of colonial animals that often share one coelomic cavity and possess lophophore feeding structure; encrusting and branching forms secrete a protective housing (zooecium) of calcium carbonate or chitinous material

Bubble netting—a coordinated feeding technique of humpback whales, in which they use bubbles to corral and trap small fish or invertebrates

Budding—asexual reproduction in which small portion of an organism grows out from and eventually develops into another individual or another equivalent part of a colony

Bull—a male seal or whale, especially an adult male

Buoy—a bright-colored float attached by rope to the seabed to mark channels in a harbor or underwater hazards

Bycatch—any species caught in a fishery, but which are not sold or kept for personal use, and includes economic and regulatory discards

Calcareous—composed of calcium or calcium carbonate

Calf—a young animal dependent on its mother

Callosity—a patch of thickened, keratinized tissue on the head of a right whale, inhabited by large numbers of whale lice

Calving interval—the period of time from one birth to the next, generally applicable to cetaceans

Cape—a darker region on the back of many species of dolphins and small whales, generally with a distinct margin

Carapace—the outer covering of the back of a sea turtle, which is bony for all sea turtle species with the exception of the leatherback, which has a leathery covering

Carbonate—type of rock or sediment formed of carbonate (CO_3^{-2}) and another element such as calcium or magnesium; limestone and dolomite are common carbonate rocks

Caridean shrimps—a caridoid decapod crustacean with phyllobranchiate gills, second abdominal pleura forming a caridean saddle, and usually two pairs of chelae but never three

Carnivora—an order of living and extinct mammals that includes such species as pinnipeds and otters

Carnivore—an animal that feeds exclusively on another animal's tissue

Catch per unit effort (CPUE)—measure of a species relative abundance

Cephalopods—any marine mollusk of the Phylum Mollusca with a well-developed pair of eyes and a ring of tentacles surrounding the mouth; shell is absent or internal (squid, octopus, cuttlefish)

Cetaceans—whales, dolphins, and porpoises

Chaetognaths—known as arrowworms that are active elongated, transparent predators in marine plankton

Charter fishing—fishing from a vessel carrying a passenger for hire (as defined in Section 2101(21a) of Title 45, U.S. Code) who is engaged in recreational fishing

Chemosynthesis—the formation of organic compounds from inorganic substances using energy derived from oxidation

Chevron—a V-shaped stripe

Chlorophyte—green algae

Circumglobal—the distribution pattern displayed by organisms around the world, within a range of latitudes

Circumtropical—organisms which occur around the tropics of the world (land or sea)

Click—a broad-frequency sound used by toothed whales for echolocation and which may serve a communicative function; usually with peak energy between 10 kHz and 200 kHz

Clutch—a total number of eggs from one nesting

Cnidarians—the phylum of animals that includes corals, sea fans, sea anemones, hydroids, and jellyfish; known for the stinging cells on their tentacles; these animals exhibit two body types, polyps (may be attached or planktonic) or medusa, sometimes at different periods of one species development

Coast—the boundary where land and water meet

Coastal water—water that is along, near, or relating to a coast

Coccolithopore—phytoplankton that surrounds itself with a microscopic plating made of limestone

Cochlea—a spiral bony structure in the inner ear that looks like a snail shell and contains over 10,000 tiny hair cells, which are the receptor organs essential for hearing and that bend in response to sound waves, the bending of the hair cells in stimulates nerve cells to send messages to the brain, which the brain interprets as sound

Coda—a patterned series of 3 to 20 clicks lasting about 0.5 to 2.5 seconds, used by sperm whales for communication

Cold-stunning—the behavior exhibited by sea turtles in response to cold water temperatures; turtle becomes lethargic and adopts a stunned floating posture

Colonial—nesting in groups or colonies rather than in isolated pairs

Colony—highly integrated group of animals; herein refers specially to birds and land-breeding pinnipeds

Commensal—relationship between two organisms of different species in which one benefits and the other is neither benefited nor harmed

Commercial fishing—fishing in which the fish is harvested, either in whole or part, are intended to enter commerce through sale, barter, or trade

Common—in the case of sea turtles, common means that sea turtles have been recorded in all, or nearly all, proper habitats, but some areas of the presumed habitat are occupied sparsely or not at all and/or the region regularly hosts large numbers of the species

Conspecific—member of the same species, and in many cases, the same age or even sex

Continental margin—the boundary or transition between the continents and the ocean basins that consists of the physiographic provinces of the continental shelf, continental slope, and continental rise

Continental rise—the province of the continental margin with a sloping seabed (1:100-1:700 gradient change) and a generally smooth surface, which lies between the abyssal plains and continental slope

Continental shelf—the province of the continental margin with a gently seaward-sloping seabed (1:1000 gradient change) extending from the low-tide line of the shoreline to 100 to 200 m water depth where there is a rapid gradient change

Continental shelf break—the area where the slope of the seabed rapidly changes from gently sloping to steeply sloping and the continental shelf gives way to the continental slope

Continental slope—the province of the continental margin with a relatively steeply sloping seabed (1:6 to 1:40 gradient change) that begins at the continental shelf break (about 100 to 200 m) and extends down to the continental rise; along many coasts of the world, the slope is furrowed by deep submarine canyons

Cool water period—the period extending from 1 October to 28 February and is associated with cooler sea surface temperatures

Copepods—very small planktonic crustaceans present in a wide variety and great abundance in marine habitats, forming an important basis of ecosystems; they are a major food of many marine animals and are the main link between phytoplankton and higher trophic levels

Coral boomies—coral outcroppings

Coral patches—rocky outcrops colonized by sessile organisms including hard coral, soft corals, hydroids, algae, and sponges

Coral polyps—are small marine animals with a tube-shaped body with a mouth which is surrounded by tentacles; many lived together in a large group or a colony

Coral reef—a massive, wave-resistant structure built largely by colonial, stony coral via deposition of calcium carbonate

Coral reef ecosystem (CRE)—those species, interactions, processes, habitats and resources of the water column and substrate located within any waters less than or equal to 50 fathoms (100 meters) in total depth

Coral reef ecosystem management unit species (CRE MUS)—an extensive list of coral reef organisms, many included by family; includes some management unit species from existing fishery management plans (bottomfish, crustaceans, precious corals) for which primary management would remain under their current fishery management plans but ecosystem effects would be addressed by the CRE FMP. CRE MUS are listed into two categories: CHCRT and PHCRT.

Coralline algae—family of red algae (Corallinaceae) having bushy or encrusting form and deposits of calcium carbonate either on branches or as crusts in the substrate

Corallivores—an organism that eats coral

Cosmopolitan—having a broad, wide-ranging distribution

Countershading—a form of camouflage exhibited by many fish and cetaceans, with dark upper body surfaces and lighter undersides. When viewed from above the darker dorsal surface blends in with the water; from below the lighter ventral surface matches the light coming from the sky, making the animal hard to see

Coverts—small feathers that cover the basis of other, usually larger feathers and provide a smooth, aerodynamic surface

Crepuscular—appearing or active at twilight

Crinoids—class of sessile echinoderms commonly called sea lilies and feather stars; these animals have a cup-shaped body that attaches to the substratum by a stalk (sea lilies) and have feathery arms

Critical habitats—the portion (minimum) of the habitat that is essential for the survival for certain protected (threatened and endangered) species (whales or sea turtles) and may include areas essential for feeding or reproduction by those species

Crustaceans—arthropods that have two pairs of antennae and a hard exoskeleton; lobster, shrimp, and crabs are the most familiar examples

Crustose—having a thin crusty thallus that adheres closely to the surface on which it is growing

Cryptic—hidden; living in holes, caves, burrows

Currently harvested coral reef taxa (CHCRT)—a sub-category of management unit species (MUS) including species that have been reported on commercial fishery catch reports for federal EEZ waters but are not MUS under any the Council's already-implemented FMPs; membership in this group is based on two criteria: (1) more than 1,000 lbs. (454.54 kg) annual harvest for all members of a taxon (families or subfamilies) based on commercial fishery catch reports and (2) within these taxa particular genera or species are identified based on their appearance on catch reports

Cyanobacteria—large and varied group of bacteria which possess chlorophyll a and carry out photosynthesis in the presence of light and air, with concomitant production oxygen; formerly regarded as algae and called blue-green algae; may be single-celled or filamentous and may or may not be colonial; many species carry out the fixation of atmospheric nitrogen; widely distributed in marine and freshwater environments in littoral zone on soil, rocks, and plants as epiphytes or symbionts; may produce harmful algal blooms in low-salinity systems with excessive nutrients

Cyclonic—counterclockwise circulation in the Northern Hemisphere or clockwise in the Southern Hemisphere; in oceanography, synonymous with cold-core ring

Decapod—order of freshwater, marine, and terrestrial crustaceans having five pairs of legs on the thorax and a carapace completely covering the throat (e.g., shrimps, crabs, lobsters)

Decibel (dB)—a logarithmic measure of sound strength; it is a ratio of intensity (pressure) at reference range compared with a with a reference level; in air, the reference pressure is 20 µPa and the reference range is 1 m, while for underwater sound, the reference is 1 µPa and the reference range is also at 1 m

Deep scattering layer—a layer of dense aggregation of fishes, squid, and other species found at depth that migrate vertically in the water column each day; the layer of organisms moves toward the surface at night to feed and returns to depth at dawn

Deepwater—the area of the ocean that is past the continental shelf break, deeper than 100 to 200 m of water

Delayed implantation—in mammals it is the suspended development of an embryo between shortly after conception and subsequent attachment (implantation) to the uterine wall

Delimitation—fixing a boundary

Demersal—applied to fish that live close to the seafloor, such as groupers

Demography—birth and death rates that determine a population's dynamics; abundance, age, and sex structure of the population and reproductive status and life cycle of individuals

Demosponges—largest and most complex group of siliceous and horny sponges; includes forms with needle-shaped or four-branched siliceous spicules, which may or may not be sported by spongin

Density—physical property measured by mass per unit volume; in biology, the number of organisms per unit of distance

Detritus—fragmented particulate organic matter derived from the decomposition of plant and animal remains

Diandric—possessing two different types of males, a large, brightly-colored and aggressive terminal phase (TP) and a smaller drab and relatively non-aggressive initial phase (IP) (e.g., wrasses)

Diatom—phytoplankton member of the Class Bacillariophycea; posses a wall of overlapping silica valves

Didemnid tunicates—ascidians that have an encrusting form, membrane-like with common cloacal siphons larger and surrounded at a different distance by many individual oral siphons

Diel—refers to 24-hour activity cycle based on daily periods of light and dark

Dimorphic—having two different forms

Dinoflagellates—microscopic single-celled plant of the Class Pyrrhophyceae that has two flagella, one propelling water to the rear and providing forward motion, attached just behind the center of the body and directly posteriorly, the other causing the body to rotate and move forwards, forming a transverse ring or spiral of several turns around the center of the body; some are naked, others are covered with a membrane or plates of cellulose; often abundant; dense growths may produce luminescent bays and harmful algal bloom in freshwater and marine habitats (*Alexandria*)

Dioecious—pertaining to an organism in which male and female reproductive systems are in different individuals

Dissolved organic matter (DOM)—is dissolved and colloidal organic material that passes through a filter with a mesh size of between ~0.1 and 1 microns; dissolved organic carbon is the carbon component of the DOM

Diurnal—active or occurring during daylight hours; having a daily cycle

Dive gear—is used to take sea urchins, abalone, or sea cucumbers. Divers use “hookah” systems consisting of a long air hose connected to an air compressor on the deck of a boat

Dominant species—species most prevalent in a particular community, or at a given period

Dorsal—relating to the upper surface of an animal

Downwelling—downward movement or sinking of surface water towards the ocean bottom; may be caused by convergent currents or density differences

Drift net—a monofilament gillnet set at or near the surface that stretches up to 60 km or more in length, used passively (drifts) to entangle fish or invertebrates, which also catches a large number of non-target species, including marine mammals and sea turtles

Drive fishery—small cetaceans (such as pilot whales) are maneuvered into a confining situation where they are either entrapped or immediately driven ashore and killed

Duty cycle—the percent of time an instrument is on

Echinoderms—phylum of marine invertebrates having bilateral symmetry in larval forms and usually a five-sided radial symmetry as adults, a calcareous endoskeleton, and a water vascular system (e.g., sea cucumbers, sea urchins)

Echolocation—the production of high-frequency sound waves and reception of echoes to locate objects and investigate the surrounding environment

Ecosystem—a system of ecological relationships in a local environment comprising both organisms and their nonliving environment, intimately linked by a variety of biological, chemical, and physical processes

Ectoparastites—a parasite that lives on the outer surface of its host

Eddy—the circular movement of water

Ejecta—material that is thrown out by a volcano

El Niño—wind-driven reversal of the Pacific equatorial currents resulting in the movement of warm water towards the coasts of the Americas, considered a natural cyclical atmospheric/oceanic phenomenon; El Niño is often termed the El Niño/Southern Oscillation, or "ENSO"

El Niño/Southern Oscillation (ENSO)—the climatic phenomenon that causes changes in wind and current patterns (reversal of the Pacific equatorial currents) that leads to changed ocean temperatures and weather patterns over vast distances; leads to the disruption of coastal upwelling and die-offs of plankton, fish, sea birds, and marine mammals

Elasmobranch—fishes of the Class Chondrichthyes that are characterized by having a cartilaginous skeleton; includes sharks, skates, and rays

Elliptical—rounded like an egg

Embayment—an indentation in the shoreline that forms a bay

Encrusting—forming or resembling a crust

Endangered species—any animal or plant species in danger of extinction throughout all or a significant portion of its range; the authority to list a species is shared by the USFWS (plants and animals on land) and NMFS (most marine species) under provisions of the ESA

Endemic—occurring in a specific area

Endogenous—originating within or produced by the body

Endolithic—living inside rock

Endemic species—species native and confined to a certain region and having restricted distribution (i.e., a species unique to a place, found naturally nowhere else

Energy flux density—the average rate of sound energy flow per area for one period.

Enter into force—point in time from which a treaty is enforced for those states that gave consent

Entrainment—the process of picking up and carrying along

Environmental impact statement (EIS)—a detailed written statement that helps public officials make decisions that are based on understanding of environmental consequences and to take actions that protect, restore, and enhance the environment

Epibenthic—refers to organisms living on the ocean floor

Epifauna—animals living on the surface of the ocean floor; any encrusting fauna

Epipelagic—oceanic zone from the surface to 200 m

Epizoically—living on the surface of another organism

Equidistant line or equidistance—a median line, every point of which is the same distance from the nearest points on the baselines of two countries

Essential fish habitat (EFH)—those habitats necessary to fish for spawning, breeding, feeding, or growth to maturity; designated by the NMFS

Estuary—a semi-enclosed body of water where freshwater mixes with saltwater; often an area of high biological productivity and important as nursery areas for many marine species

Euphotic zone—the uppermost area of the ocean (up to 150 m) that is sufficiently illuminated to permit photosynthesis by phytoplankton, algae, and submerged aquatic vegetation

Exclusive Economic Zone (EEZ)—all waters from the low-tide line outwards to 200 NM (except for those that area close together, i.e., Mediterranean countries) in which the inner boundary of that zone is a line coterminous with seaward boundary of each of the coastal states; the country has the power to manage all natural resources

Exogenous—originating or produced outside the body

Extralimital—outside the normal limits of an animal's distributional range; in the case of marine mammals, a species that does not normally occur in the area, but for which there are one or more records that are considered beyond the normal range of the species

Extrapolate—to estimate a value that falls outside a range of known values

Falcate—sickle-shaped and curved (refers to the dorsal fin of some cetaceans)

Fathom—a marine unit of measure of water depth equaling 1.83 m

Fauna—animal life of a region

Fish aggregating device (FAD)—single or multiple floating structures that are connected to the ocean floor by ballast or anchors; used to attract fish

Fishery—one or more stocks of fish that can be treated as a unit for purposes of conservation and management and that are identified on the basis of geographical, scientific, technical, recreational and economic characteristics, and any fishing for such stocks

Fishery management plan (FMP)—plan prepared by a Regional Fishery Management Council or by NMFS (if a Secretarial plan) to manage fisheries

Fission—reproduction of some unicellular organisms by division of the cell into two more or less equal parts

Flank—side of the body; used mainly to refer to the side of the posterior half of the body

Flatfish—members of the fish Order Heterosomata which swims or lies on one side of its body; sides are greatly flattened and compressed; mainly marine animals (e.g., flounders, soles)

Flipper—the flattened forelimb of a marine mammal

Flora—all the plant species of a given area

Flukes—the horizontally spread tail of a cetacean

Foliose—leaflike

Forage—search for food

Forams—single-celled marine microorganisms having a calcareous shell with openings where pseudopods protrude

Fore-arc—referring to the region ahead of the island arc (the convex side of the arc)

Fore reef—area from the seaward edge of the reef crest that slopes into deeper water to the landward edge of the bank/shelf platform. Features not forming an emergent reef crest but still having a seaward-facing slope that is significantly greater than the slope of the bank/shelf are also designated as fore reef

Forminiferans—planktonic and benthic protozoan protists that have a test (shell) composed of calcium carbonate

Fragmentation—type of asexual reproduction where a thallus breaks into two or more parts, each of which forms a new thallus

Fringing reef—a coral ref contiguous with the shore; lacks a lagoon

Fusiform—spindle-shaped or torpedo-shaped and tapering at one or both ends

Galatheid crabs—deep sea scavenging crabs found in abundance around hydrothermal vents, cold seeps, and whale falls

Gametes—mature egg or sperm, capable of reproduction after fertilization with sperm or egg from same species

Gape—the mouth in cetaceans, usually referring to the junction of upper and lower lips

Gastropods—class of symmetrical, univalve mollusks that have a true head, an unsegmented body, and a broad, flat foot

Gastrozoid—nutritive or feeding poly of cnidarians which is similar to a short hydra

Gemmules—group of overwintering amoebocytes covered by a hard outer covering; asexual reproductive method in sponges

Gempylids—closely allied to the true mackerels, these deep-water tropical/subtropical fish lack the keels on the sides of the caudal peduncle so characteristic of mackerels

Genera—one of taxonomic or scientific classifications of plants and animals

Geostrophic—balance, in the atmosphere, between the horizontal Coriolis forces and the horizontal pressure forces

Gestation—period of development in the uterus from conception until birth (pregnancy)

Gillnet—a type of fishing gear made of rectangular mesh panels that are set more or less vertically in the water so that fish swimming into it are entangled by their gills; they can be set to fish at the surface, midwater, or on the bottom of the water column

Gonozooid—a hydrozoan reproductive polyp which is often reduced, lacking mouth and tentacles, and bear gonophores

Gorgonians—coral of the Class Anthozoa, subclass Octocorallia, Order Gorgonacea; this order of corals includes sea rods, sea whips, feather plumes, and sea fans

Graben—a depression of rock lying between two faults

Green algae—division of algae (Chlorophyta) consisting of plankton and benthic forms occurring widespread in marine and freshwater habitats; marine species are primarily macroscopic forms frequently attached to moist rocks, woods, pilings, or larger algae or grow on sandy bottoms on shells in quiet estuaries; consist of motile and nonmotile types; may be unicellular, colonial, filamentous, membranous (e.g., sea lettuce), and tubular

Gregarious—used to describe animals that form social groups

Gyre—circular movement of waters, larger than an eddy; usually applied to oceanic systems

Habitat—the living place of an organism or community of organisms that is characterized by its physical or living properties

Habitat area of particular concern (HAPC)—discrete areas within essential fish habitat (EFH) that either play especially important ecological roles in the life cycles of federally managed fish species or are especially vulnerable to degradation from fishing or other human activities

Habitat preference—the choice by an organism of a particular habitat in preference to others

Haermic—pair spawning

Halfbeaks—elongated silver fish with elongated lower jaw extended into a long beak; found globally in all tropical and temperate seas

Hard coral—see scleractinian

Hardbottom—area of the sea floor, usually on the continental shelf, associated with hard substrate such as outcroppings of limestone or sandstone that may serve as attachment locations for organisms such as corals, sponges, and other invertebrates or algae.

Hardbottom community—area of bottom habitat with three-dimensional character providing physically stable shelter and substrate for large populations of sessile or attached invertebrates and fishes

Harem—a group of females whose breeding is controlled by a single male who seeks to prevent other males from breeding with them

Haul out—the process by which pinnipeds crawl or pull themselves out of the water onto land

Haulout—intertidal rock outcrops, sandbars, shoals, mudflats, or sandy beaches where marine animals, such as pinnipeds, periodically and purposefully come ashore

Hectare—a measurement of land area and is equivalent to 0.01 square kilometers

Herbivore—an animal that eats plants as its main source of energy

Herbivorous—feeding on plants; phytophagous; protozoans that feed on bacteria and/or algae

Hermaphrodite—an organism that has both male and female sex organs

Hermatypic coral—reef-building coral containing symbiotic, unicellular zooxanthallae in their endodermal tissue; usually colonial, may be solitary; found in shallow, warm, sunlit waters

Heterotrophically—obtaining nourishment from exogenous organic material

Hexacorals—coral distinguished by hexameral symmetry; scleractinian

Holocentrids—a natural family of fish including the squirrelfishes and solderfishes that hide in caverns and under large corals

Honu—Hawaiian name for the green turtle

Honu‘ea—Hawaiian name for the hawksbill turtle

Hydrographic—used with reference to the structure and movement of bodies of water, particularly currents and water masses

Hydrography—the science of measuring and describing the surface waters of the Earth

Hydrophone—transducer for detecting underwater sound pressures; an underwater microphone

Hydrothermal vent—location on the ocean floor in which water percolates down through fractures in recently formed ocean floor, is heated by underlying magma, and surfaces through chimneys. Hydrothermal vents are usually located near the axis of spreading on ocean ridges and rises

Hydrozoans—delicate marine animals usually in clusters or colonies of the Phylum Coelenterata; individual polyps are encased in gelatinous cups and often secrete coral as supporting structures; highly branched polyp or hydroid stage of many members is important component of fouling

Ice floe—a large mass of sea ice (pack ice) kept in motion by winds, currents, and wave action

Ichthyofauna—all fish that live in a particular area

In situ—in the natural or original position

Incidental fisheries bycatch—the catch of additional species, such as fishes, turtles, or marine mammals, that are not targeted by a fishery but are harvested in addition to the target or sought after species

Indigenous species—a species native to a place or biota

Indo-Pacific—widespread species with western limit west of the Andamans and eastern limit east of non-marginal areas of the Pacific Plate

Indo-West Pacific—widespread species with northeastern limit on the Pacific Plate marginally in the Carolines, but not reaching the Marshalls

Infaunal—living in and on soft bottom

Infrasonic—sound at frequencies too low to be audible to humans, generally below 20 Hz

Inshore—lying close to the shore or coast

Insular—pertaining to or situated on an island

Inter-nesting interval—the amount of time between successive sea turtle nesting events during the nesting season

Interpolate—extrapolation to predict values for a parameter between limited data points

Intertidal—the area of shore exposed between high and low tide

Intertropical Convergence Zone—location where northeast trade winds and southeast trade winds converge

Islet—a small island

Isobath—bathymetric contour of equal depth; usually shown as a line linking points of the same depth

Isohaline—contour of equal salinity, usually shown as a line connecting points of the same salinity

Isopods—shrimp-like animals of the Order Isopoda that have their body flattened dorso-ventrally

Isopycnal—a surface of constant potential density

Isostacy—the "floating" of the crust on the denser but slightly fluid mantle materials

Isotherm—contour of equal temperature; usually shown as a line linking points of the same temperature

IUCN red list—a list of animal species and subspecies thought to be threatened with extinction and those which are known or thought to have become extinct in the wild

Jetties—structure use at inlets to stabilize the position of the navigation channel, to shield vessels from wave forces, and to control the movement of sand along the adjacent beaches so as to minimize the movement of sand into the channel

Juvenile—mostly similar in form to adult but not yet sexually mature; a smaller replica of the adult

Kilopascal (kPa)—a standard unit of pressure in the International System of measurements

Kogia—the genus comprised of the pygmy sperm whale (*Kogia breviceps)* and dwarf sperm whale (*Kogia sima*)

Kona—a stormy, potentially strong, rain-bringing wind from the southwest or south-southwest in Hawaii

Krill—see euphausiids

Kuroshio—the fast-flowing western boundary current of the North Pacific subtropical gyre

Kuroshio Current—fast ocean current flowing northeastward from Taiwan to Ryukya Islands and close to coast of Japan to about 150° East

La Niña—when ocean temperatures in the eastern equatorial Pacific are unusually cold; it is essentially the opposite of the El Niño phenomenon; La Niña sometimes is referred to as the cold phase of an El Niño Southern Oscillation event (ENSO)

Lactation—secretion or formation of milk by the mammary glands for the purpose of nursing offspring

Lagoon—a shallow stretch of seawater partly or completely separated from the open ocean by an elongated, narrow strip of land such as a reef or barrier island

Landslide—an abrupt movement of soil and bedrock downhill in response to gravity

Lanternfish—small, usually deep sea fish with many luminescent spots on their bodies of the Family Myctophidae

Larval—young fish between time of hatching and attainment of juvenile characteristics

Leptocephalic—small, elongate, transparent, planktonic larva of eel

Lithosphere—The outer solid part of the earth, including the crust and uppermost mantle.

Littoral—the zone or division of the ocean bottom that lies between the high and low tide lines; intertidal

Live bottom community—a concentration of benthic invertebrates and demersal fishes that is associated with a region of vertical relief and structural complexity that can be organic (e.g., coral skeletons) and inorganic (e.g., rocks) in origin; such oasis-like communities are often surrounded by expanses of bottom with little relief or structure

Live rock—any natural, hard substrate (including dead coral or rock) to which is attached, or which supports, any living life-form associated with coral reefs

Lizardfish—any of various bottom-dwelling, large- mouthed fishes of the Family Synodontidae of warm seas, having a lizard-like head

Longitudinal fission—asexual division of new polyps within the same coral head

Longline—a type of fishing gear using a buoyed line onto which are attached numerous branch lines each terminating in a baited hook; longlines may extend for tens of kilometers and are usually left to drift in surface waters or near the seafloor

Lost year—the early juvenile stage (first years of life) of most sea turtle species that is spent far offshore; few turtles are observed during this time

Macrophyte—macroscopic plant in an aquatic environment

Magma—fluid rock material from which igneous rock is derived through solidification. It can intrude into crevices and fissures as it upwells through the crust

Marine managed area—any area of the marine environment set aside by federal, state, local, or tribal governments to protect geological, cultural, or recreational resources and which currently may not be protected as marine protected areas; marine managed areas encompass a broader spectrum of management purposes than marine protected areas

Marine protected area—any area of the marine environment reserved by federal, state, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources within the area

Malacological—branch of zoology that deals with mollusks

Mangrove—a variety of salt-tolerant trees and shrubs that inhabit the intertidal zones of tropical and subtropical regions; tropical equivalent of salt marshes

Map projection—a mathematical formulation that transforms feature locations on the Earth's curved surface (three-dimensional) to a map's flat surface (two dimensions)

Masking—obscuring of sounds of interest by interfering sounds, generally at similar frequencies

Maximum sustained (sustainable) yield (MSY)—the maximum harvest that can be sustained year after year, derived from population models

Mean—(arithmetic) average

Mean higher high water (MHHW)—average height of all daily higher high waters recorder over 19-year period, or computed equivalent period

Median—(arithmetic) the middle number in a set of data when it is calculated from lowest to highest; it is an indicator of central location in a dataset

Medusa—free-swimming, sexually mature form of coelenterates; umbrella- or bell-shaped; swims by pulsations of its body; tentacles and sense organs are located at edge of bell

Megalops—postlarval stage of crabs that has a large or flexed abdomen and the full complement of appendages

Melon—a fatty cushion forming a bulbous "forehead" in toothed whales; may act to focus sound for echolocation

Mesopelagic—occurring in the oceanic zone from 200 to 1,000 m

Mesoplodon—a genus of beaked whales, which includes the Blainville's beaked whale, Gervais' beaked whale, Sowerby's beaked whale, and True's beaked whale

Mesoscale—large scale

Mesozooplankton—medium-sized zooplankton (size range of 20 to 200 microns)

Metabolism—all biochemical reactions that take place in an organism

Metadata—information about a geographic information system (GIS) shapefile or coverage file that describes the source of the data or information, the creation date, the data format, the projection, the scale, the accuracy, and the reliability of the GIS file with regard to some standard

Metamorphosis—change in form and structure undergone by animal from embryo to adult stage

Microburst—an intense, localized downdraft of air that spreads on the ground

Microhabitat—a smaller part of a habitat that has some internal interactions allowing it to function self-sufficiently within a generally larger habitat

Microplankton—small planktonic organisms, 20 to 200 µm in diameter

Microzooplankton—single cell animals that drift with or are carried with the motion of the currents

Migration—periodic movement between one habitat and one or more other habitats involving either the entire or significant component of an animal population; this adaptation allows an animal to monopolize areas where favorable environmental conditions exist for feeding, breeding, and/or other phases of the animals' life history

Mimicry—close resemblance of one organism (mimic) to another (model) to deceive a third (operator)

Mollusk—group of marine and terrestrial invertebrates consisting of snails, slugs, squids, octopuses, clams, and others

Molt—for pinnipeds, this refers to shedding the fur; belugas are the only cetacean known to do this–the top layer of skin is shed all at one time of the year versus other cetaceans which continuously are sloughing skin

Monandric—protogynous hermaphrodites among which all males are sex-reversed females

Monospecific—genus with only one species

Morphology—the form and structure of an organism considered as a whole; appearance

Morphometric—the study of comparative morphological measurements

Mouthbrooder—fish which broods or protects the eggs or young by taking them in its mouth; oral brooder

Mudflat—relatively flat, muddy regions found in intertidal areas that are submerged by the rise of the tide

Mysids—small shrimp-like crustaceans

Mysticeti—suborder of cetaceans comprised of the baleen whales

Nasal septum—the wall of flexible cartilage dividing the nasal cavity into halves

Nautical mile (NM)—a distance unit used in the marine environment that is equal to one minute of latitude or 1.85 km

Nautilus—small cephalopod mollusk that is common fossil; found in Pacific and Indian Oceans, pearly or chambered; has many small arms and lives in outermost chamber of beautiful spiral, chamber shell

Nearshore—an indefinite zone that extends seaward from the shoreline

Neonate—a newborn

Neritic zone—shallow portion of pelagic ocean waters; ocean waters that lie over the continental shelf, usually no deeper than 200 m

Nocturnal—applied to events that occur during the nighttime hours

North Pacific—the part of the Pacific Ocean found north of the Equator

Nudibranch—member of the mollusk Class Gastropoda that has no protective covering as an adult; carries on respiration by gills or other projections on the dorsal surface (sea slug)

Occurrence record—a marine mammal or sea turtle sighting (aerial or shipboard survey), stranding, incidental fisheries bycatch, nesting, or tagging data record for which location information is available. An occurrence record, especially sighting occurrence records, may represent the occurrence of one or multiple animals of a particular species; for instance, one occurrence record from a marine mammal sighting survey may indicate that 34 short-finned pilot whales were observed at a location but this information would be plotted on a MRA map figure as one occurrence record

Ocean front—a boundary between two water or air masses that have different densities; water density differences are caused by differences in temperature or salinity

Oceanic zone—the deepwater portion of pelagic ocean waters; ocean waters beyond the continental shelf or that are deeper than the depth of water overlying the continental shelf break (typically 100 to 200 m deep)

Oceanography—the scientific study of the oceans, including the chemistry, biology, geology, and physics of the ocean environment

Octocorals—erect, non-crusting group of soft corals whose polyps are always formed into colonies; each polyp having eight pinnate (side-branching) tentacles

Odontoceti—the suborder of cetaceans comprised of toothed whales (e.g., beaked whales, dolphins, porpoises, sperm whale)

Offshore—open ocean waters over the continental slope that are deeper than 200 m; water beyond the continental shelf break

Olfactory—relating to the sense of smell

Oligotrophic—refers to a body of water which is poor in dissolved nutrients and usually rich in dissolved oxygen, resulting in low primary production

Omnivore—an animal that feeds on both plant and animal tissue

Opportunistic—used to describe organisms that take advantage of all feeding opportunities and do not prey on a few specific items

Opportunists—having the ability to exploit newly available habitats or resources

Optimum sustainable population—with respect to any population stock, the number of animals which will result in the maximum productivity of the population or the species, keeping in mind the carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element

Ostracods—crustacean-like crabs and lobsters that have thicker ornamented valves

Otariids—the eared seals (sea lions and fur seals), which use their foreflippers for propulsion; from the Family Otariidae

Overfished—any stock or stock complex whose size is sufficiently small that change in management practices is required to achieve an appropriate level and rate of rebuilding. The term generally describes any stock or stock complex determined to be below its overfished/rebuilding threshold

Overfishing/Overfished—fishing at a rate or level that jeopardizes the capacity of a stock or stock complex to produce maximum sustainable yield on a continuing basis

Ovigerous—females carrying fertilized eggs on the outside of their body

Oviparous—producing eggs that hatch outside mother's body

Ovoviviparous—giving birth to live young which have developed from eggs that hatched within the mother's body

Pacific Decadal Oscillation (PDO)—long-lived El Niño-like pattern of Pacific climate variability marked by widespread variations in Pacific Basin and North American climate

Pacific Ocean—a major ocean area contained in a basin extending approximately from 70° west longitude (Cape Horn) to 147° east longitude. The separation of the Pacific Ocean from the Atlantic Ocean is a line marking the shortest distance between Cape Horn and the South Shetland Islands. The Pacific and Indian Oceans are separated by a line running through the Malay Peninsula, Sumatra, Java, Timor, Cape Londonderry (Australia), Tasmania, and the 147° east longitude to Antarctica.

Pack ice—sea ice, especially that which is unattached to land and usually moving and shift to same extent

Pahoehoe—smooth, unbroken lava

Palinurid lobsters—spiny lobsters lacking claws and using antennae as pokers

Particulate organic matter (POM)—organic matter that is retained on a 0.45 um sieve; consists of living organisms (phytoplankton, bacteria and animals) and detritus (e.g., biogenic material in various stages of decomposition)

Parturition—act of giving birth

Patch reef—a coral boulder or a clump of corals unattached to a major reef structure

Pavement—flat, low relief, solid carbonate rock often covered by a thin layer of sand. The surface often has sparce coverage of macroalgae, hard coral, and other sessile invertebrates.

Pectoral fin—flipper; flattened fore-limb of a cetacean (supported by bone)

Pedal laceration—asexual reproduction where small masses of cells are pinched off the margins of the pedal disk; grow slowly and differentiate into small anemones

Pelage—the fur or hair covering a mammal

Pelagic—open ocean; the primary division or zone in the open ocean that encompasses the entire water column and is subdivided into the neritic (shallow) and oceanic (deep) zones

Penaeoid shrimp—small to large shrimp with five pairs of well developed legs, the first three pairs forming a pincer that is not particularly large

Peridinians—group of microscopic, unicellular, flagellated algae that are especially abundant in the ocean where some of these species comprise the deadly red tides

Peru Current—northerly extension of the cold Humboldt current off the Peruvian coast; divided into an inner coastal current and an outer oceanic current by a tongue of warm water from the South Equatorial countercurrent

Petroglyphs—drawings or carvings, usually on the surface of rock or caves, created by past civilizations

Phaeophyte—brown algae

Phocids—all of the "true" seals (i.e., "earless" species); from the Family Phocidae; generally used to refer to all recent pinnipeds that are more closely related to Phoca than to otariids or the walrus

Photic zone—the uppermost zone in the water where sunlight permits photosynthesis

Photo-identification—the use of photographs to identify animals individually; for example, dorsal fin shape and markings for dolphins and the underside of flukes for humpback whales

Photosynthesis—the autotrophic process in which solar energy is converted into organic matter (cellular energy) by synthesizing water and carbon dioxide with chlorophyll; plants, algae, and phytoplankton synthesize organic compounds via this process

Phototactic—movement of a whole organism toward (positive) or away from (negative) light

Phototrophic—capable of deriving energy from light

Phytophages—plant-eating

Phytoplankton—microscopic, photosynthetic plants and plant-like protists (algae) of the epipelagic and neritic zones that are the base of offshore food webs on which ultimately most shellfish, fish, birds, and marine mammals depend; drift with currents, but usually have some ability to control their level in the water column

Pinnacles—sharp pyramidal or cone-shaped rock partly or completely covered by water

Pinnipeds—seals, sea lions, and walruses

Piscivorous—a carnivorous animal that eats flesh

Planktivore—an animal that eats phytoplankton and/or zooplankton

Plankton—organisms (plant or animal) that drift in the water column and cannot propel or move themselves

Pleopods—one of paired abdominal appendages among crustaceans; may be used in swimming, fanning water, respiration or reproduction

Plumage—the feathers worn by a bird at any given time

Polychaete—class of soft-bodied, metamerically segmented coelomate worms; marine; may be free-swimming, errant, burrowing or tube dwelling

Polyp bail-out—dissociation and dispersal of coral polyps from adult colonies; asexual reproduction

Polyp balls—daytime corals release small balls of coral tissue which fall on the reef surface near the parent and grow into new colonies

Polyphagous—feeding on a wide variety of different foods or food species

Pomfrets—family of deep bodied, slightly compressed pelagic and bathypelagic fishes found in temperate and tropical oceans

Population—a group of individuals of the same species occupying the same area

Porifera—phylum of simple multicellular animals, called sponges; enclosed in a single central cavity or penetrated by numerous interconnected cavities; filter feeder, sessile; may be marine or freshwater

Posterior—situated near or toward the back of an animal's body

Potentially harvested coral reef taxa (PHCRT)—subcategory of MUS including coral reef organisms that are not known to be currently caught or for which very little fishery information is available; several CHCRT are also PHCRT; all genera or species in these taxa that are not listed as CHCRT are by default PHCRT

Practical salinity unit (psu)—the currently used dimensionless unit for salinity, replacing parts per thousand (ppt)

Predation—an interspecific interaction where one animal species (predator) feeds on another animal or pant species (prey) while the prey is alive or after killing it. The relationship tends to be positive (increasing) for the predator population and negative (decreasing) for the prey population

Prey—animal hunted or caught for food

Primaries—the outermost and longest flight feathers on a bird's wing, forming the wing tip and part of the outer trailing edge

Primary producer—an autotroph or organism able to utilize inorganic sources of carbon and nitrogen as starting materials for biosynthesis; uses either solar or chemical energy

Primary production—organic matter synthesized by organisms from inorganic substances

Proboscis—a flexible, elongated snout of certain animals

Protogynous hermaphrodite—sequential hermaphrodite in which the fish functions first as a female and then changes to a male

Pteropod—small, free-swimming, shelled mollusks which swims near the surface by means of a modified foot with wing-like appendages; related distantly to oysters and mussels

Pup—a young animal of various species, especially young pinnipeds

Pupping—the process of giving birth by pinnipeds

Pycnocline—a zone of marked water density gradient that is usually associated with depth

Ramp up—initial period of acoustic source operation during which the signal intensity is gradually increased

Range—the maximum extent of geographic area used by a species

Rare—a plant or animal restricted in distribution or number; in the case of sea turtles, rare means that a species occurs, or probably occurs, regularly within the region but in very small numbers

Ratify—to affirm or approve; in the case of a treaty, to agree to be bound by the treaty

Received level—level of sound that an organism receives

Re-cementation—asexual development in corals where pieces of branching and plate corals break off and reattach themselves to the surface of the reef where they continue to grow

Recreational fishing—fishing primarily for sport or pleasure

Red algae—division of algae (Rhodophyta) consisting of large multicellular, structurally complex photosynthetic organisms that grow attached to rocks or other substrates; largely marine; some forms instrumental in formation of coral reefs by precipitating calcium carbonate; form large rocky masses

Reef crest—shallow portion of a bank/barrier reef that is seaward of the lagoon

Reef flat—shallow (semi-exposed) area between the shoreline intertidal zone and the reef crest of a fringing reef. This zone is protected from the high-energy waves commonly experienced on the shelf and reef crest

Reef front—the fore reef area including the buttress reef, the reef terrace, reef escarpment, and reef slope.

Reef slope—zone of the fore reef occurring below the reef escarpment which is the steeply-sloped transition between the fore reef terrace and the fore reef slope. The fore reef slope is steeply sloped and occurs in water depths of 55 m to 60 m

Relief—the inequalities (elevations and depressions) of the sea bottom

Remigration interval—the amount of time between successive sea turtle nesting seasons

Rhodophyte—red algae

Robust—powerfully built

Rookery—an animal's breeding ground; it is the specific beach on which they nest (turtle) or pup (pinniped)

Rorqual—any of six species of baleen whales (the minke, blue, humpback, fin, Bryde's, or sei whale) belonging to the Family Balaenopteridae; characterized by a variable number of pleats that run longitudinally from the chin to near the umbilicus; the pleats expand during feeding to increase the capacity of the mouth

Rostrum—the snout or beak of a cetacean; in fish, a forward projection of the snout

Saddle—a light-colored patch behind the dorsal fin of some cetaceans

Salinity—the concentration of salt in water, measured in practical salinity units (psu)

Salt marsh—coastal ecosystem that is inundated by seawater for some period of time; plants in this ecosystem have special adaptations to survive in the presence of high salinities.

Sargassum—a genus of brown algae commonly found in temperate and tropical waters

Scavengers—an organism that feeds on carrion or organic refuse

School—a social group of fish, drawn together by social attraction, whose members are usually of the same species, size, and age; the members of a school move in unison along parallel paths in the same direction

Scleractinian—stony coral, Class Anthozoa, Order Scleractinia; solitary or colonial coral that can host symbiotic algae (zooanthellae) and form coral reefs

Sclerosponge—slow growing calcareous organisms who secrete their skeletons in carbon and oxygen isotopic equilibrium with their environment and can provide proxy records of salinity and water temperature over a 100 to 1000 year time range

Scutes—long, thickened scales that cover underlying bony plates of carapace and plastron of sea turtles that are used for protection

Sea anemones—large, heavy, complex polyps that belong to the cnidarian Class Anthozoa

Sea surface temperatures (SST)—the temperature of the layer of seawater (approximately 0.5 m deep) nearest the atmosphere

Seagrass—submerged aquatic vegetation that form extensive underwater meadows (or beds) found in shallow-water depths and various temperatures and salinity ranges

Seamount—an undersea mountain rising more than 914 m from the sea floor, but having a summit at least 305 m below sea level (in contrast to an island)

Seaweed—any macroscopic marine alga or sea grass

Sediment—solid fragmented material, either mineral or organic, that is deposited by ice, water, or air

Serial Spawning—fish that spawns in bursts or pulses more than once in a spawning season in response to an environment stimulus

Sessile—attached to a substrate; non-motile for all or part the life cycle

Sexual maturity—the state in which an animal is physiologically capable of reproducing

Sexually dimorphic—differences in the appearance of the sexes of a species; size differences are a primary difference where males are generally larger than females; other differences may be in body shape and color

Shallow water—water that is between the shore and the continental shelf break or shallower than 200 m

Shelf break—region where the slope of the seabed rapidly changes from gently sloping to steeply sloping and the continental shelf gives way to the continental slope; the world-wide average water depth at which the shelf break is found is 155 m, but on average, the shelf break usually occurs between 100 to 200 m water depth

Shelf break region—the geographic area surrounding the continental shelf break and including both the outer continental shelf and upper continental slope

Shoals—a submerged ridge, bank, or bar consisting of, or covered by, unconsolidated sediments (mud, sand, gravel) which is at or near enough to the water surface to constitute a danger to navigation

Siliceous—composed of silica

Silicoflagellates—planktonic marine chromists that are both photosynthetic and heterotrophic with internal silica skeletons composed of a network of bars that resemble those of radiolarians but are much less complex; widely distributed throughout the world ocean

Soft corals—colonial corals of the Class Anthozoa, subclass Octocorallia, Order Alcyonacea; soft colony, typically branched, composed of a thick jelly-like material containing skeletal spicules

Source level—the acoustic pressure that would be measured at a standard distance (usually 1 m) from a point source radiating the same amount of sound as the actual source

South Pacific—the part of the Pacific Ocean found south of the Equator

Spawn—the release of eggs and sperm during mating

Species—population or series of populations of organisms that can interbreed freely with each other but not with members of the other species

Species diversity—the number of different species in a given area

Spheroid—earth shaped

Sponges—any of numerous primitive, chiefly marine animals of the Phylum Porifera, characteristically having a porous skeleton composed of fibrous material or siliceous or calcareous spicules and often forming irregularly shaped colonies attached to an underwater surface

Standard deviation—a statistical measure of the amount by which a set of values differs from the arithmetical mean; simply, how widely values are dispersed from the mean

Stenella—the genus of oceanic dolphins consisting of striped, Atlantic spotted, pantropical spotted, Clymene, and spinner dolphins, which are similar in appearance

Stenellid—refers to dolphins of the Genus *Stenella*

Stenopodidean shrimps—a small shrimp with all five pairs of legs well developed, the first three pairs forming a pincer and the third being huge and massive

Stock—a group of individuals of a species that can be regarded as an entity for management or assessment purposes; a separate breeding population of a species

Stock structure—the genetic diversity of a stock

Stomatopods—group of predatory marine crustaceans that comprises the mantis shrimp, elongate, flattened and shrimp-like or lobster-like organisms with enlarged anterior pincers whose outer joints fold back against the basal joints in the praying mantis

Stony corals—see scleractinian

Stranding—the act where marine mammals or sea turtles accidentally come ashore, either alive or dead

Strategic stock—any marine mammal stock: (1) from which the level of direct human-caused mortality exceeds the potential biological removal level; (2) which is declining and likely to be listed as threatened under the Endangered Species Act; or (3) which is listed as threatened or endangered under the Endangered Species Act or as depleted under the Marine Mammal Protection Act

Subadult—maturing individuals that are not yet sexually mature

Subduction—the process of one lithospheric plate descending beneath another

Sublittoral—benthic region extending from mean low waters to a depth of about 200 m

Submarine canyon—narrow, deep depression or steep-sided valley cut in the continental shelf or slope formed by river of glacial erosion before the shelf was submerged

Subpopulations—an identifiable fraction or subdivision of a population

Subsistence fishing–fishing primarily to obtain for personal use rather than for sale or recreation

Substrate—the material to which an organism is attached or in which it grows and lives; also, the underlying layer or substance

Subtidal—marine or estuarine environment that lies below mean low-water; always submerged in a tidally-influenced area

Subtropical—the regions lying between the tropical and temperate latitudes

Suction feeding—capture of prey using suction, generally with the tongue employed as a piston to create a vacuum pressure

Surge—long wave, which is longer than wind wave, but shorted than tidal wave

Symbiont—the smaller participant in a symbiotic relationship; living in or on the host

Sympatric—species or subspecies occurring together; having overlapping areas of distribution

Tabulate—arrange in tabular form; cubit or shape with a flat surface

Talus—rock debris at the base of a cliff

Taro—a tropical food plant whose potato-like root is the basis for poi, a staple of Hawaiian cooking

Taxa (taxon)—a defined unit (e.g., species, genus, or family) in the classification of living organisms

Taxonomy—the study of the rules, principles, and practice of classification, especially of living organisms

Teleost—bony fish in the of the subclass Teleostei

Temperate—the region of the Earth at the mid-latitudes that is characterized by a mild, seasonally changing climate

Temporary threshold shift (TTS)—a temporary impairment in hearing ability caused by exposure to strong sounds

Terrigenous—derived from land or a continent

Territory—an area occupied exclusively by one animal and defended by aggressive behavior or displays

Thalliod—having no roots, stems, or leaves

Thermocline—the depth in the ocean (water column) in which there is an abrupt temperature change

Thermohaline circulation—density-driven water circulation caused by differences in temperature and/or salinity

Thermoregulatory—an organism's ability to maintain a specific body temperature regardless of the environmental temperature

Threatened species—any plant or animal species likely to become endangered within the foreseeable future throughout all or a part of its range; the authority to designate a species as threatened is shared by the U.S. Fish and Wildlife Service (terrestrial species, sea turtles on land, manatees) and National Marine Fisheries Service (most marine species) under provisions of the Endangered Species Act

Tidepools—pool of waters remaining on beach or reef after recession of tide

Topography—physical features of the ocean floor, such as mounds or ridges

Trade winds—persistent tropical winds that blow from the subtropical high pressure centers towards the equatorial low

Traffic separation scheme—a plan, generally internationally agreed on, by which vessels in congested areas use one-way lanes to lessen the danger of collisions

Transverse fission—asexual reproduction of two genetically similar individuals

Trawl net—a towed fishing gear or net that consists of a cod-end or bag for collecting the fish or other target species; trawls can be towed at any depth of the water column

Trophic level—a step in the transfer of food or energy within a chain

Trophodynamics—study of the energy relationships of feeding strategies and food webs

Tropical—the geographic region found in the low latitudes (30° north of the equator to 30° south of the equator) characterized by a warm climate

Tsunami—a great sea wave produced by a submarine earthquake, volcanic eruption, or large landslide

Tunicates—any of various chordate marine animals of the subphylum Tunicata or Urchordata having a cylindrical or globular enclosed in a tough outer covering (i.e., sea squirts and salps)

Tursiops—the genus of bottlenose dolphins comprised of the common bottlenose dolphin (*Tursiops truncatus*) and the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)

Underwing—the underside of the wing

Unisexual—individuals that are both male and female

Unknown—for the MRA occurrence polygons, it is the area and habitats for which insufficient information is available to establish occurrence due to lack of survey effort (best judgment follows then whether the area would be anticipated to be of primary or secondary occurrence)

Upwelling—upward movement or rising of deep, usually nutrient- and oxygen-rich, water to the surface; may be caused by wind-forcing, divergent currents, or density differences

Uro-genital area—portion of ventral surface around and near the excretory and genital orifices

Urochordates—a subphylum of Chordata distinguished by having a notochord, a dorsal hollow nerve cord, gill slits, and a post-anal tail; sea squirts

Vagile—wandering, free motile, mobile

Vagrant—a wanderer, in the same sense of an animal moving outside the usual limits of distribution for its species or population

Ventral—relating to the underside (or belly side) of an animal

Vertebrates—animals with a backbone

Viviparous—type of development in which the young are born alive after having been nourished in the uterus by blood from the placenta

Warm water period—the period extending from 1 March to 30 September and is associated with warmer sea surface temperatures and little to no rainfall

Water column—a vertical column of seawater extending from the surface to the sea bottom

Water mass—a body of water that can be identified by a specific temperature or salinity

Weaning—the end of the lactation period; the process of changing from milk to a solid diet in juvenile mammals

Westerlies—the winds that blow from west to east at middle latitudes

Whale lice—amphipod crustaceans of the Family Cyanidae; adapted for living in crevices and other secure places on the skin of cetaceans (for example, gray whales), on which whale lice largely feed

Whistle—a narrow band frequency sound produced by some toothed whales and used for communication; they typically have energy below 20 kHz

Young-of-the-year (YOY)—a juvenile fish less than 1 year old

Zoobenthos—animals living in or on the sea bed

Zooplankton—ensemble of small animals that drift freely in the water column; the zooplankton is composed of a wide range of invertebrates and the larval forms of fish and shellfish

Zooxanthallae—diverse group of non-photosynthesizing organisms that drift freely in the water or its surface; zooplankton are composed of a wide range of invertebrates, including larval forms of fish and shellfish

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APPENDIX A: INTRODUCTION

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Appendix A-1. Data confidence and Hawaiian Islands OPAREA geographic information system (GIS) maps.

The level of data confidence is dependent upon three factors: precision, accuracy, and currency. Each of these three factors are in turn affected by all the variables involved in obtaining data and putting the data into a GIS in order to display the data on a map. Following is a brief description of the three main factors and some of the subsequent variables that figure into overall level of confidence.

- ***Precision***—Refers to whether or not the description of the data is specific or non-specific. It is possible to have data recorded very precisely but with very low accuracy. In other words we may say that 2 + 2 = 5.12546732, where the sum is given very precisely but inaccurately. GPS (global positioning systems) offer the highest level of precision for recording locations.

- ***Accuracy***—Refers to how well the data reflect reality. There may be 10 sightings of bottlenose dolphins in an area, but they may actually have been spotted dolphins. Even if the locations were precisely recorded, the data are still not accurate. Some variables that affect accuracy are who originally recorded the data (source reliability), how many people have processed/altered the data since it originated (number of iterations), and the method used to record the data.

- ***Currency***—Refers to how recently the data were obtained. Because recent developments in equipment and methods have improved precision and accuracy, confidence is higher for data that have been recorded more recently.

Hawaiian Islands OPAREA Map Examples	Description of Map Data	Confidence Level
Bathymetry, Sea Surface Temperature, Chlorophyll, Benthic Habitats, Marine Mammal and Sea Turtle Occurrence Maps, Maritime Boundaries, Marine Managed Areas	Data from original/reliable sources. Provided in a digital format with geographic coordinates given. Identified as "*source data*" in map captions.	**High** 103 maps (70% of total number of maps)
Seismic Activity, Geologic Features, Dive Sites	First- or second-hand data sources. Locations obtained through scanning geo-referenced* maps. Identified as "*source map(s) scanned*" in map captions.	**Medium** 17 maps (12% of total number of maps)
EFH Maps (majority), Migration Maps, Fisheries Maps	First- or second-hand data sources. Locations obtained by digitizing from written descriptions with no coordinate data or by altering and/or interpreting raw data. Identified respectively as "*source information*" or "*map adapted from*" in map captions.	**Low** 26 maps (18% of total number of maps)

* Geo-referenced–Refers to data, maps, and images with points that can be matched to real world coordinates so that the data can be accurately positioned in a GIS.

Appendix A-2. Map projections.

Since understanding the role map projections play in the creation of valid and usable maps is so critical, further explanation of this issue is provided. A geographic reference system (such as latitude and longitude) is based on the angles measured from the earth's center. A planar coordinate system, on the other hand, is based on measurements on the surface of the earth. To meaningfully transfer real world coordinates (in three dimensions) to planar coordinate (two dimensions), a transformation process has to be applied. This transformation process is called a projection. Such a transformation involves the distortion of one or more of the following elements: shape, area, distance, and/or direction. The user typically dictates the choice of a projection type to ensure the least distortion to one or more of the four elements. Choice of a particular projection is dictated by issues such as the location of the place on Earth, purpose of the project, user constraints, and others.

The length of one degree of longitude will vary depending on what latitude on Earth the measurement is taken. The geographic coordinate system measures the angles of longitude from the center of the Earth and not distance on the Earth's surface. One degree of longitude at the equator measures 111 km versus 0 km at the poles. Using a map projection mitigates this difference or seeming distortion when using geographic coordinates. However, when multiple data sources with multiple projection systems are used, the most flexible system to standardize the disparate data is to keep all data unprojected. Thus, the maps in this MRA are untransformed, meaning they are shown unprojected on the map figures and their associated geographic data are delivered unprojected.

Since the measurement units for unprojected, geographic coordinates are not associated with a standard length, they cannot be used as an accurate measure of distance. Since the maps in the assessment report are in geographic coordinates, the map figures should not be used for measurement and the scale information only provides approximate distances. The map scales and reference datum used on all maps in this MRA are presented in nautical miles.

Appendix A-3. Overview of research efforts that provide occurrence information for marine mammals and sea turtles in the Hawaiian Islands OPAREA.

To subjectively determine the areas of occurrence for marine mammals and sea turtles in the Hawaiian Islands OPAREA, attempts were made to compile available records from aerial and shipboard survey sightings, strandings, incidental fisheries bycatch, taggings, pinniped and sea turtle haulout sites, and miscellaneous/opportunistic encounters in the OPAREA and vicinity. The following is intended to be a review of the many comprehensive research efforts conducted and/or sponsored by federal, state, and academic institutions directed to the marine mammal and sea turtle species here. For a variety of reasons, it was not possible to obtain every data source in existence; however, multiple data sets were collected (**Table A-1**). Comprehensive data sources that were available for inclusion in this MRA are described below. The occurrence polygons were based on both the aerial and shipboard survey (on-effort) data as well as known habitat preferences of individual species around the Hawaiian Islands.

Aerial and Shipboard Surveys

Aerial and shipboard surveys constitute the majority of the marine mammal data collected for this MRA. Henwood and Epperly (1999) and Forney (2002) provide brief descriptions of how aerial and shipboard surveys are conducted. Aerial or shipboard observers collect line-transect data during daylight hours, weather permitting (i.e., no rain, Beaufort sea state <4). Surveys are conducted along pre-designated transect lines following established sampling methods that allow for abundance estimates in an area of interest. Any animal sightings that occur while the observation platform (e.g., ship or plane) is traveling along the transect line and observers are actively searching for animals are noted as “on-effort” sightings, and can be included when estimating abundances and/or densities in an area. Any animal sightings that occur while the observation platform is diverted from or in transit to the transect line are recorded as “off-effort” sightings. Buckland et al. (2001, 2004) provide in-depth explanations of how abundance estimates are made using line-transect survey methods.

To meet the mandate established in Section 117 of the MMPA, the NMFS must prepare, in consultation with regional Scientific Review Groups, stock assessment reports for each marine mammal stock that occurs in U.S. waters. These stock assessment reports contain a description of the stock, information on its distribution, as well as a minimum population estimate (Wade and Angliss 1997). One of the primary ways the NMFS collects marine mammal population data to use in stock assessment reports is by conducting aerial and shipboard surveys. The typical goal of an aerial or shipboard survey is to estimate the overall density or abundance of a given marine mammal population. Aerial and shipboard surveys are appropriate when little is known about the distribution and abundance of a population or species over relatively large areas. Such surveys help identify “hot spots” for future studies. Surveys can then be conducted to monitor trends in seasonal or annual variations in distribution and abundance patterns.

The NMFS is also responsible for assessing and monitoring sea turtle stocks, which requires distribution and population estimates for determination of the status of stocks in relation to past and future human activities. While aerial and shipboard surveys may not be the most optimal methods to estimate sea turtle population sizes, sighting records from these types of surveys often provide valuable information that can be used to determine distribution and life history patterns.

Aerial and shipboard surveys for which marine mammal and sea turtle occurrence records and survey effort data were available are listed in **Table A-1**. These surveys primarily cover nearshore waters surrounding all of the MHI, with far less survey effort being conducted in waters of the OPAREA that are located a good distance offshore (especially near the limits of the U.S. EEZ). The waters closely surrounding the MHI have been surveyed more intensely during fall and winter (October through February) than during spring and summer (March through September), presumably due to the annual presence of humpback whales in Hawaiian waters during those months. The waters surrounding Nihoa have not been the subject of any recent aerial or shipboard surveys (**Figures A-1** and **A-2**).

Table A-1. Inventory of the marine mammal and sea turtle data sources included in the marine resources assessment for the Hawaiian Islands OPAREA.

DATA SOURCE	RECORD DATES	EFFORT DATA AVAILABLE
Aerial Surveys		
MHI statewide surveys (including the Acoustic Thermometry of Ocean Climate Marine Mammal Research Program [ATOC MMRP] surveys)	1993, 1995, 1998, 2000, 2003	√
North Pacific Acoustic Laboratory (NPAL) surveys	2001-2004	√
Pacific Missile Range Facility (PMRF) surveys	2002	√
Shipboard and Boat-Based Surveys		
NMFS-SWFSC Monitoring of Porpoise Stocks (MOPS) surveys	1986-1987	√
NMFS-SWFSC *Stenella* Abundance and Research (STAR) surveys	1998-2000, 2003	√
Cascadia Research Collective (CRC) Hawaiian odontocete surveys	2000-2005	√
NMFS-SWFSC Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS)	2002	√
Cetos Research Organization surveys off Kaua‘i, Ni‘ihau, and O‘ahu	2005	√
Aerial and Ground-Based Surveys		
NMFS-PIFSC aerial and ground-based surveys for Hawaiian monk seals	2000-2001	
Strandings		
NMFS Marine Mammal Health and Stranding Database	1923-2004	
NMFS-PIFSC Marine Turtle Research Program (MTRP) Stranding Database	1982-2003	
Incidental Fisheries Bycatch		
NMFS-PIFSC Hawai‘i Longline Observer Data System (LODS)	1994-2005	
Miscellaneous Data Sources		
North Pacific Right Whale Database	1900-1999	
NMFS Platforms of Opportunity Program (POP)	1976-1997	
Pacific Whale Foundation (PWF) Wild Whale and Dolphin Research Project	2001-2002	
PMRF Hawaiian monk seal and green turtle basking/nesting sites	2004	
Published Literature and Personal Communications		
Edmondson	1948	
Richards	1952	
Pryor et al.	1965	
Shomura and Hida	1965	
Hubbs et al.	1973	
Balazs	1978	
Shane et al.	1993	
Mobley et al.	1996, 2001b	
McDonald and Fox	1999	
Migura and Meadows	2002	
Ohizumi et al.	2002	
Maldini	2003a	
Wilson	2003	
Fertl (personal communication)	2004	
Forney	2004	
Kubota	2004, 2005a, 2005b	
Anonymous	2005	
Baird et al. (unpublished data)	2005a	
Boulis (personal communication)	2005	
Fujimori	2005	
Leone	2005	
Parrish (personal communication)	2005	
Salden (personal communication)	2005	

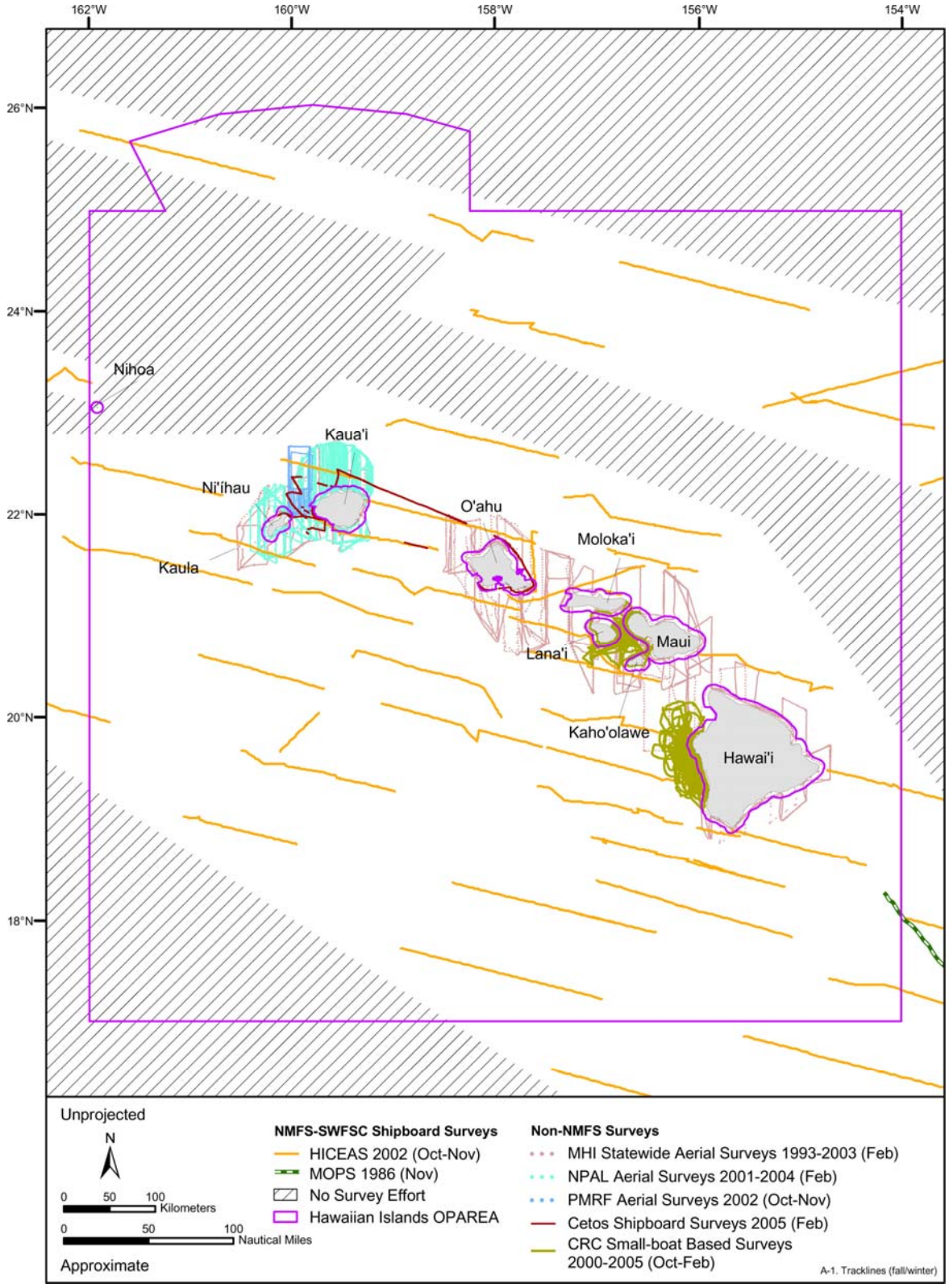

Figure A-1. On-effort tracklines for aerial and shipboard surveys conducted in the Hawaiian Islands OPAREA during fall/winter (October through February). Source data: Marine Mammal Research Consultants, Ltd. (2004), NMFS-SWFSC (2004a), Cetos Research Organization (2005a, 2005b), and CRC (2005).

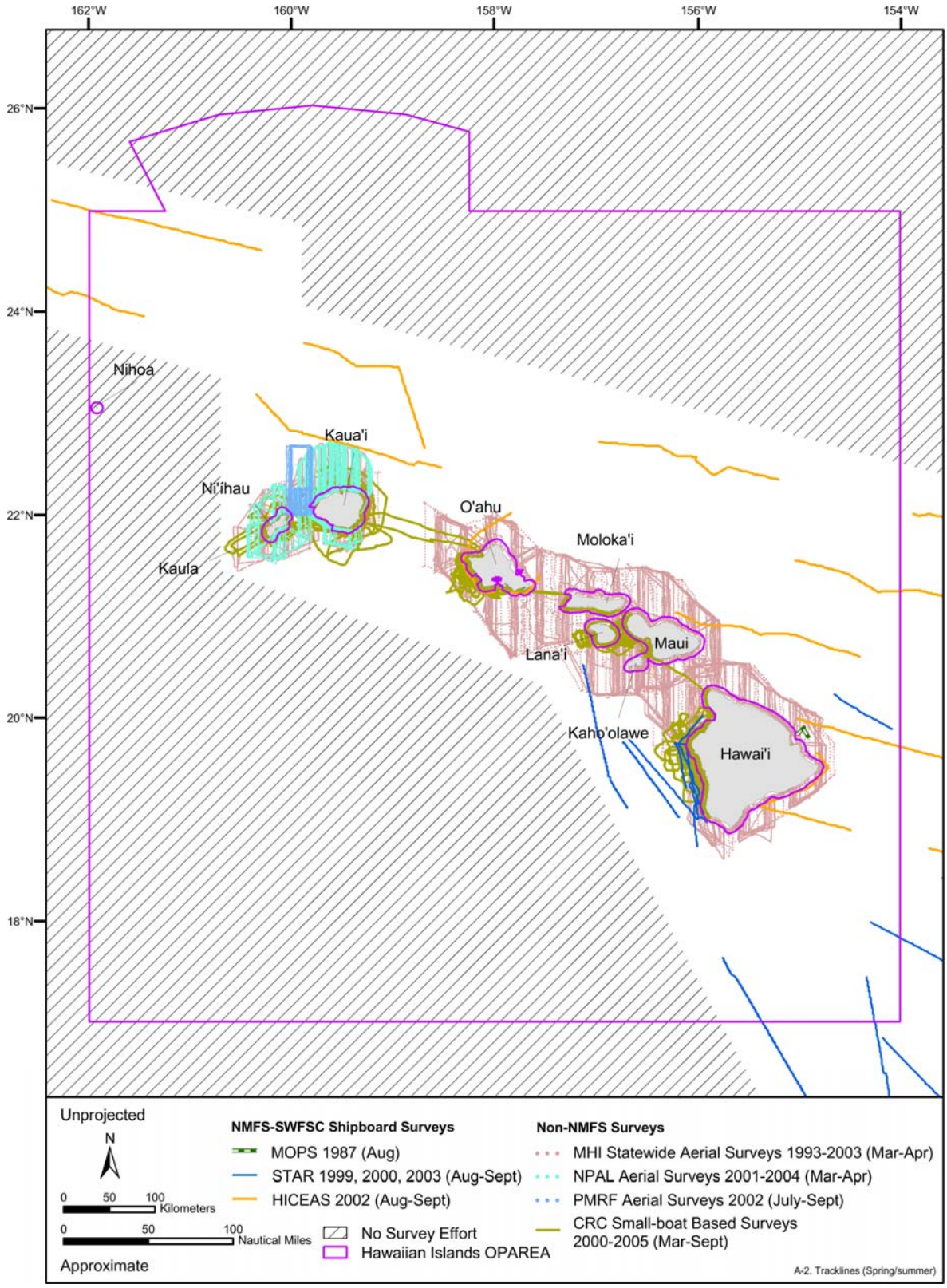

Figure A-2. On-effort tracklines for aerial and shipboard surveys conducted in the Hawaiian Islands OPAREA during spring/summer (March through September). Source data: Marine Mammal Research Consultants, Ltd. (2004), NMFS-SWFSC (2004a, 2004b, 2005), and CRC (2005).

- **Aerial Surveys**

In the Hawaiian Islands OPAREA, aerial surveys have been conducted by a number of different organizations for a wide variety of purposes. The most comprehensive aerial survey programs in the OPAREA have been performed by an interdisciplinary research team led by Dr. Joseph Mobley, founder of Marine Mammal Research Consultants, Ltd. and professor at the University of Hawaiʻi-West Oʻahu. The majority of these surveys were flown in order to gather baseline data on the distribution, abundance, and diversity of marine mammals (most notably humpback whales [*Megaptera novaeangliae*]) in areas where surveys had not yet been conducted or where little survey effort had been expended previously. Other surveys were flown in order to monitor the potential impacts of underwater sound sources on marine mammals in areas where the sound sources were operating.

- A research team led by Mr. Kenneth Norris flew 23 **aerial surveys around the entire coast of Hawaiʻi**, usually on a bi-weekly basis, from 22 August 1979 to 31 August 1980. These aerial surveys were designed to provide census data and to study the group structure and behavior of spinner dolphin (*Stenella longirostris*) schools at times of the day when they tend to inhabit nearshore waters. Surveys were flown alternately clockwise and counterclockwise around the island to standardize for the tendency of spinner dolphins to move offshore in the late afternoon. Three additional flights in August and September 1980 were dedicated to the examination of dolphin school structure and movements along the Kona shore. All sightings of dolphins, whales, sharks, and rays were recorded during these surveys (Norris et al. 1994). Marine mammal occurrence data from these surveys were not available for inclusion in this MRA.

- In late June and early July 1989, Drs. Stephen Leatherwood and Randall Reeves conducted **aerial surveys for cetaceans along the leeward shores of Hawaiʻi, Lānaʻi, and Oʻahu** where scientists had reported seeing false killer whales (*Pseudorca crassidens*). The objective of these surveys was to determine whether or not there were at least 400 false killer whales present in Hawaiian waters. Once located, groups of cetaceans were orbited until species identifications and minimum counts or estimates could be made. There were 82 cetacean sighting events involving at least ten different species during the eight-day survey period (Leatherwood and Reeves 1989). Rough locations of cetacean sightings were hand-drawn on maps within the survey report for this study; however, the sighting locations were not at an acceptable level of resolution for incorporation into this MRA. Specific dates for each sighting event were also lacking. Dr. Randall Reeves was contacted about the availability of this data in either electronic or tabular form. Unfortunately, he could not locate the raw data due to its age.

- From 1993 to 2003, at least five **MHI statewide surveys** were flown to investigate the abundance and distribution of marine mammals in Hawaiian waters. These line-transect aerial surveys, which were performed throughout the waters adjoining the eight MHI out to approximately 46 km from shore, are the most extensive systematic surveys of marine mammals conducted to date in the Hawaiian Islands OPAREA (Mobley et al. 1994). In 1993, 1995, and 1998, the Acoustic Thermometry of Ocean Climate (ATOC) Marine Mammal Research Program (MMRP) sponsored these surveys to establish baseline parameters of marine mammal distribution and abundance around the MHI and to assess the possible effects of ATOC transmissions on these animals. The ATOC MMRP also sponsored aerial surveys in 1994, but those were limited to the 40-km range around the ATOC sound source off Kauaʻi (Mobley and Grotsfendt 1994). Following the cessation of ATOC transmissions in October 1999, the MHI statewide surveys began being sponsored by other agencies (ONR 2001). The Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Scientific Research Program and the HIHWNMS sponsored the statewide surveys in 2000 and the Office of Naval Research (ONR) sponsored them in 2003.

  All statewide aerial surveys were flown between late February and early April. The MHI were divided up into four main regions: Big Island (Hawaiʻi), Four Island (Molokaʻi, Lānaʻi, Maui, and Kahoʻolawe), Oʻahu/Penguin Bank, and Kauaʻi/Niʻihau. Each region generally took a full day to survey. Although the surveyors recorded sighting locations for all marine mammals and sea turtles that were observed, the primary focus was on two endangered cetacean species,

humpback whales and sperm whales (*Physeter macrocephalus*) (ARPA 1995; Mobley et al. 2000, 2001a). Dr. Joseph Mobley provided sighting and effort data from these five statewide aerial surveys in coordinate form. He was not able to provide sighting and effort data for the 1994 ATOC MMRP-sponsored surveys off Kaua‘i.

- Twelve **aerial surveys for Hawaiian odontocetes** were performed **around the island of O‘ahu** between July 1998 and June 2000. These aerial surveys covered ten months of the year and were flown at altitudes between 153 and 213 m. The overall survey effort resulted in 255 sighting events, the majority of which were of humpback whales. Odontocetes observed during the surveys included short-finned pilot whales (*Globicephala macrorhynchus*), spinner dolphins, bottlenose dolphins (*Tursiops truncatus*), pantropical spotted dolphins (*Stenella attenuata*), rough-toothed dolphins (*Steno bredanensis*), beaked whales (*Mesoplodon* spp.), and false killer whales (Maldini 2003b). Sighting and effort data were requested from Dr. Joseph Mobley, but were not made available.

- The ONR funded aerial surveys to be conducted around the islands of Kaua‘i and Ni‘ihau from 2001 to 2004 as part of the marine mammal monitoring program of the **North Pacific Acoustic Laboratory (NPAL)**. Eight weekly surveys were flown each year between 1 February and 31 March, which is the period of peak residency of humpback whales. Although the survey mission was to locate and identify all marine mammals present in the study area, the results for humpback whales (which represented over 80% of all sightings) were of most interest. In 2001, the NPAL source was not transmitting. This allowed for the determination of baseline conditions (or normal patterns of distribution) within the study area. From 2002 through 2004, the NPAL source was transmitting. This gave researchers an opportunity to determine whether NPAL transmissions resulted in the displacement of whales from the study area or a change in whale distribution within the study area (Mobley 2005). Marine mammal sighting records and survey effort data were provided for inclusion in this MRA by Dr. Joseph Mobley.

- From 12 July through 17 November 2002, aerial surveys of marine mammals were performed over the BSURE and BARSTUR ranges off **Pacific Missile Range Facility (PMRF)** Barking Sands, Kaua‘i (Mobley 2004). These surveys were conducted as part of the Marine Mammal Monitoring on Navy Undersea Acoustic Ranges (3MR) program (Jarvis n.d.). The missions of this program were to use instrumented underwater naval ranges to detect and localize vocalizing marine mammals and then to correlate those detections with visual sightings from aerial surveys. The specific objectives of the PMRF surveys were to identify the species and record the positions and compositions of all marine mammals sighted. Only three cetacean species were positively identified during these surveys: pantropical spotted dolphins, spinner dolphins, and short-finned pilot whales. Dr. Joseph Mobley supplied sighting and effort data for these surveys as well.

➢ **Shipboard and Small-Boat Based Surveys**

The NMFS-SWFSC, with its several large research vessels, has conducted the majority of the shipboard surveys in the oceanic waters of the Hawaiian Islands OPAREA. Closer to shore, however, research institutions with smaller vessels have conducted numerous small-boat based surveys over the past three decades. Oftentimes these smaller scale surveys include acoustic monitoring, photo-identification, mark-recapture (i.e., tagging), and biopsy sampling components. The Pacific Whale Foundation (PWF), Cascadia Research Collective (CRC), Wild Whale Research Foundation, and Kula Nai‘a Wild Dolphin Research Foundation are just a few of the many organizations that possess extensive sighting databases and photo-identification catalogues for marine mammals that have been amassed through the use of small-boat based surveys around the Hawaiian Islands.

- The **first complete censuses of wintering humpback whales in the MHI** were undertaken from 24 February to 6 March 1976 and from 8 to 20 February 1977 aboard the fishing research vessel *Easy Rider*. A total of 373 whales were counted during the first survey while 411 were counted during the second. Survey transects approximately coincided with the 91 m isobath, about midway between the shore and the seaward edge of the banks. Positions of whale pods

were estimated visually and then plotted on charts accurate to within 0.8 km. Other cetaceans sighted during these surveys included pygmy killer whales (*Feresa attenuata*), pantropical spotted dolphins, spinner dolphins, bottlenose dolphins, and false killer whales (Wolman and Jurasz 1977; Rice and Wolman 1979). Marine mammal sighting data collected during these boat-based surveys were not available for use in this MRA.

- Between 1986 and 1990, the NMFS-SWFSC completed a long-term, large-scale research effort known as the **Monitoring of Porpoise Stocks (MOPS)**. The NMFS-SWFSC utilized the NOAA ships *David Starr Jordan* and *McArthur* between late July and early December each year. These surveys were designed to estimate the abundance of several stocks of cetaceans in the eastern tropical Pacific Ocean, namely those dolphin species that were being incidentally taken in the purse seine fishery for yellowfin tuna (Wade and Gerrodette 1993). In 1986 and 1987, the MOPS surveys aboard the *McArthur* (Cruises AR 8690-12 and AR 87-0812, SWFC Observer Cruises 990 and 1080) extended into Hawaiian waters since Hilo was a port of call (Holt and Jackson 1987, 1988). Sighting data and tracklines from these shipboard surveys were provided by Drs. Steve Reilly and Jay Barlow of the NMFS-SWFSC.

- The **Kula Naiʻa Wild Dolphin Research Foundation** has been studying spinner dolphins in the waters surrounding the island of Hawaiʻi for the past 30 years, the longest-running study of spinner dolphins in the world. This work was originally spearheaded by Mr. Kenneth Norris, Dr. Randall Wells, and Ms. Melany Würsig, but is now overseen by Dr. Jan Östman-Lind and Ms. Ania Driscoll-Lind. Currently, the foundation is also investigating populations of pantropical spotted dolphins and bottlenose dolphins. Researchers are building photo-identification catalogues of unique individuals and studying the population structure, habitat usage, movements, and residency patterns of these three dolphin species. Small-boat based surveys off the west coast of Hawaiʻi have been conducted by the foundation in 1989, 1992, and most recently from March through November 2003. Sighting locations from the 2003 surveys are depicted in Östman-Lind et al. (2004); however, specific dates and coordinates for the sightings were not. Occurrence records from recent Kula Naiʻa Foundation surveys were requested from Dr. Jan Östman-Lind and Ms. Ania Driscoll-Lind, but were not available for inclusion in this MRA.

- The PWF's **Wild Whale and Dolphin Research Project** began in 1996, with an initial focus on documenting the abundance, diversity, social dynamics, and behaviors of wild spinner dolphins through a photo-identification and observation study off the coast of Lānaʻi. Since then, the project has widened in scope to also include bottlenose dolphins, pantropical spotted dolphins, false killer whales, and melon-headed whales (*Peponocephala electra*) (PWF 2005a). In 2001 and 2002, the PWF conducted systematic small-boat based line-transect studies on odontocetes around the islands of Molokaʻi, Lānaʻi, Maui, and Kahoʻolawe. The pilot study, performed in October and November of 2001, showed that the area around Lānaʻi had the highest density of odontocetes. As a result, survey efforts in 2002 were designed to estimate odontocete density and abundance in that specific area (Roberts and Meadows 2004). Sighting data from these shipboard surveys were provided to the Navy by Ms. Alison Roberts of the PWF. However, survey tracklines were not available for inclusion in this MRA.

- From 1998 to 2000 and also in 2003, the NMFS-SWFSC continued the ***Stenella* Abundance Research (STAR) Project**, a multi-year study designed to assess the status of dolphin stocks that were being taken as incidental catch by the yellowfin tuna purse seine fishery in the eastern tropical Pacific Ocean. This project began with a series of periodic surveys in the 1970s and includes the MOPS surveys from 1986 to 1990. The next STAR survey is scheduled for 2006. In 1998, the R/V *Endeavor* surveyed waters around the MHI as it made its way to Honolulu, one of the survey ports of call (NMFS-SWFSC 2004c). In 1999 and 2000, the NOAA ship *McArthur* did the same, as did the NOAA ship *McArthur II* in 2003. Occurrence data and survey effort information from these surveys were provided by Dr. Tim Gerrodette of the NMFS-SWFSC.

- Since 2000, an interdisciplinary research team led by Dr. Robin Baird (CRC) has conducted small-boat based **Hawaiian odontocete surveys** around the MHI. Agencies and institutions

involved in these surveys include the CRC, Hawai‘i Wildlife Fund, HIHWNMS, Island Marine Institute, NMFS-NMML, NMFS-SWFSC, University of Hawai‘i, and Wild Whale Research Foundation. Genetic, tagging, time-depth recorder, and photo-identification studies are currently being performed under this research program. Marine mammal species being studied include false killer whales, bottlenose dolphins, spinner dolphins, pantropical spotted dolphins, rough-toothed dolphins, melon-headed whales, short-finned pilot whales, Cuvier's and Blainville's beaked whales (*Ziphius cavirostris* and *Mesoplodon densirostris*), and dwarf and pygmy sperm whales (*Kogia* spp.). Dr. Robin Baird provided odontocete sighting records and survey effort information from small-boat based surveys conducted in the MHI between 2000 and 2005. The occurrence records provided for this MRA include several sightings of *Kogia* spp. that are also detailed in Baird (2005). More information on recent Hawaiian odontocete research in the MHI can be found in Baird et al. (2001, 2002, 2003, 2004, 2005b, 2005c, 2005d).

- From 27 July to 9 December 2002, the NMFS-SWFSC conducted the **Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS)** aboard the NOAA ships *David Starr Jordan* and *McArthur* (Cruises DS-02-07 and AR-02-07, SWFSC Cruise Numbers 1621 and 1622). The purpose of this line-transect survey was to determine the distribution and estimate the abundance of cetaceans within the Hawaiian EEZ by visual and acoustic methods. The HICEAS was the first comprehensive survey of marine mammals covering all waters within the EEZ surrounding the Hawaiian Islands (Barlow 2003; Barlow et al. 2004). Drs. Steve Reilly and Jay Barlow supplied marine mammal sighting records and survey effort information for these cruises while Dr. Lisa Balance and Mr. Robert Pitman, also with the NMFS-SWFSC, provided seabird counts by cruise leg. No sea turtle sightings were recorded during the HICEAS cruises.

- The **Structure of Populations, Levels of Abundance, and Status of Humpbacks (SPLASH)** project is an international cooperative effort to understand the population structure of humpback whales across the North Pacific Ocean, and to assess the status, trends, and potential human impacts to this population. SPLASH is a three-winter, two-summer research program that began in December 2003 and is projected to run through the summer of 2006. Sampling for the SPLASH project in the Hawaiian Islands is being coordinated and funded by the NOAA's HIHWNMS. The Sanctuary and its partner, the State of Hawai‘i, have contracted local humpback whale researchers, who have been consistently active in the region, to collect spatiotemporal data for SPLASH during winter months (i.e., the breeding season) when humpback whales are present in Hawaiian waters. These researchers comprise eight teams: Kaua‘i (1), O‘ahu (1), Penguin Bank (1), Maui (4), and Hawai‘i (1). During the winter 2004 survey, the different teams made an estimated 1,200 identifications and collected around 500 biopsy samples (HIHWNMS 2004a). Occurrence data from this program were not acquired for this MRA.

- From 17-24 February 2005, **Cetos Research Organization** teamed with Pelagikos, a non-profit organization that operates the R/V *Dariabar*, to conduct passive acoustic-visual **surveys of cetaceans off Kaua‘i, Ni‘ihau, and O‘ahu**. The primary goals of the study were to (1) conduct a preliminary pilot survey for cetaceans in deep waters (>183-4,572 m) where previous survey effort had been limited and (2) test and implement passive acoustic methods (complemented with standard visual survey methods) in order to maximize encounter rates of deepwater species (Norris et al. 2005). Using a dual hydrophone array system, researchers aboard the R/V *Dariabar* were able to detect vocalizations from target cetacean species. After locating a specific animal, the researchers noted its GPS location and then, when possible, photo-identified the animal and obtained a biopsy sample (Cetos Research Organization 2004). Marine mammal sighting locations, survey effort data, and a technical and cruise report from this eight-day field study were provided by Ms. Ann Zoidis and Mr. Thomas Norris from Cetos Research Organization.

➢ **Aerial and Boat-Based Surveys**

- Between November 1956 and July 1958, **Mr. Dale Rice (USFWS)** made frequent low-altitude reconnaissance flights over all of the NWHI from Nihoa to Kure Atoll. During that time he also traversed at least twice the entire length of the NWHI by ship. Although these aerial and boat-

based surveys were not dedicated to sighting marine mammals, Rice (1960) recorded several incidental observations of bottlenose dolphins in the waters surrounding the NWHI. Sightings were documented at Kure Atoll, Midway Atoll, Pearl and Hermes Reef, Laysan Island, and French Frigate Shoals. Bottlenose dolphins were not sighted around Nihoa during any of the excursions. As a result, occurrence records from Rice (1960) were not pursued for inclusion in this MRA.

- In 1975 and 1976, the University of Hawaiʻi's **Kewalo Basin Marine Mammal Laboratory (KBMML)** pioneered the scientific study of humpback whales wintering in the MHI through the use of aerial, shipboard, and underwater surveys (Herman and Antinoja 1977). Aerial surveys conducted between 1976 and 1980 provided the first complete description of seasonal trends in humpback whale distribution and abundance around various islands of the archipelago (Baker and Herman 1981). These surveys were conducted approximately every two weeks from January through April, corresponding to the time of year when most humpback whales were known to be present in Hawaiian waters. Mobley et al. (1999) also conducted aerial surveys for humpback whales in 1990, using methods consistent with those of 1976 through 1980 surveys. Small boat observations of wintering humpback whales in the Hawaiian Islands have been made annually since 1975 (Dolphin Institute 2002). Marine mammal occurrence data collected since the inception of the KBMML whale research program were requested from Dr. Lou Herman, KBMML Director, but were not available for inclusion in this MRA.

- The **Naval Ocean Systems Center (NOSC)** at Kaneʻohe, more often known for its physiological research on captive bottlenose dolphins, has also made attempts at determining the diversity and abundance of cetacean species present in Hawaiian waters through the use of aerial and boat-based surveys. From July through August 1976, staff from the NOSC conducted aerial (helicopter) surveys for marine mammals off the coast of Oʻahu. Species identifications, group sizes, geographic locations, and headings were recorded. These data were not available for inclusion in this report, but are referenced in an unpublished report by Simmons (Shallenberger 1981). In 1987, the NOSC performed a combined aerial and vessel survey of inshore waters adjacent to Oʻahu, Molokaʻi, Lānaʻi, Maui, and Hawaiʻi. Unpublished data from these surveys were also not available, but are briefly mentioned in Nitta and Henderson (1993).

- The PWF's **Hawaiian Humpback Whale Study** aims to investigate the distribution, seasonal abundance, and behavior of humpback whales in the nearshore waters off Maui, Lānaʻi, and Kahoʻolawe. Researchers with the PWF have been conducting field studies in the MHI since 1979. During that time they have photo-identified nearly 1,500 individual humpback whales. In addition, they have investigated the effects of human activities on the distribution and behavior of humpback whales; conducted aerial surveys to document distribution patterns and frequencies of different size classes of whales; carried out small boat-based surveys to document geographical preferences of mothers with calves; and collected recordings of humpback whale songs. Recent studies from 1997 through 2000 involved photo-identification efforts aboard small research vessels as well as investigations into whale watching activities and humpback whale/bottlenose dolphin interactions (PWF 2005b). Data from these humpback whale surveys were not available electronically.

➢ **Aerial and Ground-Based Surveys**

- In 2000 and 2001, the **NMFS-PIFSC** performed **aerial and ground-based surveys for Hawaiian monk seals** (*Monachus schauinslandi*) throughout the MHI. These were the first-ever systematic surveys into the abundance of this species in the MHI. All surveys were made during the summer and fall, after most births should have occurred and when the weather was most favorable. The 2000 survey was conducted using a twin-engine, high-wing aircraft at altitudes ranging from 30 to 150 m. The following year, a slower-moving helicopter was utilized as the survey platform to improve detection of seals (Baker and Johanos 2001, 2004). Sightings of Hawaiian monk seals as well as incidental observations of sea turtles and other marine mammals recorded during this study were provided by Mr. Jason Baker of the NMFS-PIFSC. Mr. Baker also supplied the locations of Hawaiian monk seal landing sites at Nihoa, where the species is also known to occur.

Strandings

- Marine mammal stranding networks are under the jurisdiction of the NMFS and are nominally based on the agency's administrative regions (Geraci and Lounsbury 1993). Wilkinson and Worthy (1999) discuss the genesis of marine mammal stranding networks in the U.S. while Nitta (1991) provides an historical overview of the marine mammal stranding network for the State of Hawai'i. Legal authority for U.S. stranding networks is contained in the MMPA. In the Marine Mammal Health and Stranding Response Act (in the 1992 Amendments to the MMPA), Congress made it a national policy to monitor the various factors affecting the health of marine mammal populations. Collection and analyses of stranded marine mammals have contributed much to what is known about each species (Becker et al. 1994). The Marine Mammal Health and Stranding Response Program, which is coordinated and managed by the NMFS, maintains a database of all cetacean and pinniped strandings in the Pacific Islands region, which includes the Hawaiian Islands, American Samoa, and Guam. The **NMFS Marine Mammal Health and Stranding Database** was received from Mr. Bradley Ryon, Resource Management Liaison with the NMFS-PIR. Nearly 400 stranding records for the Pacific Islands region from 1923 through 2004 were included in this data set. The marine mammal stranding locations were only available as locality descriptions (e.g., beach, bay, or landmark location); none of the records were available in coordinate (latitude/longitude) form. Most of the stranding records received are also listed in Maldini et al. (2005).

- Sea turtle strandings in the Hawaiian Islands are reported to the Marine Turtle Research Program (MTRP), a branch of the Protected Species Division of the NMFS-PIFSC. One of the many functions of the MTRP is to conduct a sea turtle stranding and salvage network for research and rehabilitation (NMFS-PIFSC 2005). Dr. George Antonelis, Chief of the Protected Species Division of the NMFS-PIFSC, provided sea turtle stranding records from 1982 to 2003, which were compiled by Mr. George Balazs, Team Leader of the MTRP. The **NMFS-PIFSC MTRP Stranding Database** includes over 3,800 stranding records for the MHI and NWHI, all of which are available only as locality descriptions.

Incidental Fisheries Bycatch

The NMFS has been using observers to record catch and incidental bycatch data aboard U.S. commercial fishing and processing vessels since 1972. The National Observer Program (NOP), which collects information on incidental bycatch of marine mammals, sea turtles, and seabirds, was established under the authority of the MMPA of 1972, the ESA of 1973, and the MSFCMA of 1976 (Carretta et al. 2004). Observers employed under this program have monitored fishing activities along all U.S. coasts and have collected data for a range of conservation, management, compliance, and economic issues (NMFS 2005). Observers are required to complete sighting forms, document the circumstances of capture, and obtain biological data (e.g., measurements, biopsy samples) on incidentally captured marine mammals, sea turtles, and federally protected seabirds. Observer data are then submitted to the NMFS Regional Offices (e.g., NMFS-PIR), which calculate official estimates and produce technical reports. Biological samples are sent to the NMFS Fisheries Science Centers (e.g., NMFS-PIFSC) for analysis.

Interactions between commercial fisheries and protected marine species have been documented around the Hawaiian Islands since the 1940s and were exacerbated during the 1970s and 1980s with the deployment of a deep-water buoy and other FADs off the Hawaiian coast. A longline fishery for tunas and billfish has burgeoned in the Hawaiian Islands since 1987, resulting in numerous interactions with protected species. Marine mammals, sea turtles, and seabirds take both bait and catch and may also become hooked by or entangled in longline fishing gear (Nitta and Henderson 1993).

In 1994, concern over sea turtle bycatch and under-reporting of takes led the NMFS to initiate a mandatory observer program for the Hawai'i-based longline fishery, which operates in the central North Pacific Ocean in an area extending roughly from 10°N to 45°N and 170°E to 140°W (Forney 2004). This ruling, passed as an amendment to the 1986 FMP for the Pelagic Fisheries of the Western Pacific Region, mandated that observers be placed aboard all Hawai'i-based pelagic longline vessels targeting tunas and billfish. Species that interact with this fishery include sea turtles (especially loggerheads, leatherbacks, and greens), seabirds (notably Laysan and black-footed albatrosses), and, to a lesser

extent, some cetaceans. In waters located far offshore, incidental bycatch records from commercial fisheries are often the only occurrence records available for protected species, especially sea turtles.

- A comprehensive set of incidental bycatch data, collected by the Pacific Islands Region Longline Observer Program and housed within the **Hawai'i Longline Observer Data System (LODS)**, was obtained from the NMFS-PIR and NMFS-PIFSC. The LODS is a complete suite of tools designed to collect, process, and manage fisheries data and information. Guided by the principles of the NOAA Data Quality Act, the LODS is the result of the collaboration and cooperation of scientists, data collectors, and information management experts across the Pacific Islands region (NMFS-PIR 2005a). The LODS includes both incidental bycatch and opportunistic sighting records of marine mammals, sea turtles, and seabirds aboard Hawaiian longline vessels since 1994 (NMFS-PIR 2005b).

Miscellaneous Data Sources

- The **North Pacific Right Whale Database** is a review of all available 20th century records of this species in the North Pacific Ocean. There has been a total of 1,965 recorded sightings since 1900; of these 988 came from the western North Pacific, 693 from the eastern North Pacific, and 284 had no location specified. Thirteen strandings (all but one from the western North Pacific) were recorded. Known catches for commercial or scientific purposes totaled 742 (331 in the western North Pacific, 411 in the eastern North Pacific). Overall, the data support the hypothesis that at least two stocks of right whales exist in the North Pacific (Brownell et al 2001). This database was provided by Ms. Caroline Good (Duke University) with the permission of Dr. Phillip Clapham (NMFS-Alaska Fisheries Science Center).

- The **NMFS Platforms of Opportunity Program (POP)** collects data on opportunistic sightings of marine mammals throughout the world (particularly in the North Pacific Ocean). POP sighting data are opportunistically collected aboard NOAA, Navy, and U.S. Coast Guard vessels as well as aboard commercial fishing and tourist boats (NMML 2004). Observer effort is dependent upon the level of interest of the observer and their workload. The National Marine Mammal Laboratory (NMML), a branch of the NMFS, assigns a species identification as either "sure," "likely," "unsure" or "not possible." Dr. Sally Mizroch of the NMML provided POP sighting data used in this MRA; these data only represent confirmed (i.e., "sure") sightings.

- The **NMFS Large Whale Ship Strike Database** is a collection of ship strike reports involving large whales from 1975 to present. Agency staff from the NMFS Northeast, Southeast, Northwest, Southwest, Alaska, and Pacific Islands Fisheries Science Centers and Regional Offices have contributed records to the database. In compiling this database, records of ship strikes are drawn from ship reports, marine mammal stranding reports, and NMFS Office of Law Enforcement reports. As of 2002, the database contained 292 records of confirmed or possible ship strikes to large whales, seven of which occurred around the Hawaiian Islands. Of those seven, six involved collisions with humpback whales. In an effort to use this database to better protect marine mammals, the NMFS intends to continue adding to the database as additional ship strike incidents occur (Jensen and Silber 2003). This database was unavailable for inclusion in the MRA.

- **Long-range hydrophone systems** have been in use for many years and their use in long-term studies of cetacean distribution is becoming more commonplace. Hydrophone studies have been conducted off several of the MHI including O'ahu, Maui, and Hawai'i. These studies record the vocalizations and echolocations of pantropical spotted dolphins, spinner dolphins, humpback whales, fin whales, blue whales, short-finned pilot whales, and sperm whales among others (Watkins and Schevill 1974; Thompson and Friedl 1982; Frankel and Clark 1998; Schotten et al. 2004). Hydrophones can provide indications of position for calling animals in both two and three dimensions. Occurrence data from hydrophone studies were not available from the sources referenced above.

- Since 1975, **Center for Whale Studies** researchers Ms. Deborah Glockner-Ferrari and Mr. Mark Ferrari have conducted annual studies on the behavior of humpback whales off the west coast of

Maui. Using non-invasive observational techniques, they take photographs, video, and biopsy samples in order to identify individual humpbacks (including both mothers and calves). These nonsystematic vessel surveys have shed light on essential facts on the life history, behavior, and reproductive cycles of these animals (Glockner-Ferrari and Ferrari 1987, 1990; HIHWNMS 2004b). Humpback sighting records from these surveys were not obtained for inclusion in this assessment.

- The **Hawai‘i Whale Research Foundation (HWRF)** is a small nonprofit organization that has conducted field research on the social affiliation, behavior, and communication of humpback whales around the Hawaiian Islands since 1978 (HWRF 2005a). The HWRF annually surveys waters off Maui (between 20°47’N and 21°12’N latitude and 156°33’W and 157°00’W longitude) from the second week of January through the end of April. Occasionally, the HWRF also surveys waters off the west coast of Hawai‘i, depending upon the availability of marine biologist Mr. Doug Perrine (Salden 2002). Surveys are conducted six days a week for an average of eight hours per day. Upon sighting whales, the HWRF research vessel closes to within 100 m of the pod in order to obtain fluke identification photographs. For each encounter, the following information is recorded: (1) encounter start and end time, (2) encounter start and end position (using a handheld GPS device), (3) number of humpbacks observed (including both adults and calves), (4) a behavior classification for the encounter, (5) summaries of identification and behavior photographs taken during the encounter, and (6) a narrative summary of behavioral interactions. These data are then entered into a computer database each evening for subsequent analysis (HWRF 2005b). HWRF annual reports from 1989 through 2002, all of which were submitted to the NMFS, are available online at http://www.hwrf.org/publications.html. Occurrence data collected during HWRF surveys for humpbacks were not acquired for this MRA.

- The Marine Mammal Research Program of the **NMFS Honolulu Laboratory** began research on **Hawaiian monk seals at most major reproductive sites in the NWHI** in 1980 (Lisianski Island), 1981 (Laysan Island and Kure Atoll), 1982 (French Frigate Shoals and Pearl and Hermes Reefs), and 1983 (Midway Atoll). Nearly every year thereafter, field camps of several days to nine months were established to monitor and enhance the recovery of this species. Limited population monitoring (i.e., counts from zero to a few times in a single year) has also been conducted at Nihoa and Necker Islands, where boat access to shore is limited and Hawaiian monk seal subpopulations are small due to a lack of suitable haulout sites. Sporadic counts of Hawaiian monk seals at Nihoa date back to 1964 with the first complete census being conducted by the NMFS in 1985. Interatoll movements and mortality of Hawaiian monk seals are also documented on occasion during these counts. Hawaiian monk seal pups have been tagged opportunistically at Midway Atoll and Necker and Nihoa Islands since 1983 (Carretta et al. 2004; Johanos and Baker 2004; Baker personal communication). Sighting data from Hawaiian monk seal counts and tagging initiatives at Nihoa were not available for inclusion in this MRA.

- Between February and November 1985, scientists from the **NMFS Honolulu Laboratory** conducted a series of **underwater and terrestrial surveys to identify and assess resident foraging habitats for green turtles** (*Chelonia mydas*) along the coasts of O‘ahu, Maui, Moloka‘i, and Lāna‘i. Field studies also included capture, tagging, and biological sampling efforts. The three principal study sites were Kawela Bay on O‘ahu, Pala‘au on Moloka‘i, and Kahului Bay on Maui. These sites were selected based on previous exploratory surveys as well as information obtained from interviews with fishermen and other local residents indicating high concentrations of sea turtles. An additional nine other sites were chosen for less intense appraisal (Balazs et al. 1987). Attempts to obtain green turtle sighting locations and dates recorded during these studies were unsuccessful.

- During the 1988 and 1989 winter calving seasons, **humpback whales were tracked from shore** to determine habitat use patterns in an area relatively undisturbed by human activity **off western Hawai‘i**. Land-based observations were made from the Kuili cinder cone from 9 February to 29 March 1988 and from 20 January to 5 April 1989, dates coinciding with the known seasonal occurrence of humpback whales around the Hawaiian Islands during the breeding-calving season. The study area for this project encompassed coastal waters within a 5-km radius of the land station with bottom depths ranging from 0 to 128 m. A total of 536 groups comprising 950 humpbacks were observed

during the study period. Initial positions of all groups were plotted on nautical charts by the principal investigators (Smultea 1994). These positional data were not available for inclusion in this MRA.

- The **School for Field Studies (SFS)** is an international nonprofit academic institution that provides interdisciplinary education and field research opportunities to undergraduate students. The SFS developed the Center for Marine Mammal Studies Program on Kaua‘i in the late 1980s. This program focused on spinner dolphin research in the Kaua‘i area. Scientists and students collected photo-identification data from boat-based surveys and behavioral data from shore-based observations of spinner dolphins in 1987, 1988, and 1989 (Jefferson personal communication). Information and data from these studies have not been published and were therefore not pursued for inclusion in this MRA.

- The **Spinner Study**, initiated in 1995 and sponsored by the wildlife protection organization Earthtrust, is a long-term science and conservation study monitoring populations of wild spinner dolphins that swim in the shallow coastal waters around O‘ahu (Psarakos and Marten 1999). Since 1995, regular shore and underwater observations have been made off the island’s Waianae (west) coast. The principal study area is a large, protected, sandy bottom bay. Shore-based observations at the study site are made during daylight hours. When dolphins are sighted, an initial count of group size is made from shore and, if possible, species are identified. Observers then enter the water to attempt underwater observation, photo-identification, or video logging. Opportunistic video/sound recordings are also made to document and verify behavioral interactions (Psarakos et al. 2003). Marine mammal occurrence records collected during the Spinner Study were not obtained for use in this assessment.

- In 1993, the NMFS and the Hawai‘i Institute of Marine Biology conducted an **evaluation of the nearshore coral reef resources at Kaho‘olawe**. Sightings of marine mammals and sea turtles were also recorded during this study. Marine mammals and sea turtles were sighted during vessel and underwater surveys from 22 to 26 March and during a helicopter survey on 14 May. Six sea turtles were observed during the March survey and 14 were observed during the May survey. One pod of humpback whales and several schools of spinner dolphins were spotted during these surveys as well (Naughton 1995.). Sighting data from these surveys were not available for inclusion in this report.

- Between February and March 1998, the Navy sponsored shipboard surveys (visual and acoustic) and shore-based observational studies to assess the potential effects of the SURTASS LFA sonar system on the behavior, vocalizations, and movements of humpback whales off the coast of Kona, Hawai‘i. This project, entitled **Phase III of the SURTASS LFA Scientific Research Program**, utilized the R/V *Cory Chouest* as both a playback vessel and observation platform. Vessel and shore-based observers sighted more than 950 humpbacks during these surveys. Three aerial surveys for humpback whales were also flown over the Phase III study area, but were conducted as part of a separate research project (DoN 2001a). Dr. Joe Mobley was consulted regarding the availability of sighting and survey effort data from this project, however no data were received.

- Established in 1998, the **Nai‘a Kuwili Project** is a long-term study of spinner dolphins that reside along the shores of O‘ahu. Dr. Marc Lammers, President of **Oceanwide Science Institute (OSI)**, is the principal investigator for this project. The project's goals are to decipher the behavior and ecology of this species and determine the effects of human interactions on local populations and their habitat. Current research efforts are focused on the acoustic behavior of these animals and their use of nearshore habitats. The movements and behavioral patterns of spinner dolphin groups are recorded and quantified to better understand the dynamics of resident populations. Most of the work for this project is conducted aboard the *Meleana*, a 10-m long motorboat (Lammers and Au 2003; Lammers 2004; OSI n.d.). From January to March 2000, OSI conducted line-transect boat-based surveys off the Ewa/Honolulu (south) coast of O‘ahu to determine marine mammal distribution patterns in the area. From May through July 2000, they also performed studies on the behavioral ecology of spinner dolphins off the island’s Waianae (west) coast (Lammers et al. 2000). From February to May 2001, OSI also surveyed the waters off Kalaeloa Barbers Point Harbor, O‘ahu for dolphins and humpback whales. Both on- and off-effort sightings of marine mammals were recorded (Lammers et al. 2001). Marine mammal occurrence data from this project were not obtained for inclusion in this MRA.

- In 2000, the Office of Response and Restoration, a branch of the **National Ocean Service (NOS)**, collected data characterizing coastal environments and wildlife by their sensitivity to oil spills. Data and information obtained for the Hawaiian Islands were incorporated into an **Environmental Sensitivity Index (ESI) Atlas**, which depicts the locations of marine resources along the shorelines of the MHI and NWHI. The ESI Atlas for the Hawaiian Islands includes sea turtle nesting and basking beaches as well as foraging areas and sites of in-water concentrations (NOS 2001). This information was used to create a map of sea turtle basking/nesting sites in the MHI (found in Section 3.2) and was vital to the production of maps depicting sea turtle areas of occurrence within the OPAREA and vicinity (found in Appendix C).

- Since 2001, the **Hawai‘i Marine Mammal Consortium (HMMC)** has been recording shore-based observations of humpback whales, vessels, aircraft, and other marine mammals (e.g., false killer whales, melon-headed whales, and spinner, bottlenose, and pantropical spotted dolphins) in Kawaihae Bay on the northwest coast of Hawai‘i. The HMMC also conducts vessel-based research in this area as part of the SPLASH program and performs acoustic studies as well. This multifaceted research initiative, known as the **Kohala Research Program**, is a follow-up study to Helweg (1989), who investigated seasonal and daily changes in whale distribution, numbers, and behavior at the same location (Gabriele et al. 2001). Marine mammal sighting locations from 2001 to 2003 are presented on maps in Gabriele et al. (2003), but are not in a usable format for incorporation into this MRA. The HMMC is in the process of analyzing data collected in 2004 and 2005, and will soon incorporate them into a manuscript assessing trends in the relative distribution and abundance of humpback whales in Kawaihae Bay since 1988 (HMMC 2005). Attempts to acquire marine mammal sighting data from this research program were unsuccessful as the data provider, Ms. Christine Gabriele (HMMC), was not comfortable with releasing any data that are not yet published. It is hoped that once the above manuscript is published, all available data will then be released to the Navy.

- Through its Integrated Natural Resource Management Plan (INRMP) for the PMRF, the Navy is charged with monitoring and protecting all threatened and endangered species known to occur in the vicinity of Barking Sands, Kaua‘i (DoN 2001b). This includes the Hawaiian monk seal and the green turtle, both of which are known to occur on the shores of the PMRF. As part of its on-going conservation mapping efforts, the Navy has recently documented the locations of important **PMRF Hawaiian monk seal and green turtle basking/nesting sites** in a Microsoft® Access database (DoN 2004). The point location of a basking Hawaiian monk seal at the PMRF is displayed on the occurrence map for that species in Appendix B, while shapefiles of green turtle basking/nesting sites are plotted on a sea turtle basking/nesting map in Section 3.2.

- **Sea turtle nesting and basking data** for the MHI and Nihoa are collected by individuals from several organizations including the Hawai‘i DLNR, NMFS, USFWS, and Hawai‘i Wildlife Fund. Researchers with the Hawai‘i Volcanoes National Park (managed by the USFWS) have located, monitored, and protected sea turtle nesting beaches on the southeast coast of the Big Island (Hawai‘i) since 1989 (Katahira et al. 1994). Hawksbill turtle nesting and green turtle basking activities are frequently observed on those beaches. On Maui, organized efforts to systematically document sea turtle nesting occurrences began in 1996 (King et al. 2004). These efforts were initiated following two hawksbill turtle fatalities that resulted from vehicle strikes on coastal highways adjacent to Ma‘alaea Bay (Jensen et al. 2000; Mangel et al. 2000). Sea turtle nesting and basking records were requested from both the Hawai‘i DLNR and the NMFS-PIFSC, yet none were received.

Published Literature and Personal Communications

Oftentimes published papers, press releases, and personal communications are the most useful media for presenting and disseminating opportunistic sighting, stranding, bycatch, and haul out records. The occurrence data contained within the documents or provided by the individuals listed under the last heading of **Table A-1** were especially useful for species that are not frequently seen during dedicated surveys, that are not easily distinguished to species, or for which there is little information regarding their occurrence in the OPAREA.

- During the 1960s and 1970s, the Pacific Ocean Biological Survey Program (POBSP) and the Bureau of Sport Fisheries and Wildlife (BSFW) conducted periodic surveys of the fauna at Nihoa Island. From 1964 through 1973, 16 visits were made totaling 30.3 days of observation. Several Hawaiian monk seals and green turtles were observed on and around Nihoa during this period. These observations are listed in **Clapp et al. (1977)**, although the specific sighting locations at Nihoa are not reported. As a result, they could not be included in this assessment.

- On 23 June and from 23 to 25 August 1978, Mr. George Balazs (Hawai‘i Institute of Marine Biology) and others conducted surveys for sea turtles at Kaho‘olawe. These surveys consisted of aerial reconnaissance, direct observations on land, underwater observations, and collection of algae. The June aerial survey covered most of the island's coastline while the three-day August survey concentrated on the island’s west end. Sighting locations of sea turtles around Kaho‘olawe are presented in **Balazs (1978)** and are included in this MRA.

- In 1981, Dr. Edward Shallenberger of Manta Corporation synthesized all available information on Hawaiian cetaceans in a report for the U.S. Marine Mammal Commission. Although this document was extremely useful in detailing the historical distribution patterns of cetaceans around the MHI and Nihoa, **Shallenberger (1981)** did not contain any occurrence data that could be mapped in this MRA.

- In January and February 1993, Japanese scientists conducted a shipboard survey for cetaceans in the western and central North Pacific Ocean aboard the *Hakuho-maru* research vessel. This survey was designed to gather information on the winter distribution of whales in the tropical waters of the North Pacific between Japan and the Hawaiian Islands. Eight cetacean sighting events were recorded in the Hawaiian Islands OPAREA and vicinity during the cruise; the only species positively identified was the humpback whale. Sighting records from this survey that were available for inclusion in this MRA can be found in **Ohizumi et al. (2002)**.

- Tiger sharks (*Galeocerdo cuvier*) have been observed to attack cetaceans and sea turtles off the MHI on several occasions. **Maldini (2003a)** and **Boulis (personal communication)** provided eyewitness accounts of tiger shark predation on pantropical spotted dolphins and green turtles, respectively. These eyewitness records were plotted on the occurrence maps for both species.

- Prior to receiving data from the NMFS-PIR and NMFS-PIFSC, incidental bycatch records of cetaceans in the Hawai‘i-based pelagic longline fishery were accumulated from **Forney (2004)**. This document is a technical assessment of cetacean mortality and injury in the Hawaii- and California-based pelagic longline fisheries and provides coordinate locations for all recorded cetacean bycatch events between 1994 and 2002.

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APPENDIX B: MARINE MAMMALS

LIST OF FIGURES

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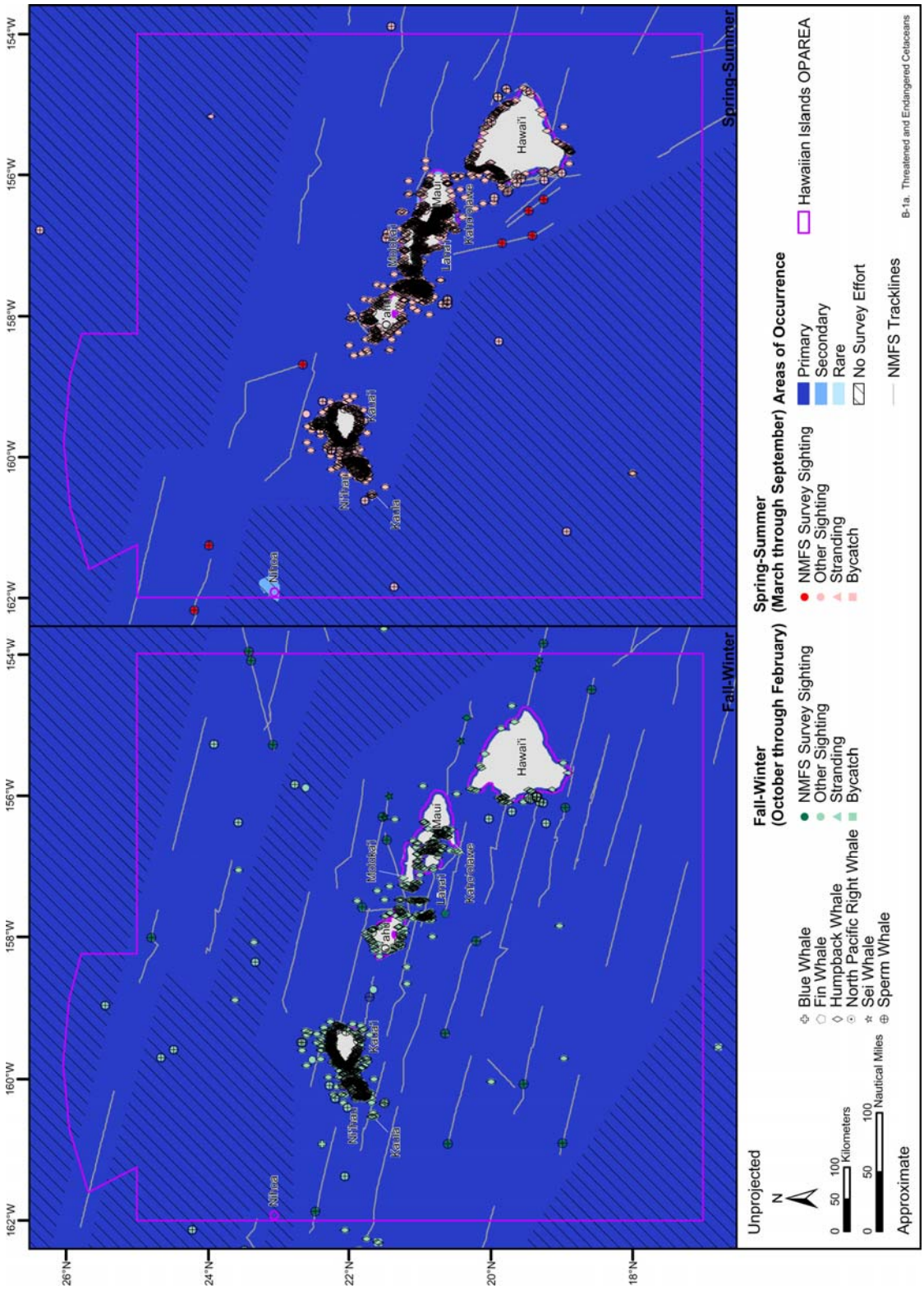

Figure B-1a. Areas of occurrence for threatened and endangered cetaceans in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

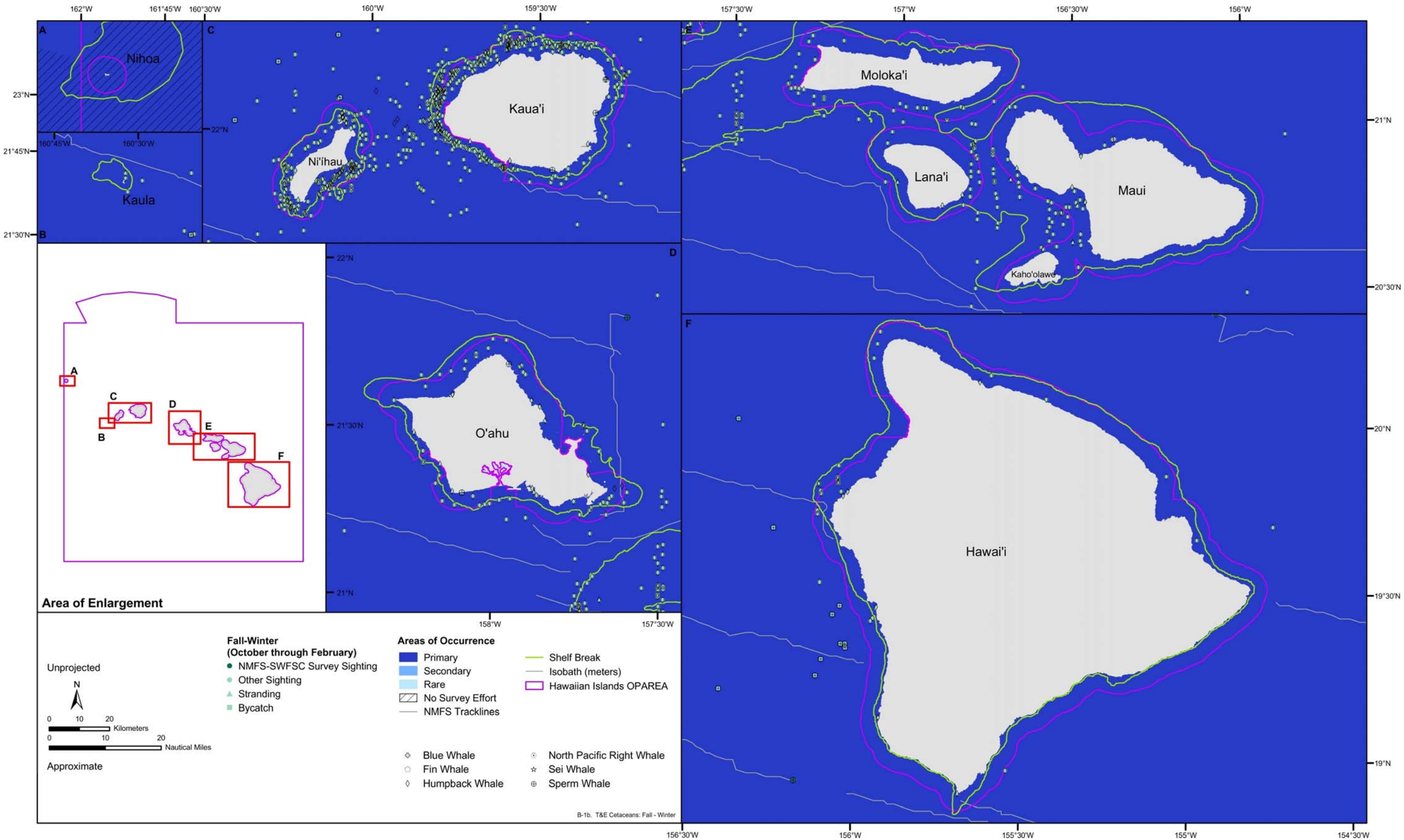

Figure B-1b. Areas of occurrence for threatened and endangered cetaceans around the MHI, Nihoa, and Kaula during fall/winter. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

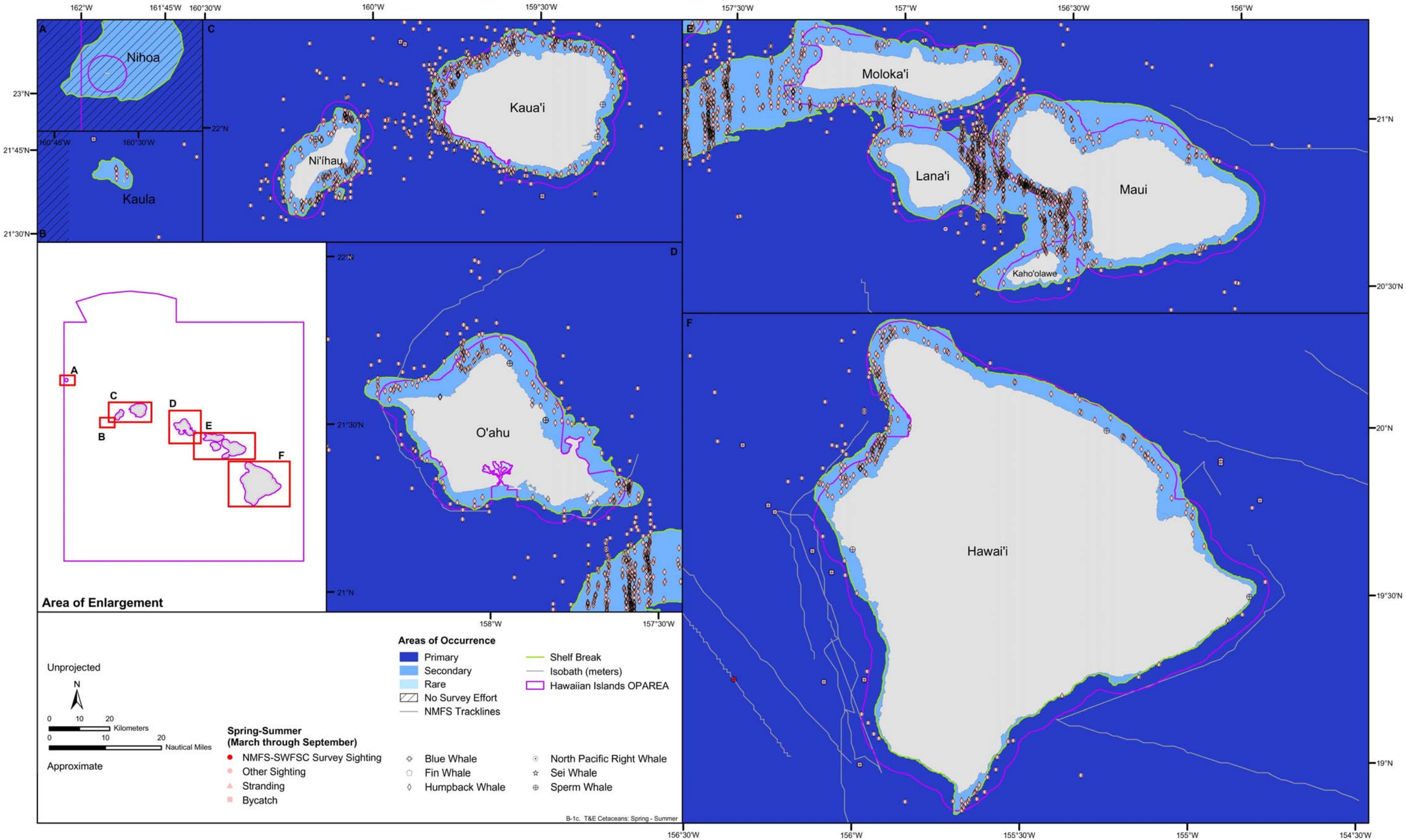

Figure B-1c. Areas of occurrence for threatened and endangered cetaceans around the MHI, Nihoa, and Kaula during spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

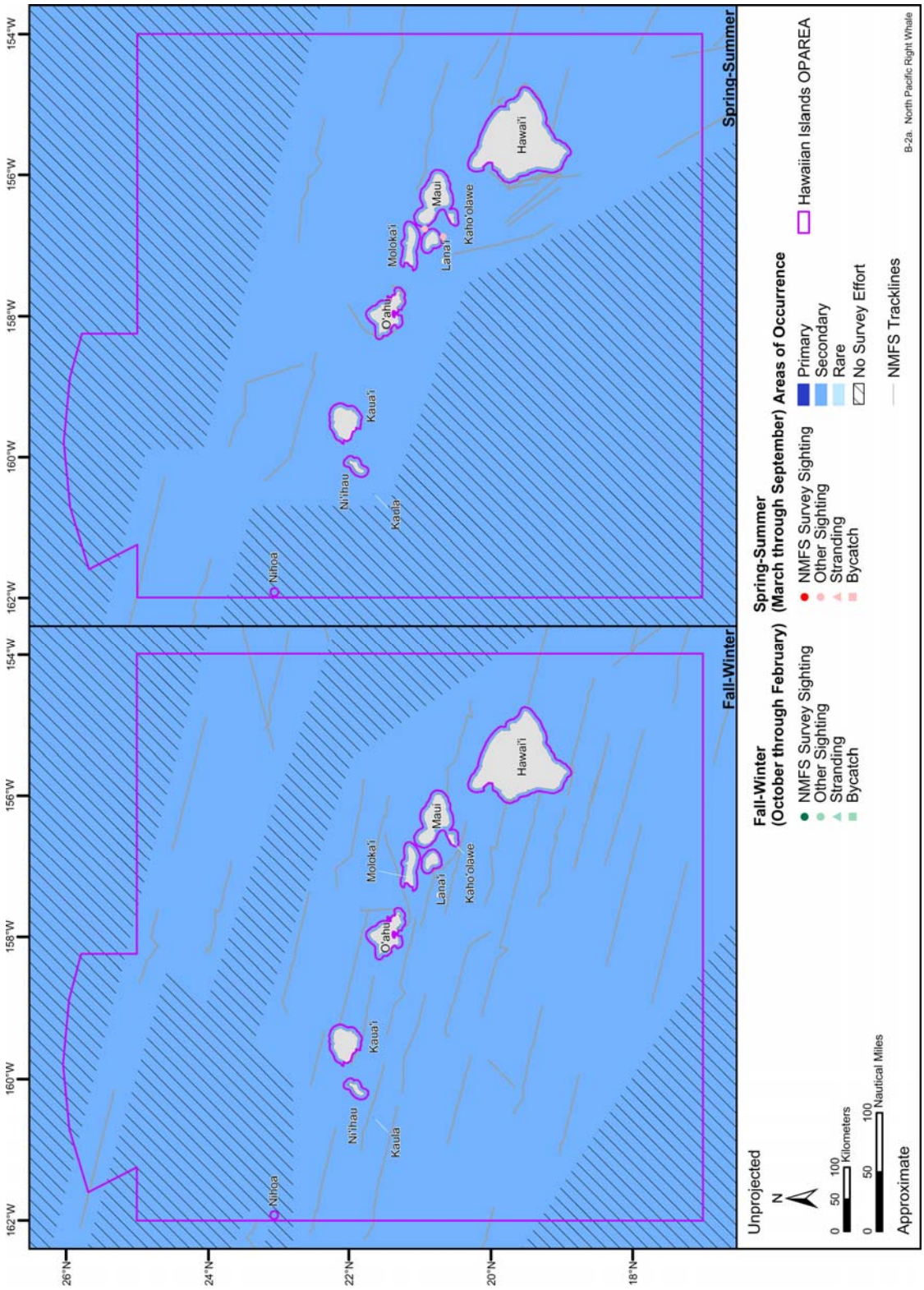

Figure B-2a. Areas of occurrence for the North Pacific right whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

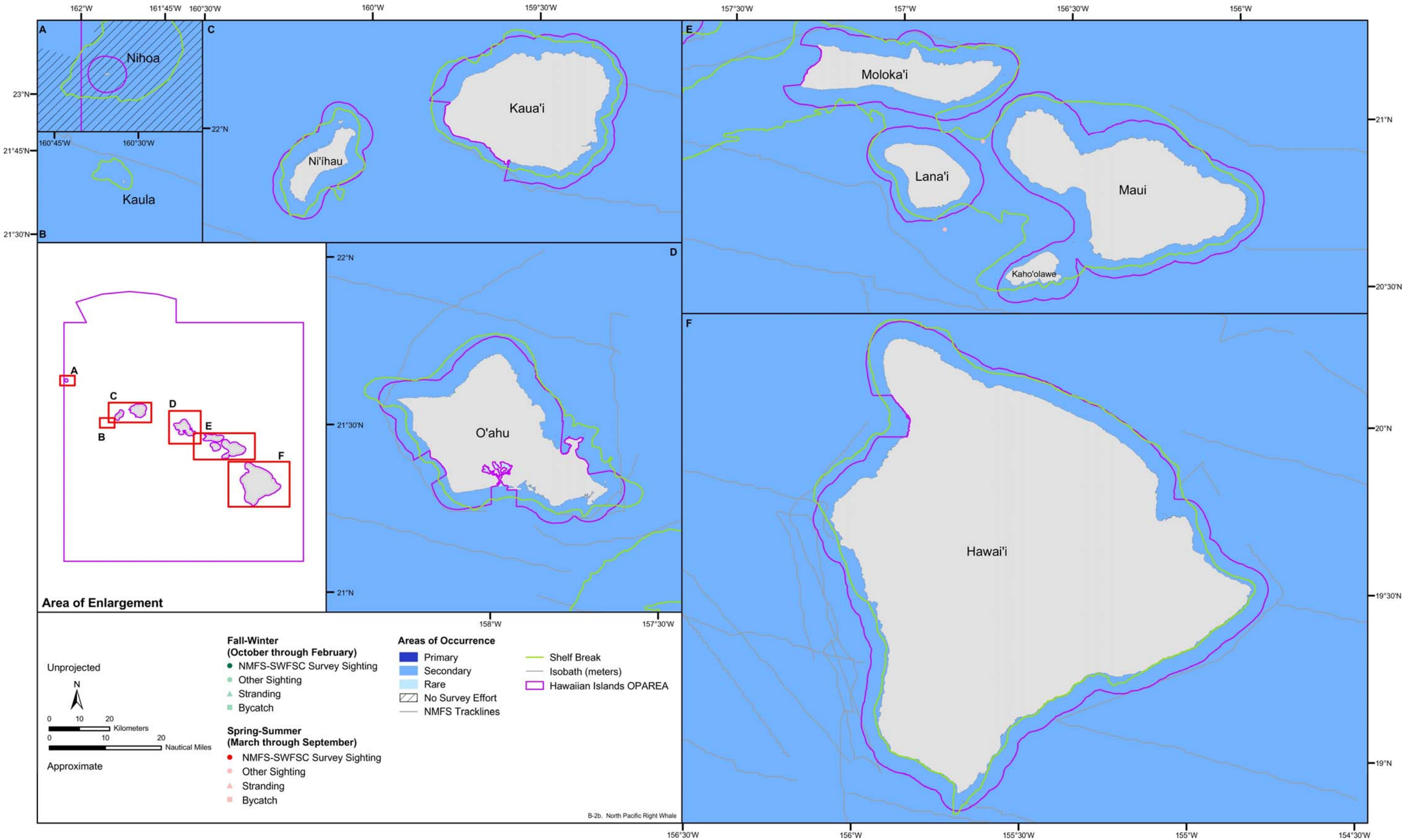

Figure B-2b. Areas of occurrence for the North Pacific right whale around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

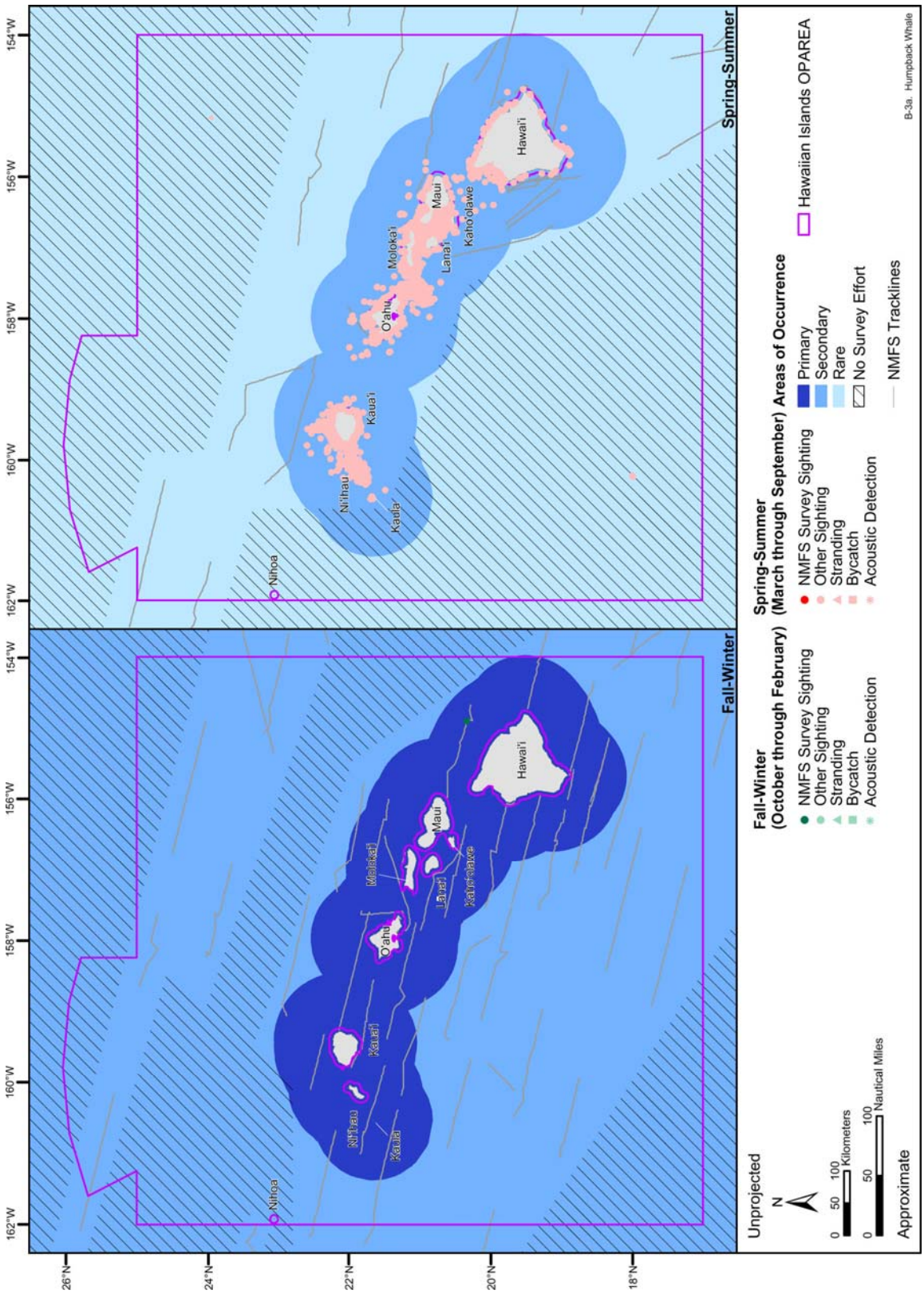

Figure B-3a. Areas of occurrence for the humpback whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

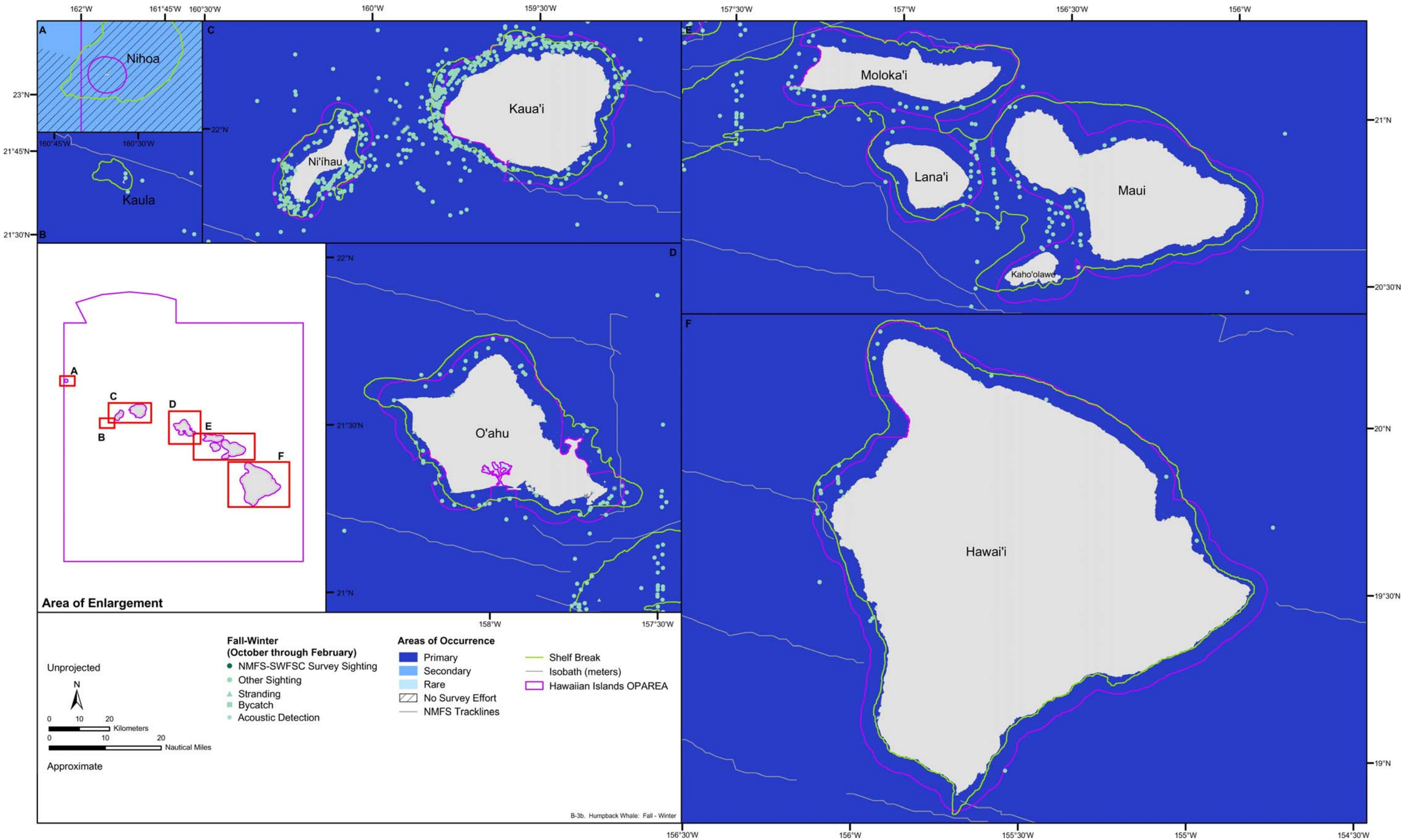

Figure B-3b. Areas of occurrence for the humpback whale around the MHI, Nihoa, and Kaula during fall/winter. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

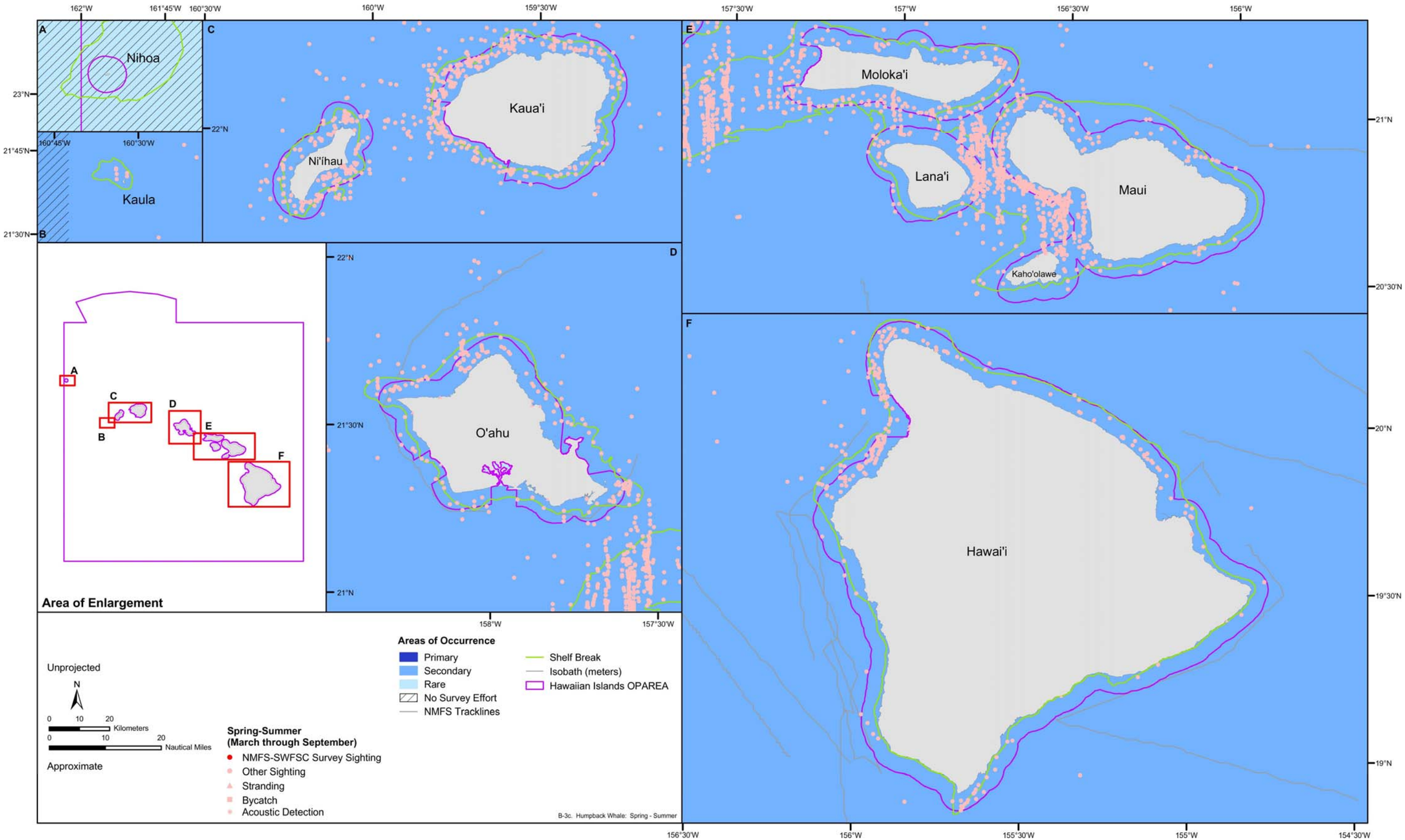

Figure B-3c. Areas of occurrence for the humpback whale around the MHI, Nihoa, and Kaula during spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

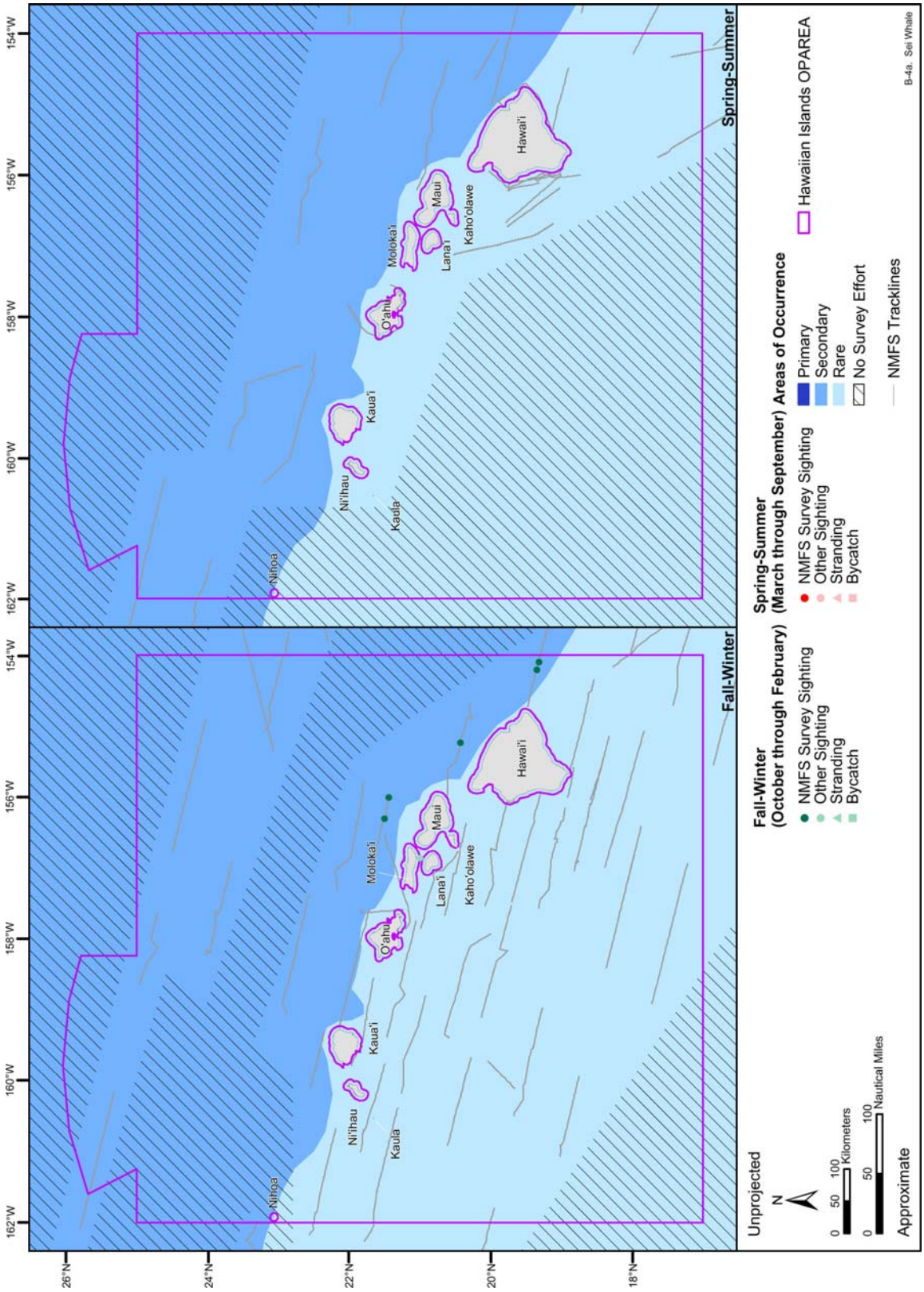

Figure B-4a. Areas of occurrence for the sei whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

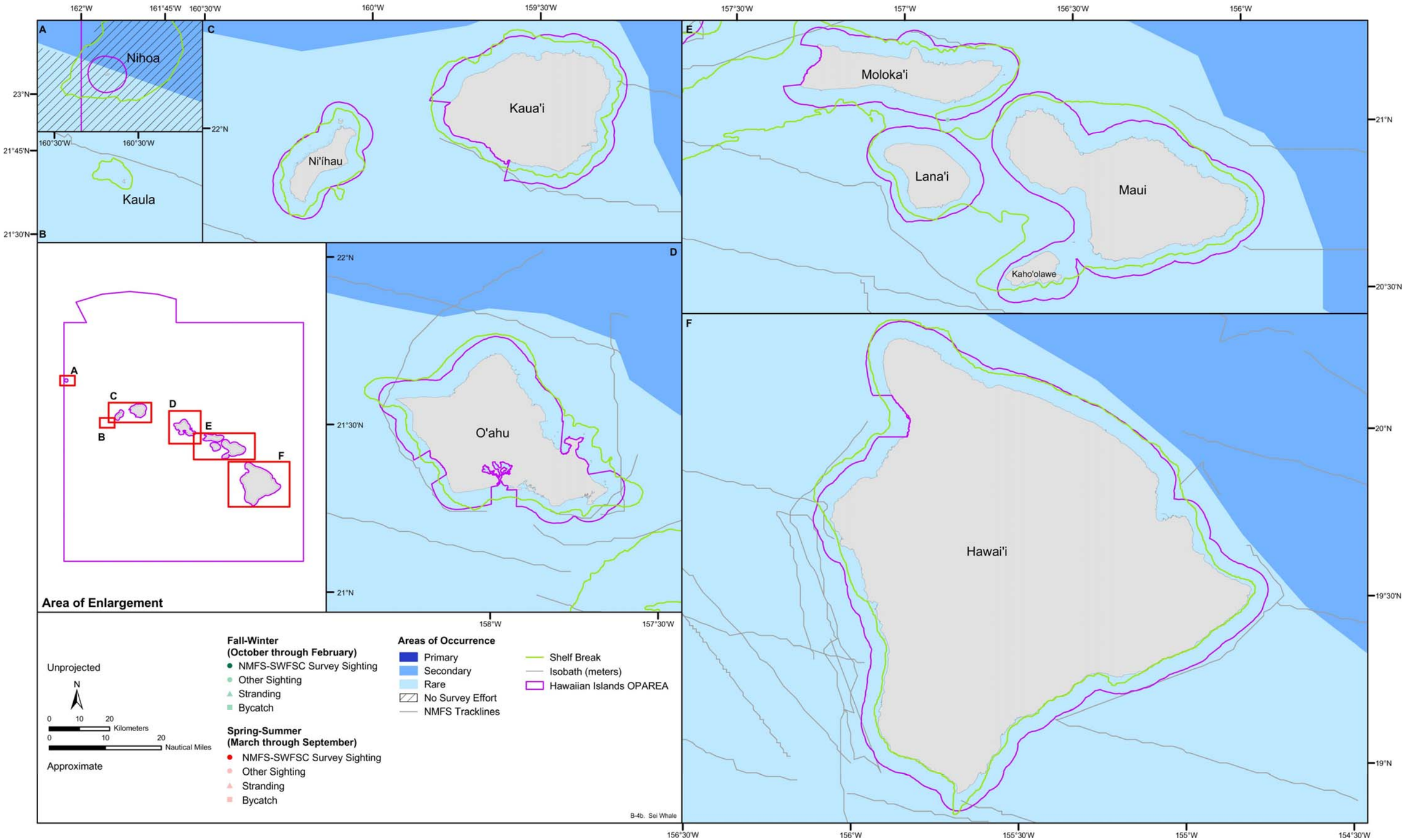

Figure B-4b. Areas of occurrence for the sei whale around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

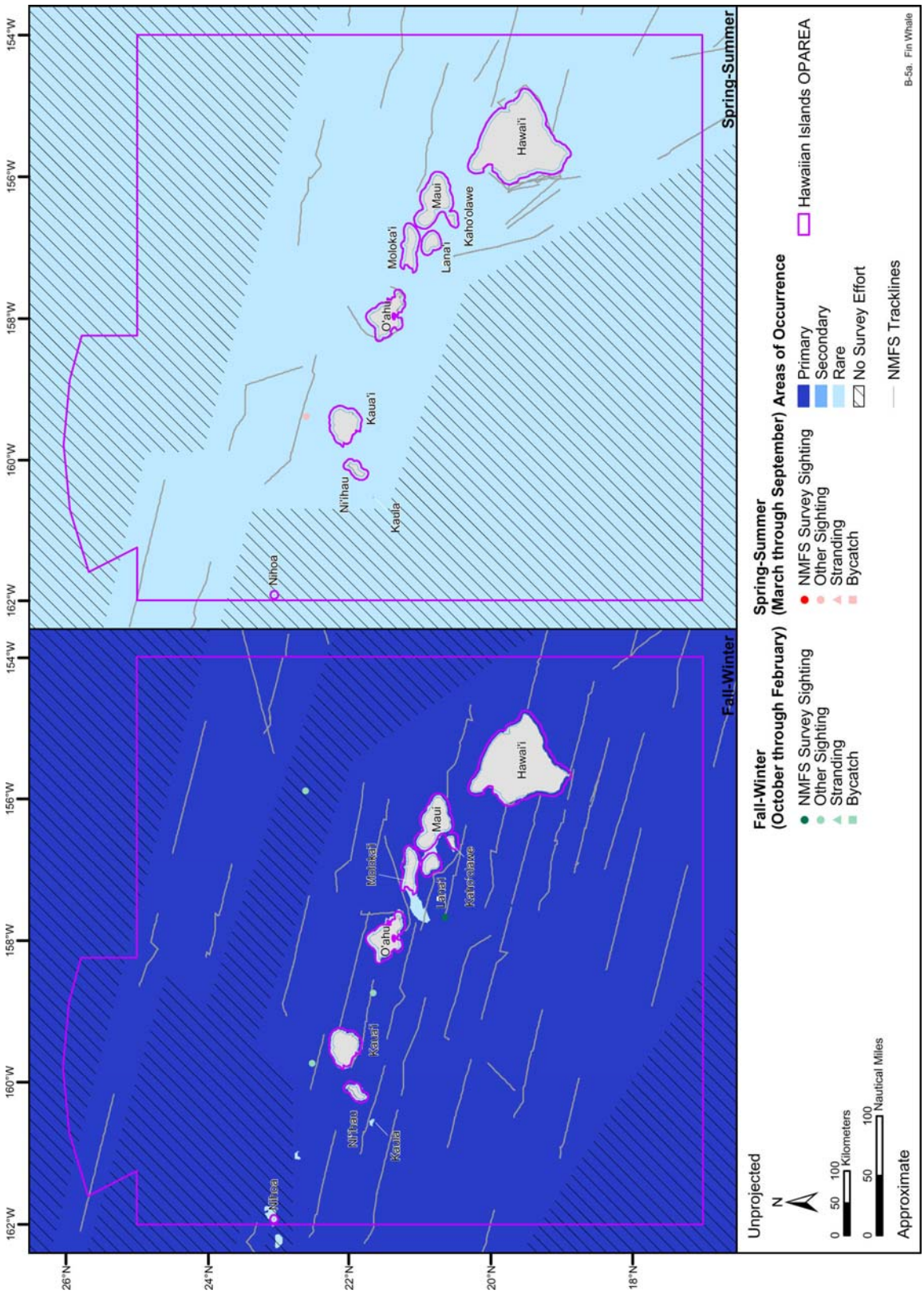

Figure B-5a. Areas of occurrence for the fin whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

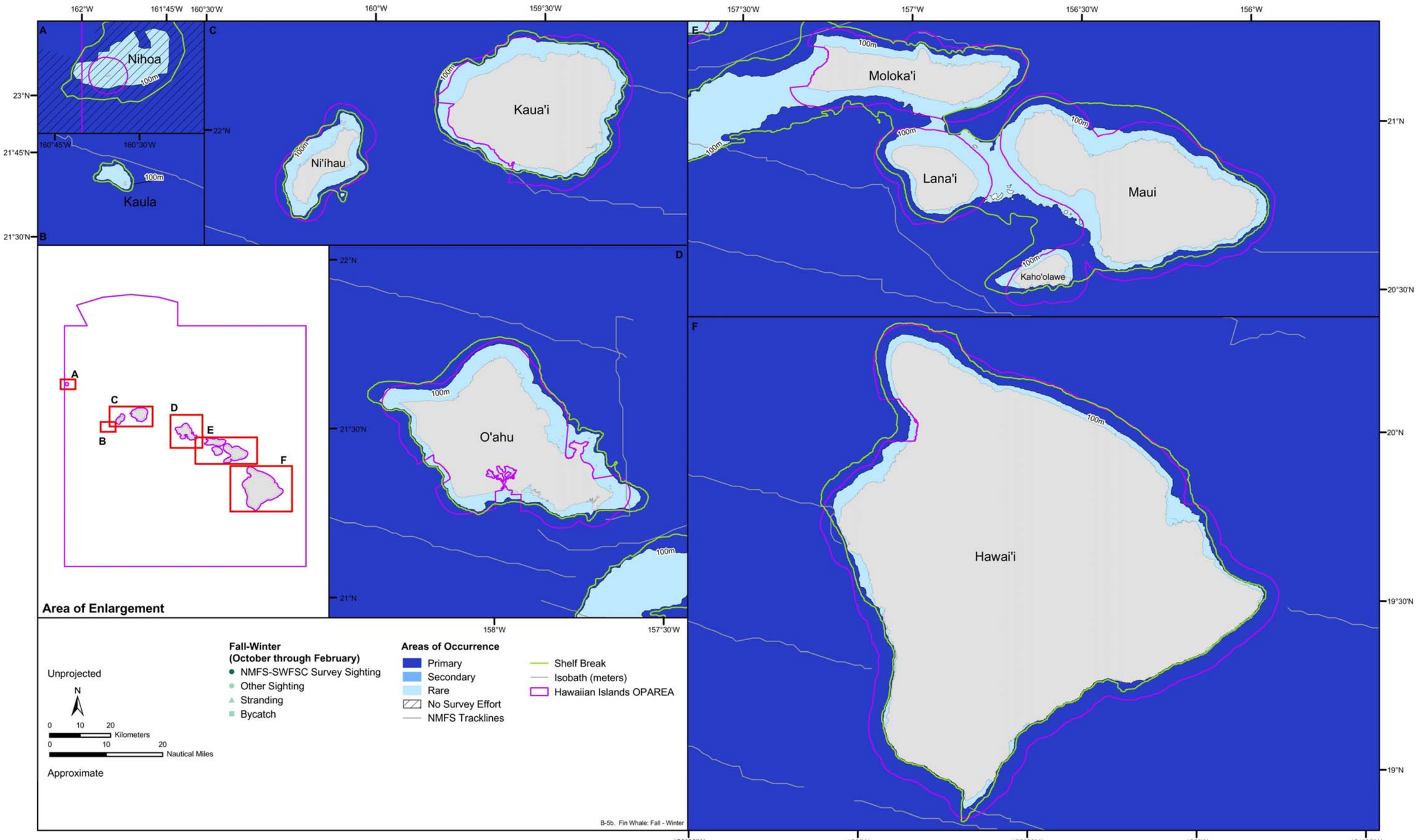

Figure B-5b. Areas of occurrence for the fin whale around the MHI, Nihoa, and Kaula during fall/winter. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

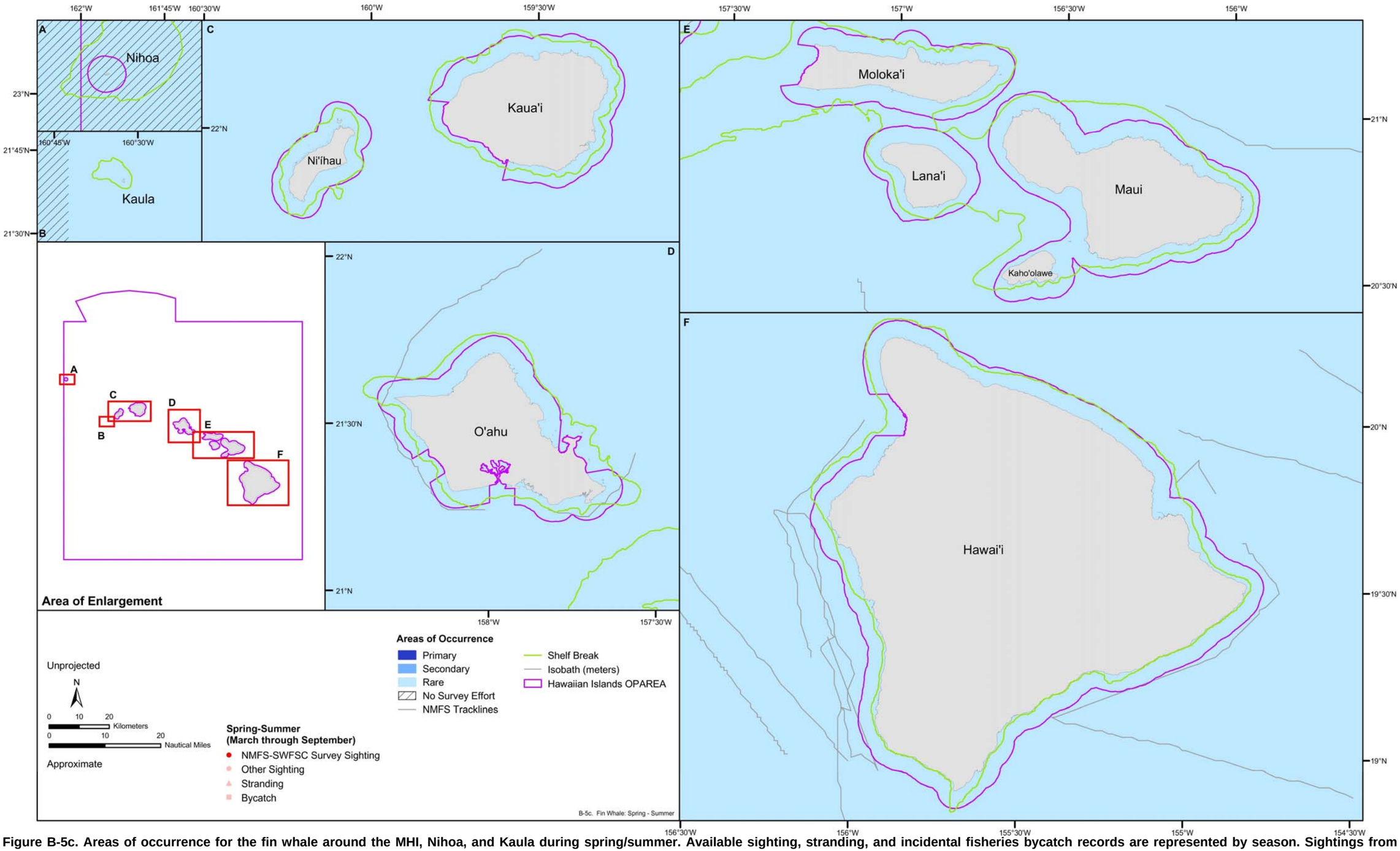

Figure B-5c. Areas of occurrence for the fin whale around the MHI, Nihoa, and Kaula during spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

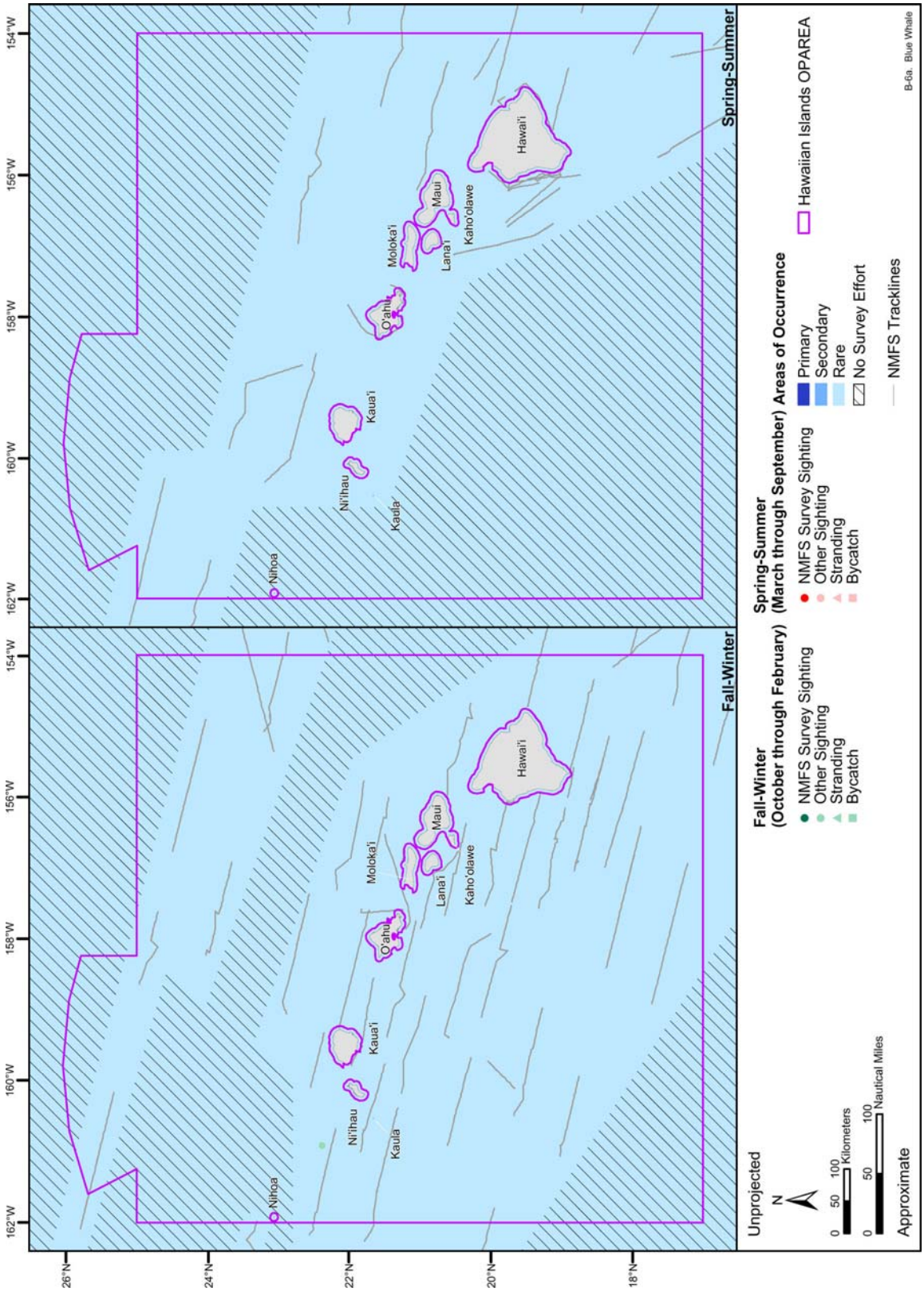

Figure B-6a. Areas of occurrence for the blue whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

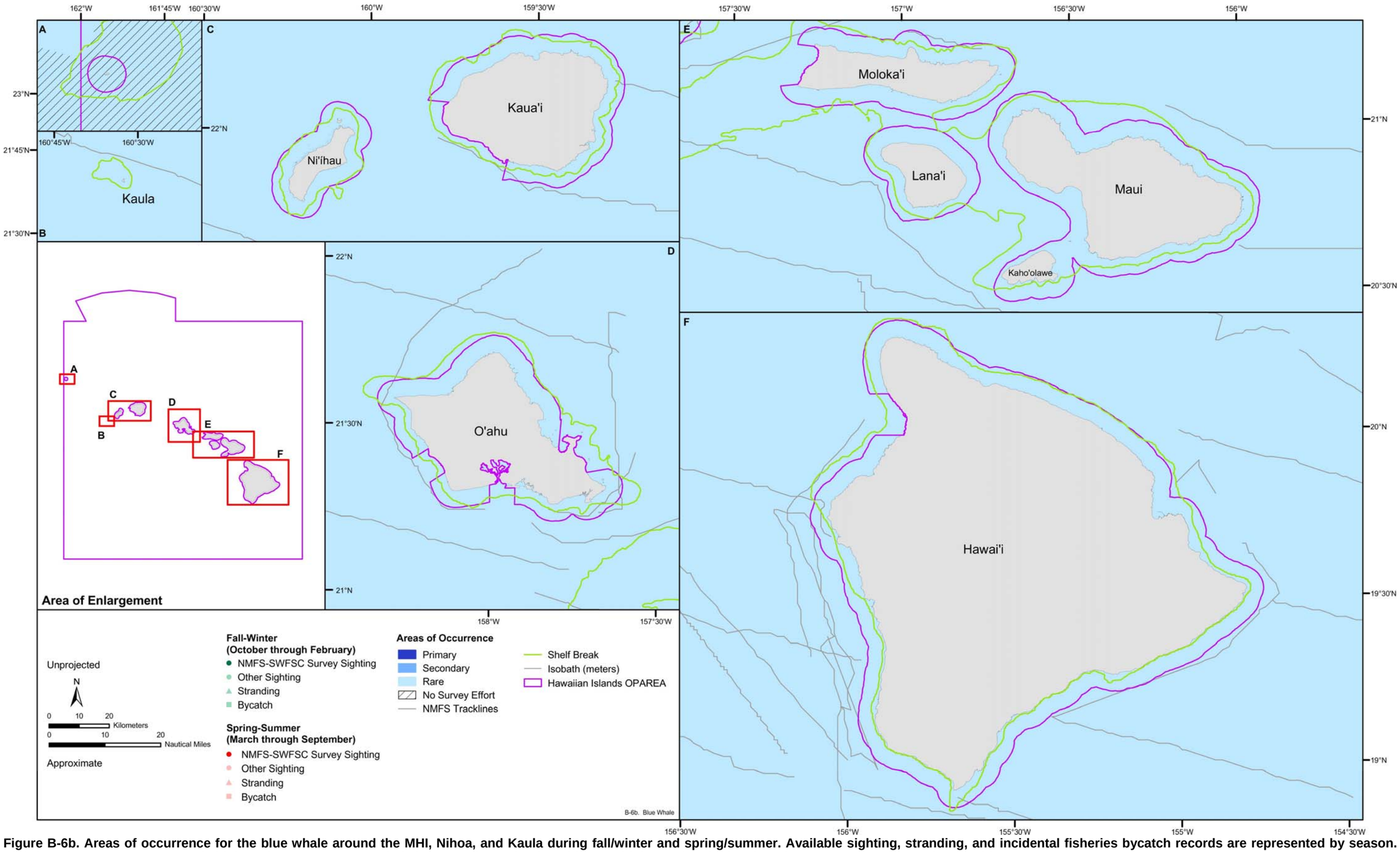

Figure B-6b. Areas of occurrence for the blue whale around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

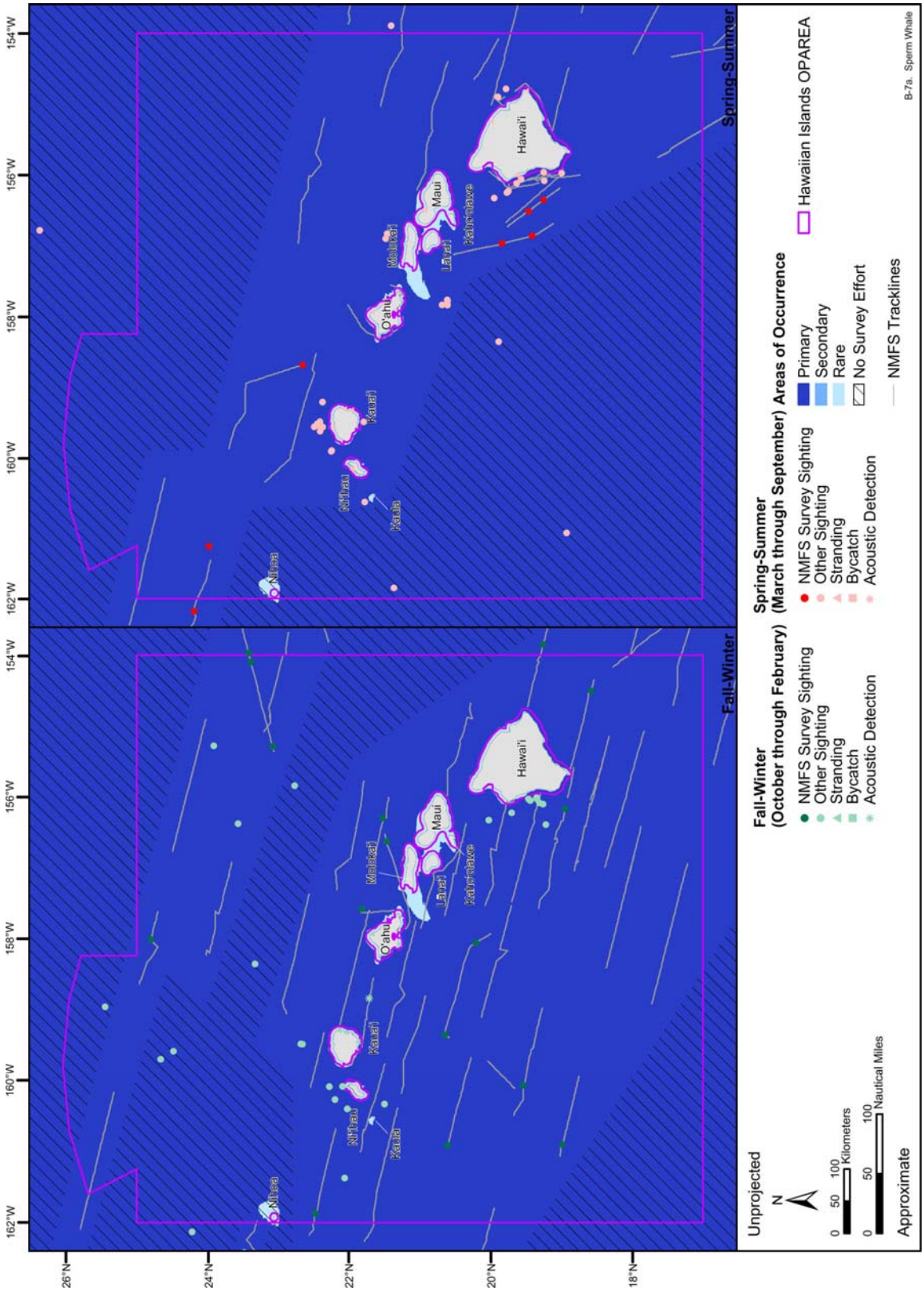

Figure B-7a. Areas of occurrence for the sperm whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

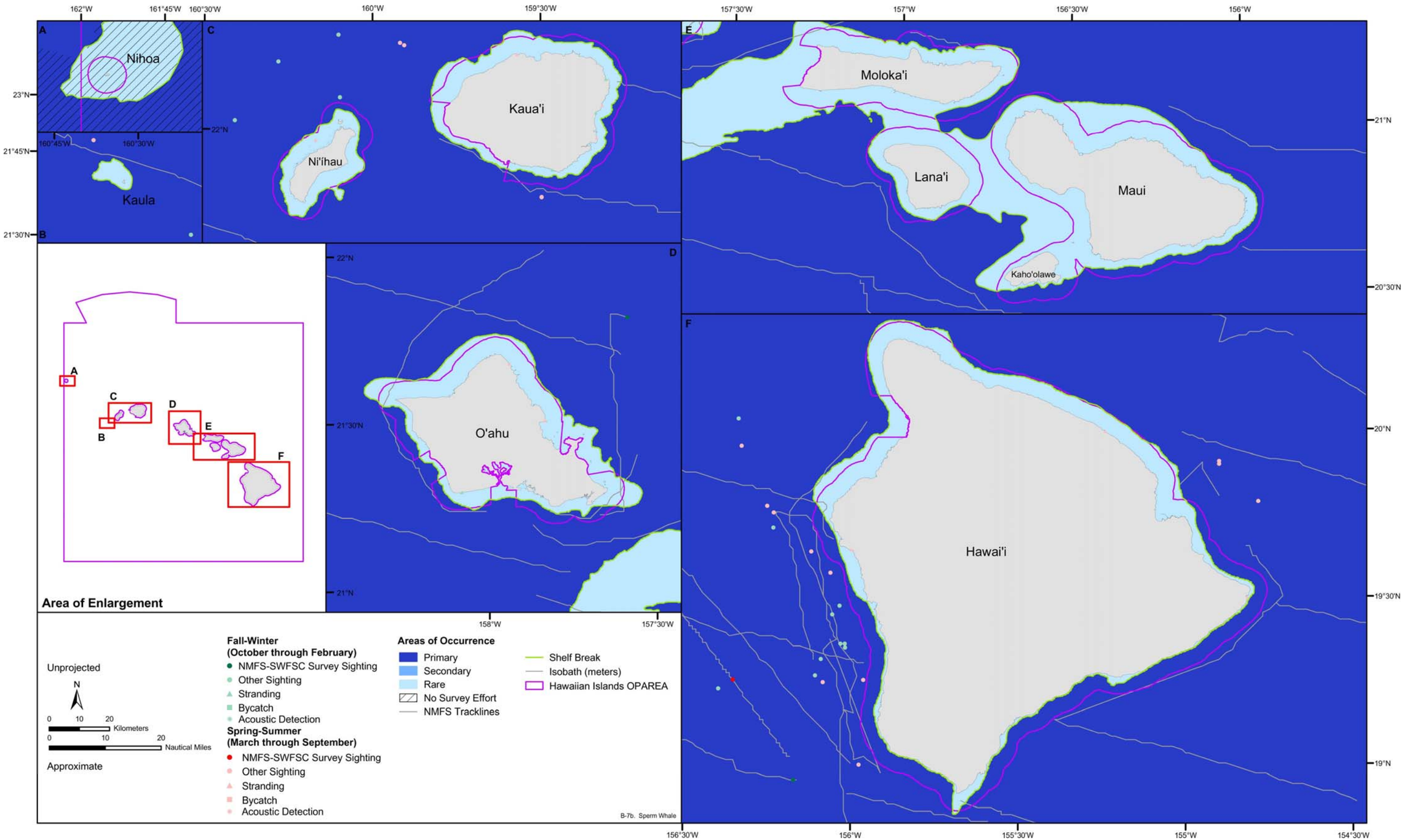

Figure B-7b. Areas of occurrence for the sperm whale around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

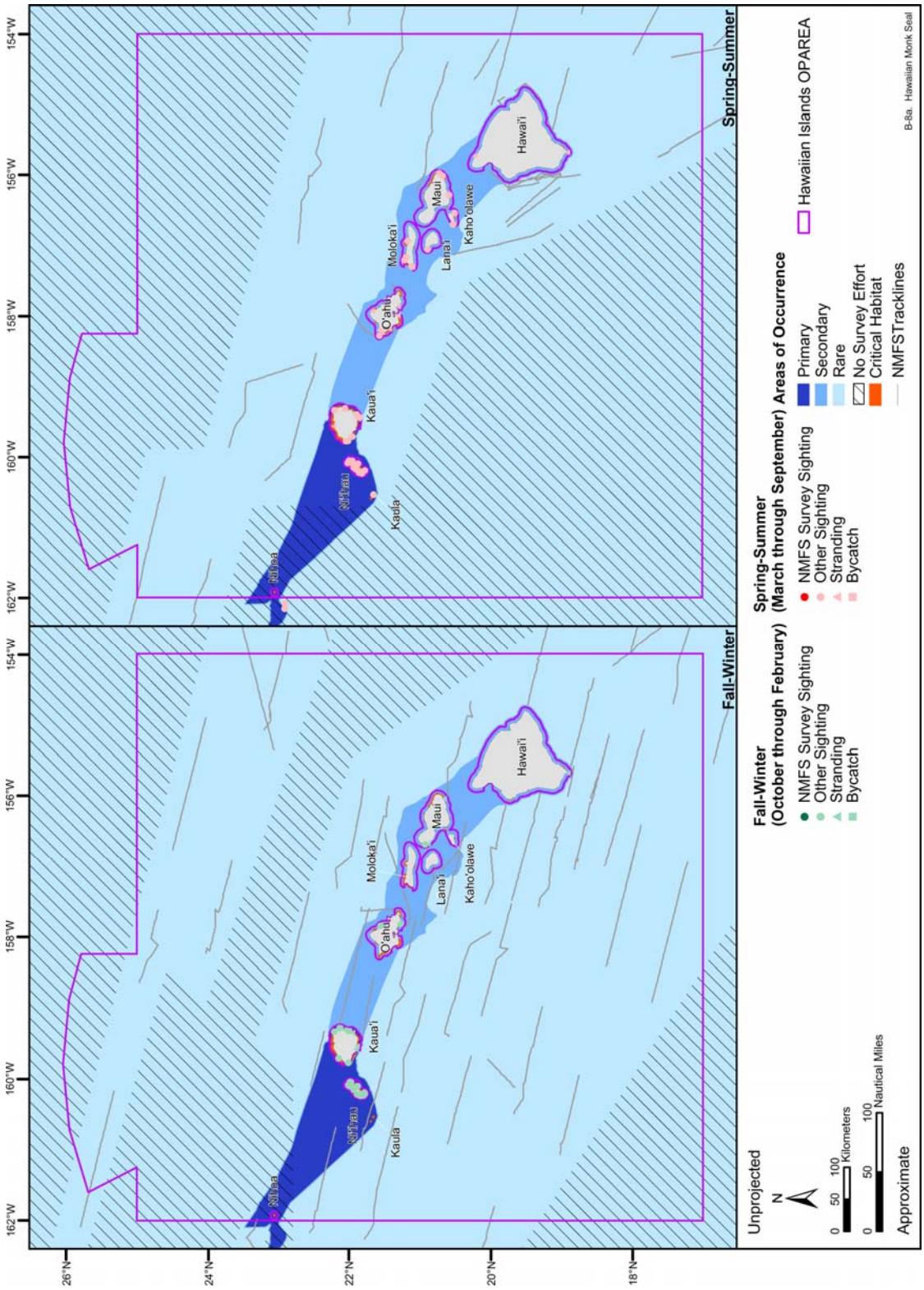

Figure B-8a. Areas of occurrence for the Hawaiian monk seal and main pupping locations in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

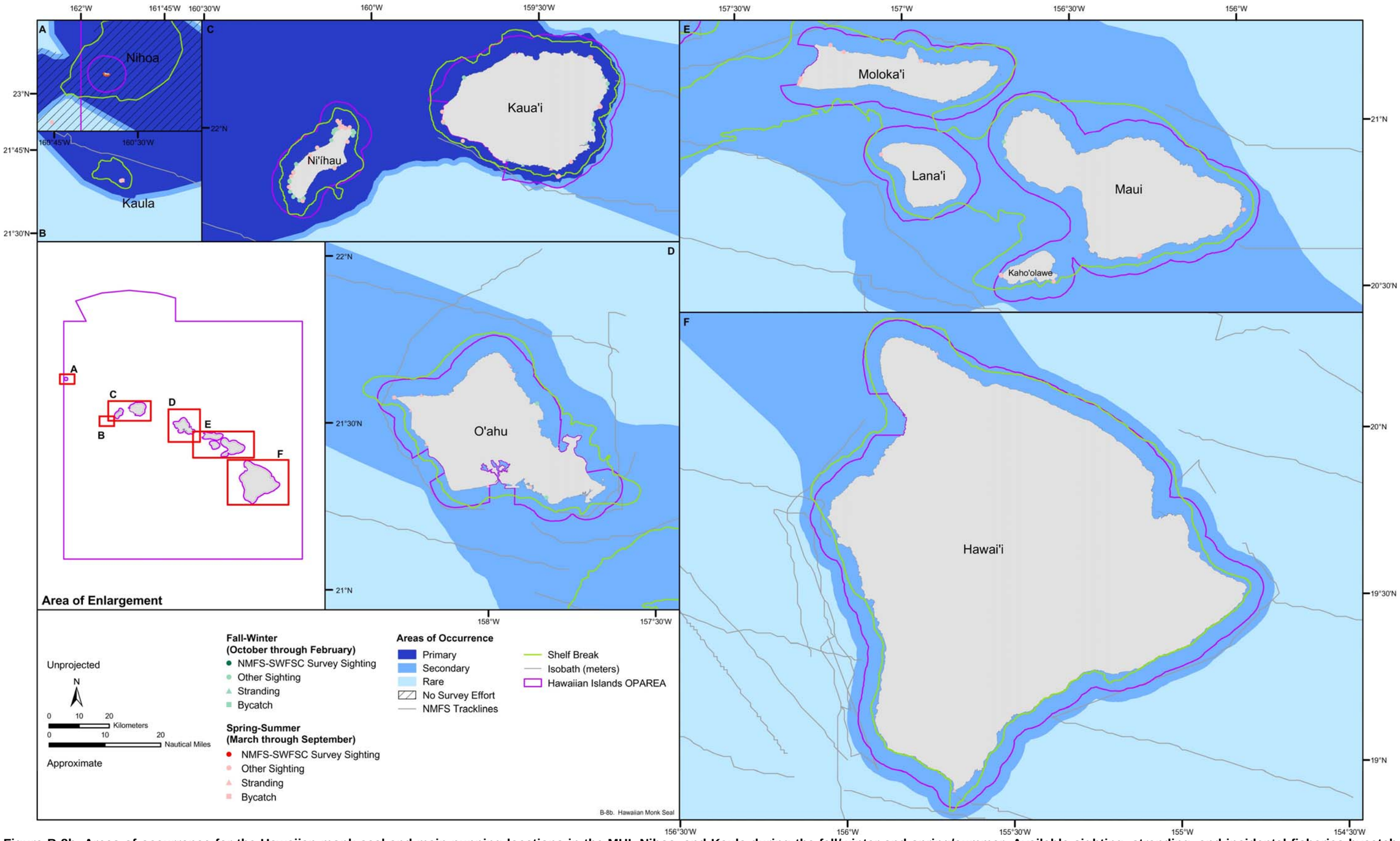

Figure B-8b. Areas of occurrence for the Hawaiian monk seal and main pupping locations in the MHI, Nihoa, and Kaula during the fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

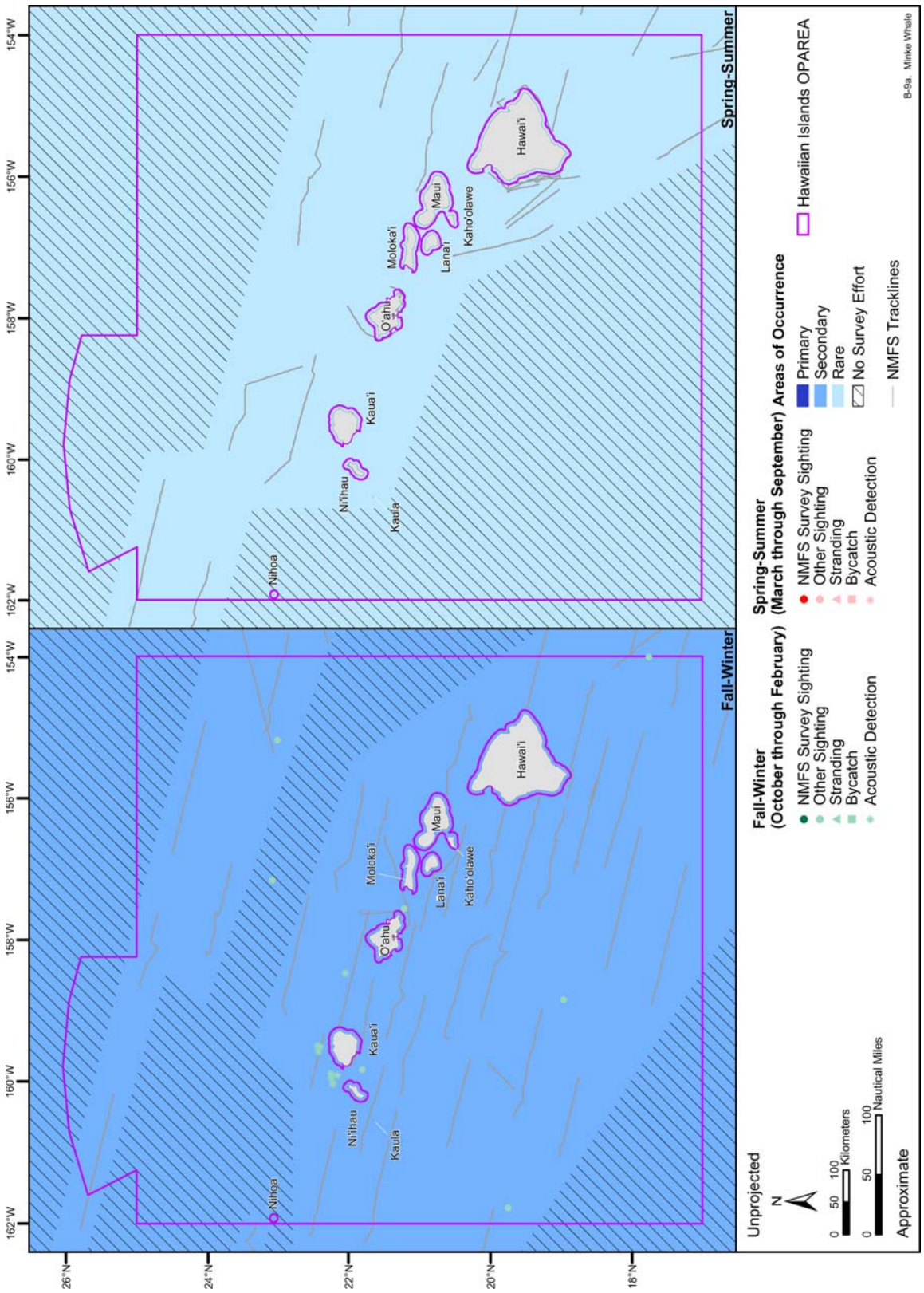

Figure B-9a. Areas of occurrence for the minke whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

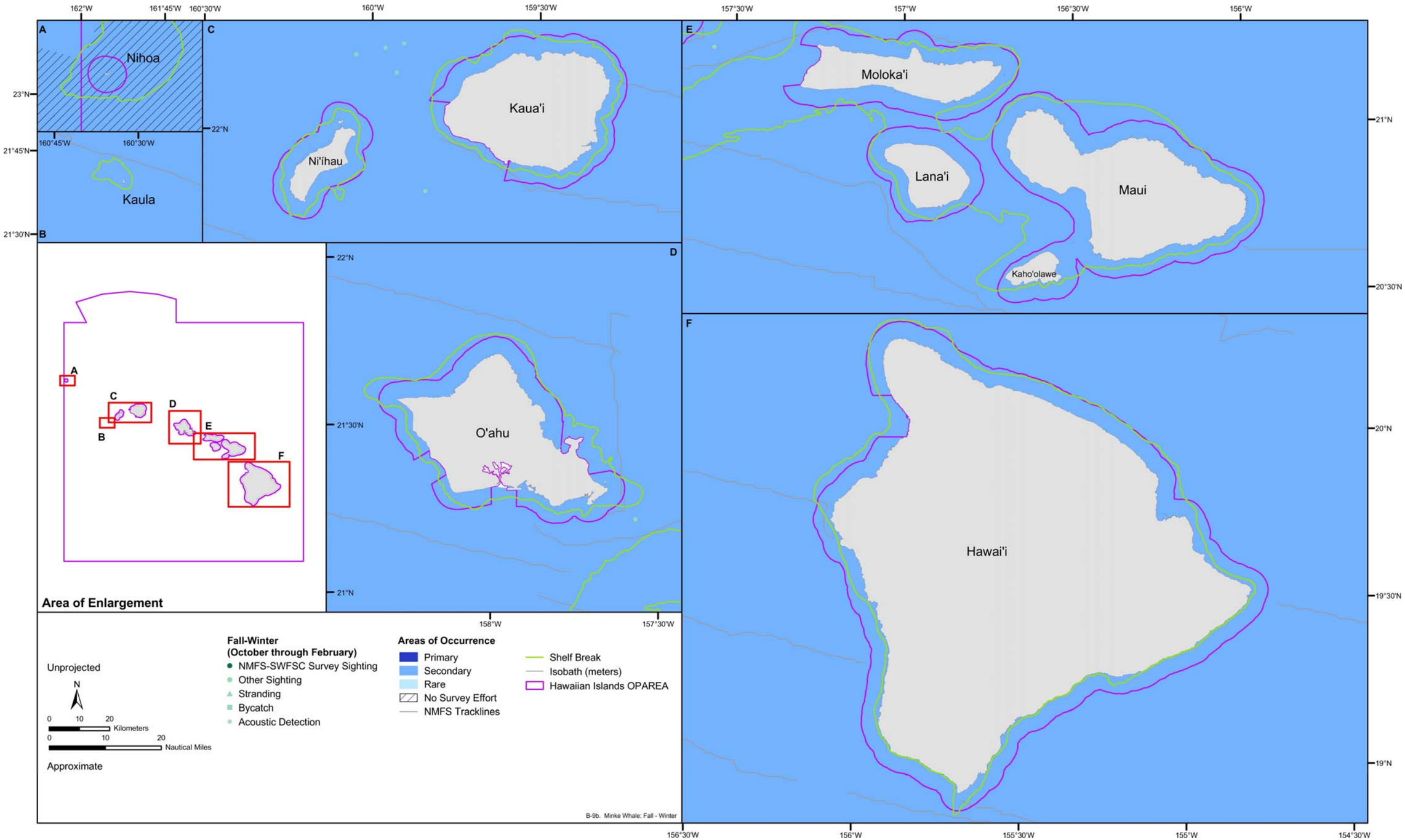

Figure B-9b. Areas of occurrence for the minke whale around the MHI, Nihoa, and Kaula during fall/winter. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

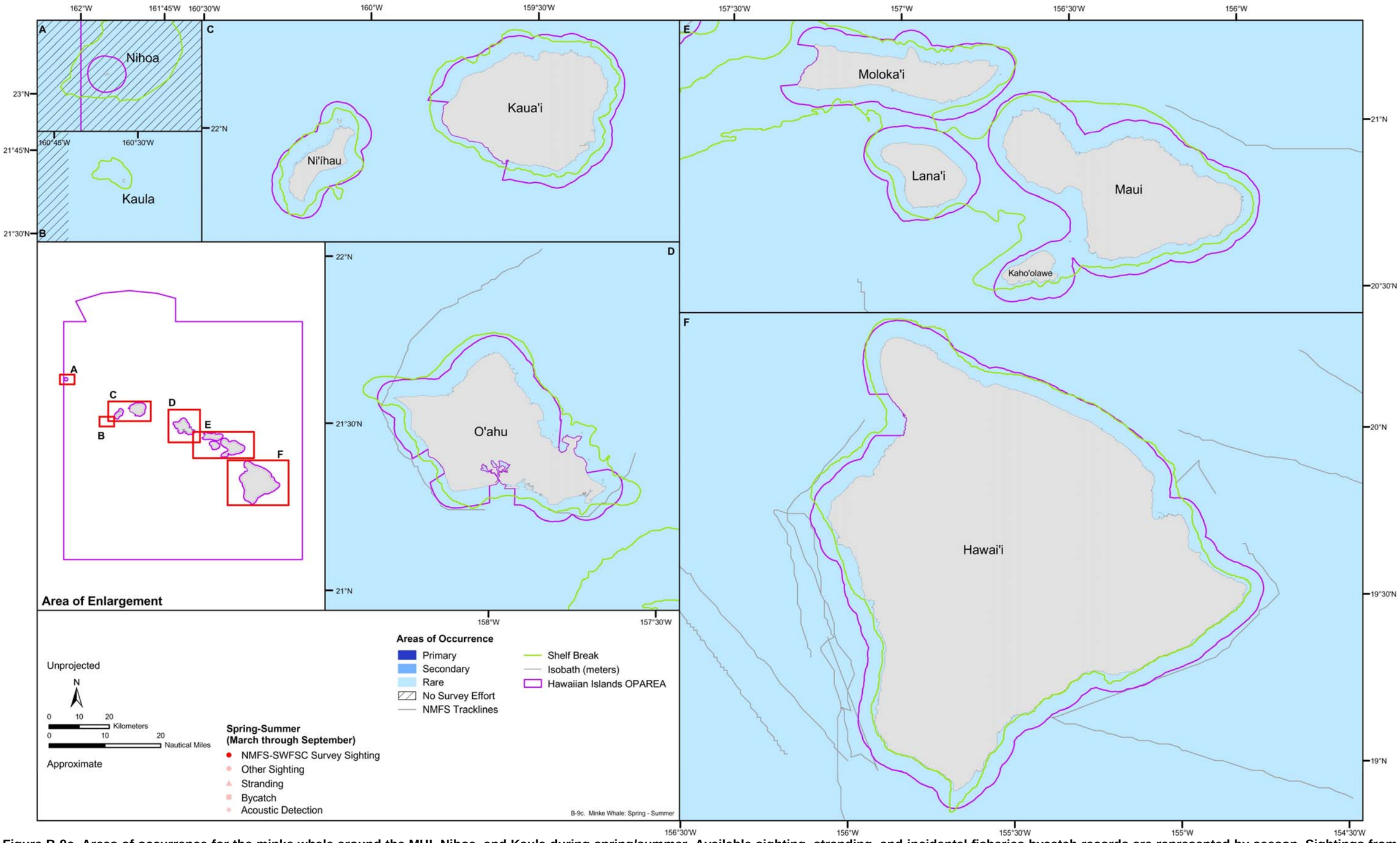

Figure B-9c. Areas of occurrence for the minke whale around the MHI, Nihoa, and Kaula during spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

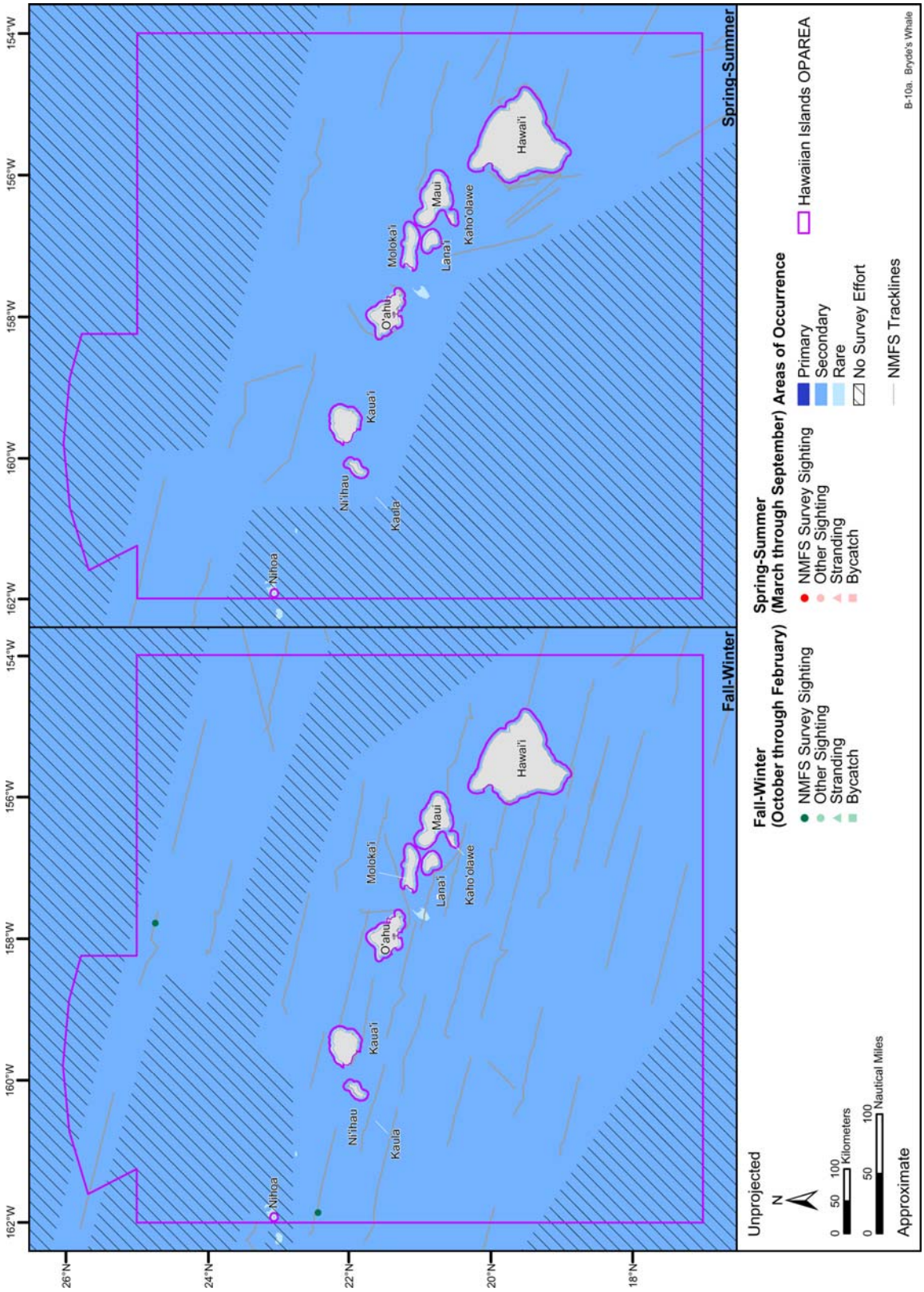

Figure B-10a. Areas of occurrence for the Bryde's whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

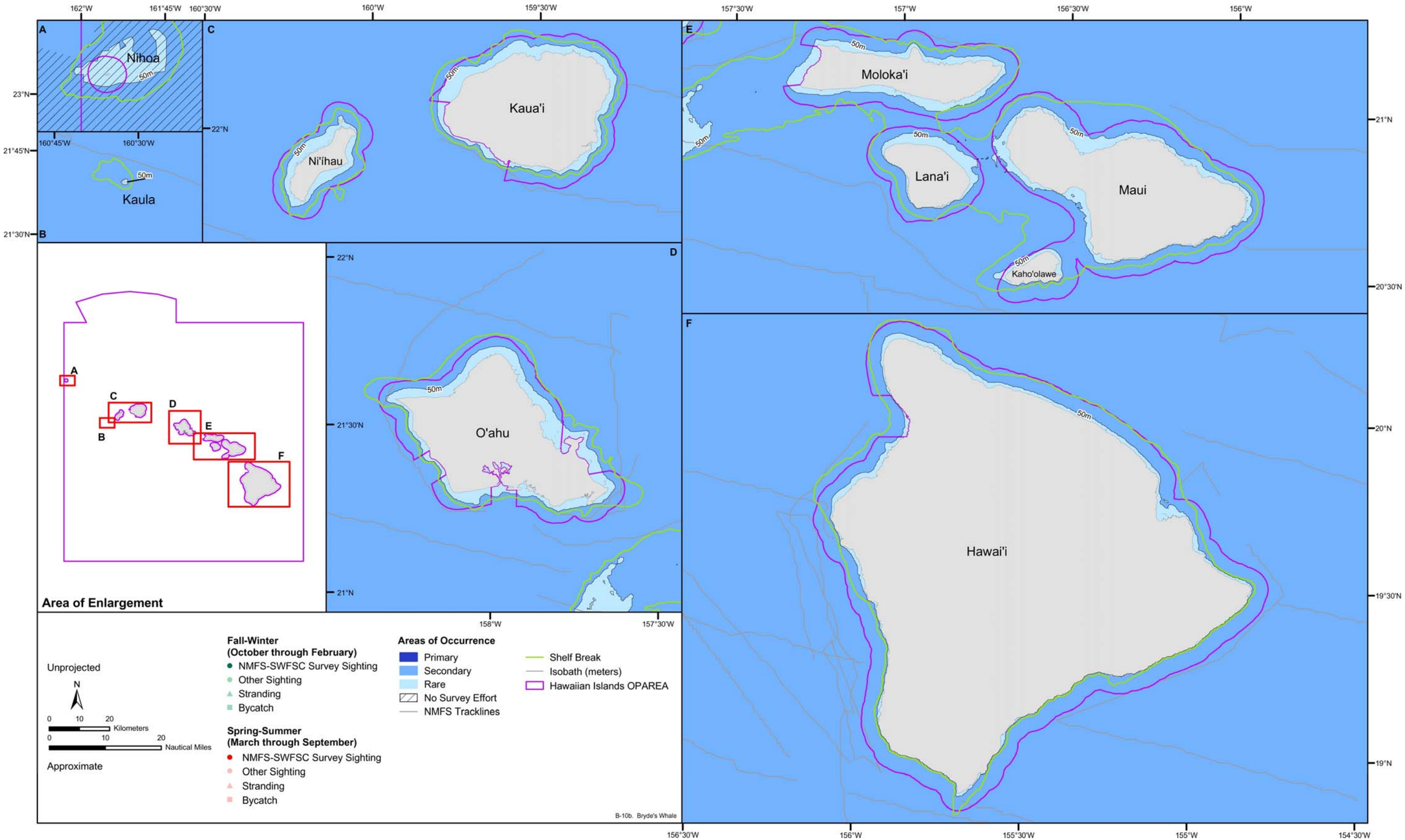

Figure B-10b. Areas of occurrence for the Bryde's whale around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

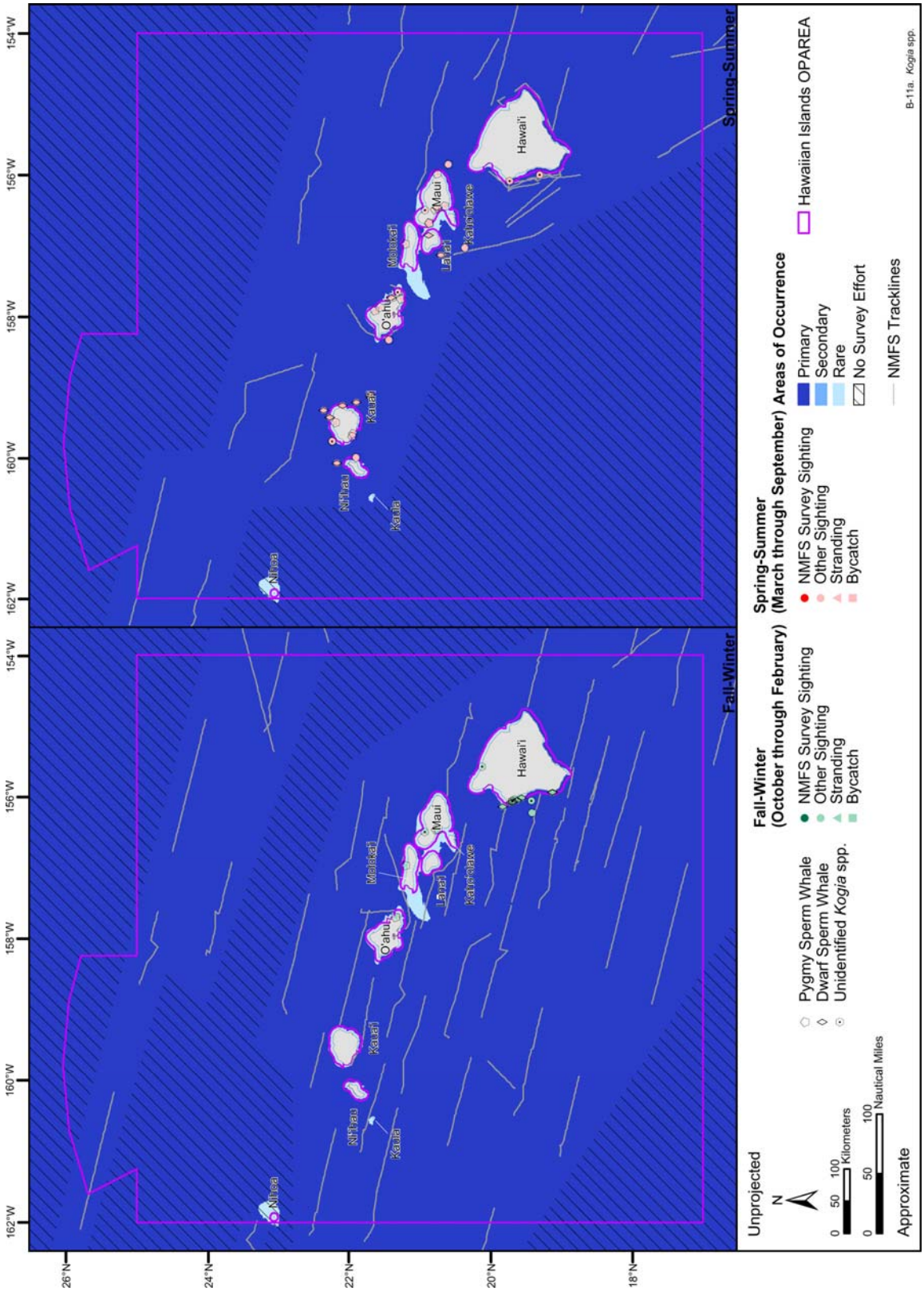

Figure B-11a. Areas of occurrence for *Kogia* spp. in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

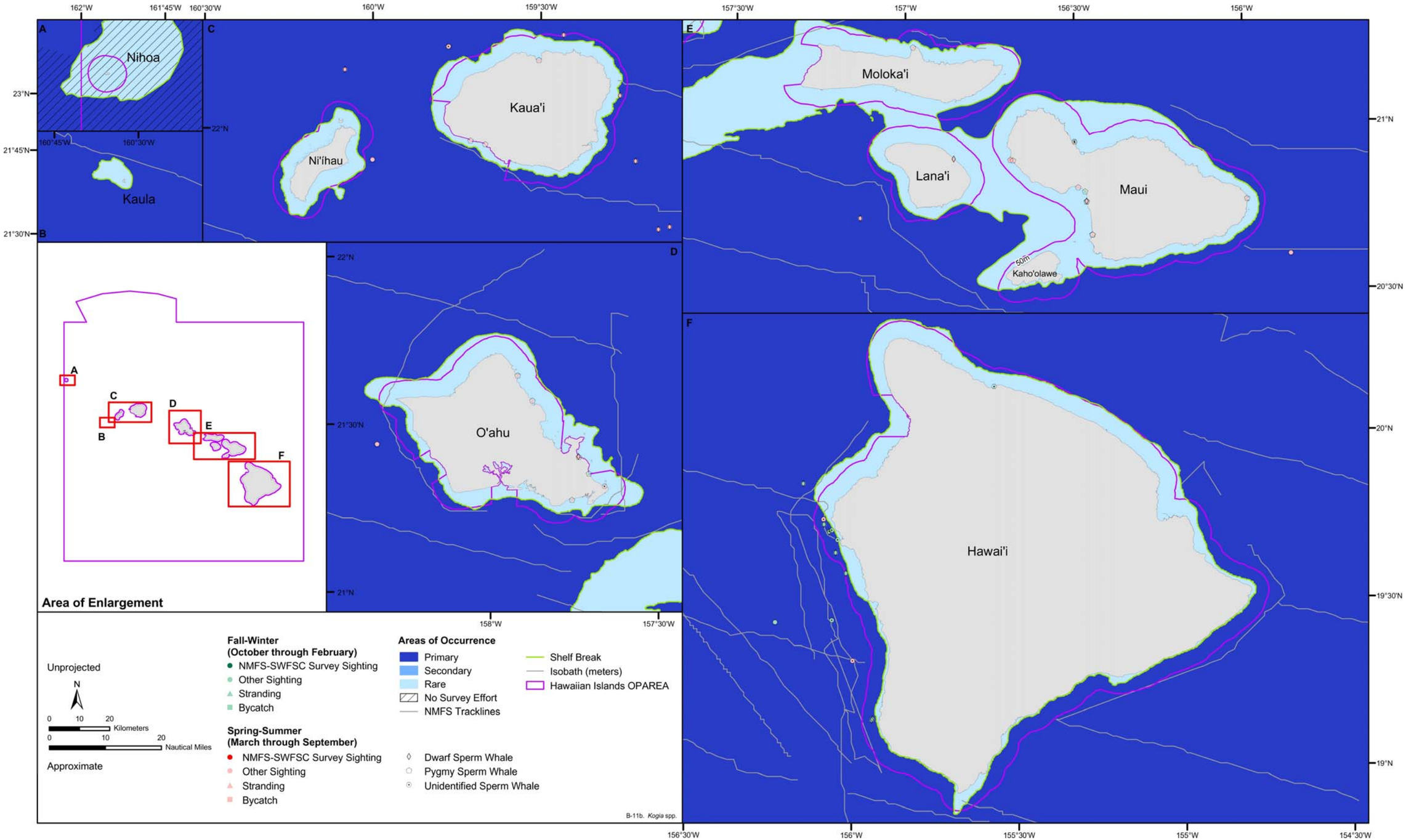

Figure B-11b. Areas of occurrence for *Kogia* spp. around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

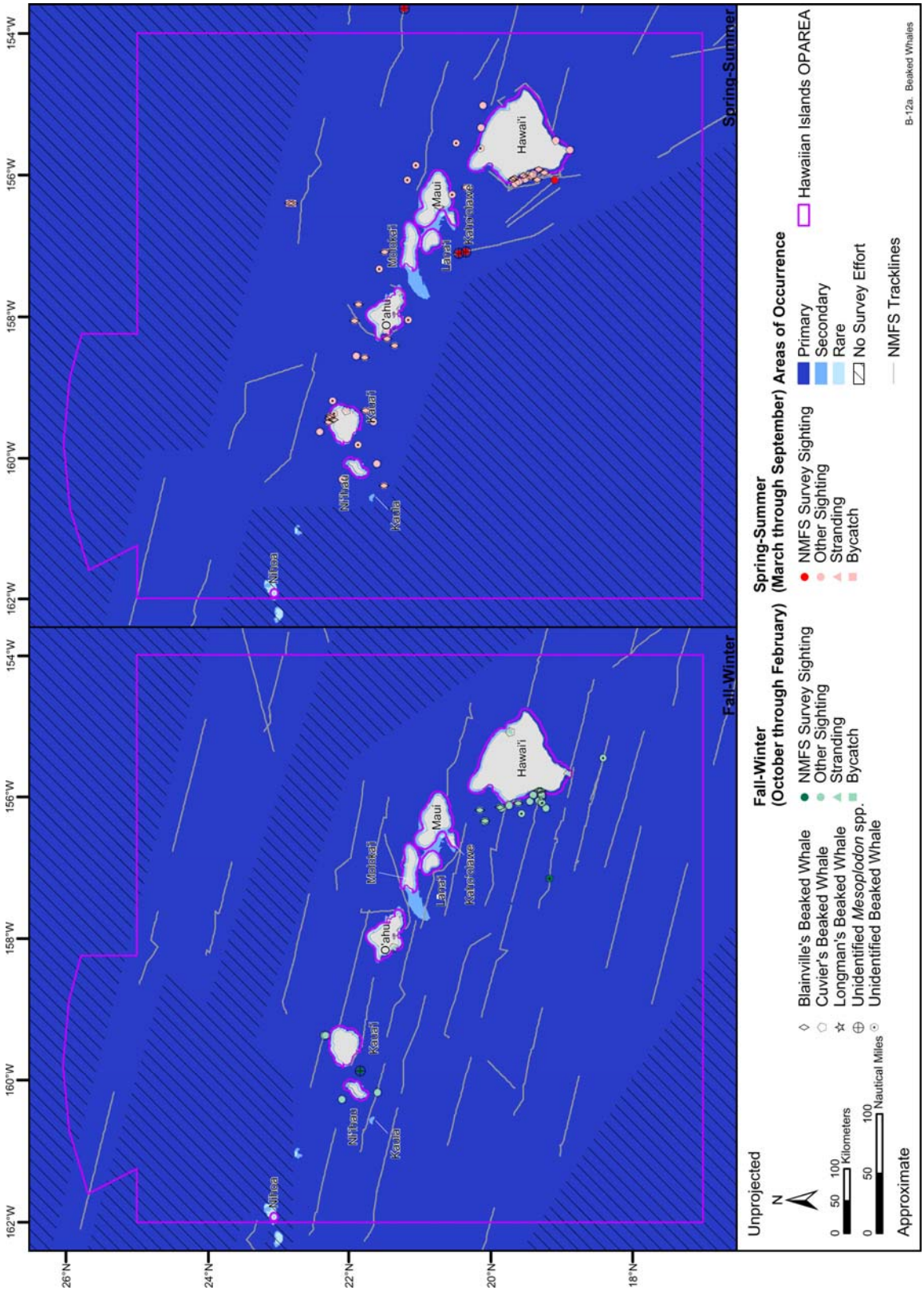

Figure B-12a. Areas of occurrence for beaked whales in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

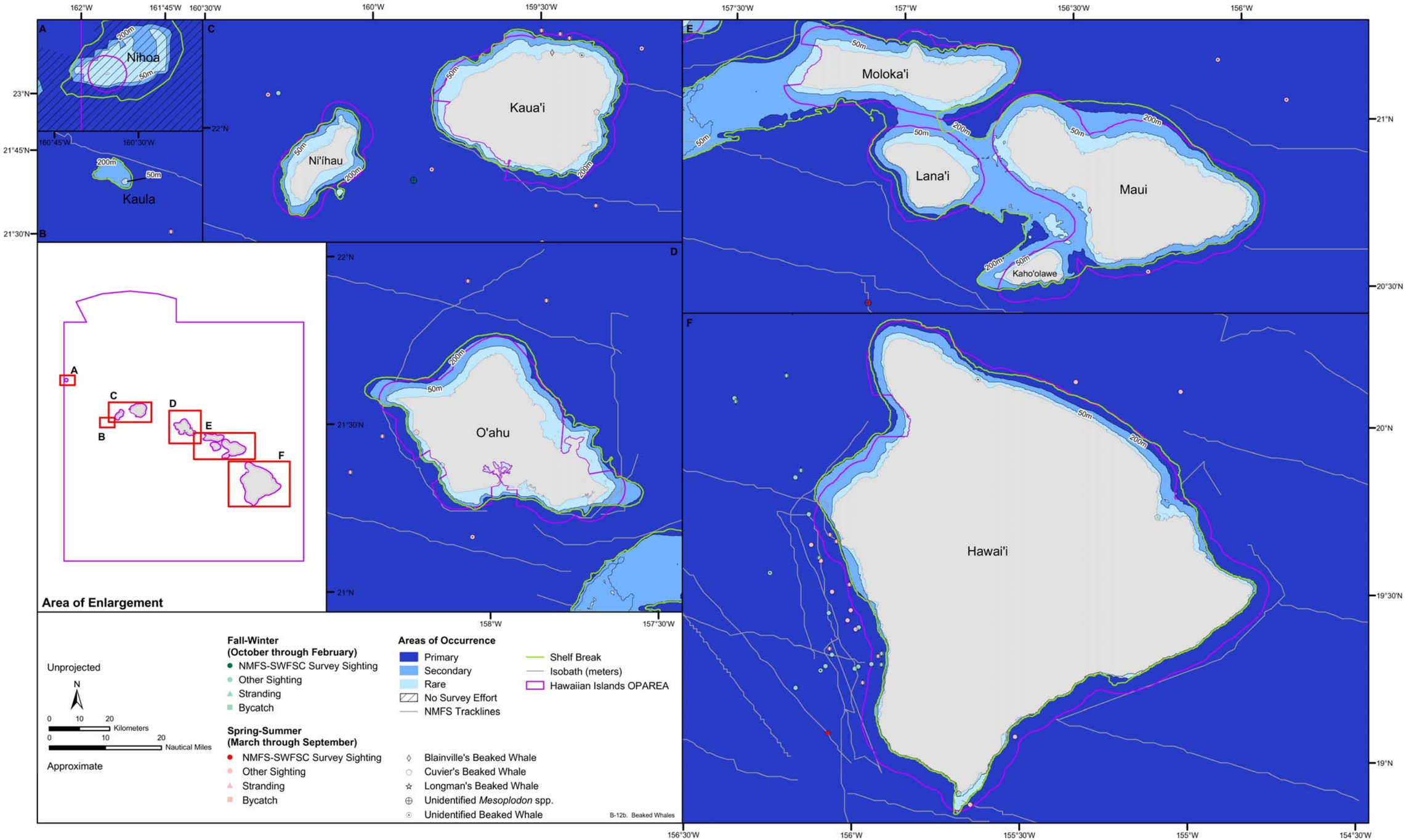

Figure B-12b. Areas of occurrence for beaked whales around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

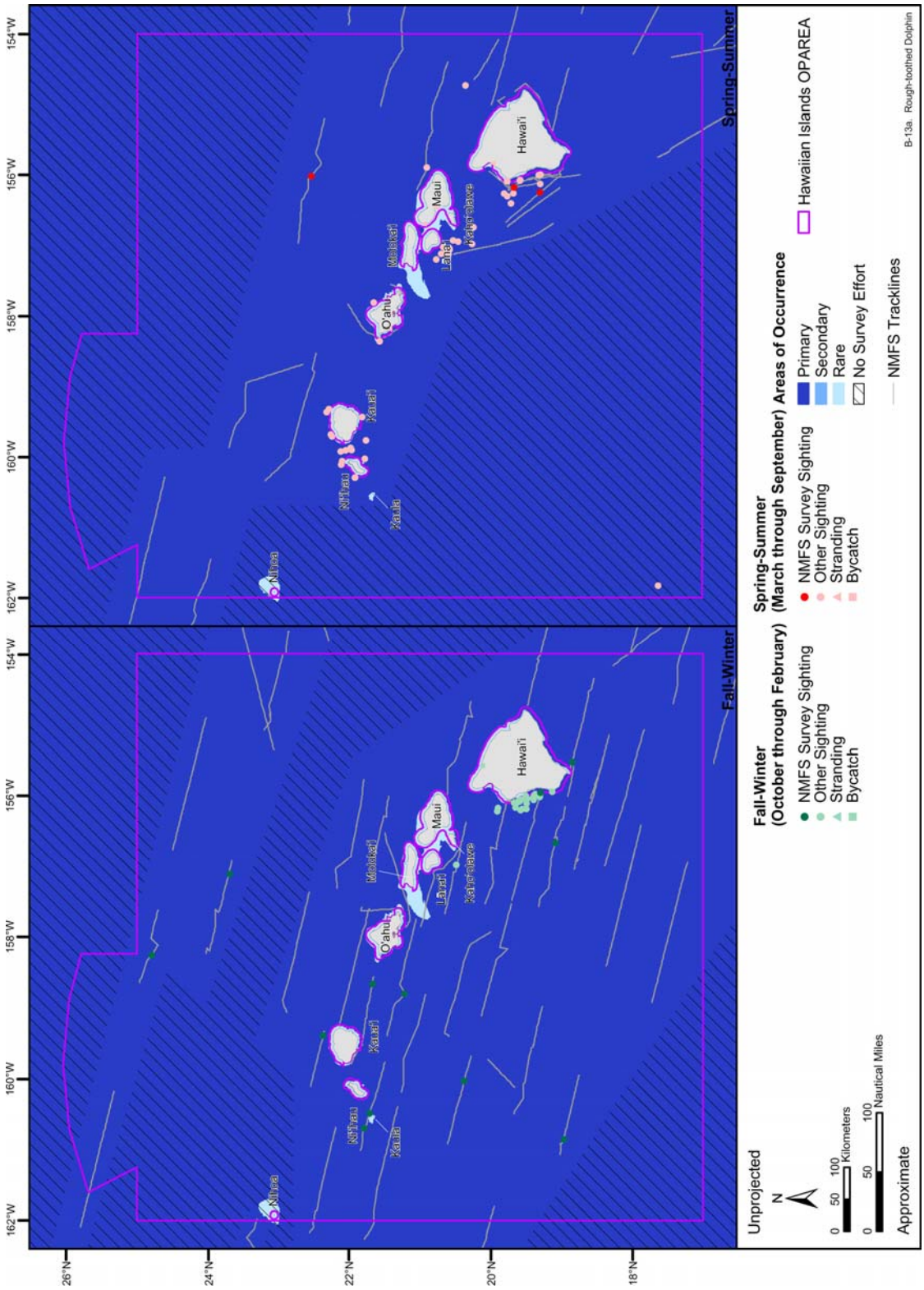

Figure B-13a. Areas of occurrence for the rough-toothed dolphin in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

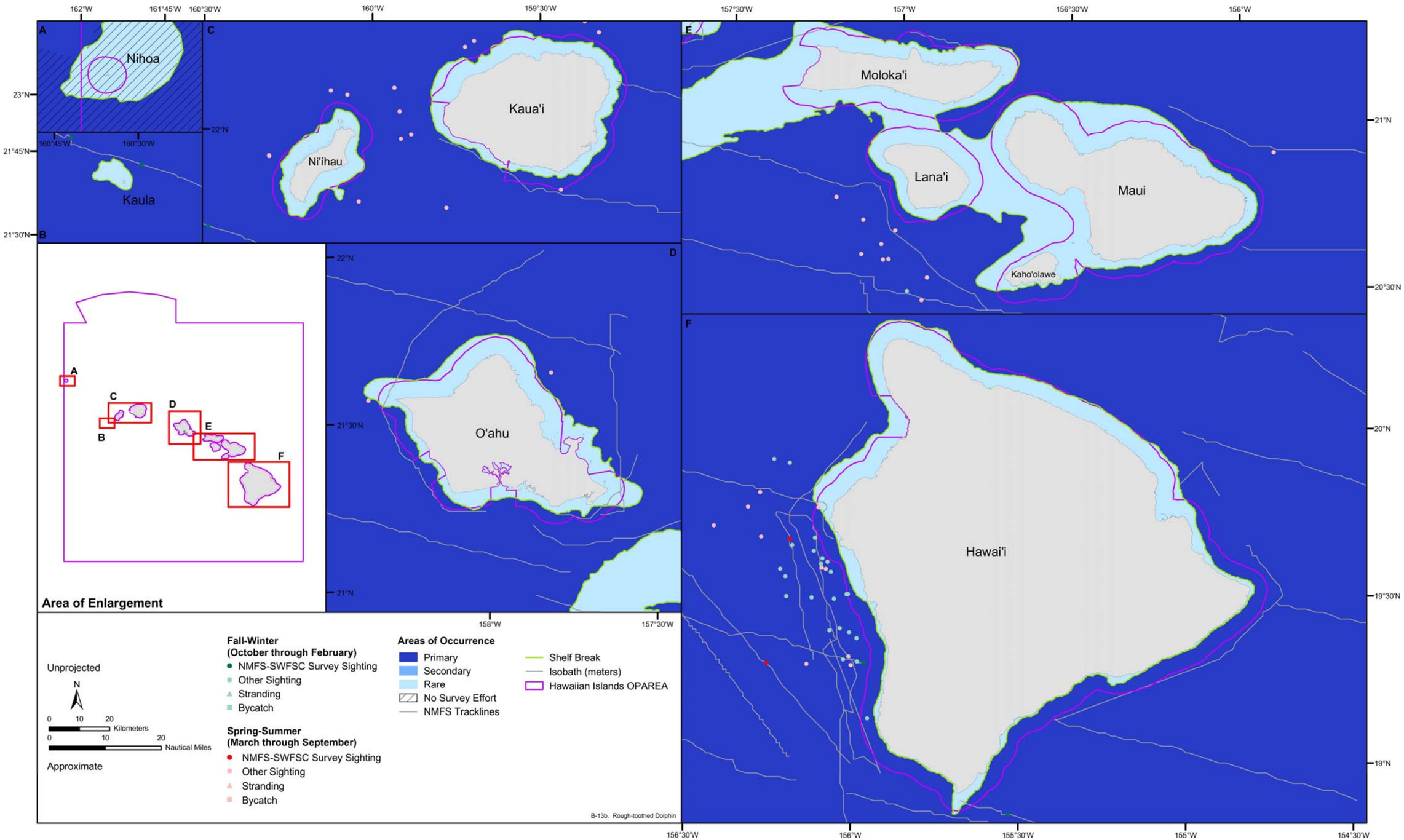

Figure B-13b. Areas of occurrence for the rough-toothed dolphin around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

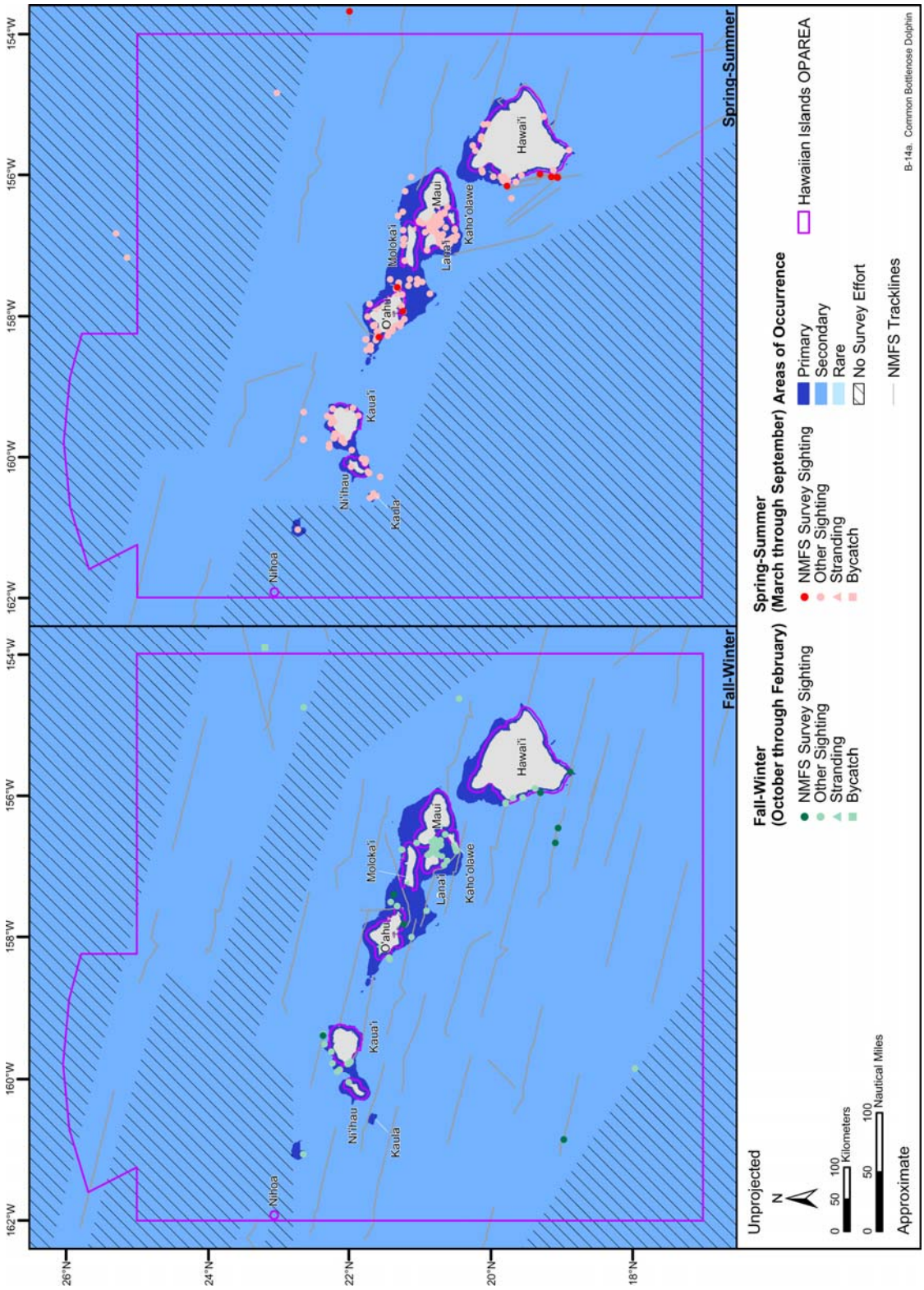

Figure B-14a. Areas of occurrence for the common bottlenose dolphin in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

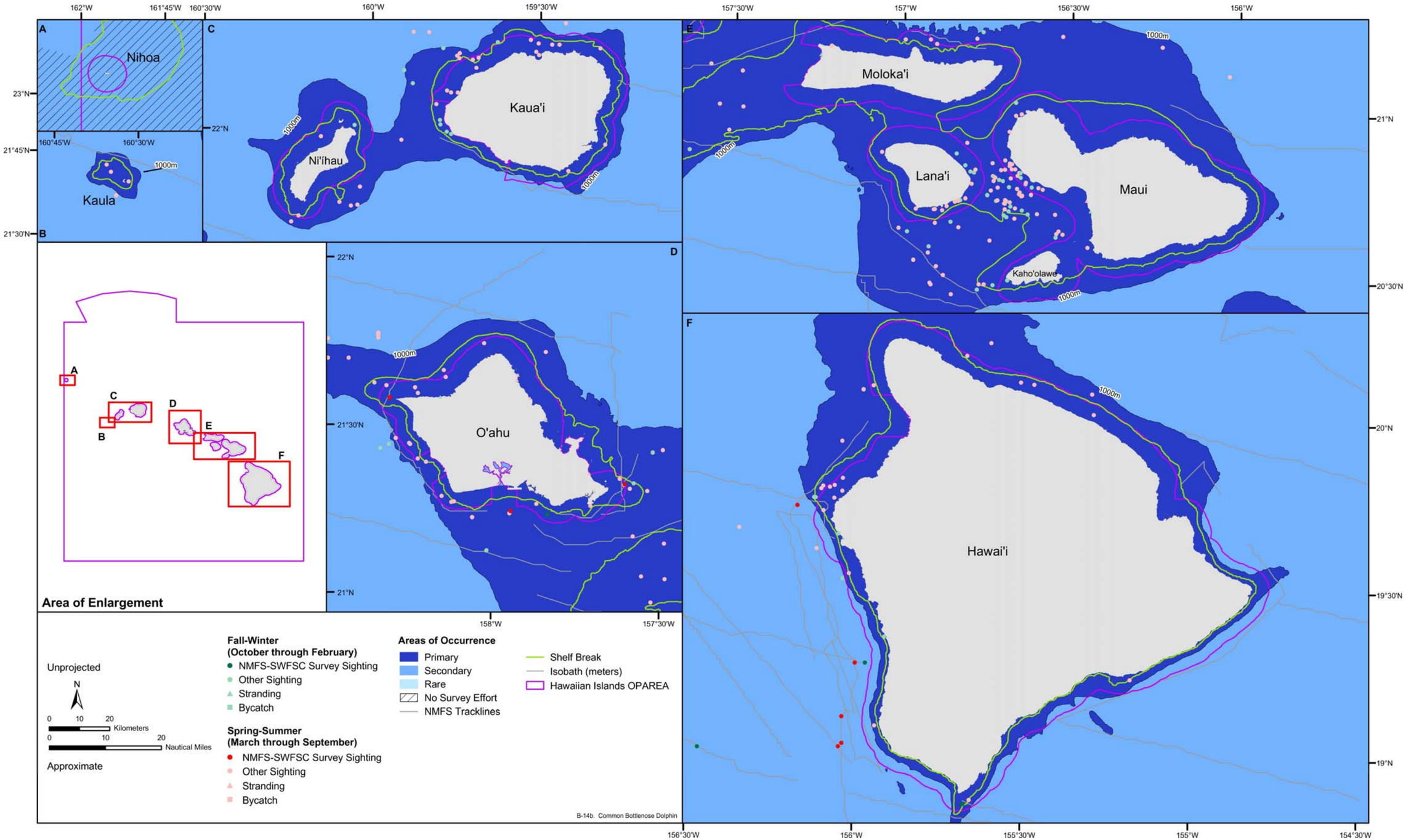

Figure B-14b. Areas of occurrence for the common bottlenose dolphin around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

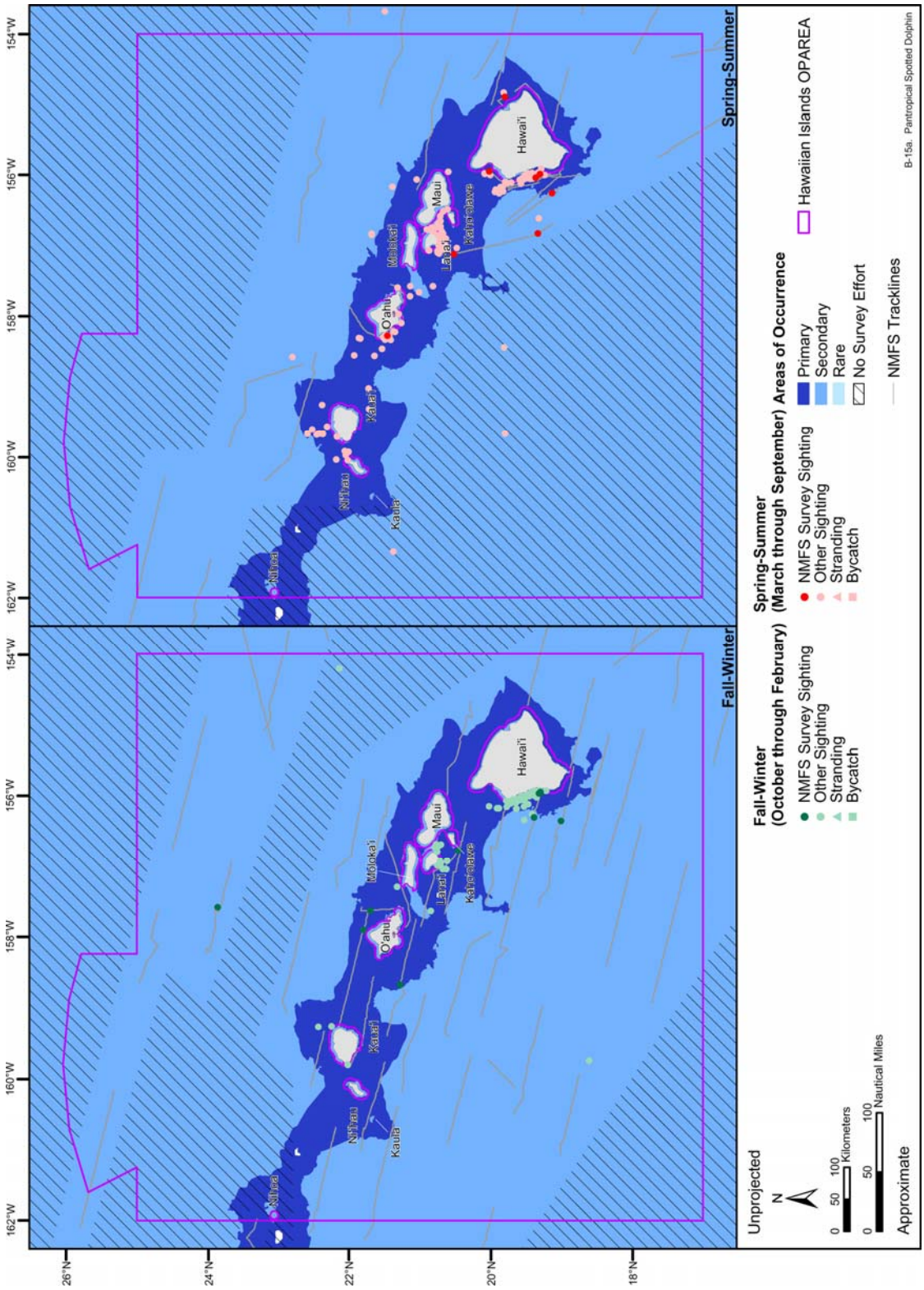

Figure B-15a. Areas of occurrence for the pantropical spotted dolphin in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

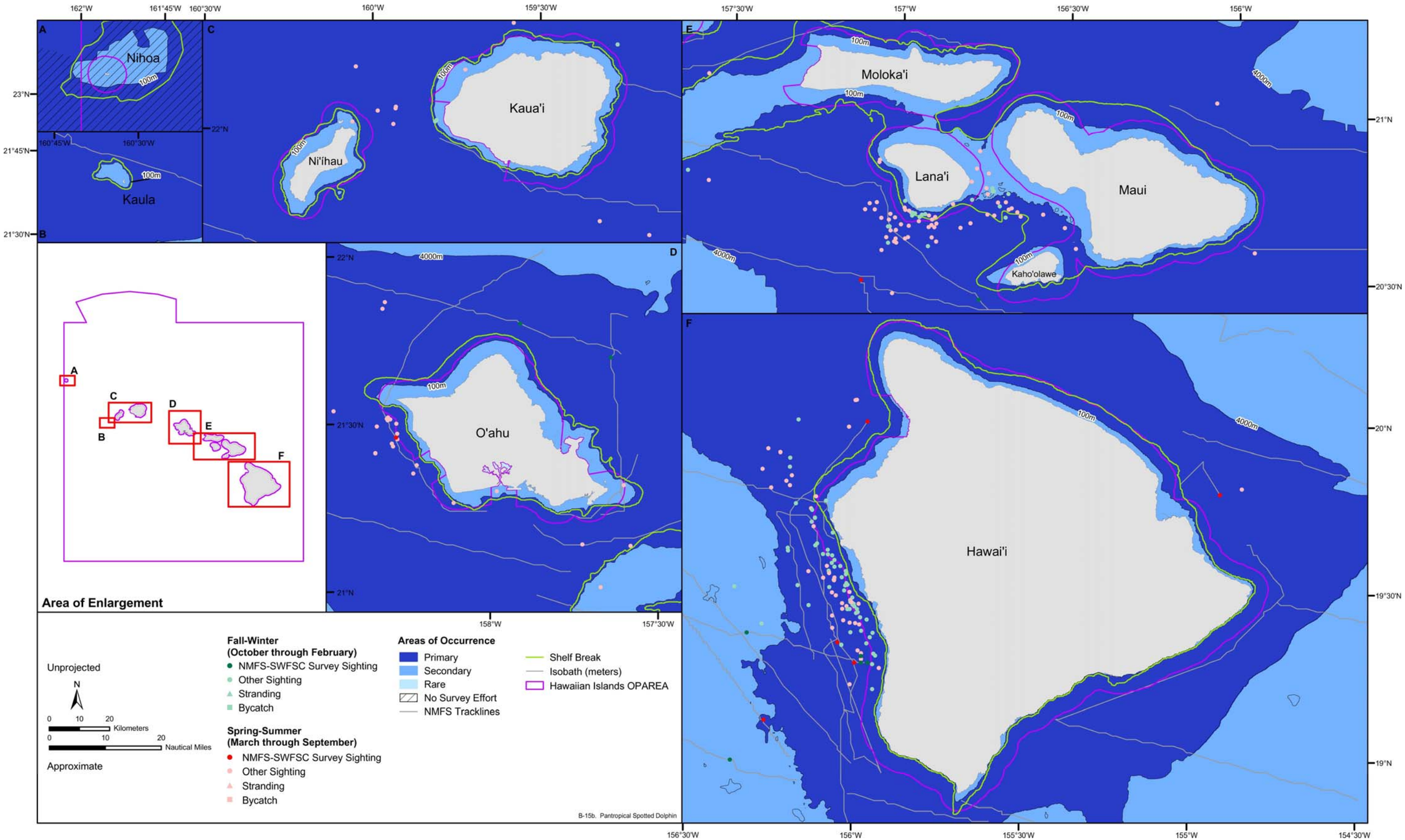

Figure B-15b. Areas of occurrence for the pantropical spotted dolphin around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

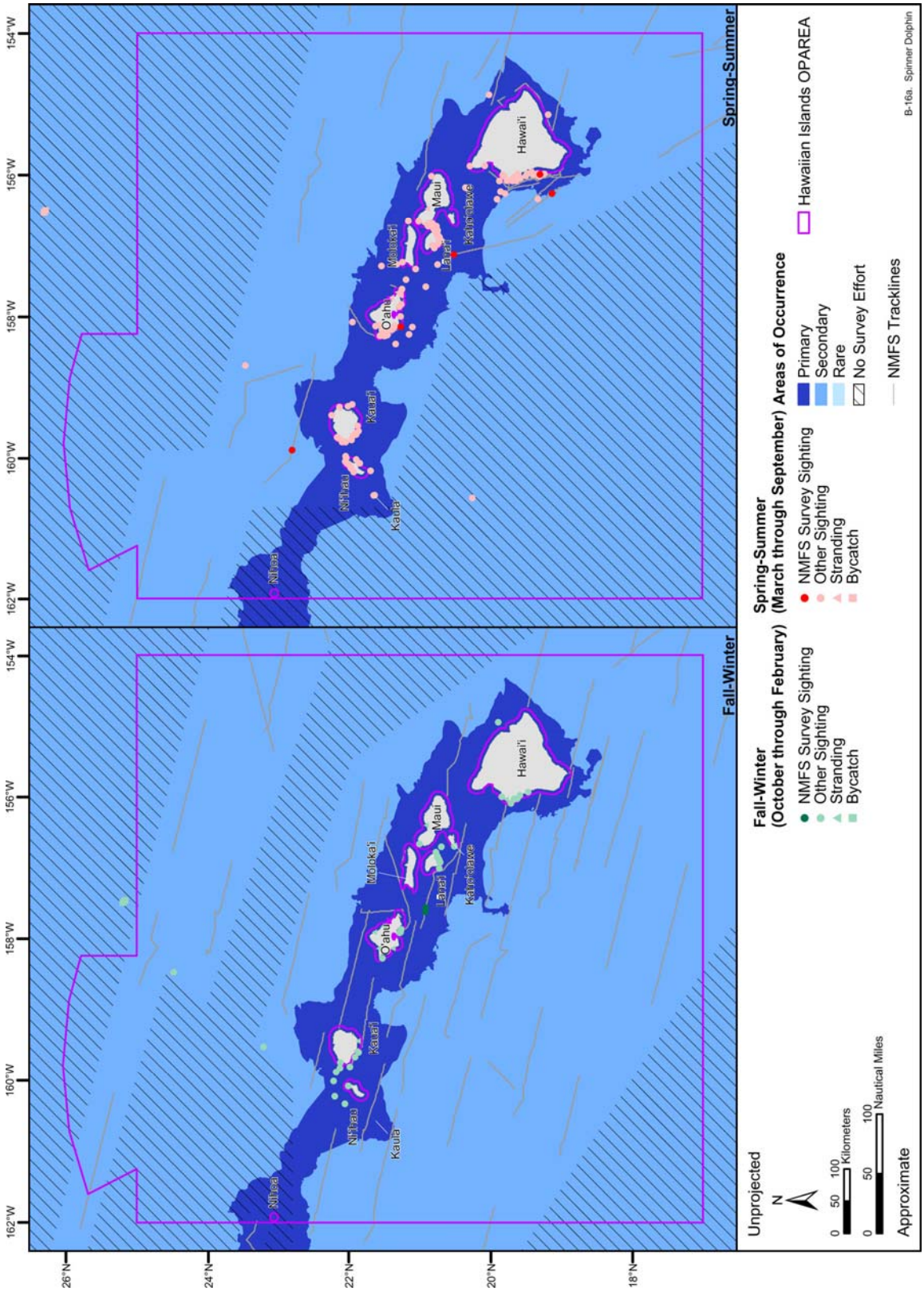

Figure B-16a. Areas of occurrence for the spinner dolphin in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

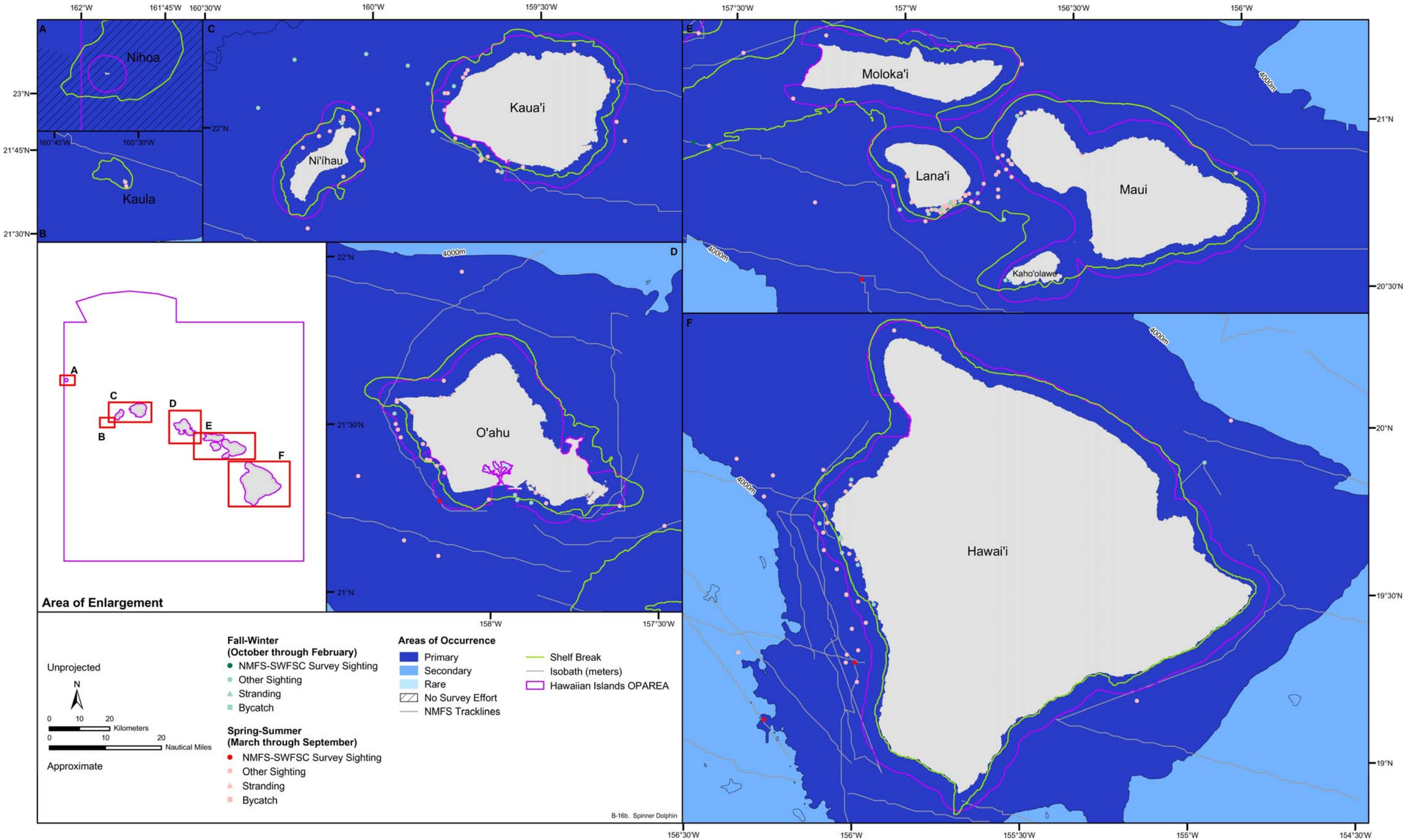

Figure B-16b. Areas of occurrence for the spinner dolphin around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

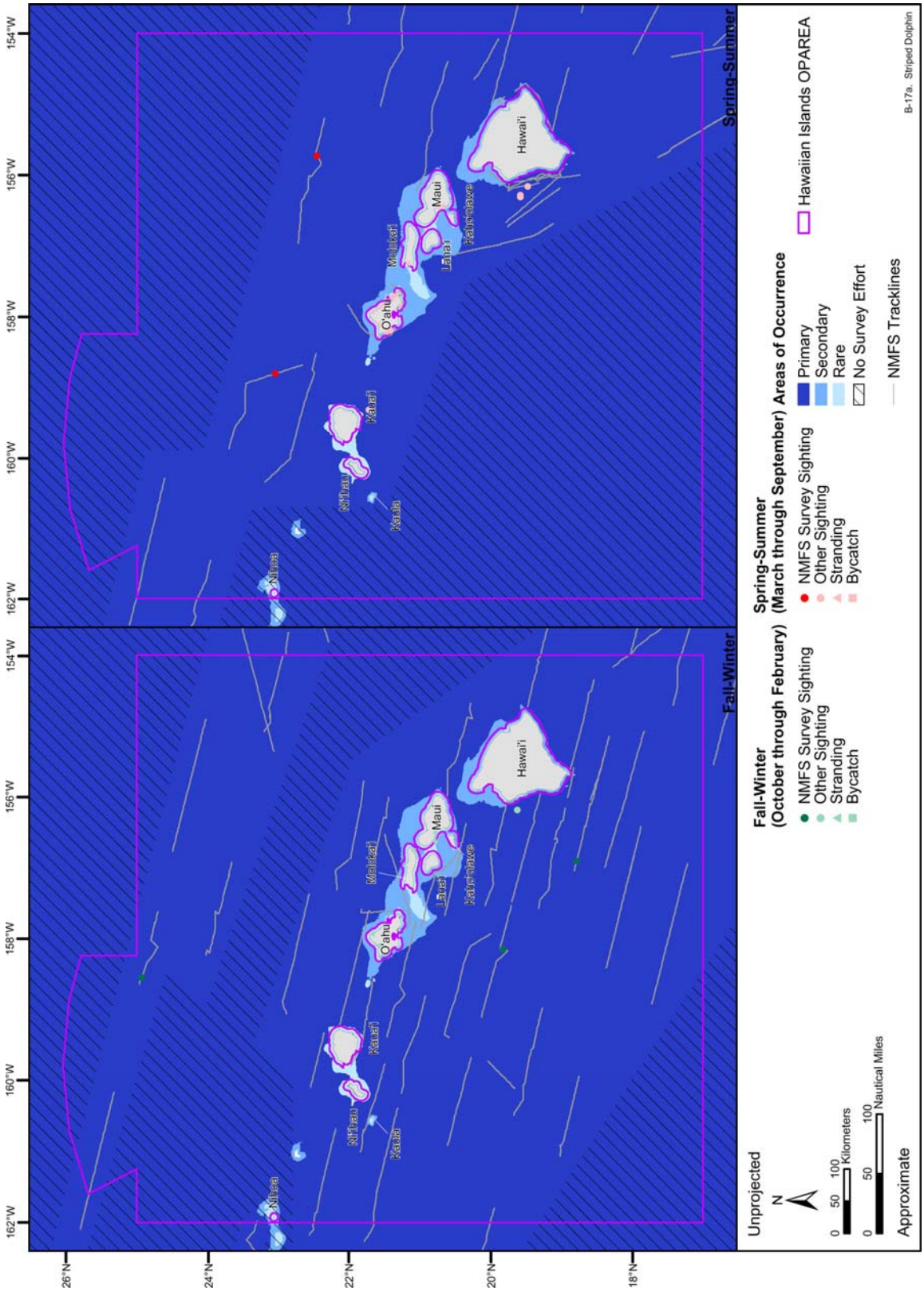

Figure B-17a. Areas of occurrence for the striped dolphin in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

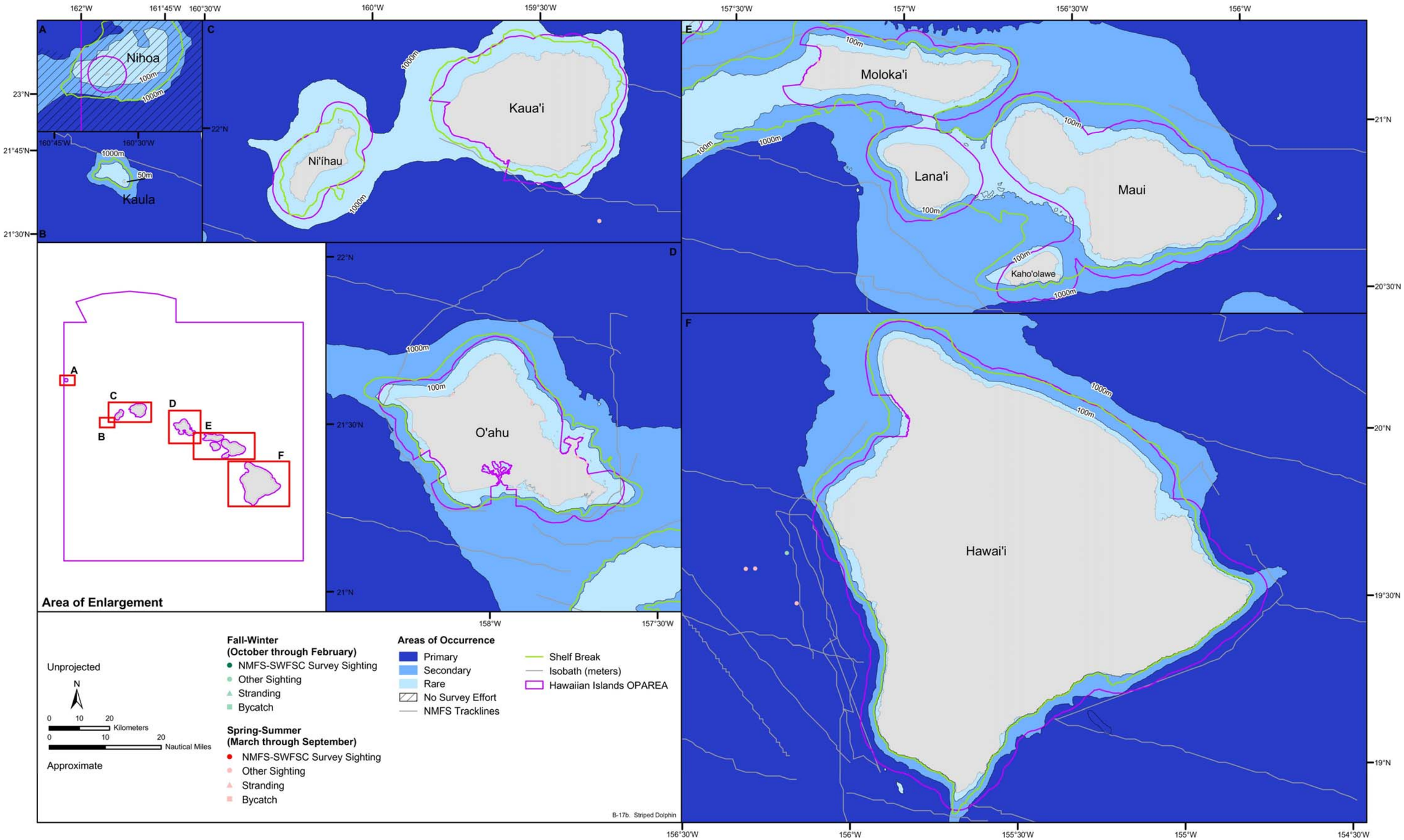

Figure B-17b. Areas of occurrence for the striped dolphin around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

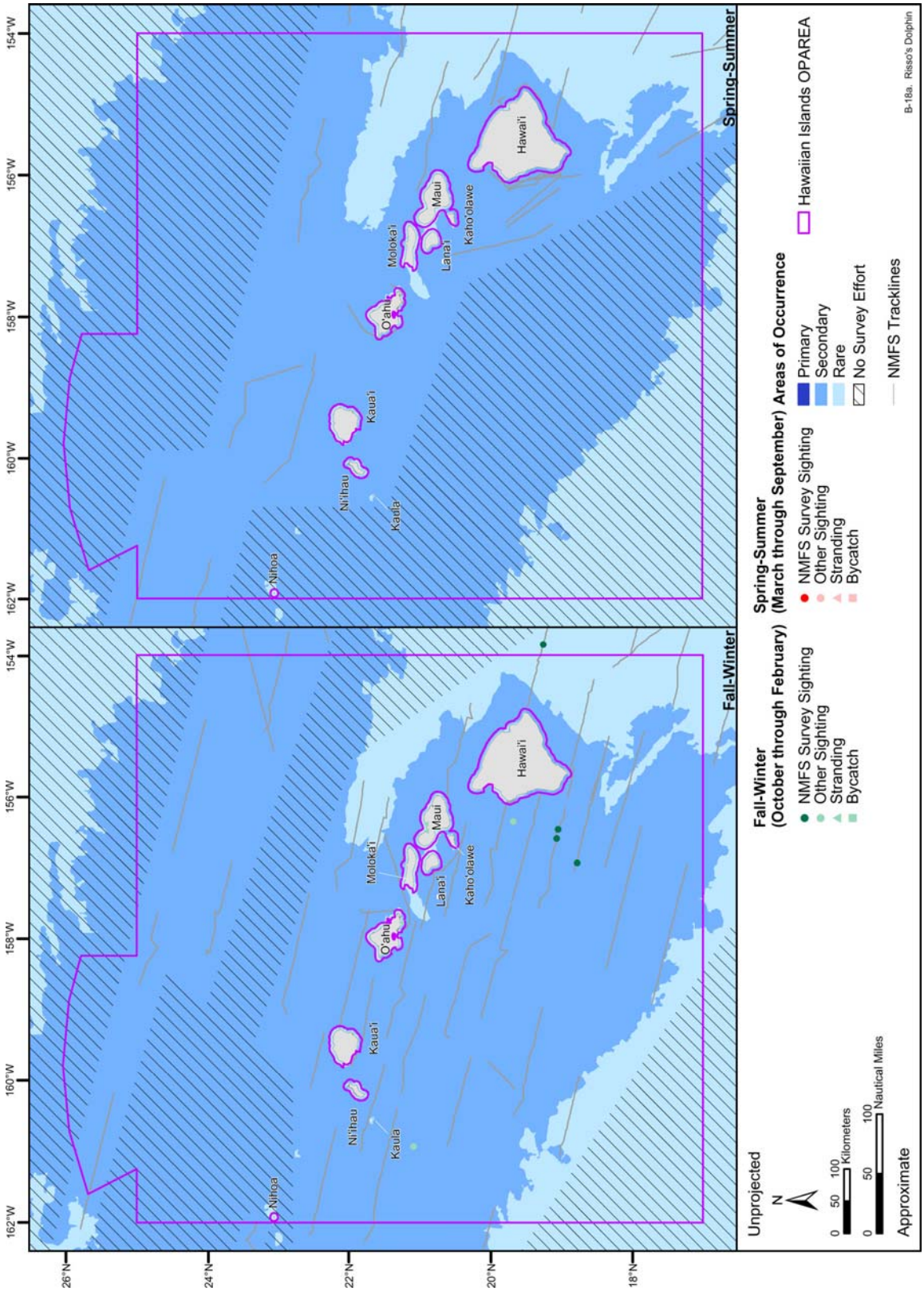

Figure B-18a. Areas of occurrence for the Risso's dolphin in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

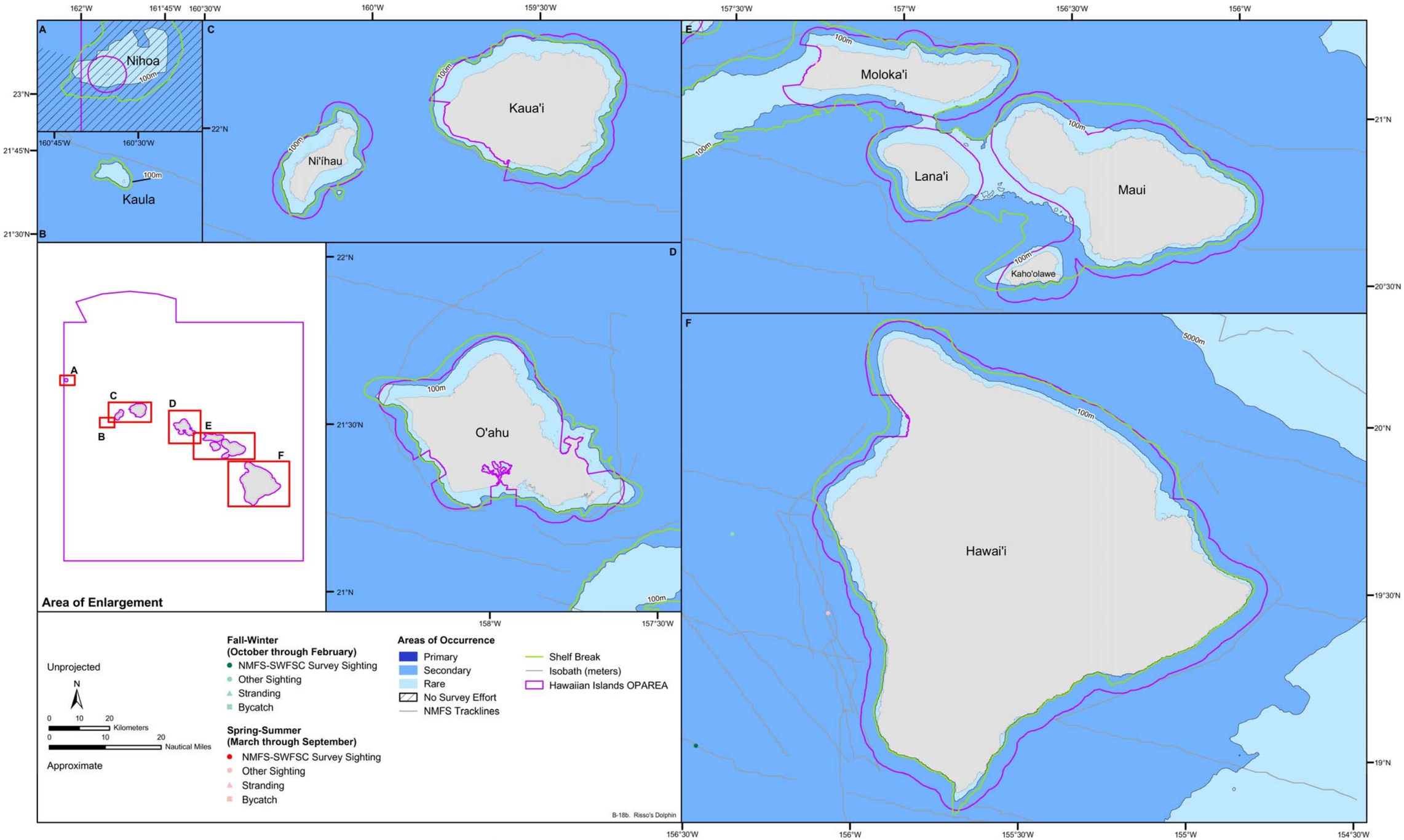

Figure B-18b. Areas of occurrence for the Risso's dolphin around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

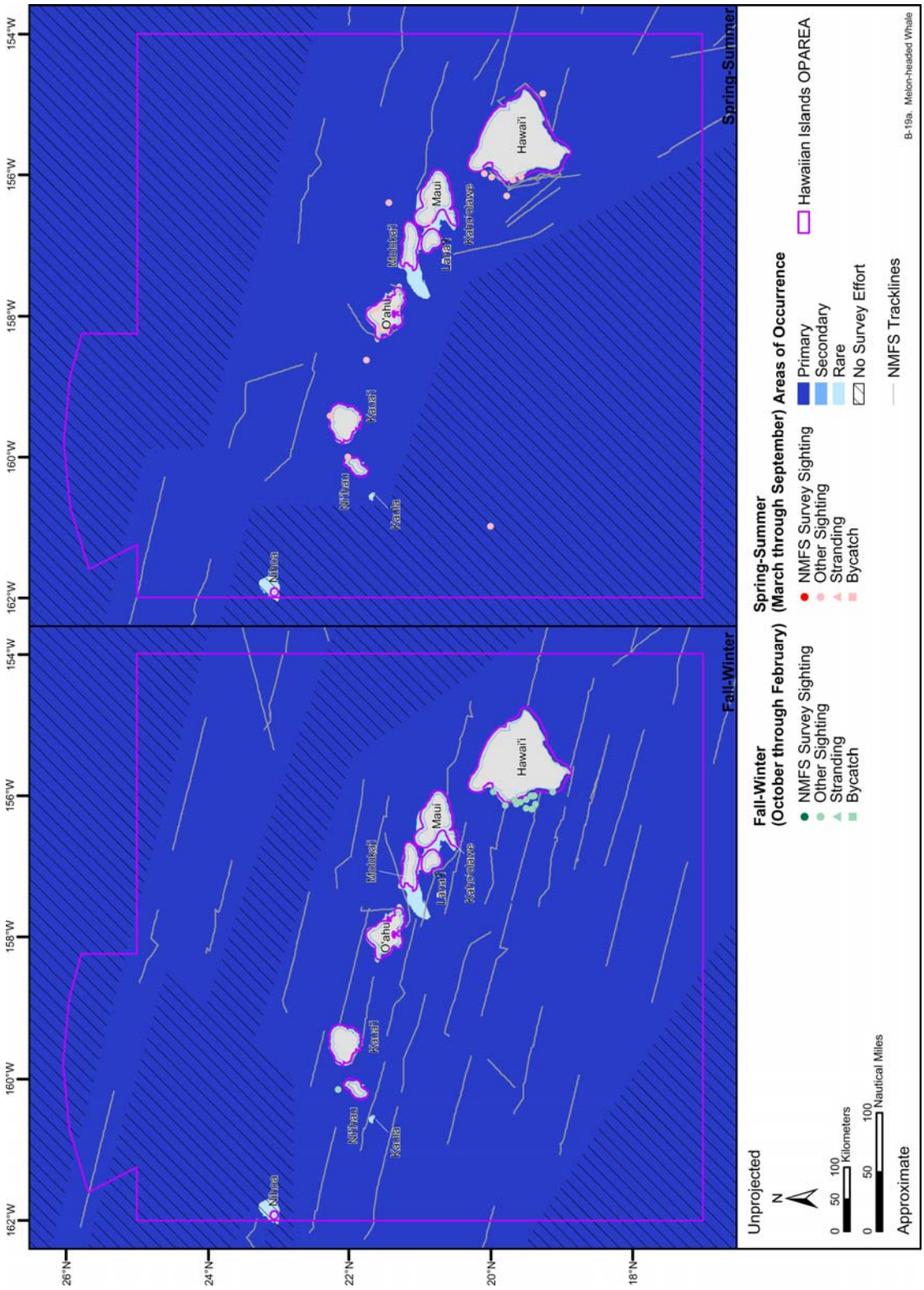

Figure B-19a. Areas of occurrence for the melon-headed whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

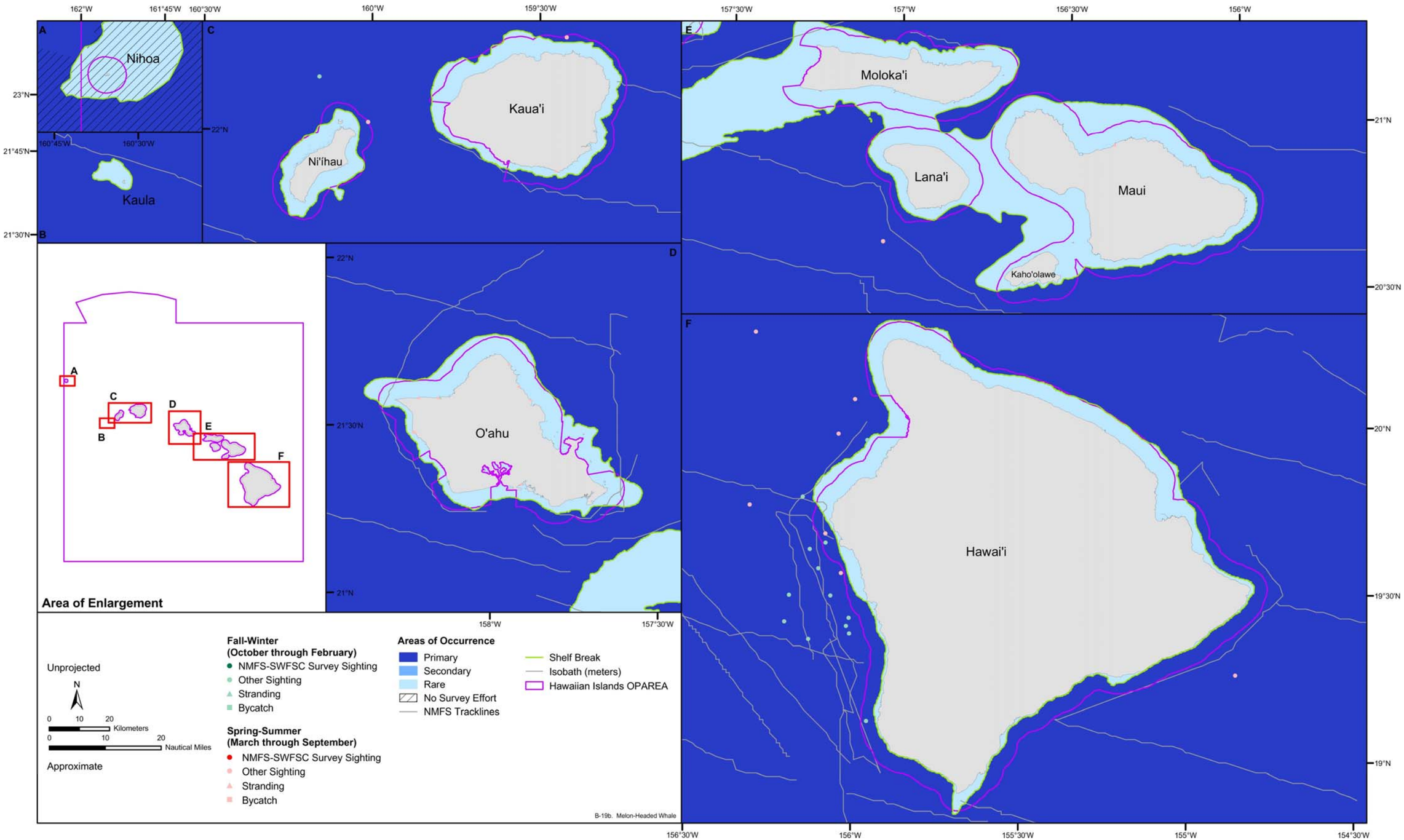

Figure B-19b. Areas of occurrence for the melon-headed whale around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

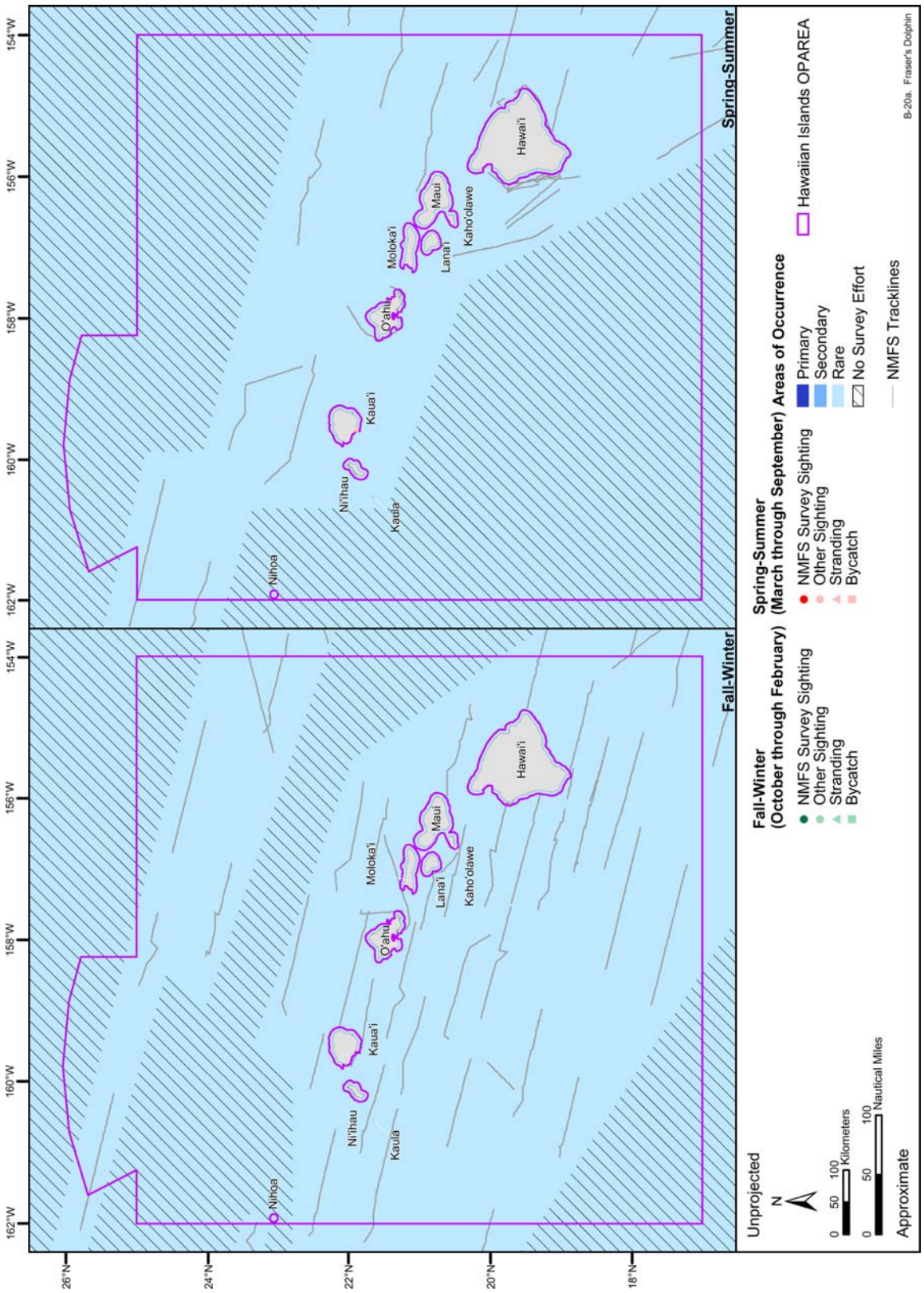

Figure B-20a. Areas of occurrence for the Fraser's dolphin in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

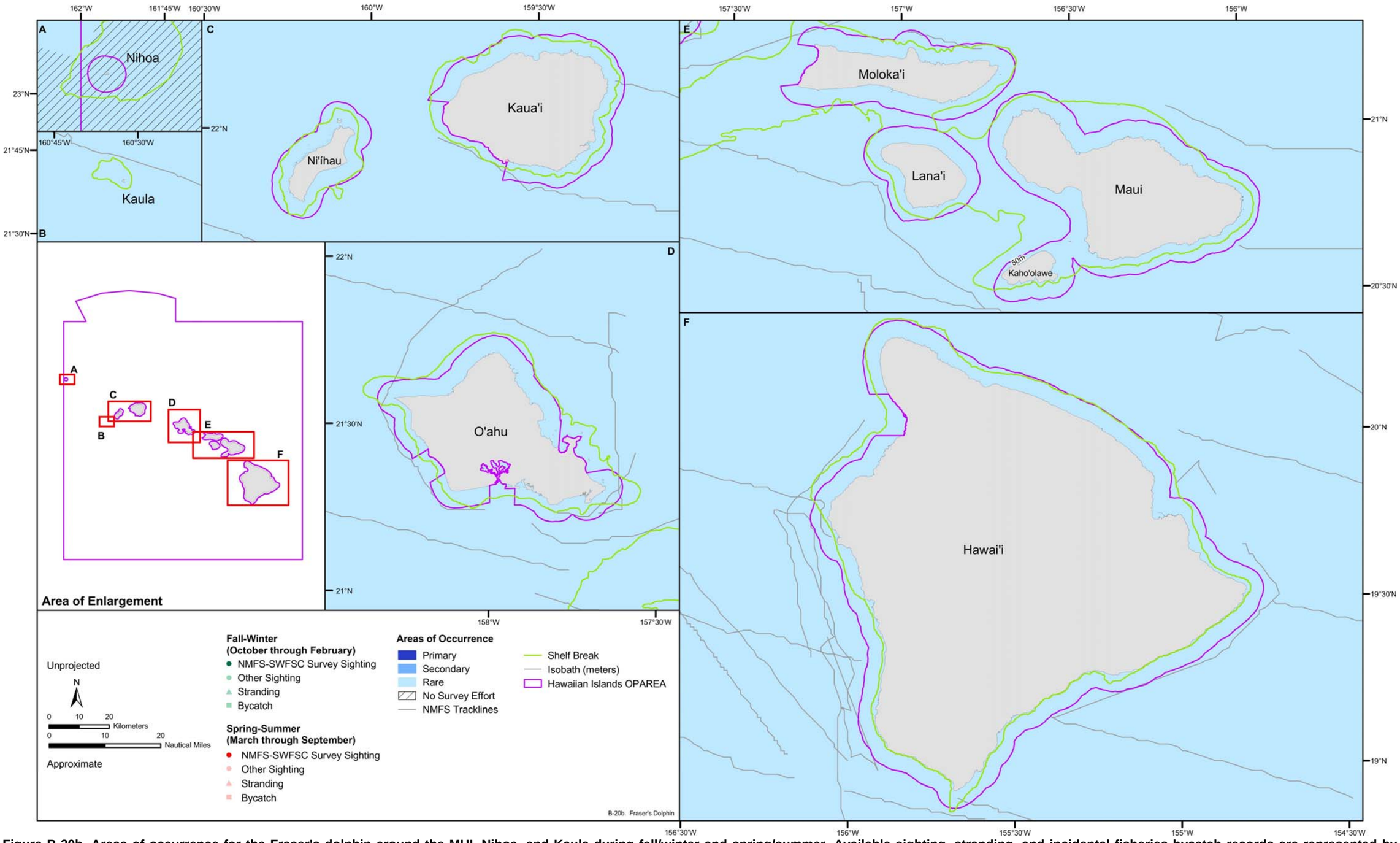

Figure B-20b. Areas of occurrence for the Fraser's dolphin around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

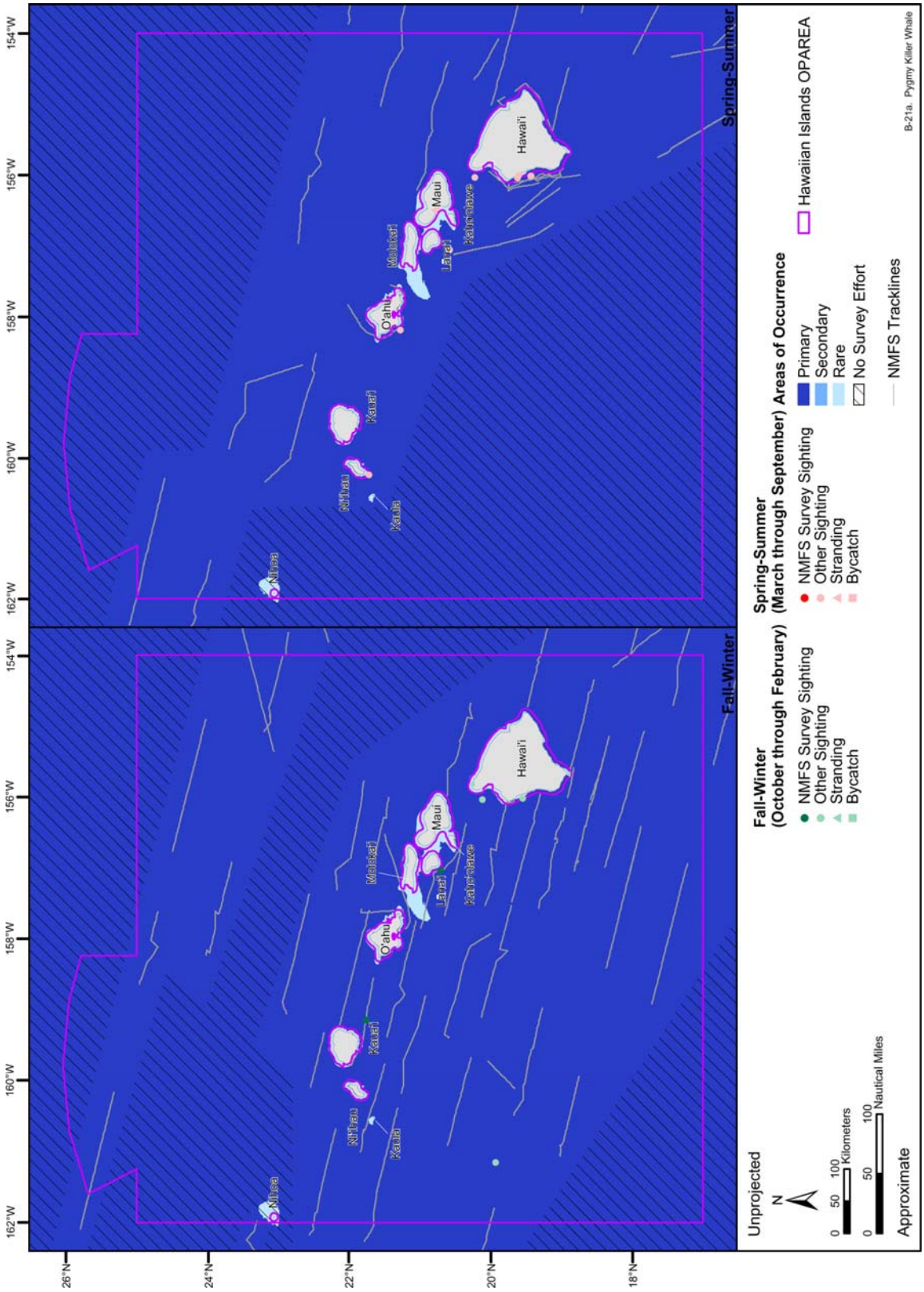

Figure B-21a. Areas of occurrence for the pygmy killer whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

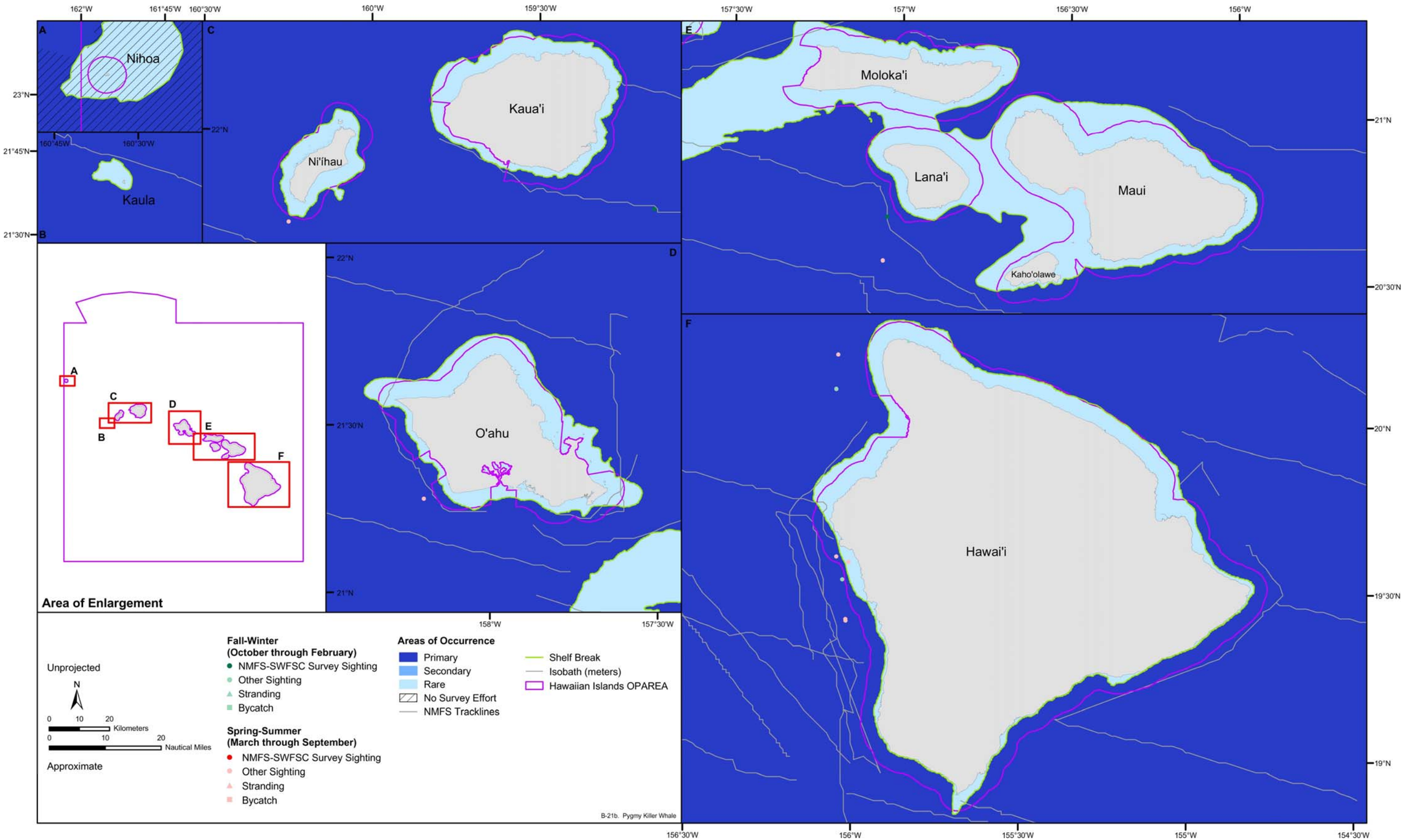

Figure B-21b. Areas of occurrence for the pygmy killer whale around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

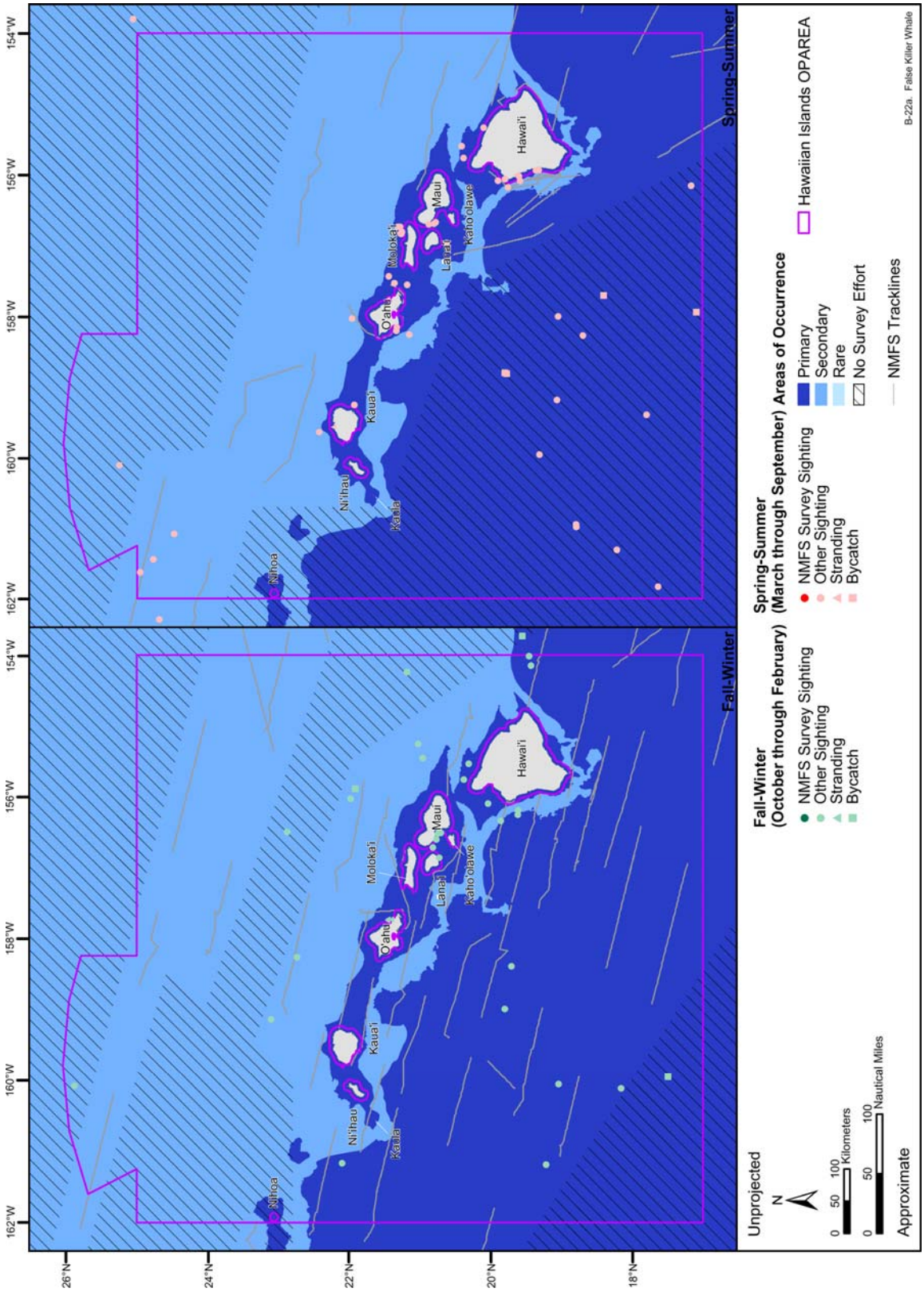

Figure B-22a. Areas of occurrence for the false killer whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

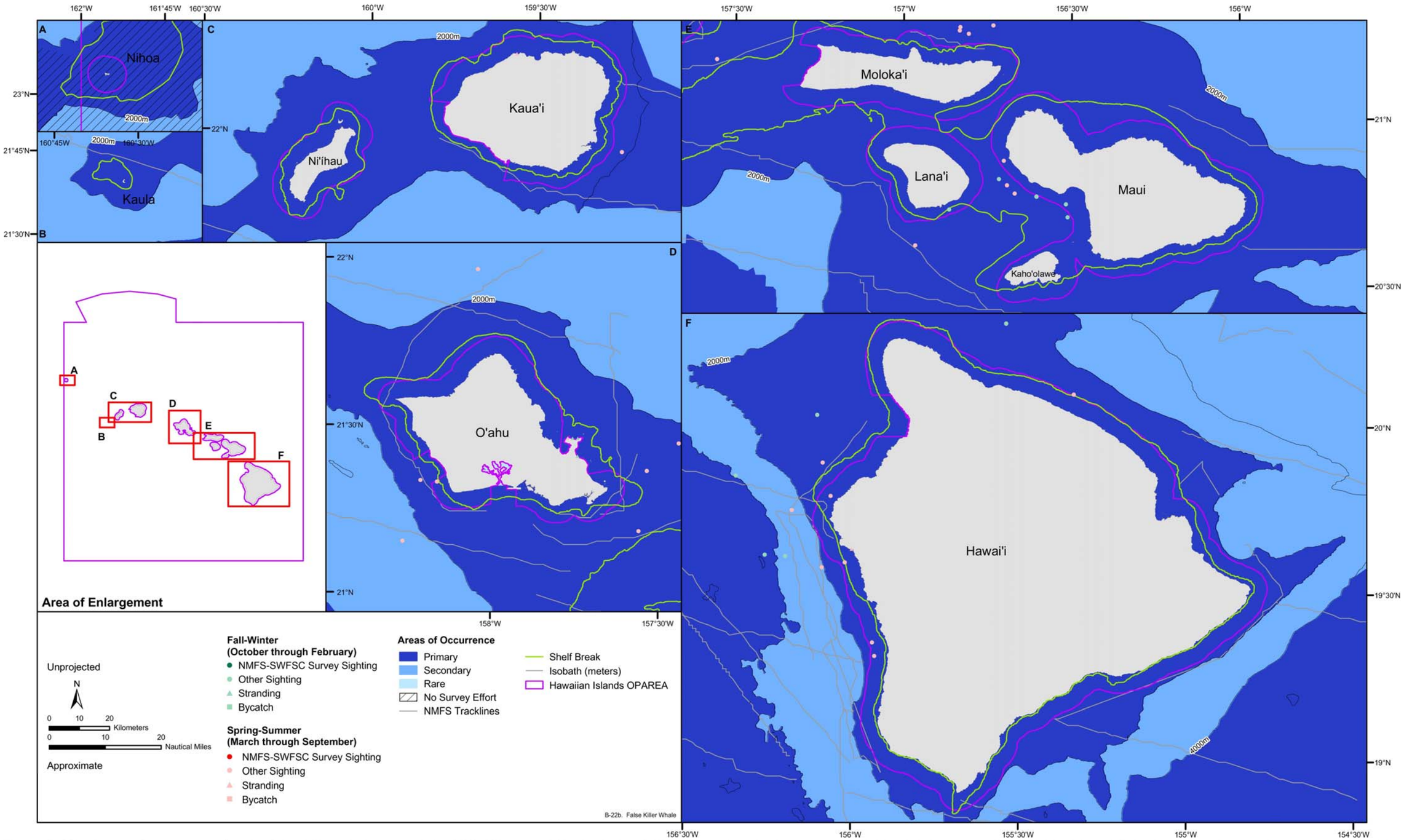

Figure B-22b. Areas of occurrence for the false killer whale around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

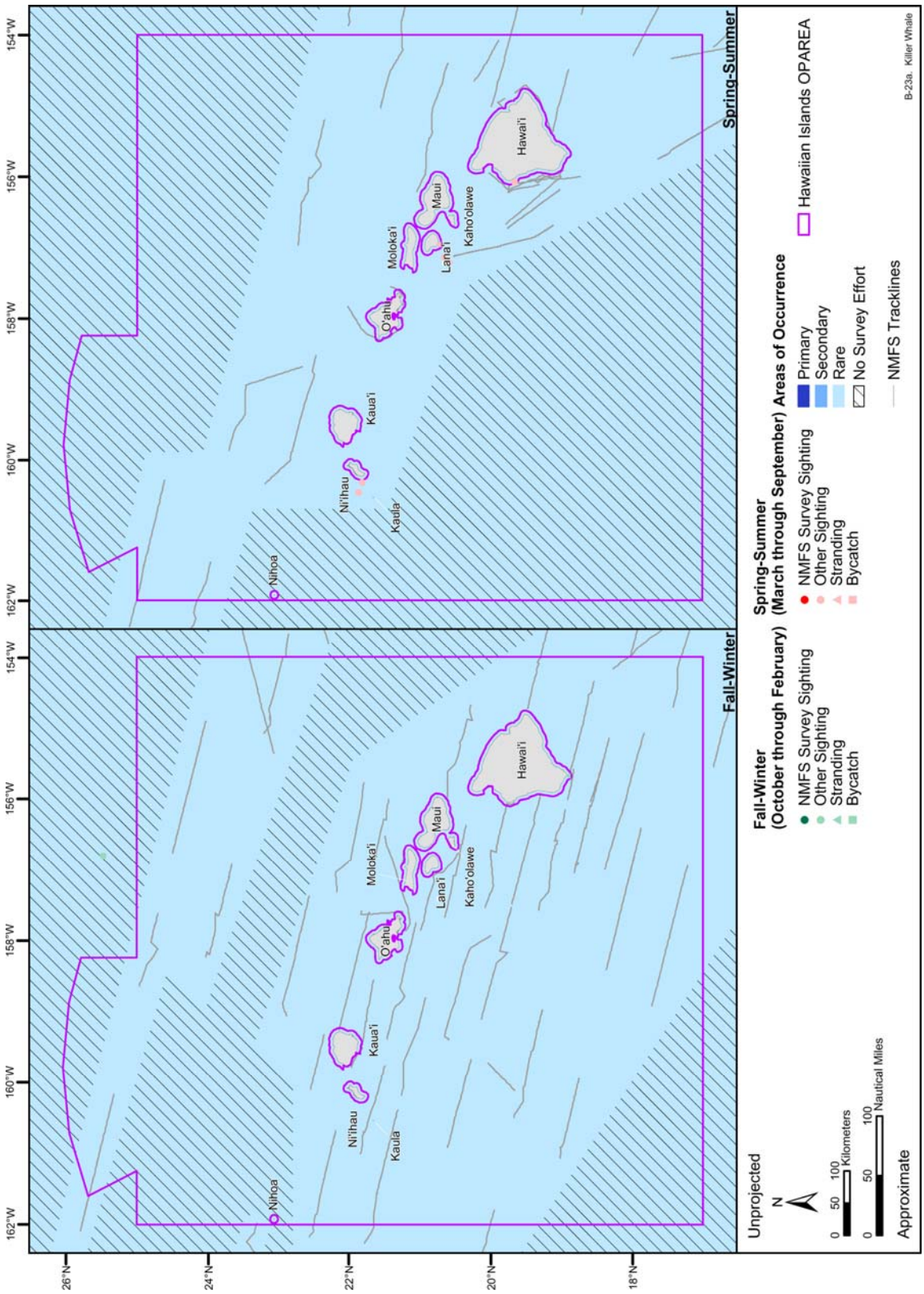

Figure B-23a. Areas of occurrence for the killer whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

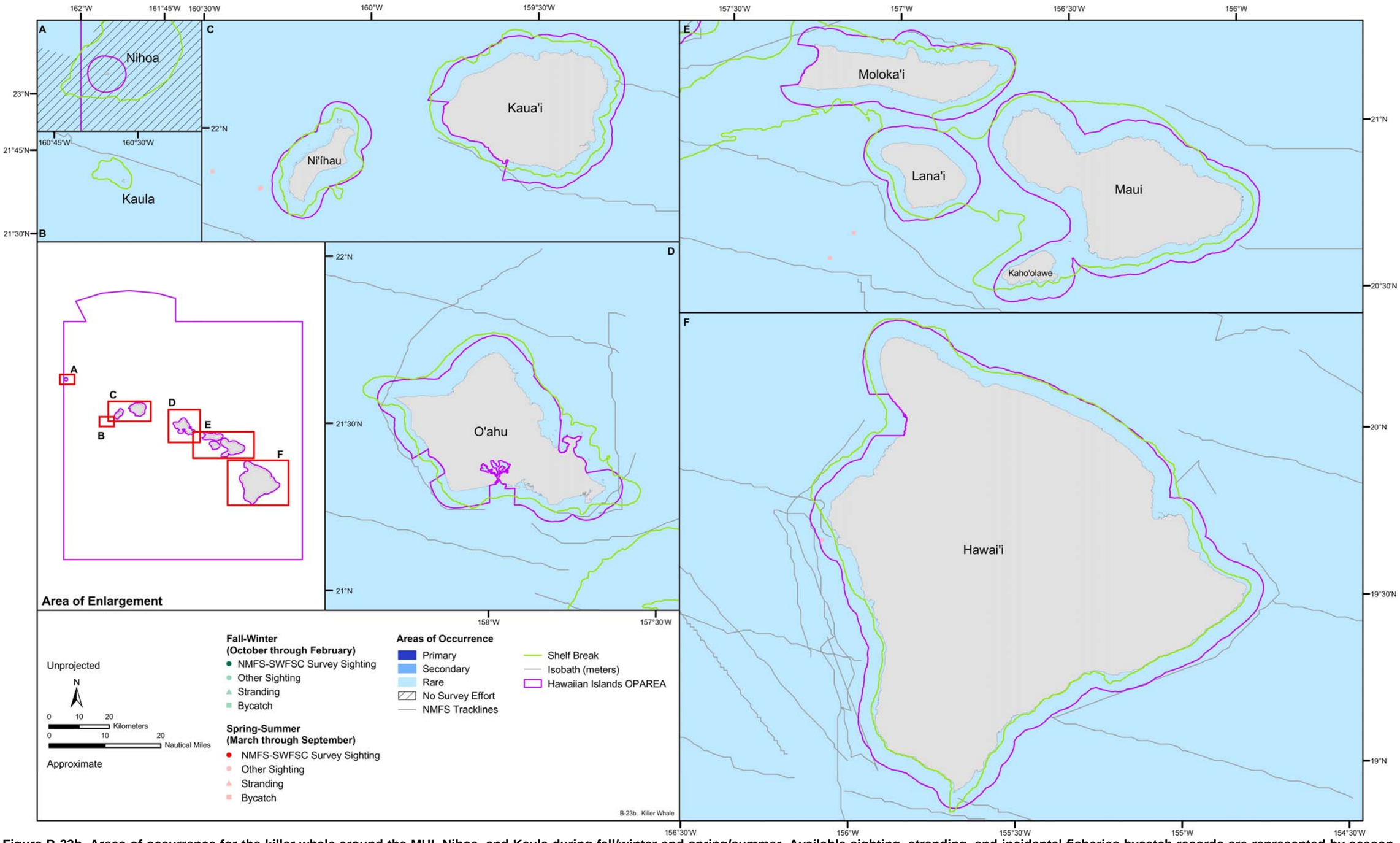

Figure B-23b. Areas of occurrence for the killer whale around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

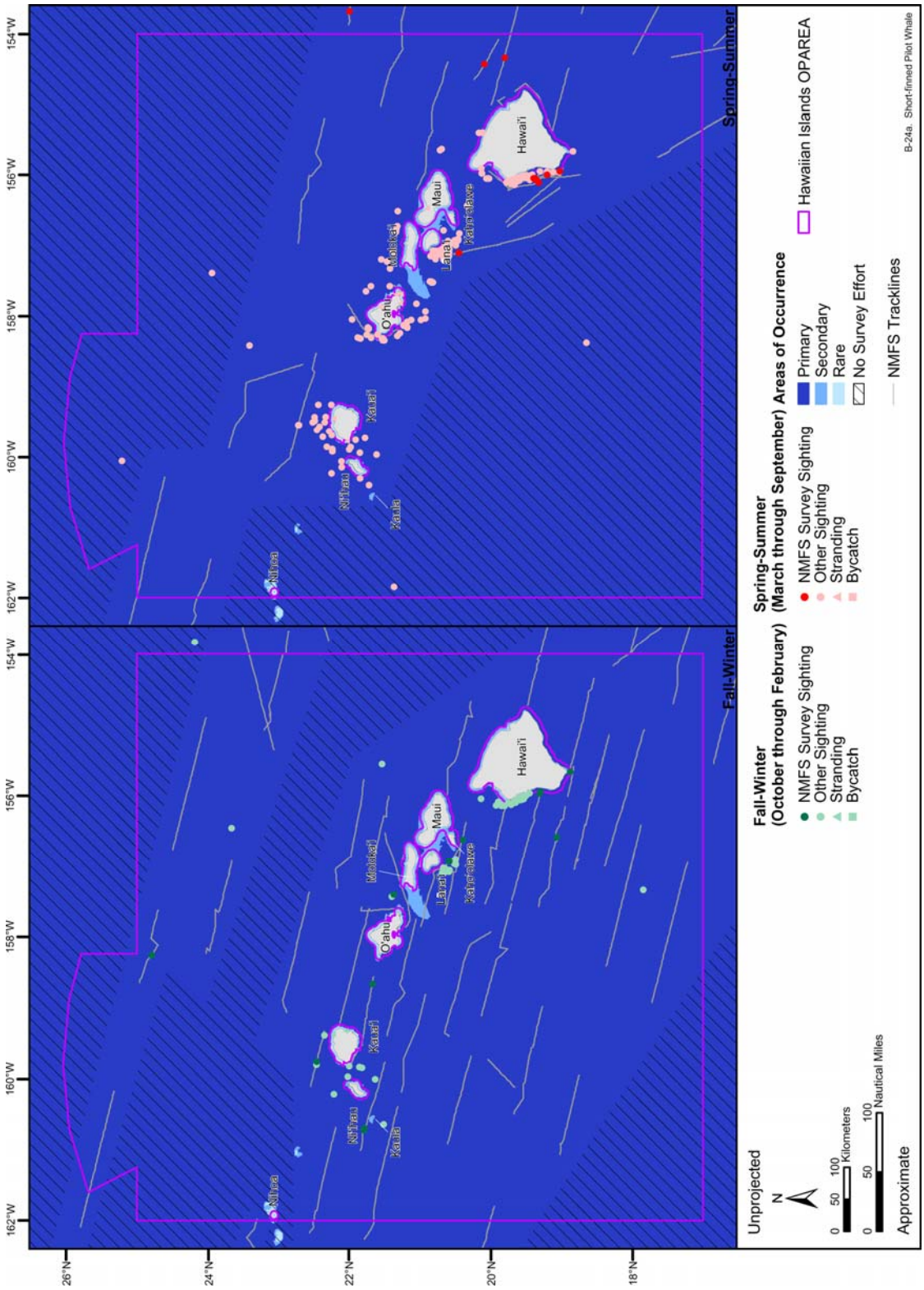

Figure B-24a. Areas of occurrence for the short-finned pilot whale in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

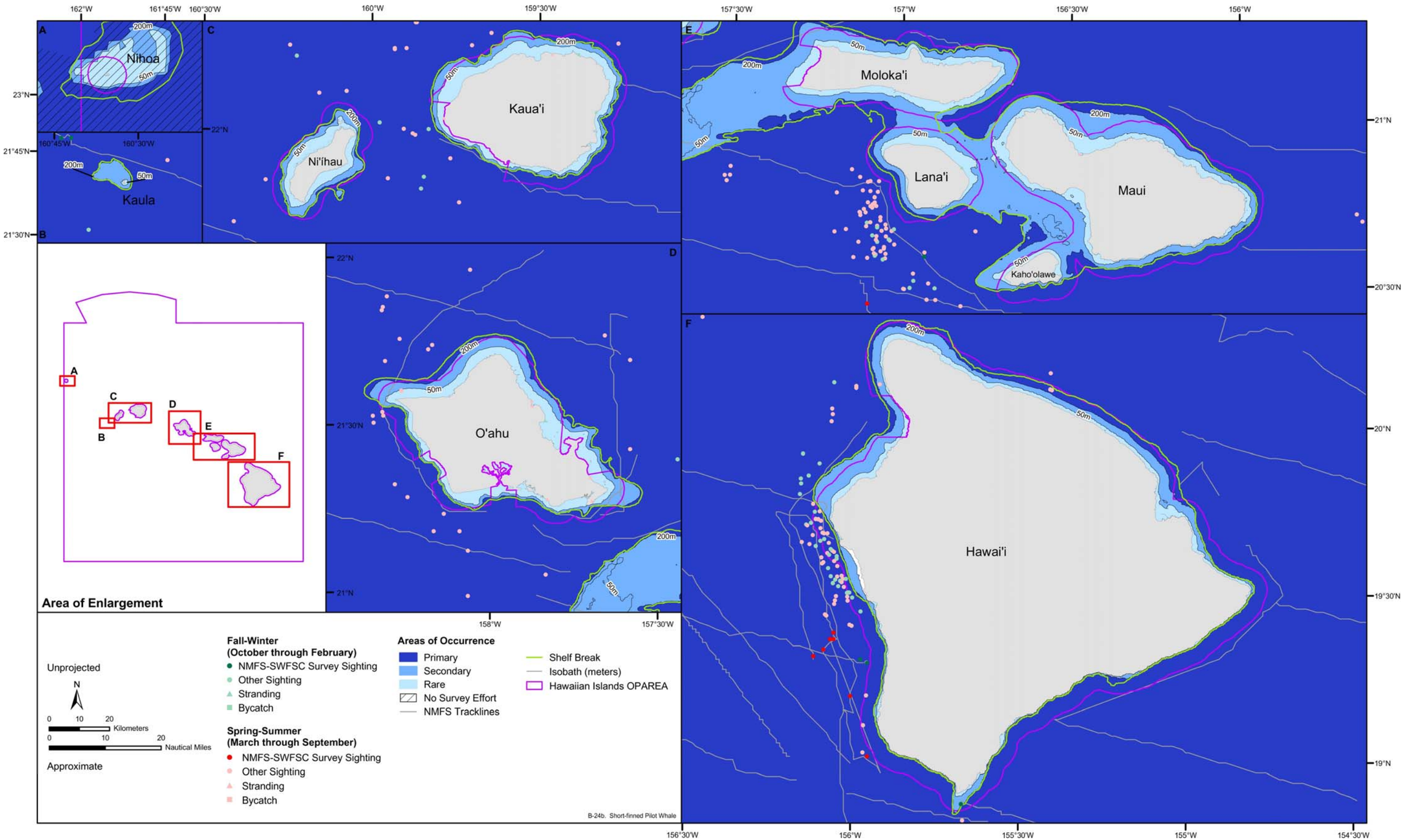

Figure B-24b. Areas of occurrence for the short-finned pilot whale around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

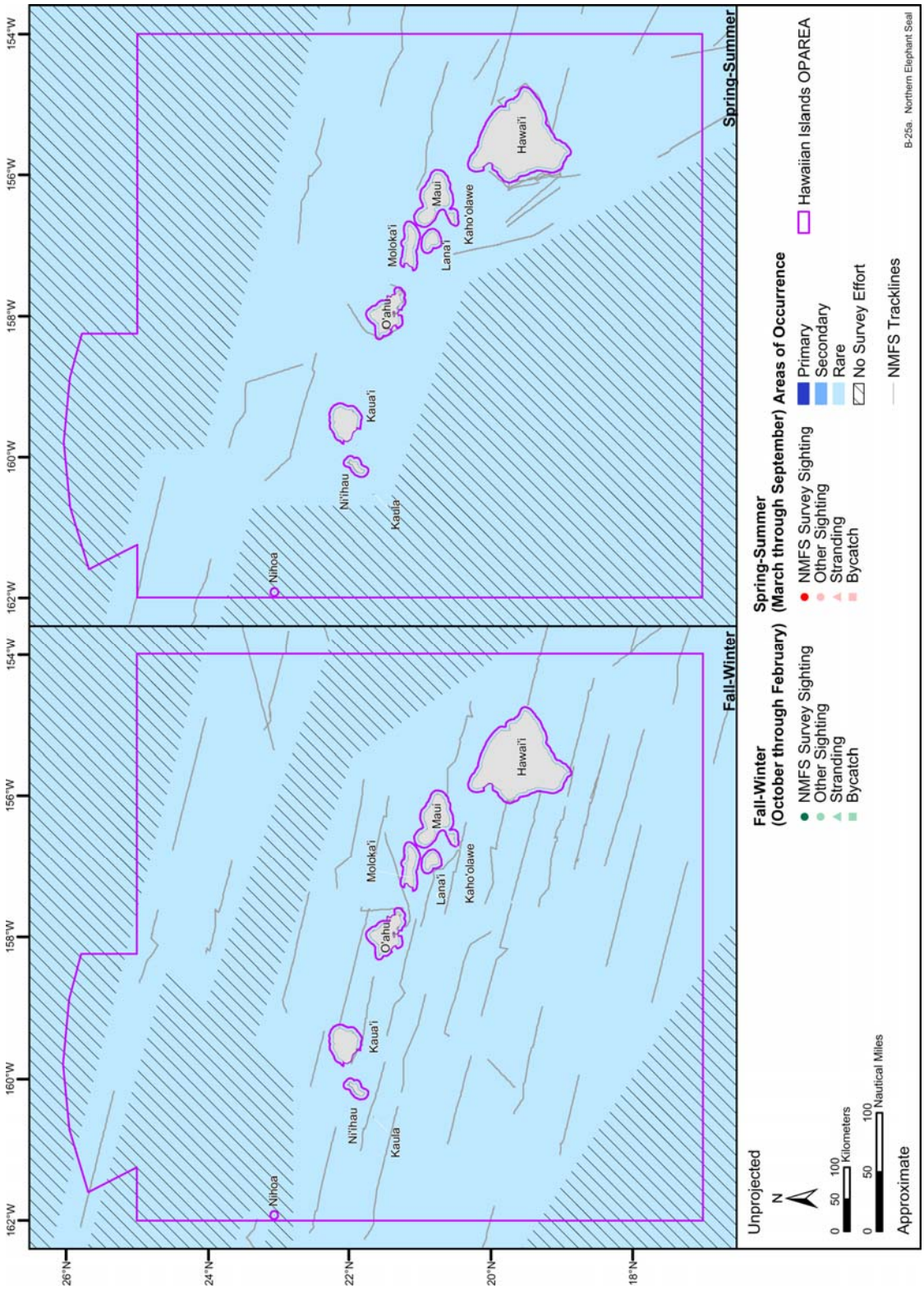

Figure B-25a. Areas of occurrence for the northern elephant seal in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

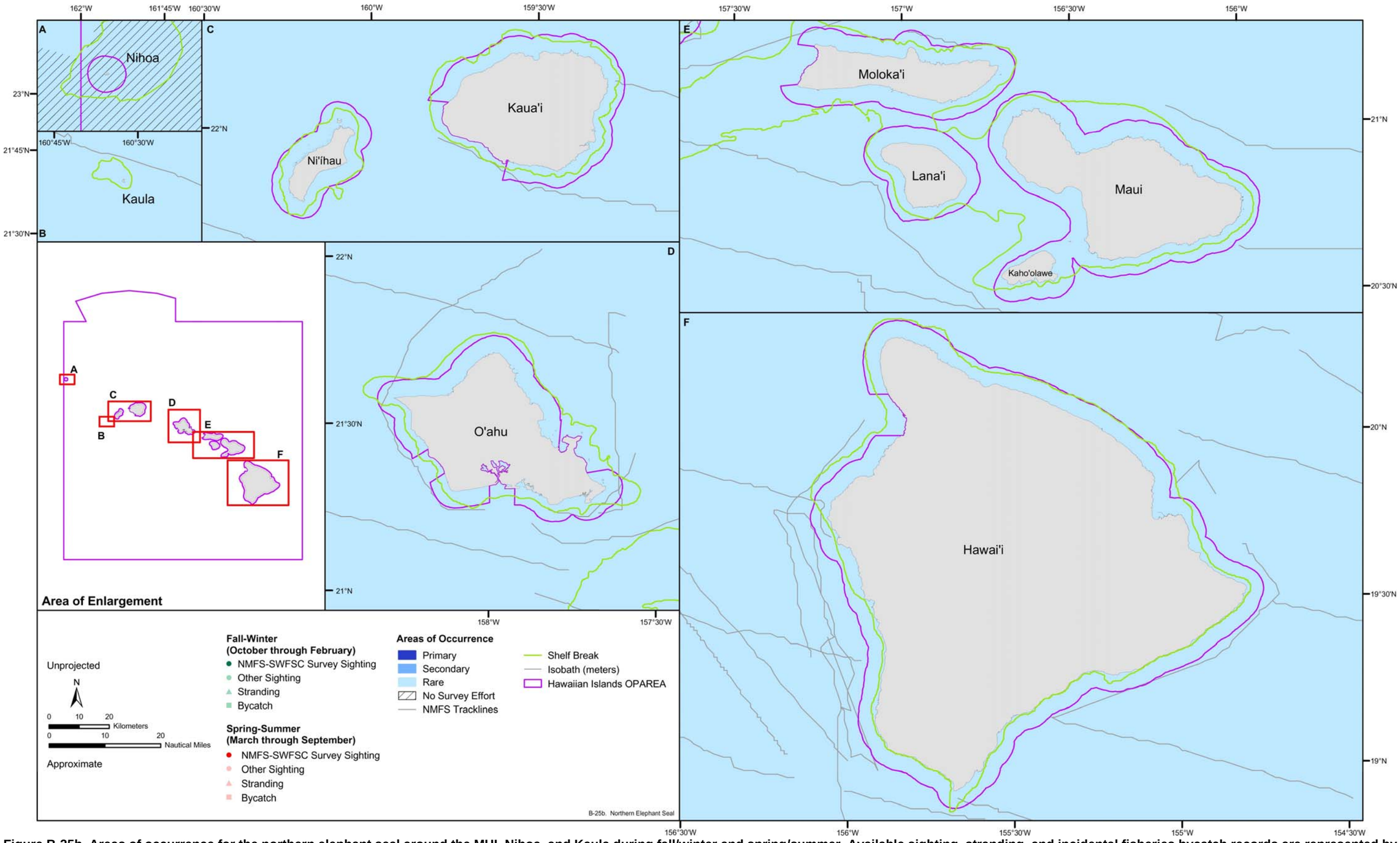

Figure B-25b. Areas of occurrence for the northern elephant seal around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

APPENDIX C: SEA TURTLES

LIST OF FIGURES

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C-2a	Areas of occurrence for the green turtle in the Hawaiian Islands OPAREA and vicinity.
C-2b	Areas of occurrence for the green turtle around the MHI, Nihoa, and Kaula during fall/winter and spring/summer.
C-3a	Areas of occurrence for the hawksbill turtle in the Hawaiian Islands OPAREA and vicinity.
C-3b	Areas of occurrence for the hawksbill turtle around the MHI, Nihoa, and Kaula during fall/winter and spring/summer.
C-4a	Areas of occurrence for the loggerhead turtle in the Hawaiian Islands OPAREA and vicinity.
C-4b	Areas of occurrence for the loggerhead turtle around the MHI, Nihoa, and Kaula during fall/winter and spring/summer.
C-5a	Areas of occurrence for the olive ridley turtle in the Hawaiian Islands OPAREA and vicinity.
C-5b	Areas of occurrence for the olive ridley turtle around the MHI, Nihoa, and Kaula during fall/winter and spring/summer.
C-6a	Areas of occurrence for the leatherback turtle in the Hawaiian Islands OPAREA and vicinity.
C-6b	Areas of occurrence for the leatherback turtle around the MHI, Nihoa, and Kaula during fall/winter and spring/summer.

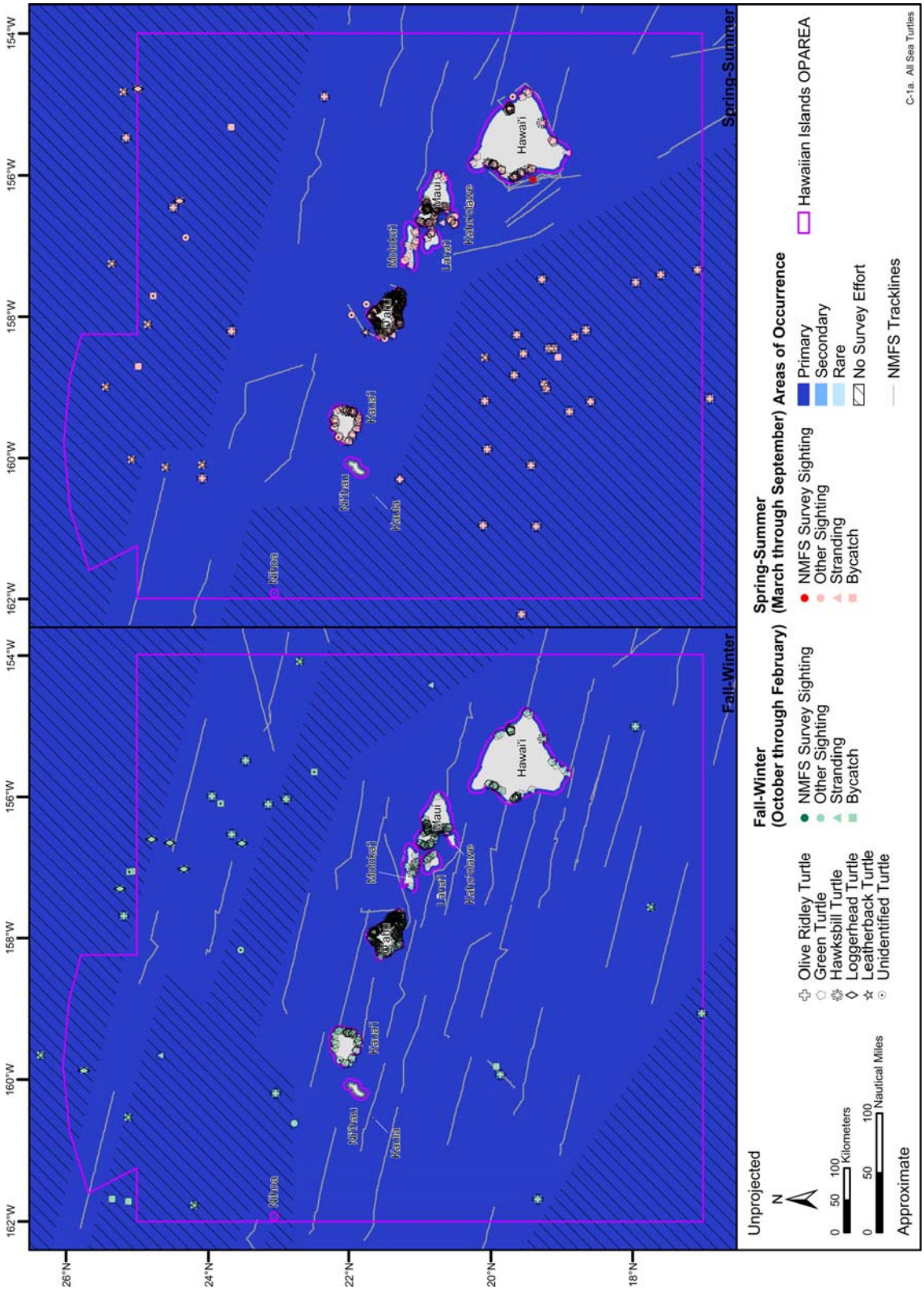

Figure C-1a. Areas of occurrence for all sea turtles in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

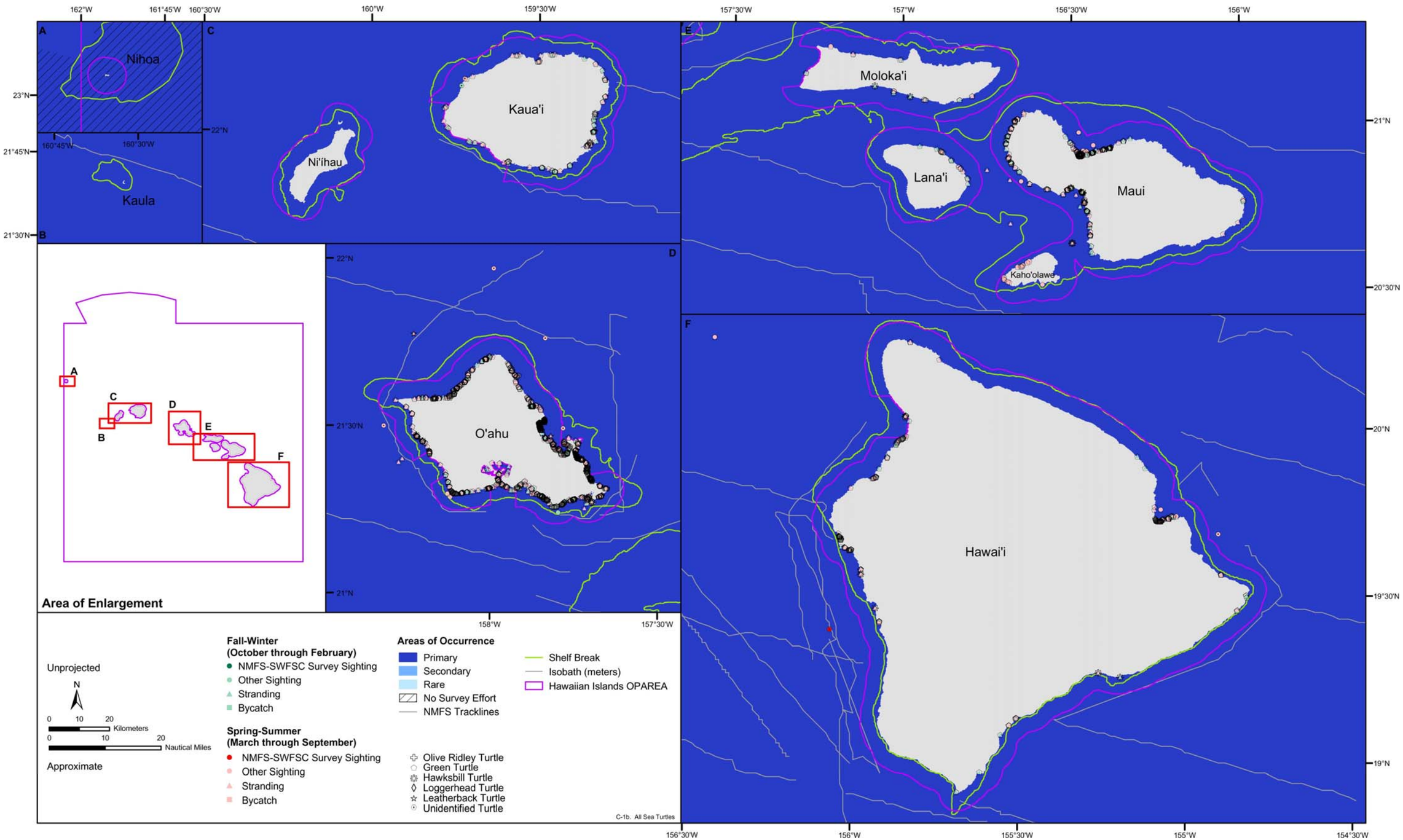

Figure C-1b. Areas of occurrence for all sea turtles around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

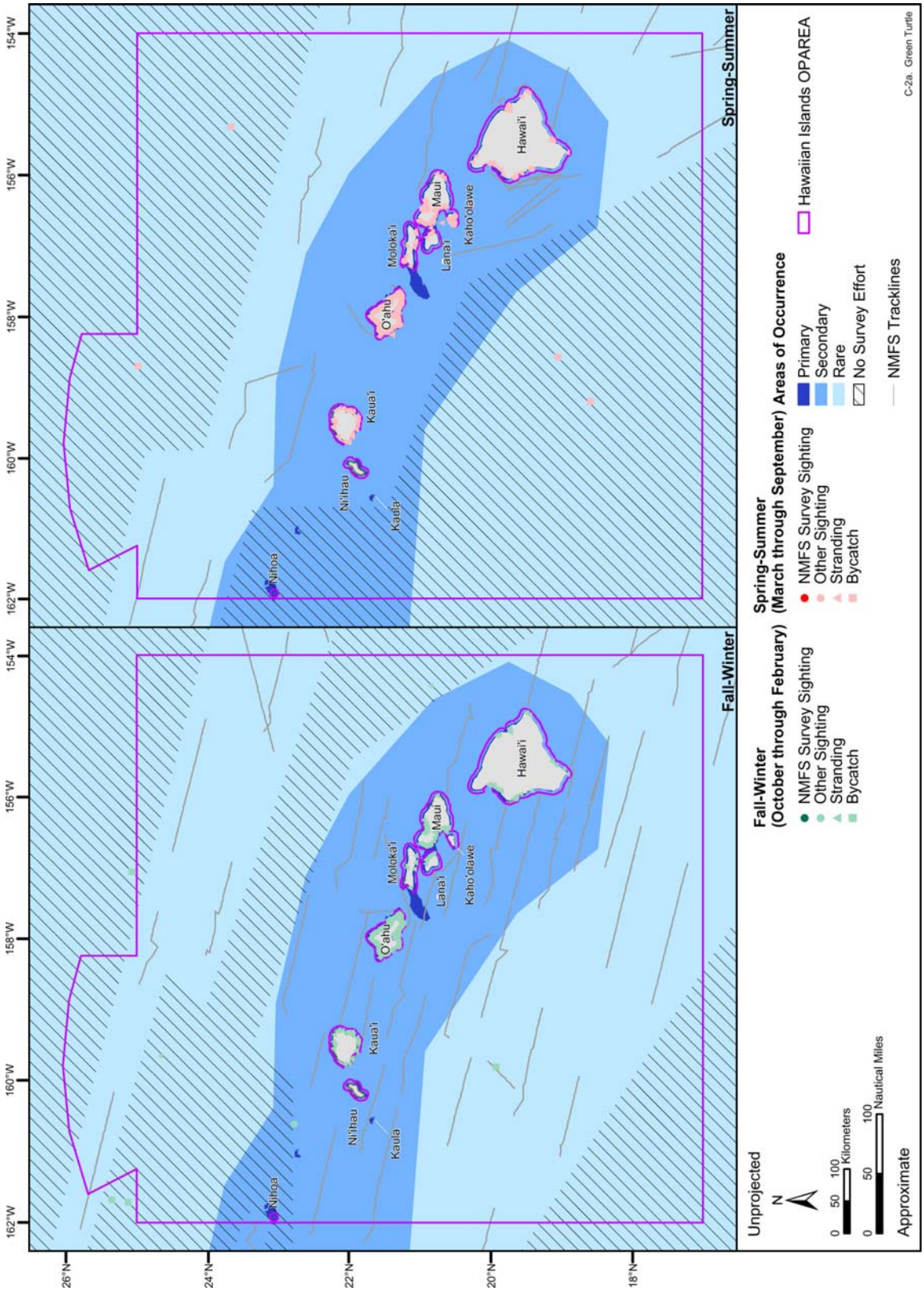

Figure C-2a. Areas of occurrence for the green turtle in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

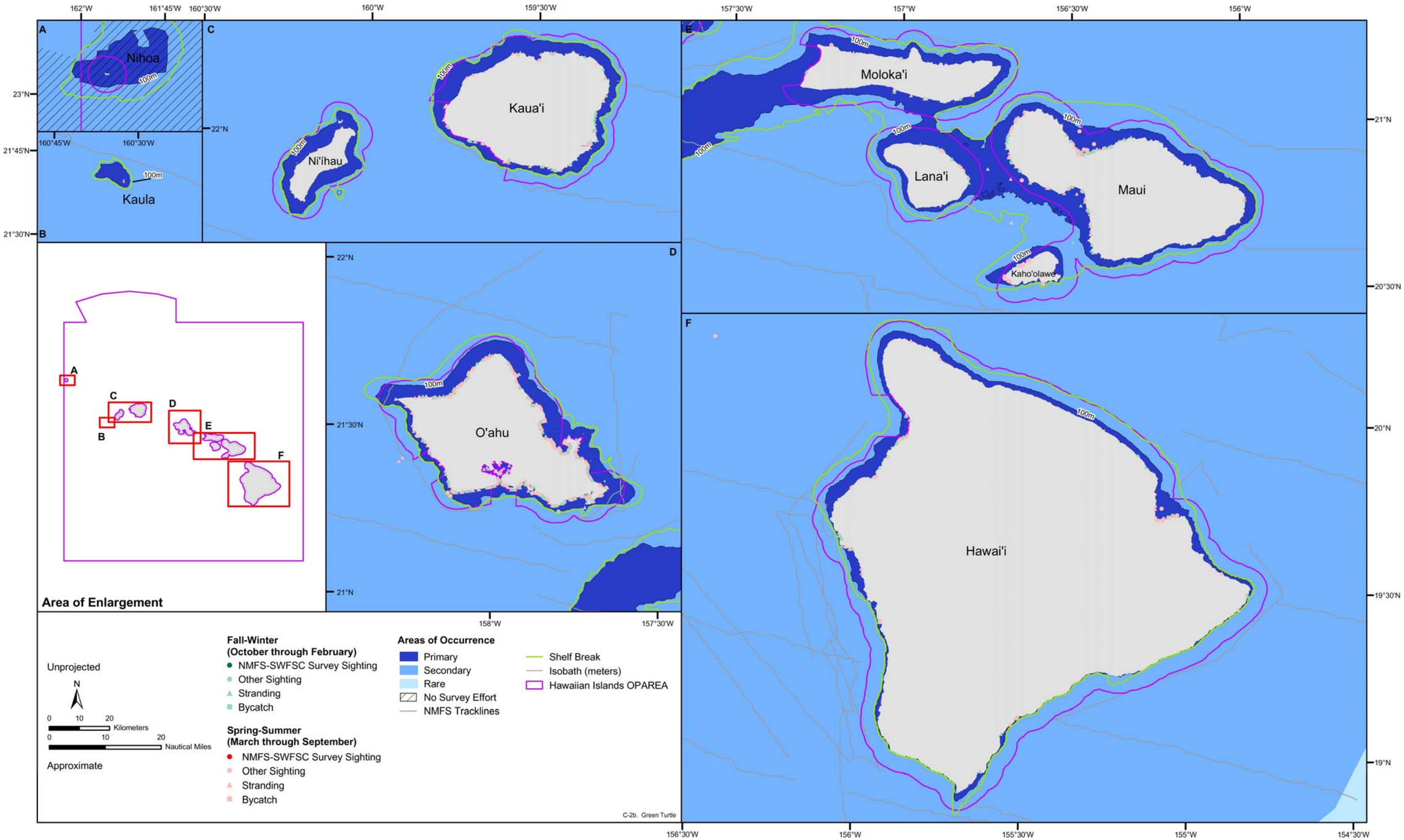

Figure C-2b. Areas of occurrence for the green turtle around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

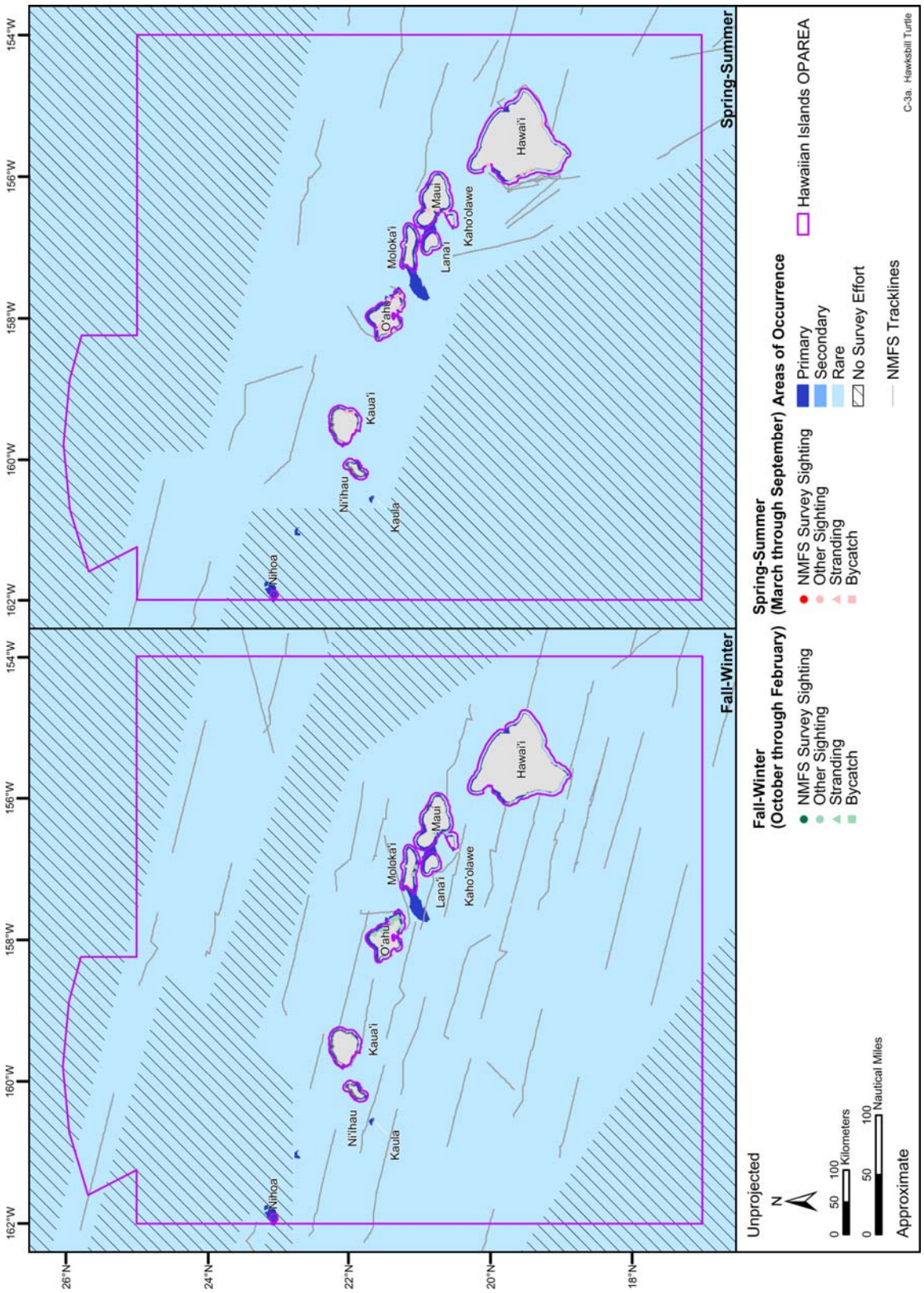

Figure C-3a. Areas of occurrence for the hawksbill turtle in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

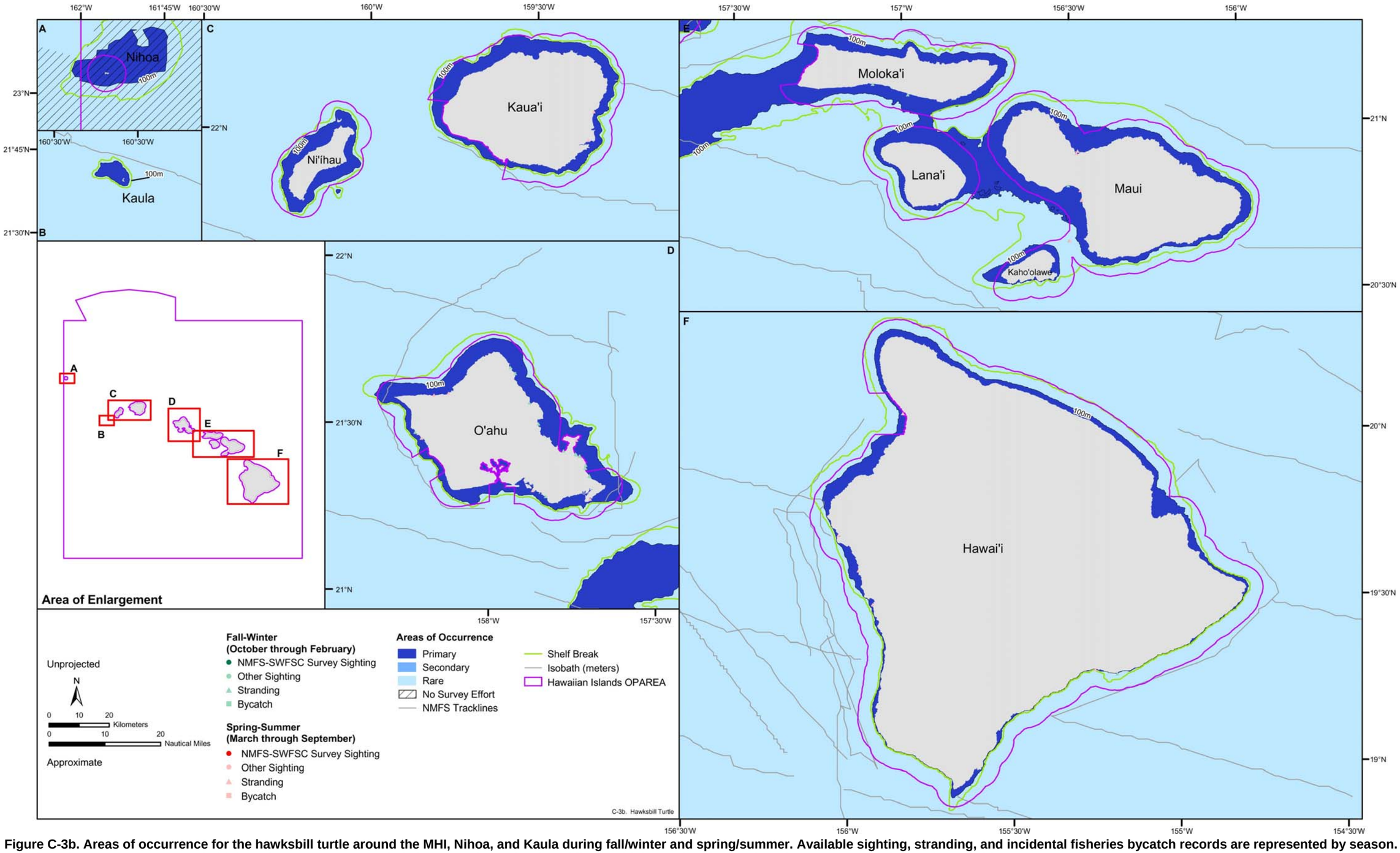

Figure C-3b. Areas of occurrence for the hawksbill turtle around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

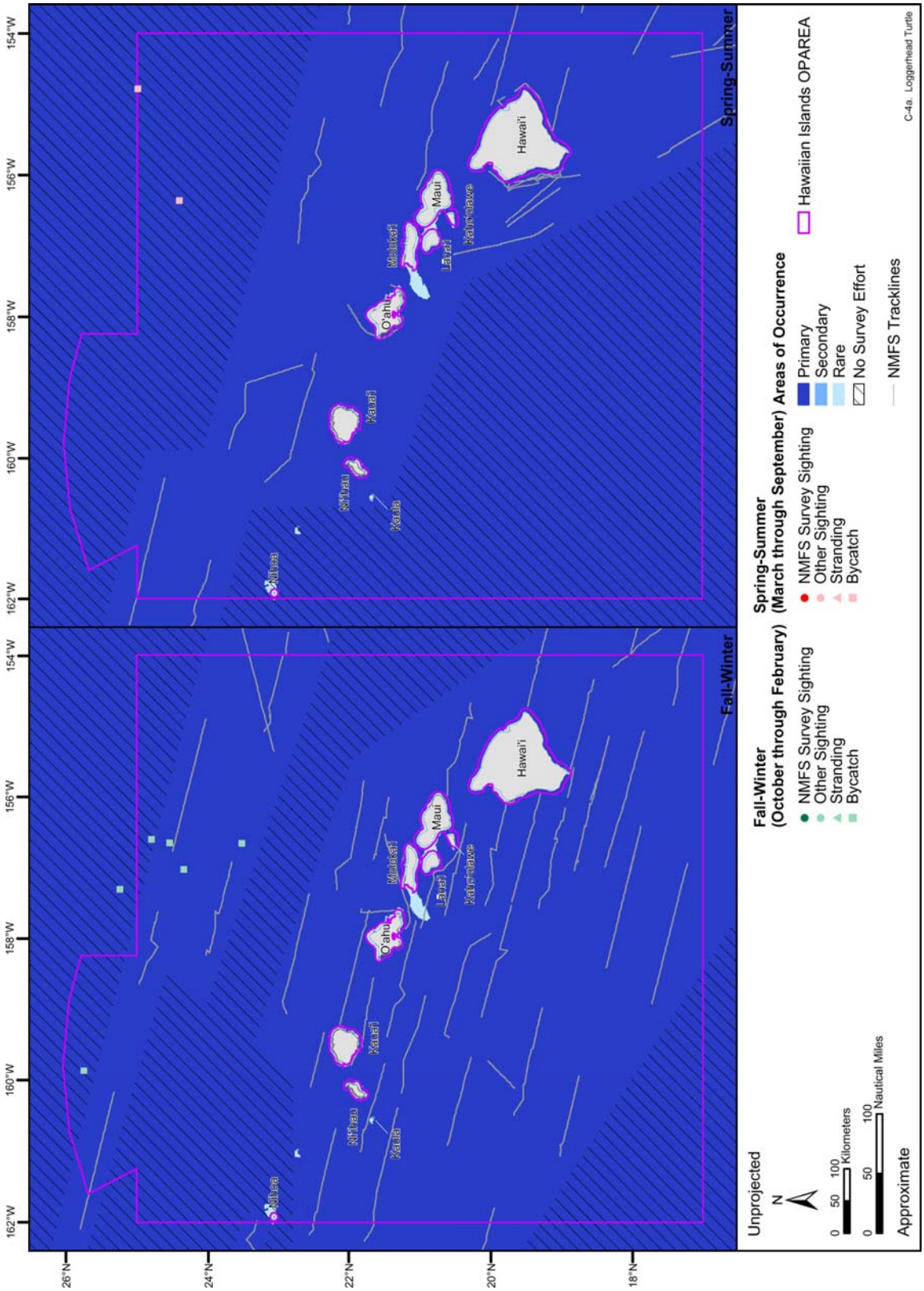

Figure C-4a. Areas of occurrence for the loggerhead turtle in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

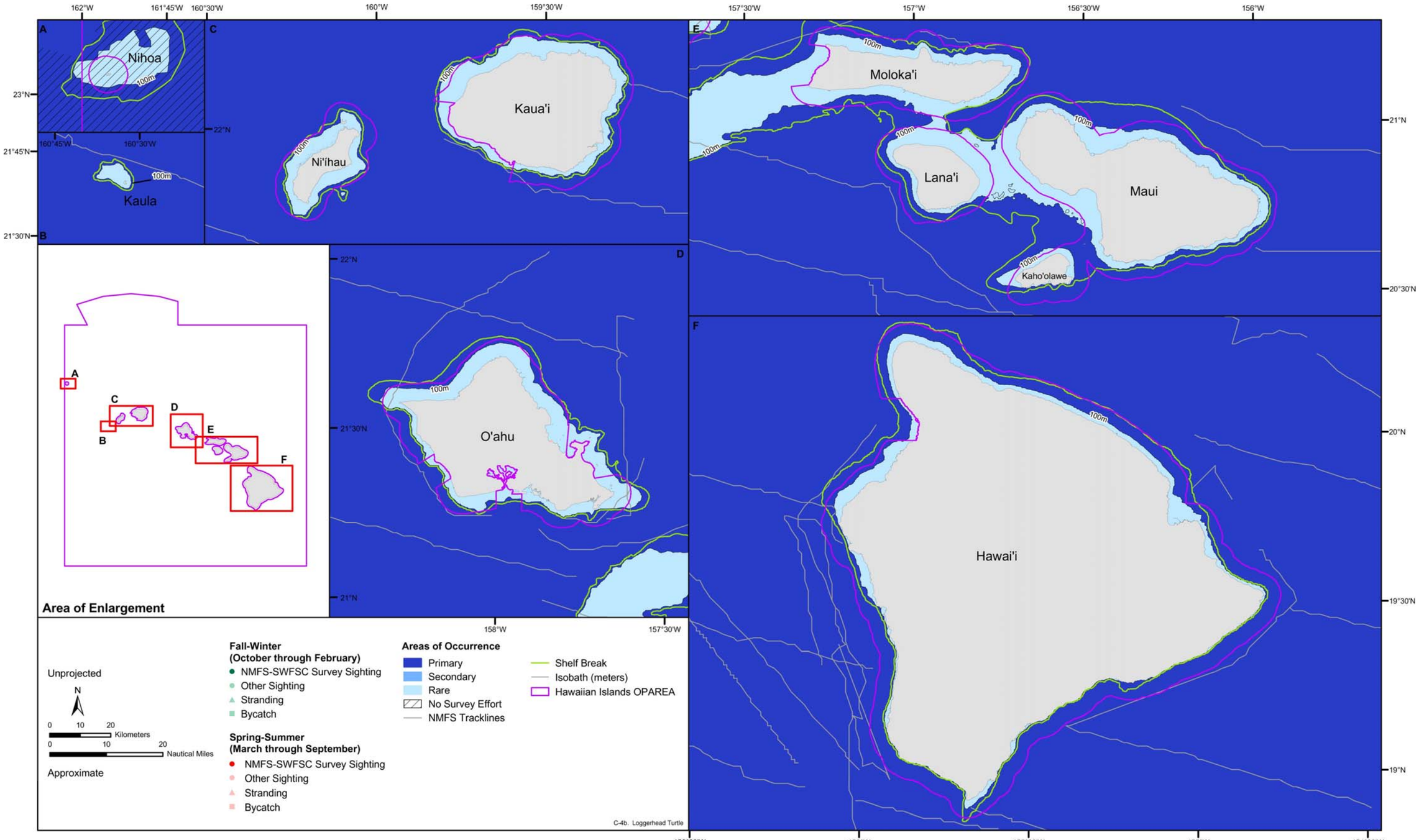

Figure C-4b. Areas of occurrence for the loggerhead turtle around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

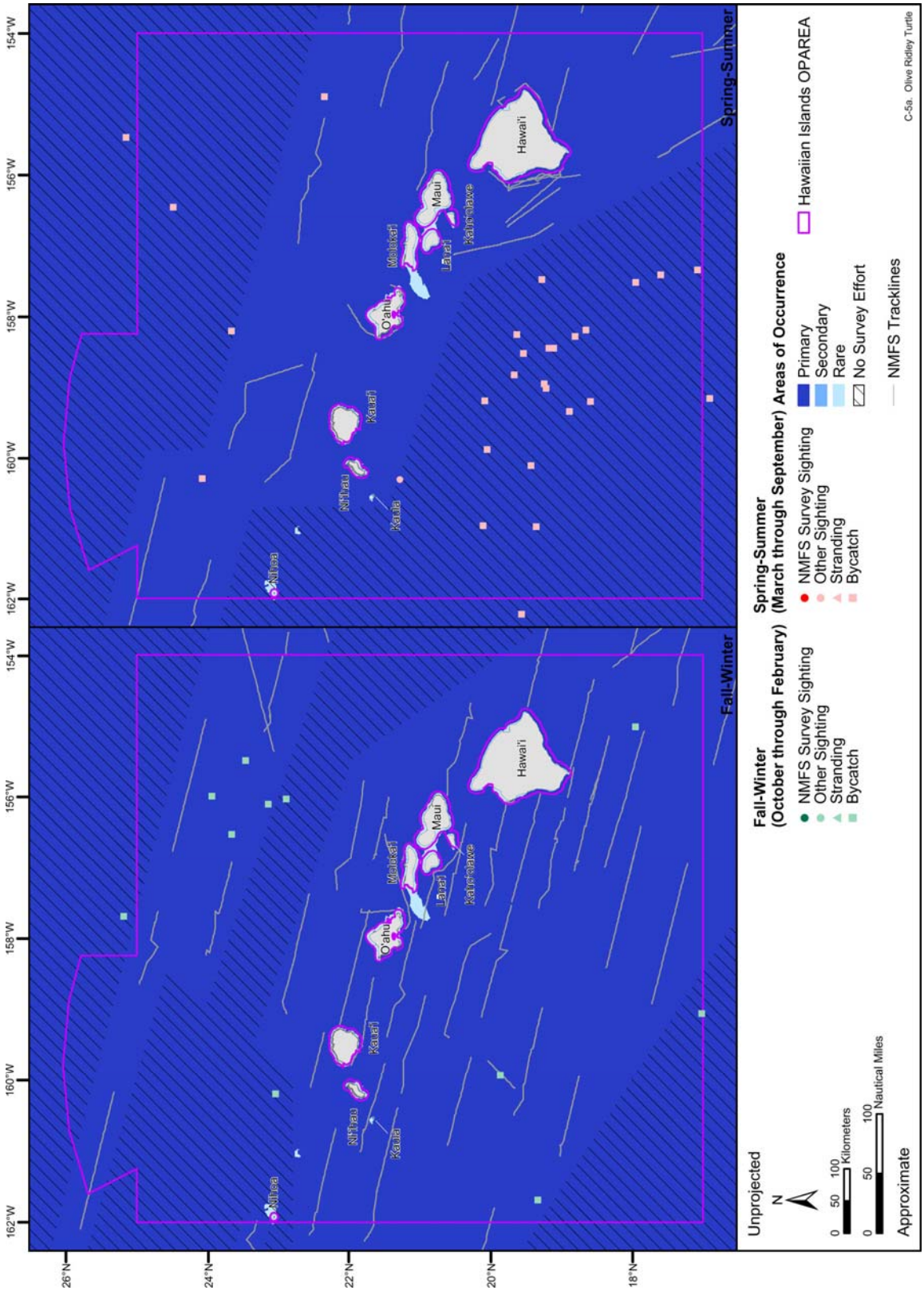

Figure C-5a. Areas of occurrence for the olive ridley turtle in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

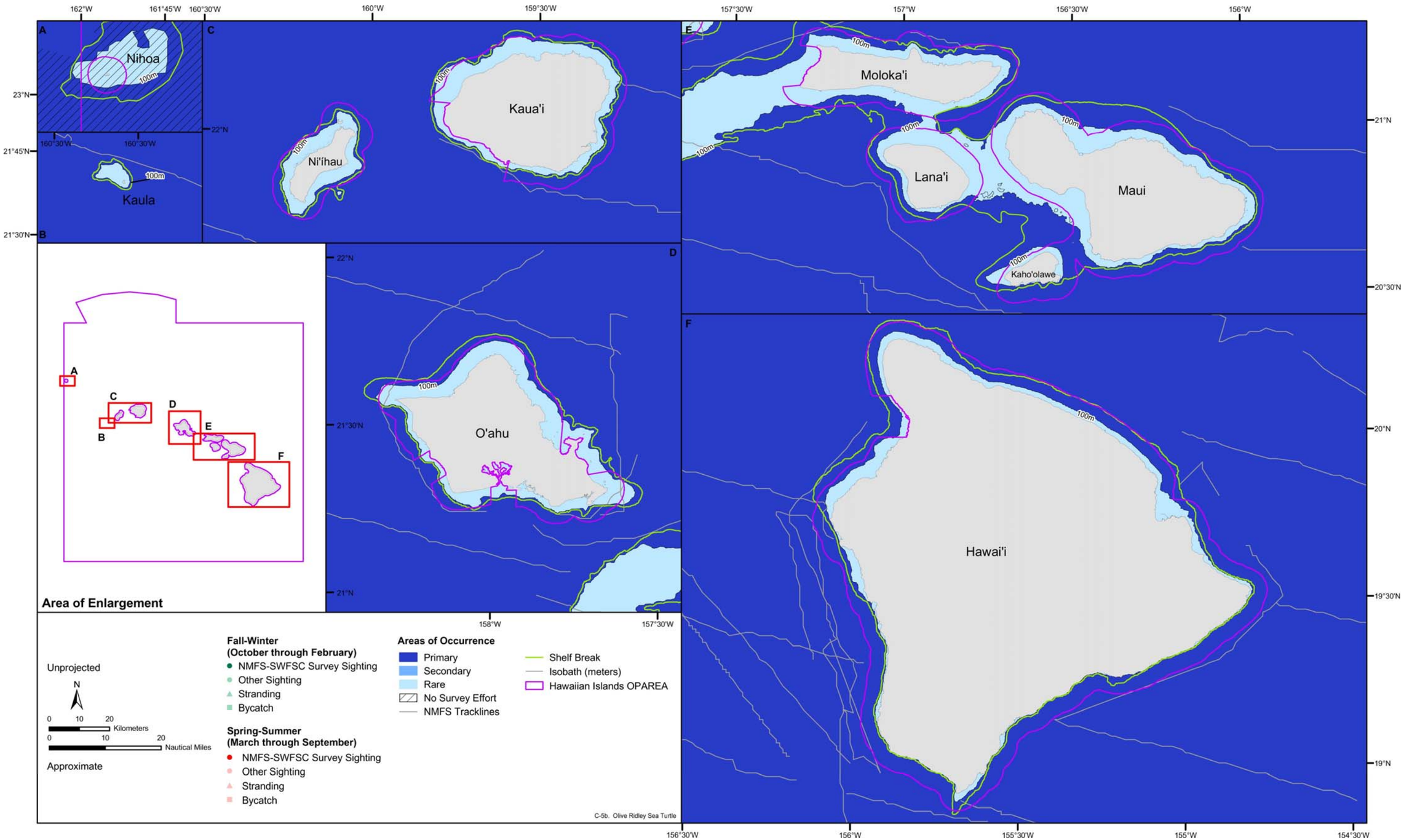

Figure C-5b. Areas of occurrence for the olive ridley turtle around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

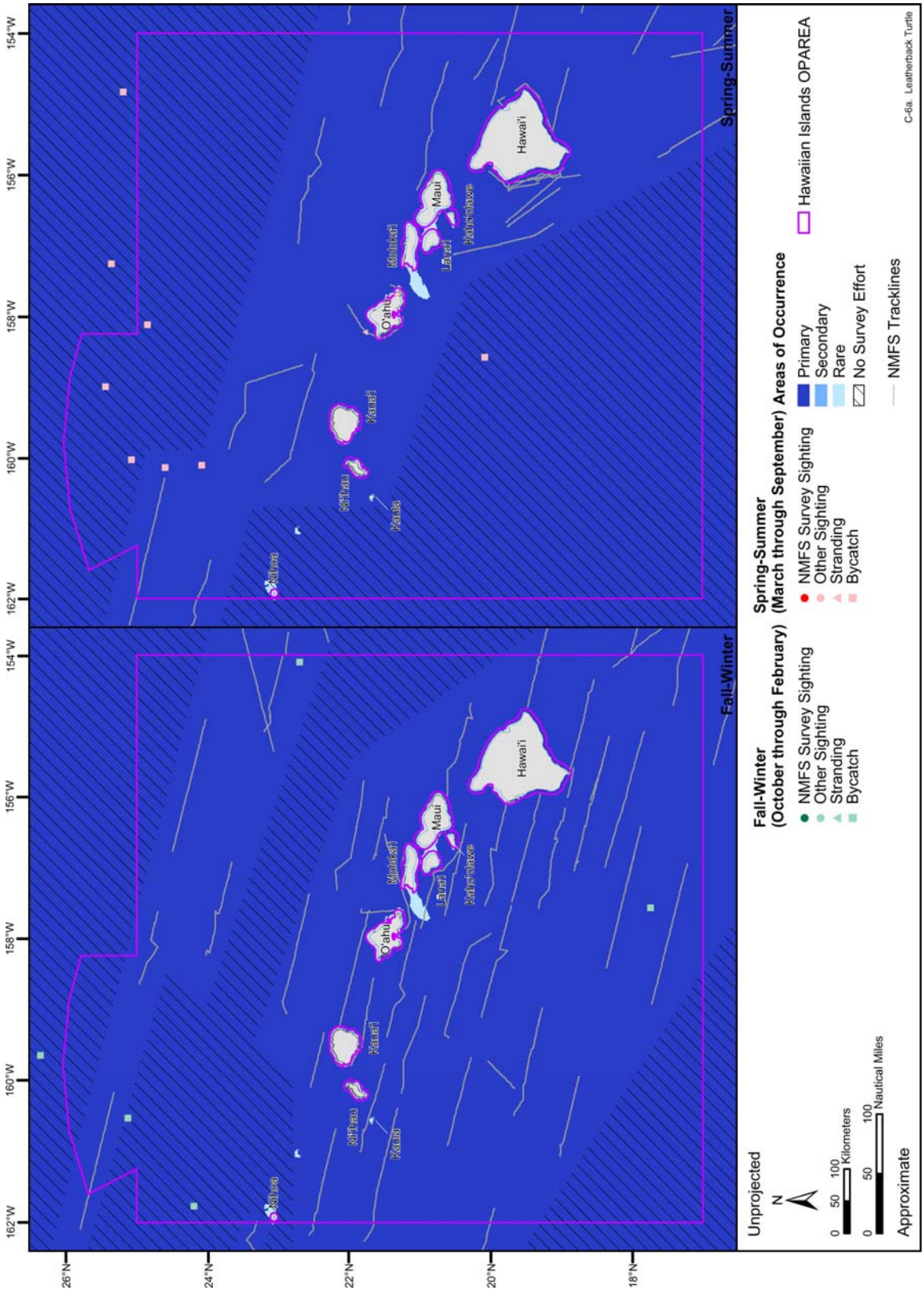

Figure C-6a. Areas of occurrence for the leatherback turtle in the Hawaiian Islands OPAREA and vicinity. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

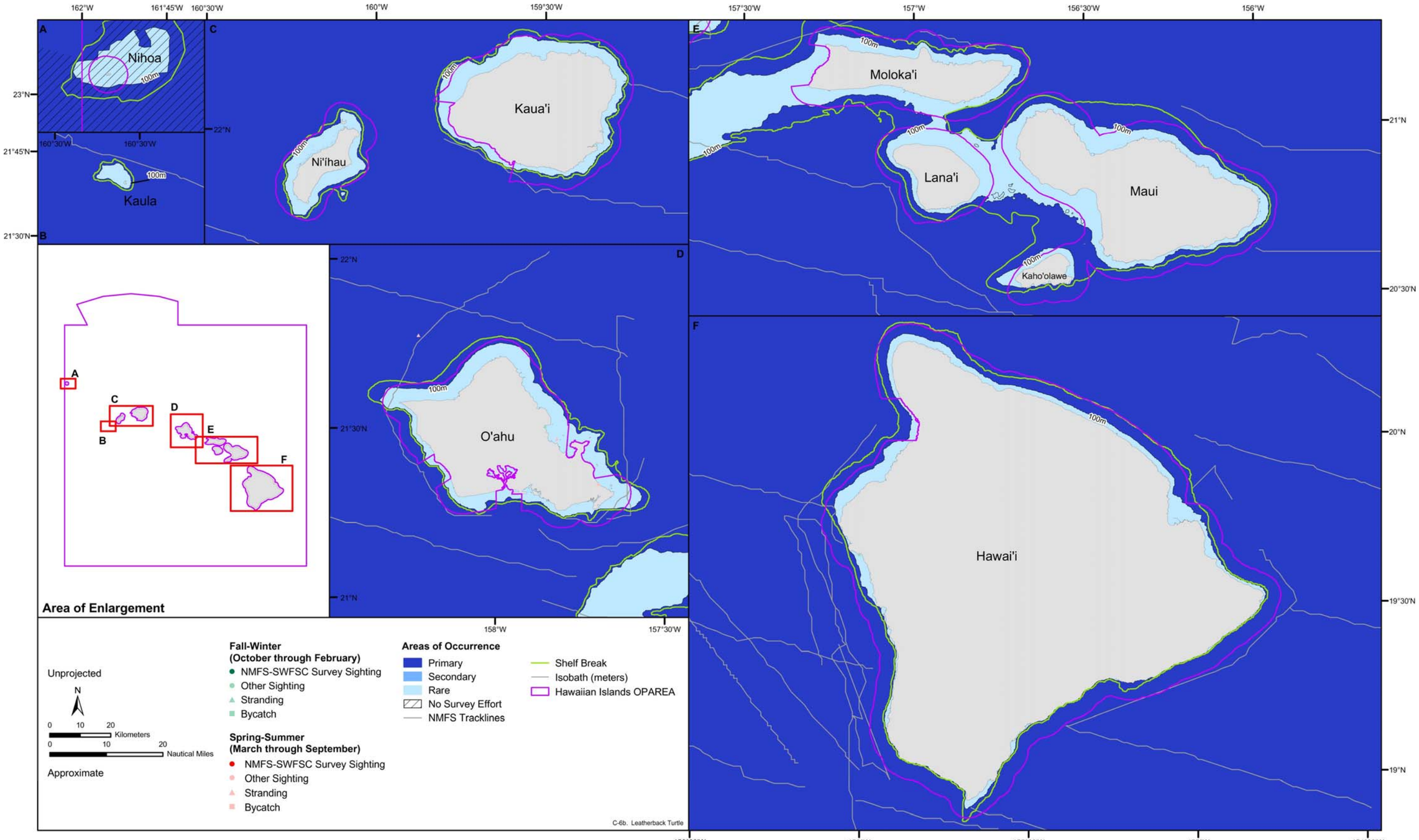

Figure C-6b. Areas of occurrence for the leatherback turtle around the MHI, Nihoa, and Kaula during fall/winter and spring/summer. Available sighting, stranding, and incidental fisheries bycatch records are represented by season. Sightings from NMFS-sponsored shipboard surveys are recorded along pre-determined tracklines, which are also depicted on the map. Source data: refer to Table A-1.

APPENDIX D: FISH

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D-3	EFH for all juvenile and adult lifestages of bottomfish and HAPC designated on Maui, Kahoʻolawe, Lānaʻi, and Molokaʻi in the Hawaiian Islands OPAREA.
D-4	EFH for all juvenile and adult lifestages of bottomfish and HAPC designated on Oʻahu in the Hawaiian Islands OPAREA.
D-5	EFH for all juvenile and adult lifestages of bottomfish and HAPC designated on Kauaʻi and Niʻihau in the Hawaiian Islands OPAREA.
D-6	EFH for all juvenile and adult lifestages of bottomfish and HAPC designated on Nihoa (NWHI) in the Hawaiian Islands OPAREA.
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D-9	EFH for all juvenile and adult lifestages of crustaceans designated on the main island of Hawaiʻi in the Hawaiian Islands OPAREA.
D-10	EFH for all juvenile and adult lifestages of crustaceans designated on Maui, Kahoʻolawe, Lānaʻi, and Molokaʻi in the Hawaiian Islands OPAREA.
D-11	EFH for all juvenile and adult lifestages of crustaceans designated on Oʻahu in the Hawaiian Islands OPAREA.
D-12	EFH for all juvenile and adult lifestages of crustaceans designated on Niʻihau and Kauaʻi in the Hawaiian Islands OPAREA.
D-13	EFH for all juvenile and adult lifestages of crustaceans designated on Nihoa (NWHI) in the Hawaiian Islands OPAREA.
D-14	EFH for all lifestages of precious corals (black, pink/red, gold, and bamboo) designated on the main island of Hawaiʻi in the Hawaiian Islands OPAREA.
D-15	EFH for all lifestages of precious corals (black) designated on Mauʻi, Kahoʻolawe, Lānaʻi, and Molokaʻi in the Hawaiian Islands OPAREA.
D-16	EFH for all lifestages of precious corals beds and HAPC designated on Oʻahu in the Hawaiian Islands OPAREA.
D-17	EFH for all lifestages of precious corals beds designated on Kauaʻi in the Hawaiian Islands OPAREA.
D-18	HAPC for the CRE designated in the Hawaiian Islands OPAREA.
D-19	EFH for various lifestages of the CHCRT-CRE and HAPC designated in the main Hawaiian Islands and on Nihoa in the Hawaiian Islands OPAREA.
D-20	EFH for all juvenile and adult lifestages of the CHCRT-coral reef ecosystem and HAPC designated in the Hawaiian Islands OPAREA.
D-21	EFH for all juvenile and adult lifestages of the CHCRT-coral reef ecosystem and HAPC designated on Mauʻi, Kahoʻolawe, Lānaʻi, and Molokaʻi in the Hawaiian Islands OPAREA.
D-22	EFH for all juvenile and adult lifestages of the CHCRT-coral reef ecosystem and HAPC designated on Oʻahu in the Hawaiian Islands OPAREA.

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Figure	Title
D-23	EFH for all juvenile and adult lifestages of the CHCRT-coral reef ecosystem and HAPC designated on Kaua‘i and Ni‘hau in the Hawaiian Islands OPAREA.
D-24	EFH for all juvenile and adult lifestages of the CHCRT-coral reef ecosystem and HAPC designated on Nihoa in the Hawaiian Islands OPAREA.
D-25	EFH for all lifestages of the PHCRT-coral reef ecosystem and HAPC designated in the Hawaiian Islands OPAREA.

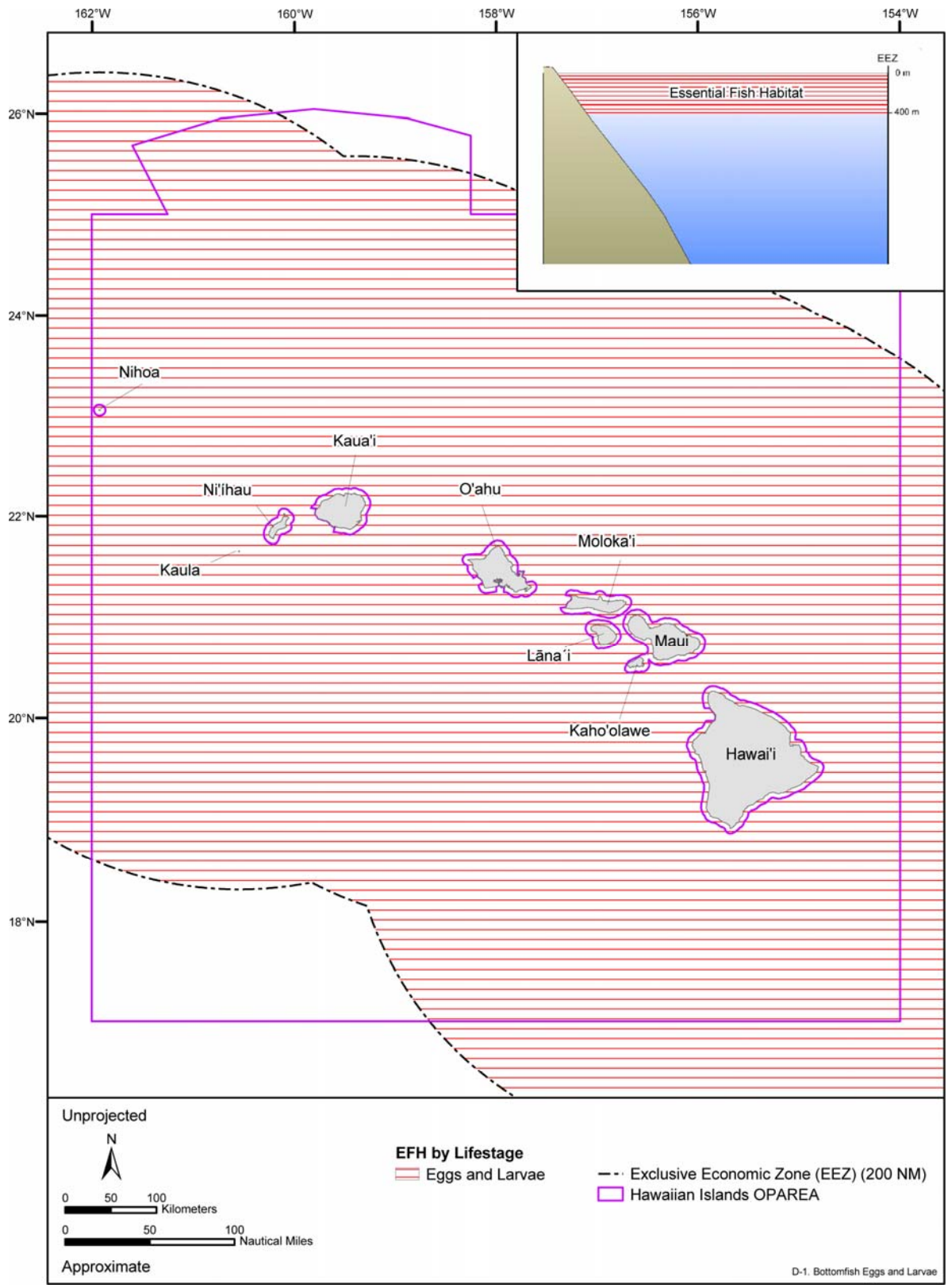

Figure D-1. EFH for all eggs and larval lifestages of bottomfish designated in the Hawaiian Islands OPAREA. Depth ranges noted in legend apply from shoreline to the outer limit of the EEZ. Map adapted from WPRFMC (1998) and GDAIS (2004).

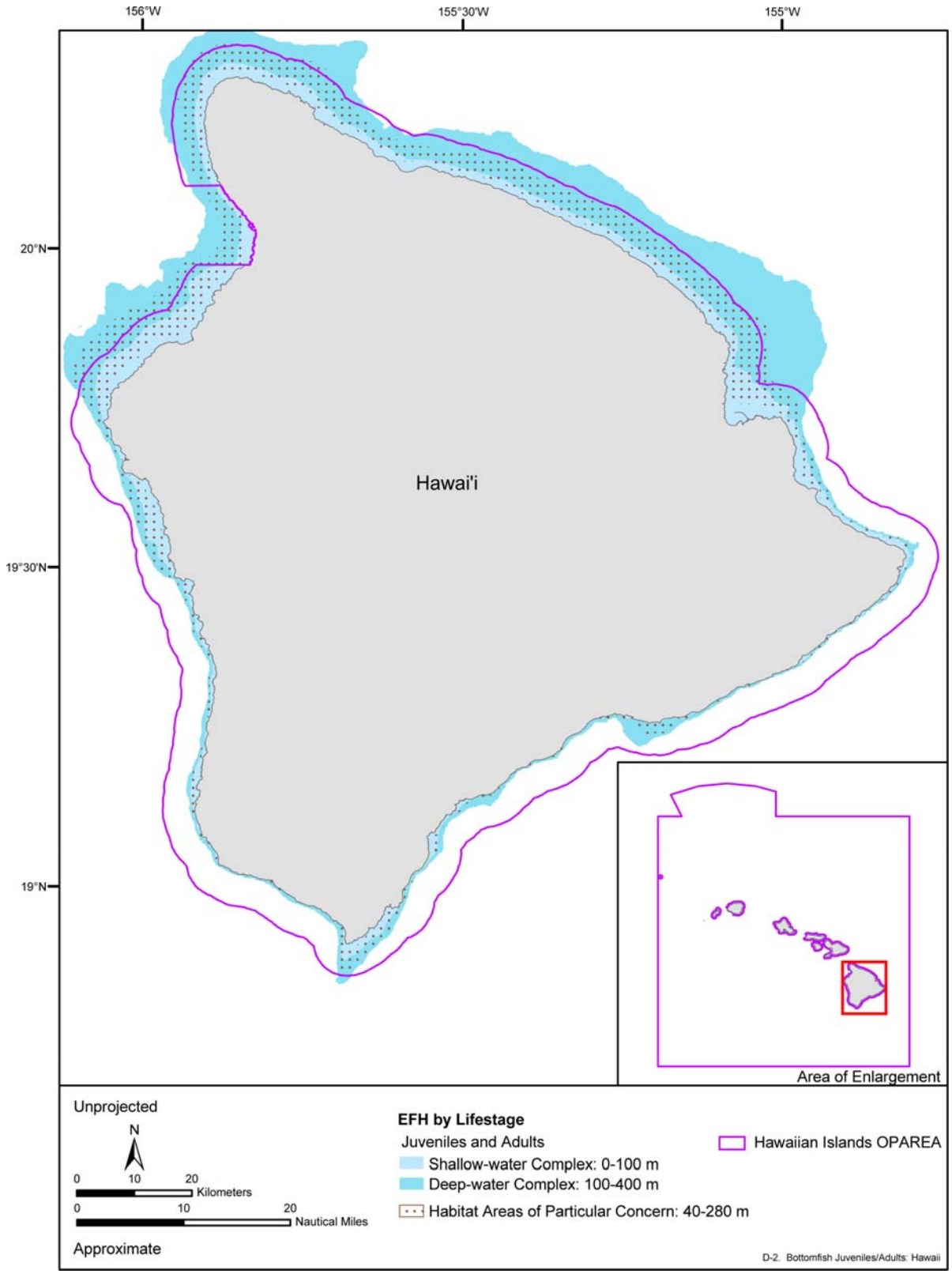

Figure D-2. EFH for all juvenile and adult lifestages of bottomfish and HAPC designated on the main island of Hawai‘i in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998).

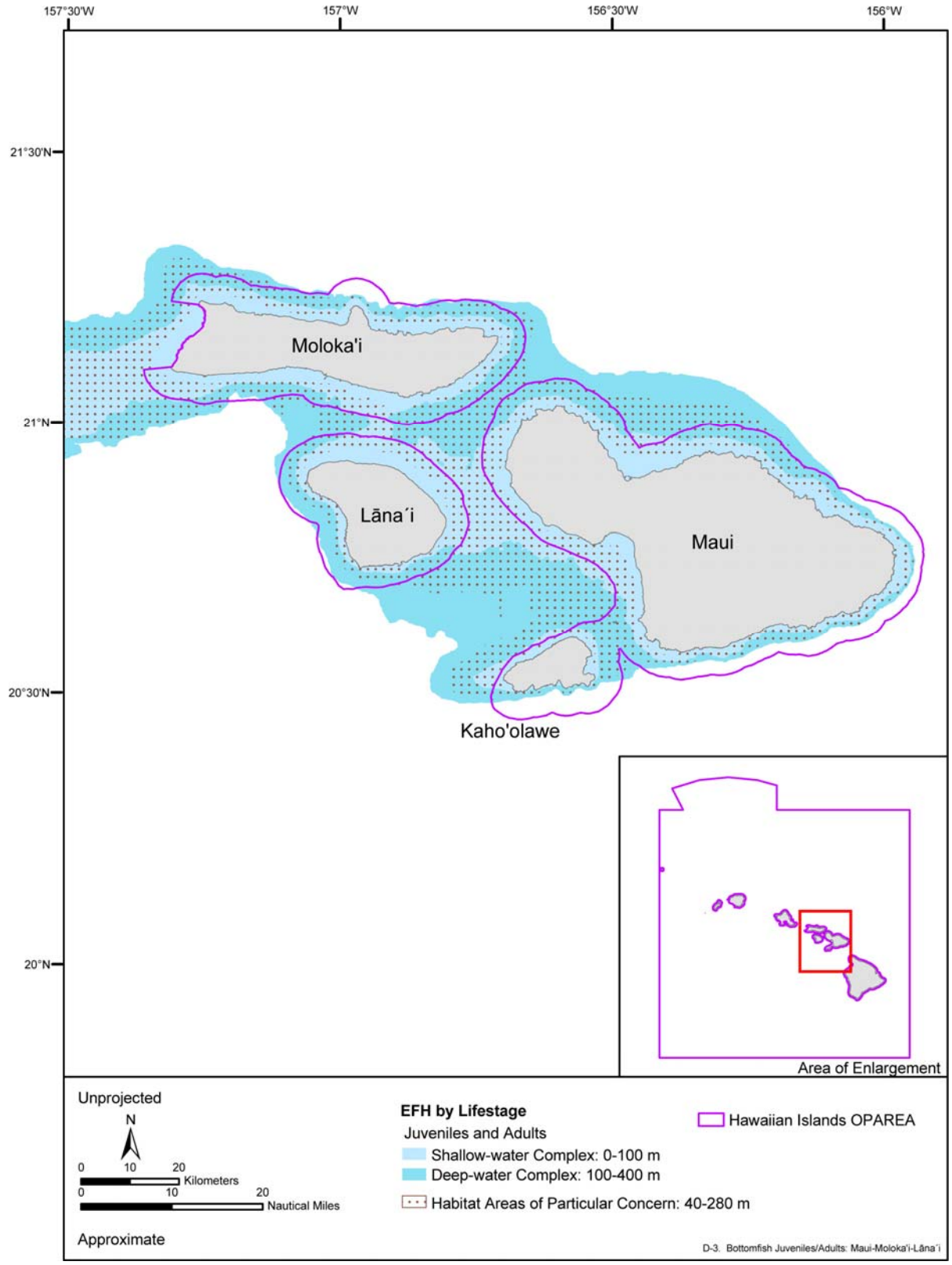

Figure D-3. EFH for all juvenile and adult lifestages of bottomfish and HAPC designated on Maui, Kahoʻolawe, Lānaʻi, and Molokaʻi in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998).

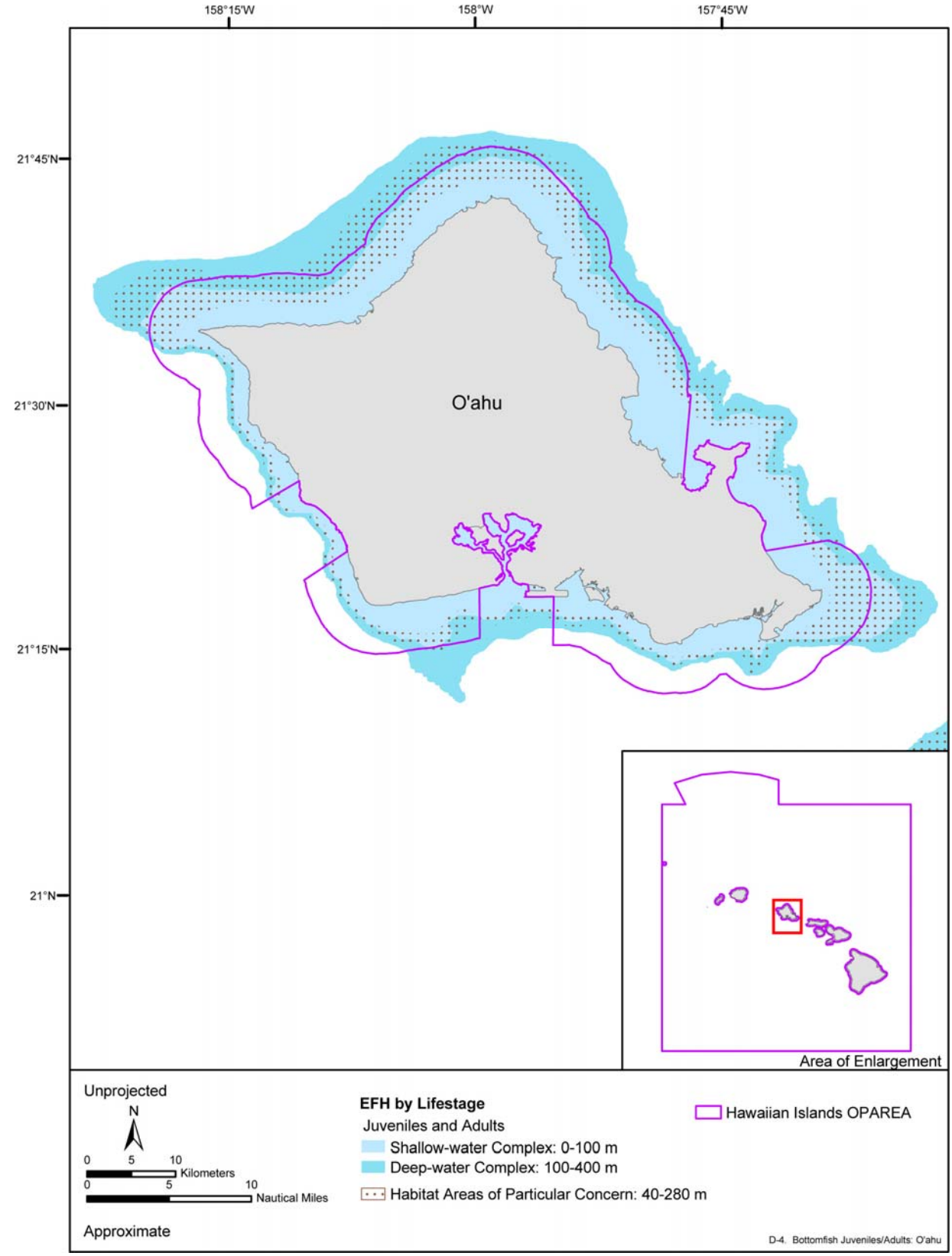

Figure D-4. EFH for all juvenile and adult lifestages of bottomfish and HAPC designated on O‘ahu in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998).

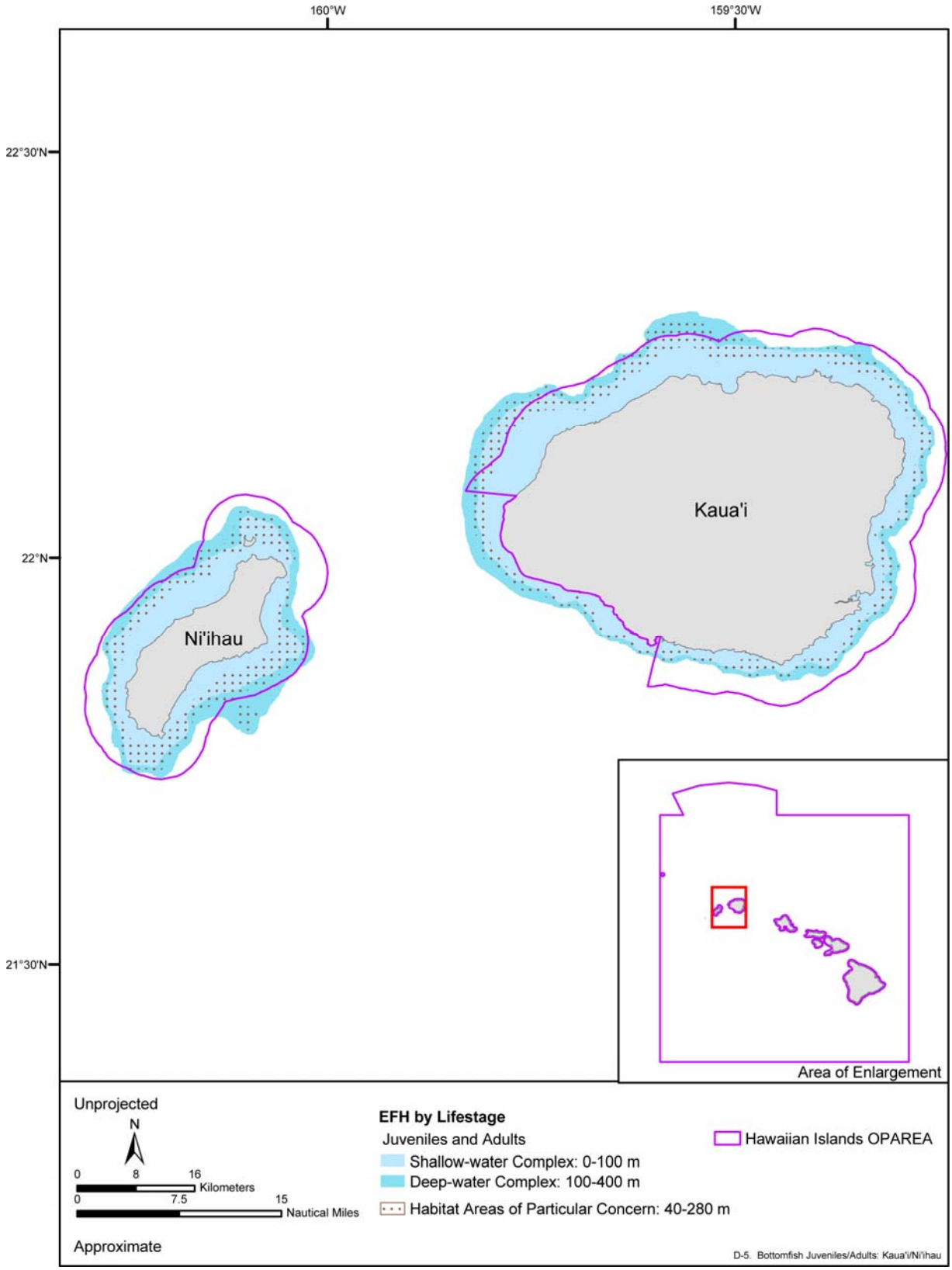

Figure D-5. EFH for all juvenile and adult lifestages of bottomfish and HAPC designated on Kaua‘i and Ni‘ihau in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998).

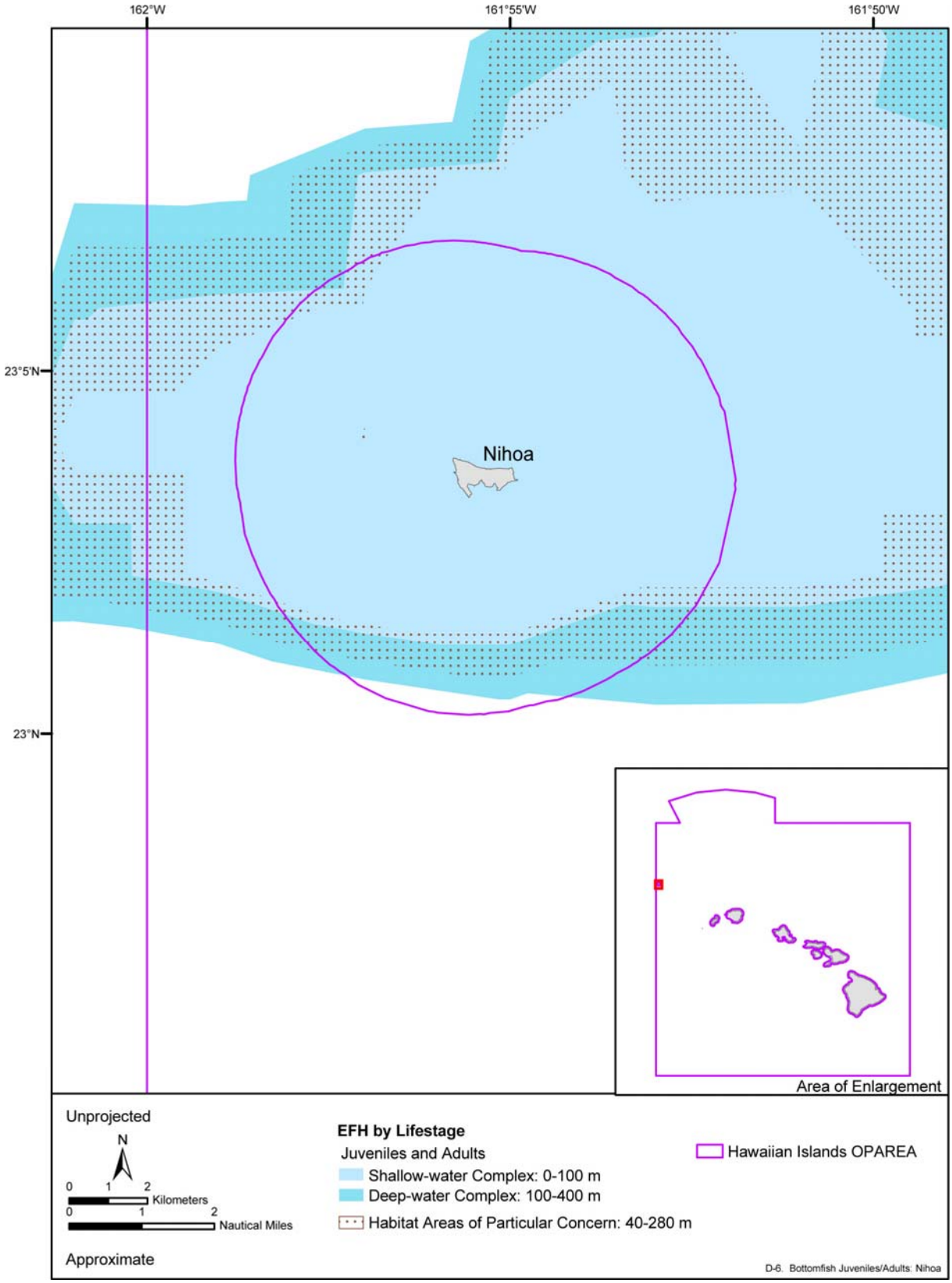

Figure D-6. EFH for all juvenile and adult lifestages of bottomfish and HAPC designated on Nihoa (NWHI) in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998).

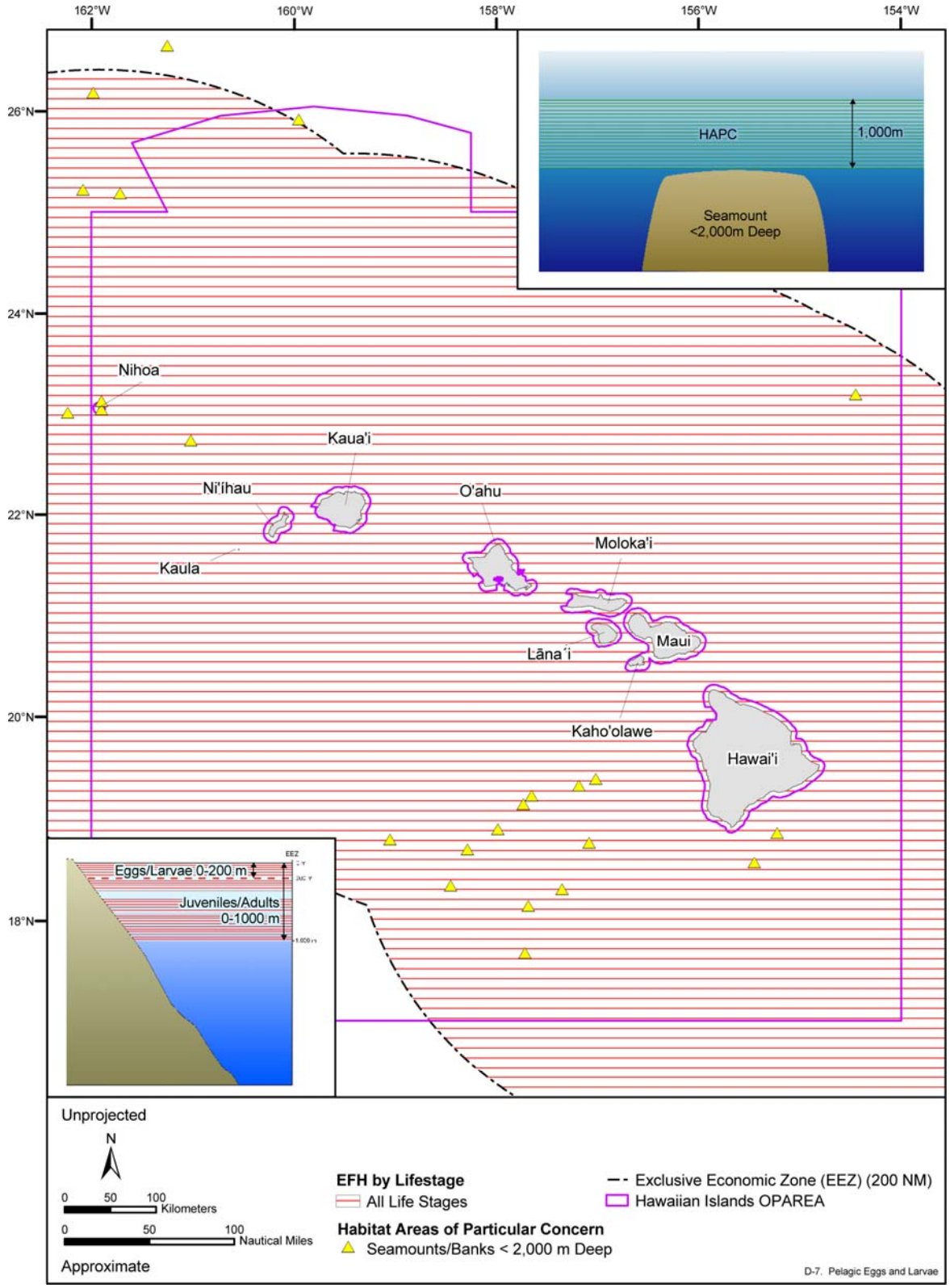

Figure D-7. EFH for all lifestages of pelagic fishes and HAPC designated in the Hawaiian Islands OPAREA. Depth ranges noted in legend apply from the shoreline to the outer limit of the EEZ. HAPC locations illustrate the vertical distributions associated with the seamounts and banks EFH designations. Map adapted from: WPRFMC (1998) and GDIAS (2004).

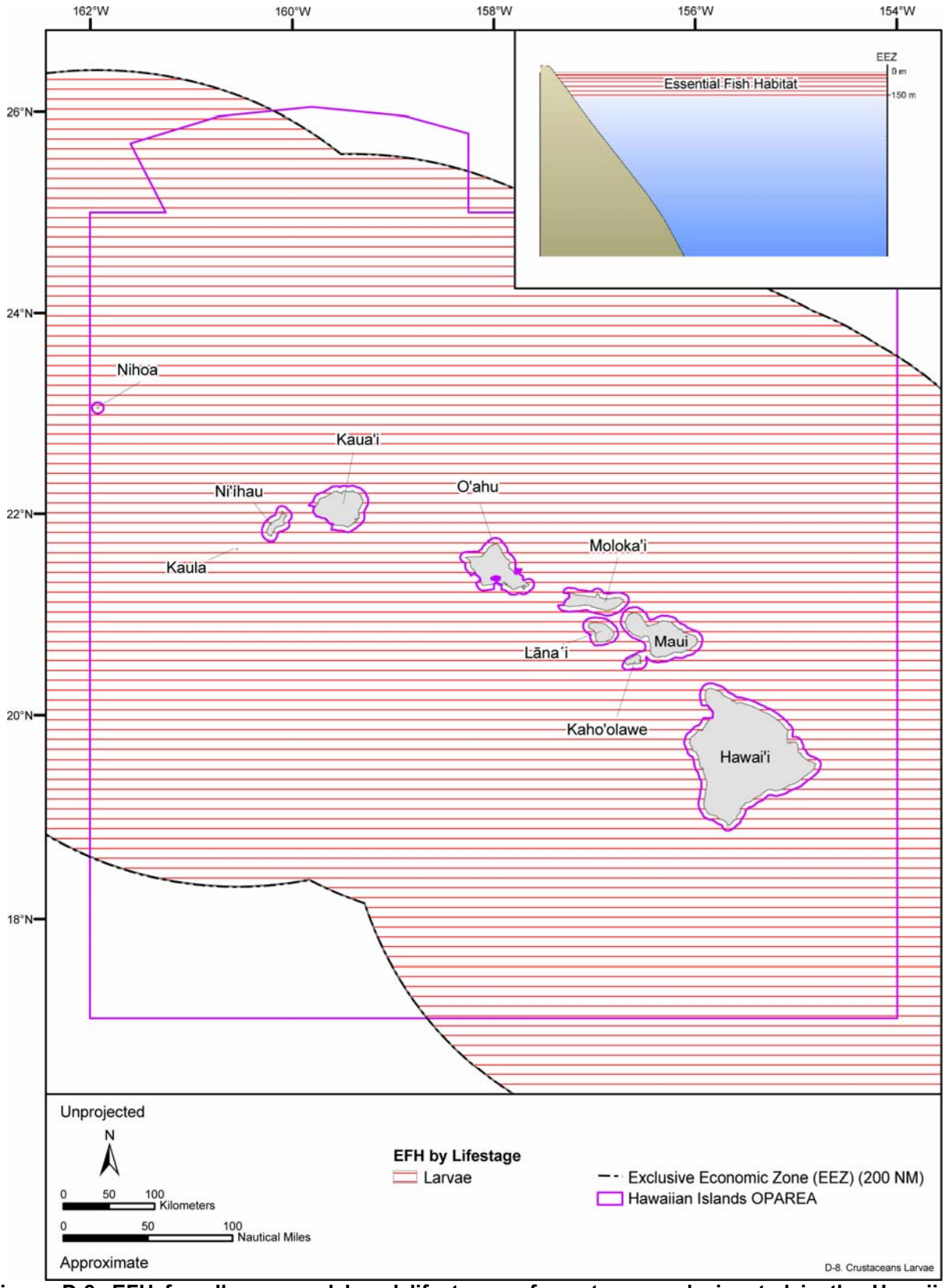

Figure D-8. EFH for all eggs and larval lifestages of crustaceans designated in the Hawaiian Islands OPAREA. Depth ranges noted in legend from the shoreline to the outer limit of the EEZ. Map adapted from: WPRFMC (1998) and GDIAS (2004).

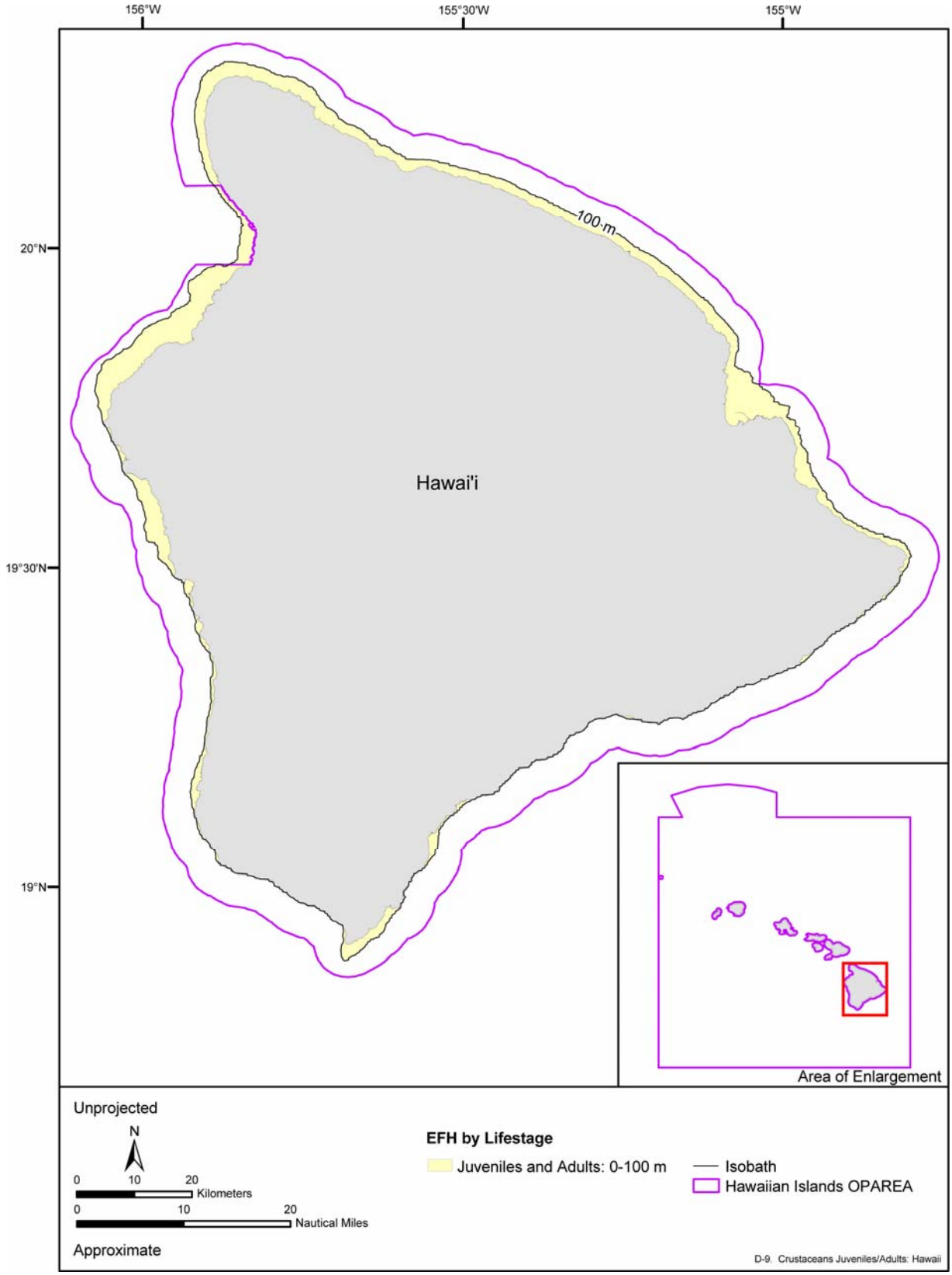

Figure D-9. EFH for all juvenile and adult lifestages of crustaceans designated on the main island of Hawai‘i in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998).

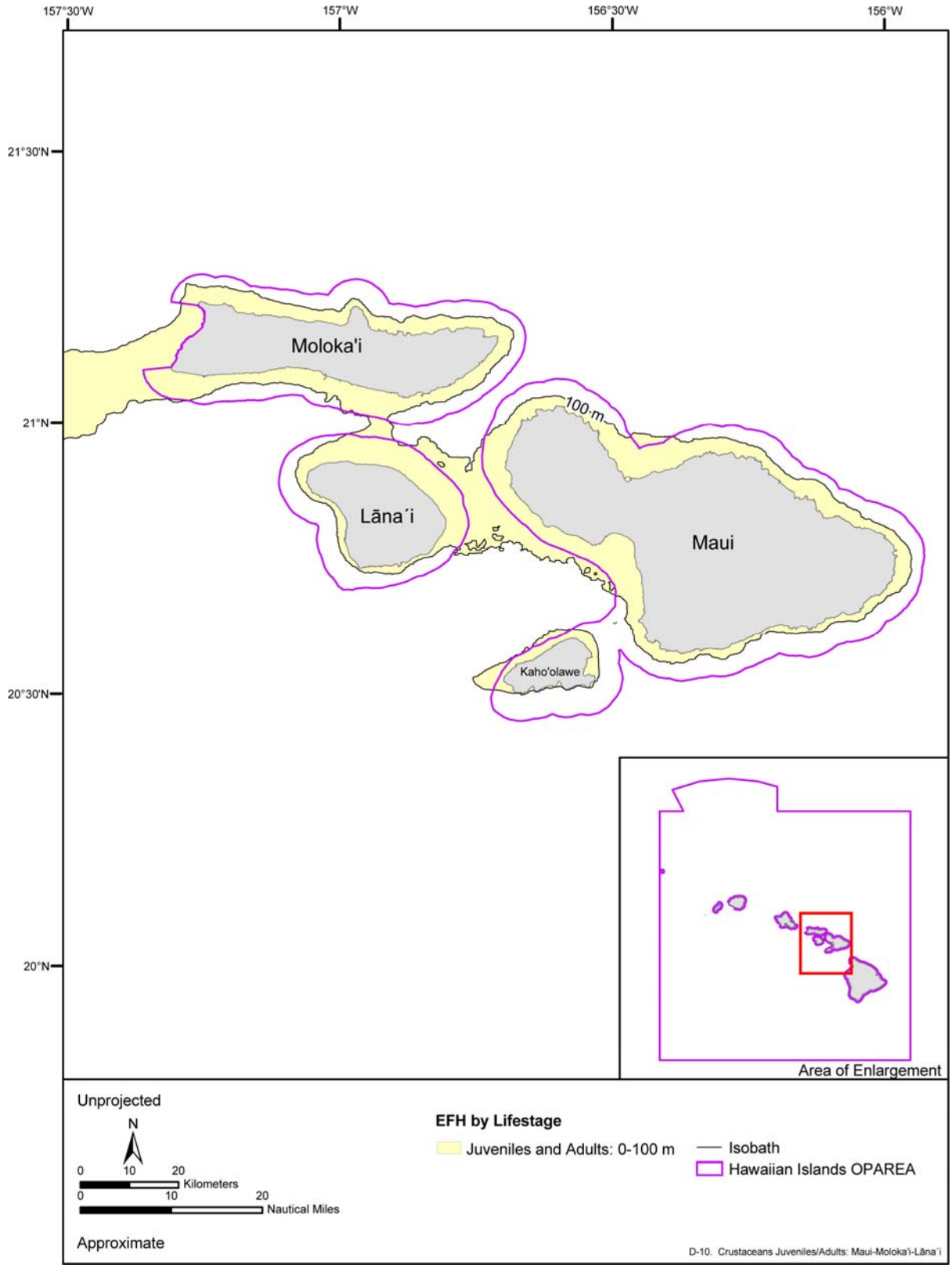

Figure D-10. EFH for all juvenile and adult lifestages of crustaceans designated on Maui, Kahoʻolawe, Lānaʻi, and Molokaʻi in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998).

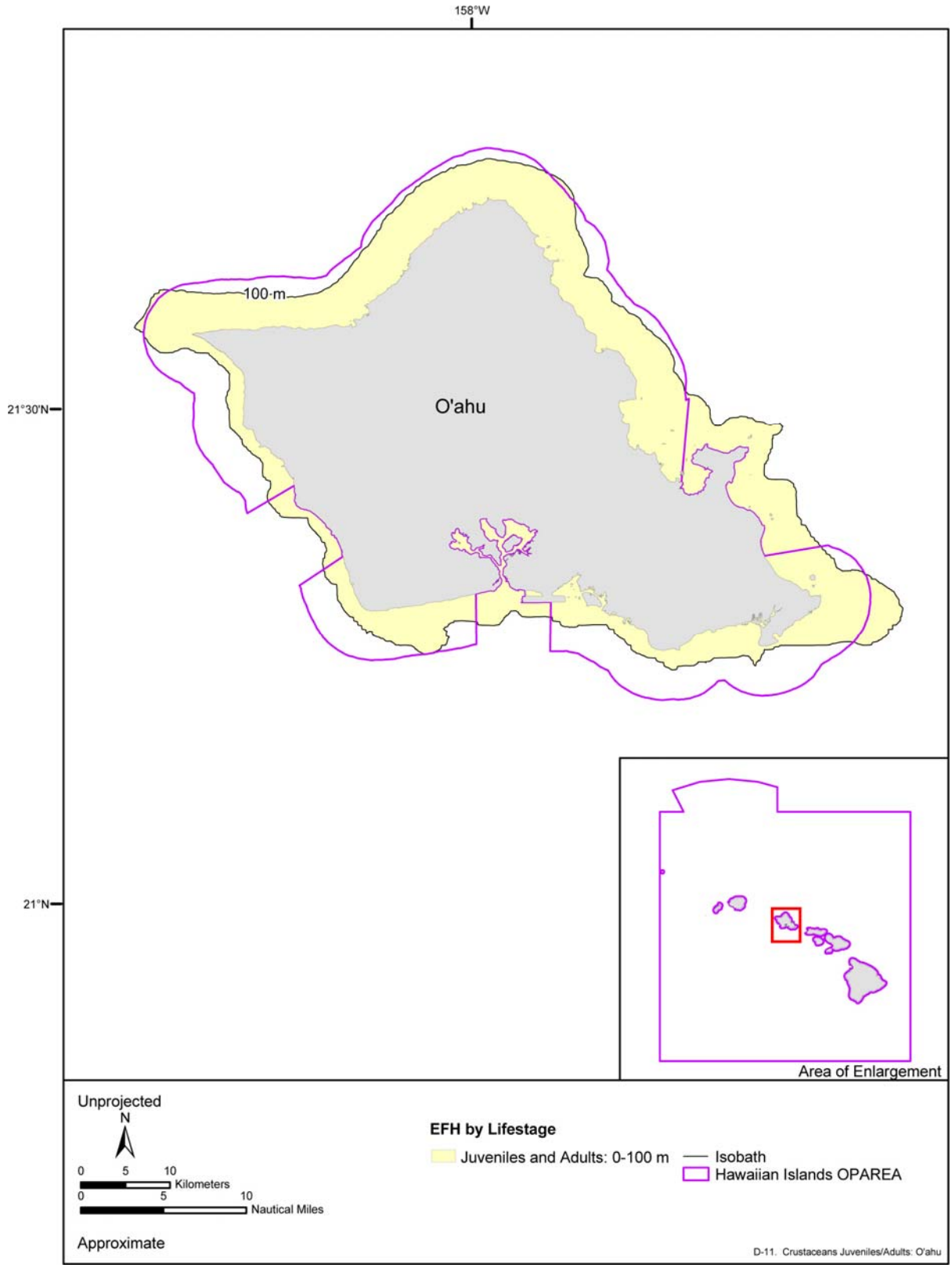

Figure D-11. EFH for all juvenile and adult lifestages of crustaceans designated on O‘ahu in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998).

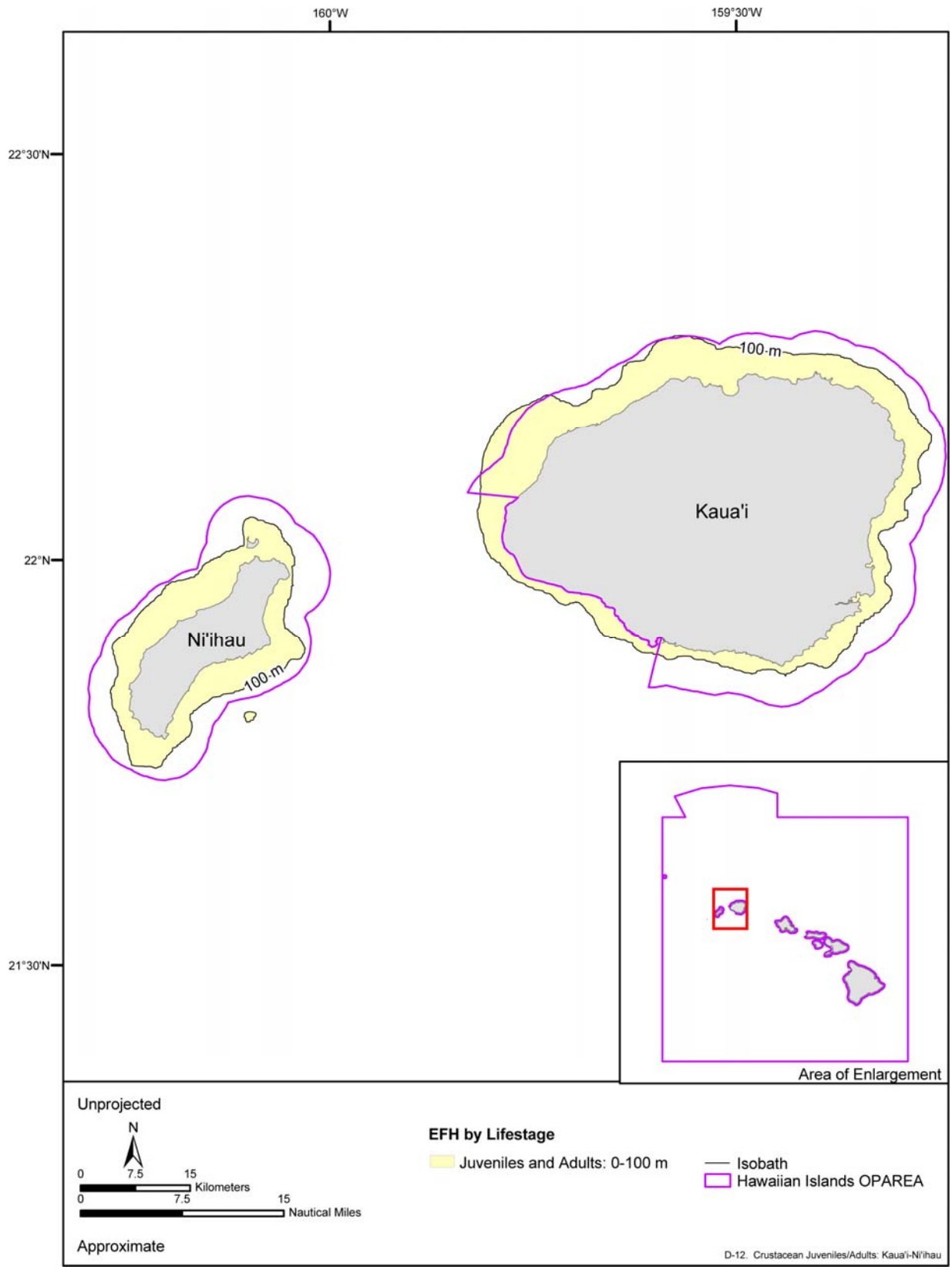

Figure D-12. EFH for all juvenile and adult lifestages of crustaceans designated on Ni‘ihau and Kaua‘i in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998).

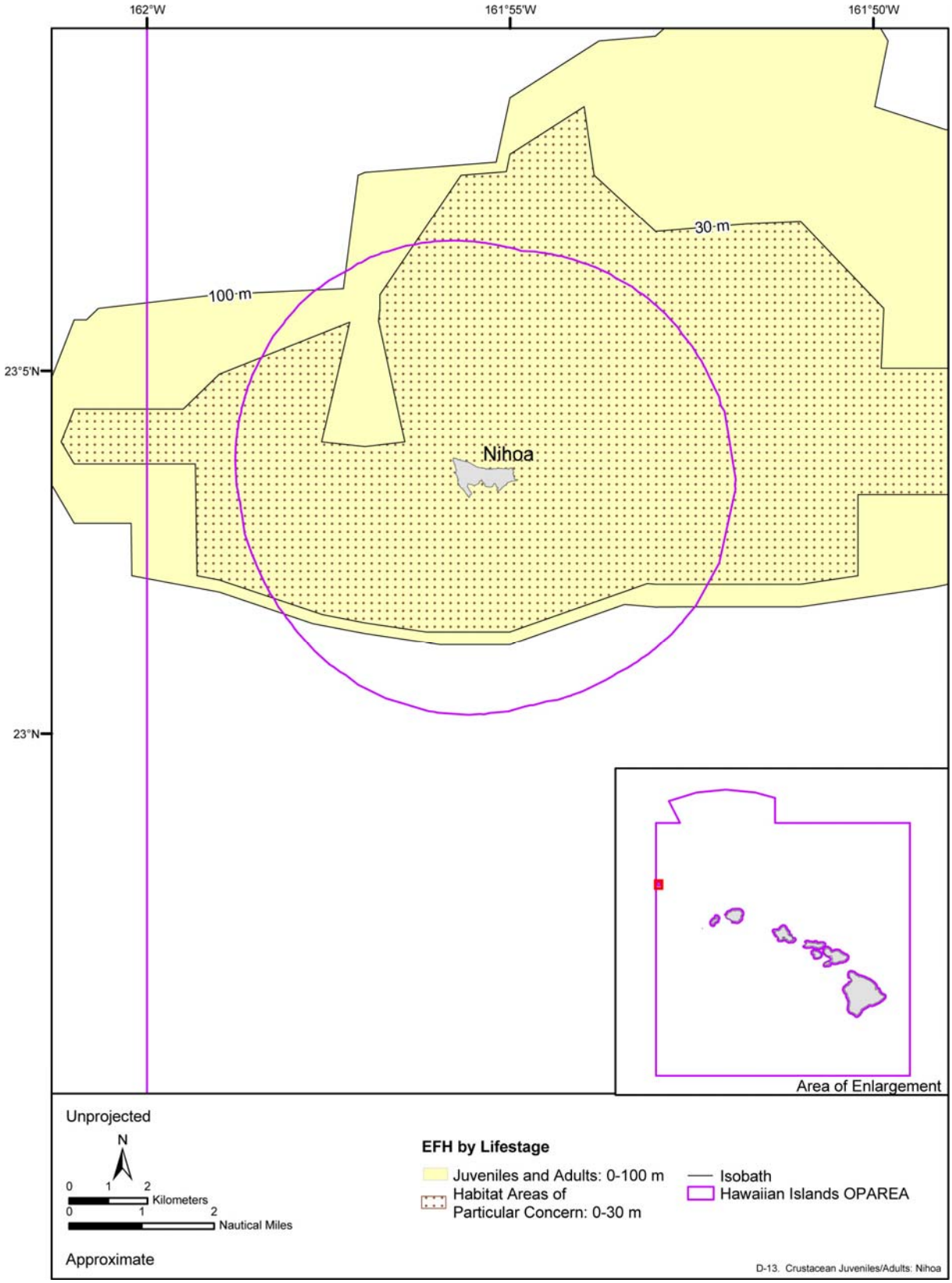

Figure D-13. EFH for all juvenile and adult lifestages of crustaceans designated on Nihoa (NWHI) in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998).

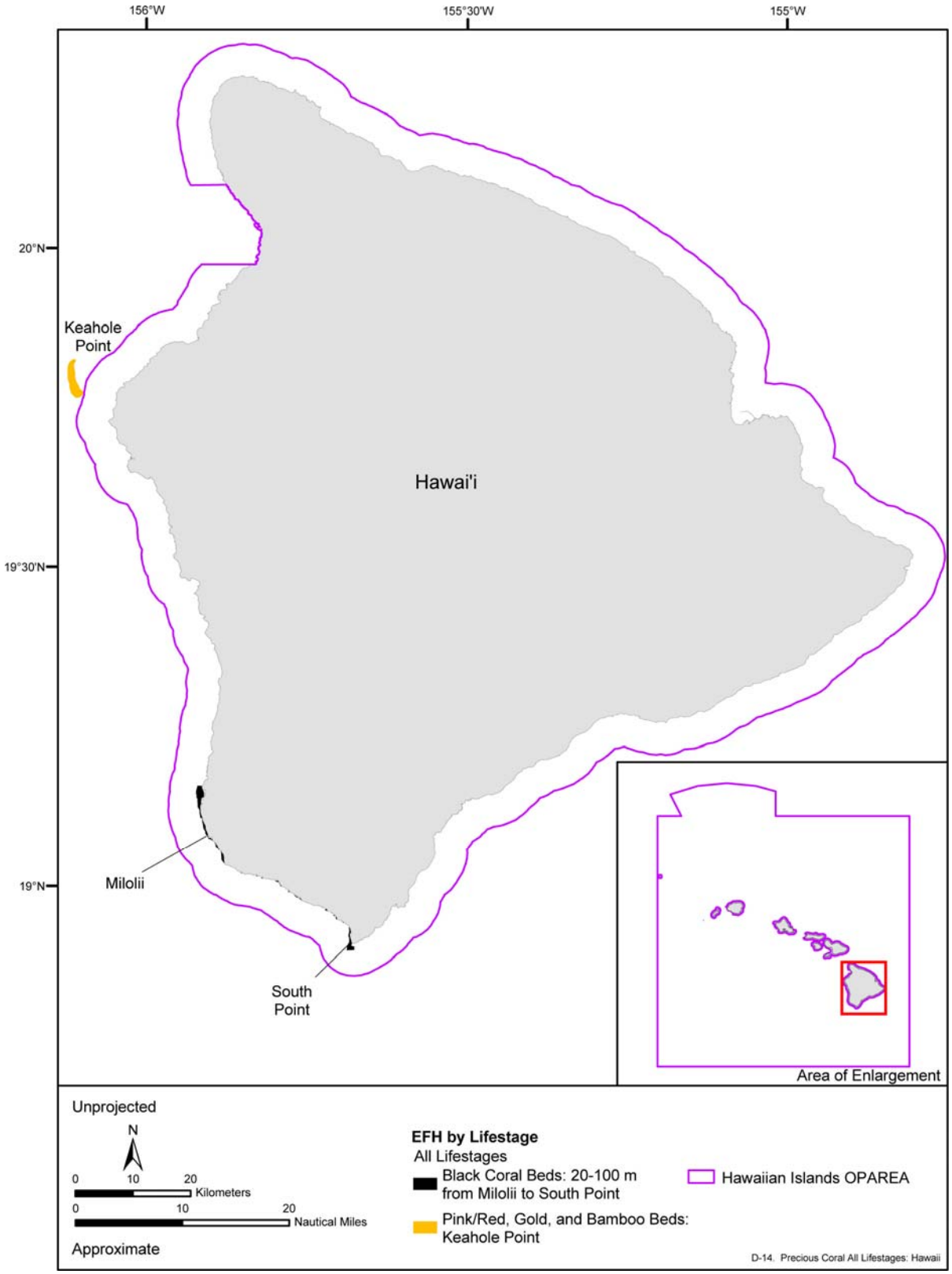

Figure D-14. EFH for all lifestages of precious corals (black, pink/red, gold, and bamboo) designated on the main island of Hawai‘i in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998) and GDIAS (2004).

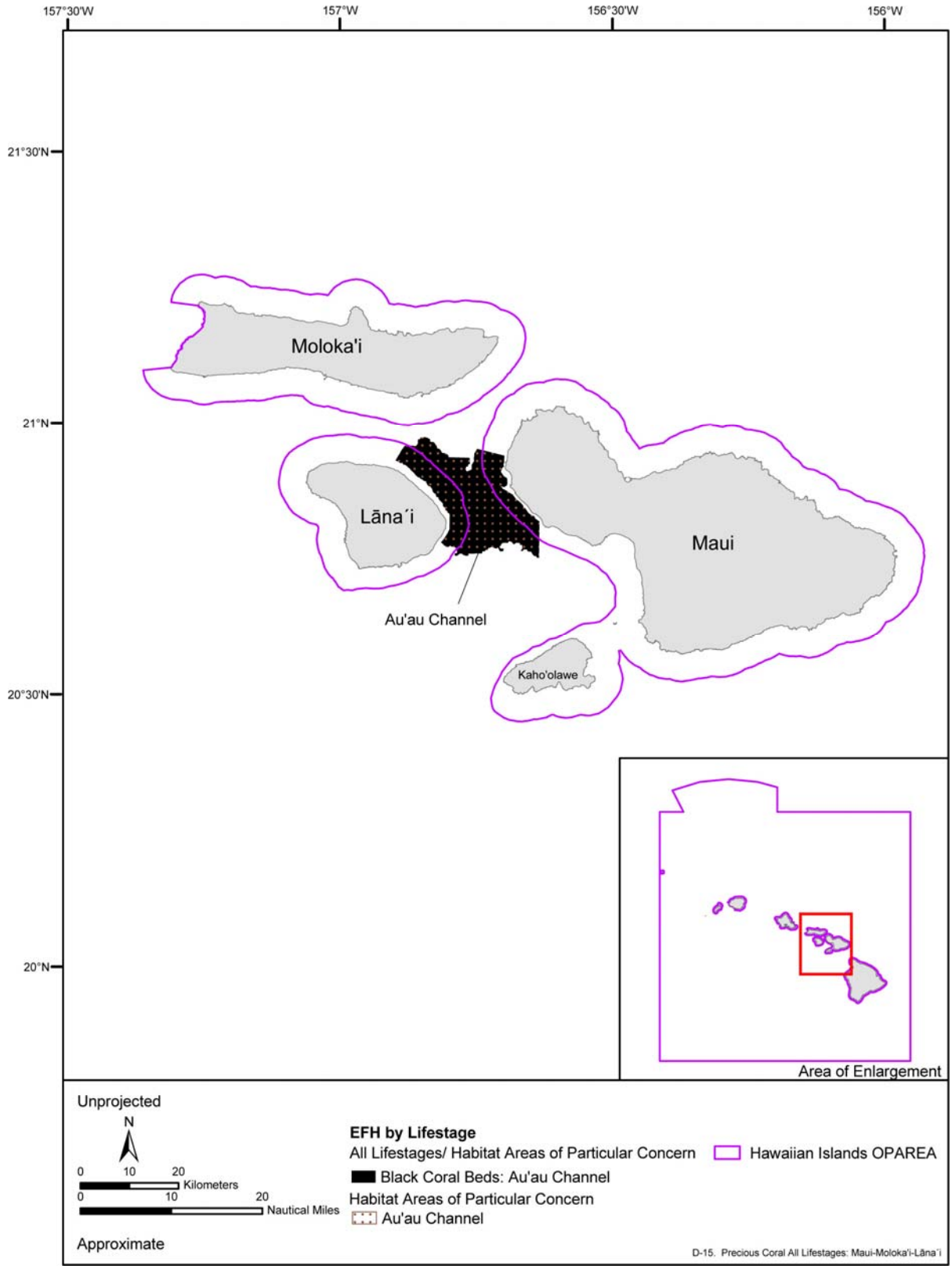

Figure D-15. EFH for all lifestages of precious corals (black) designated on Mau‘i, Kaho‘olawe, Lāna‘i, and Moloka‘i in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998) and GDIAS (2004).

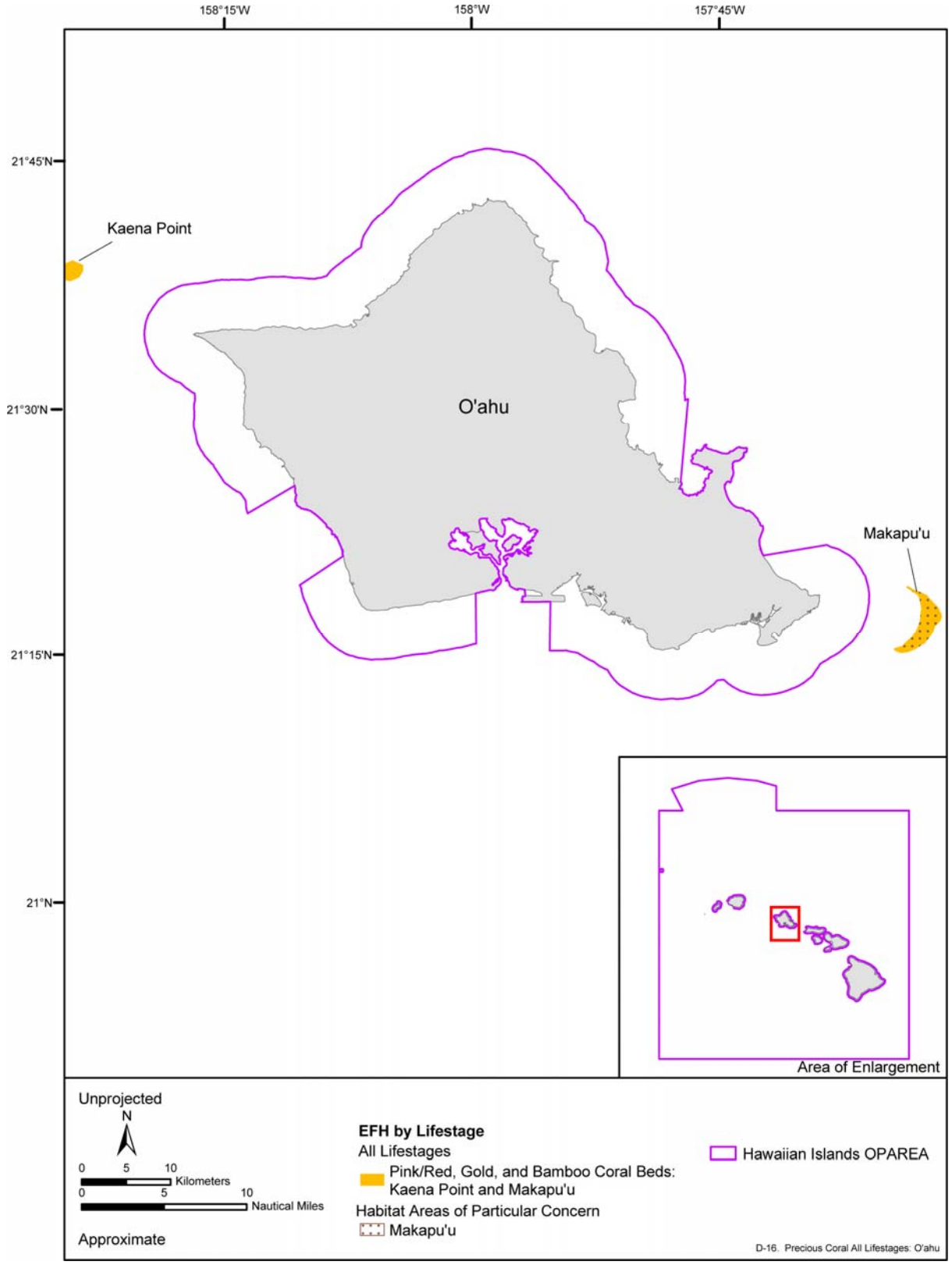

Figure D-16. EFH for all lifestages of precious corals beds and HAPC designated on O‘ahu in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998) and GDIAS (2004).

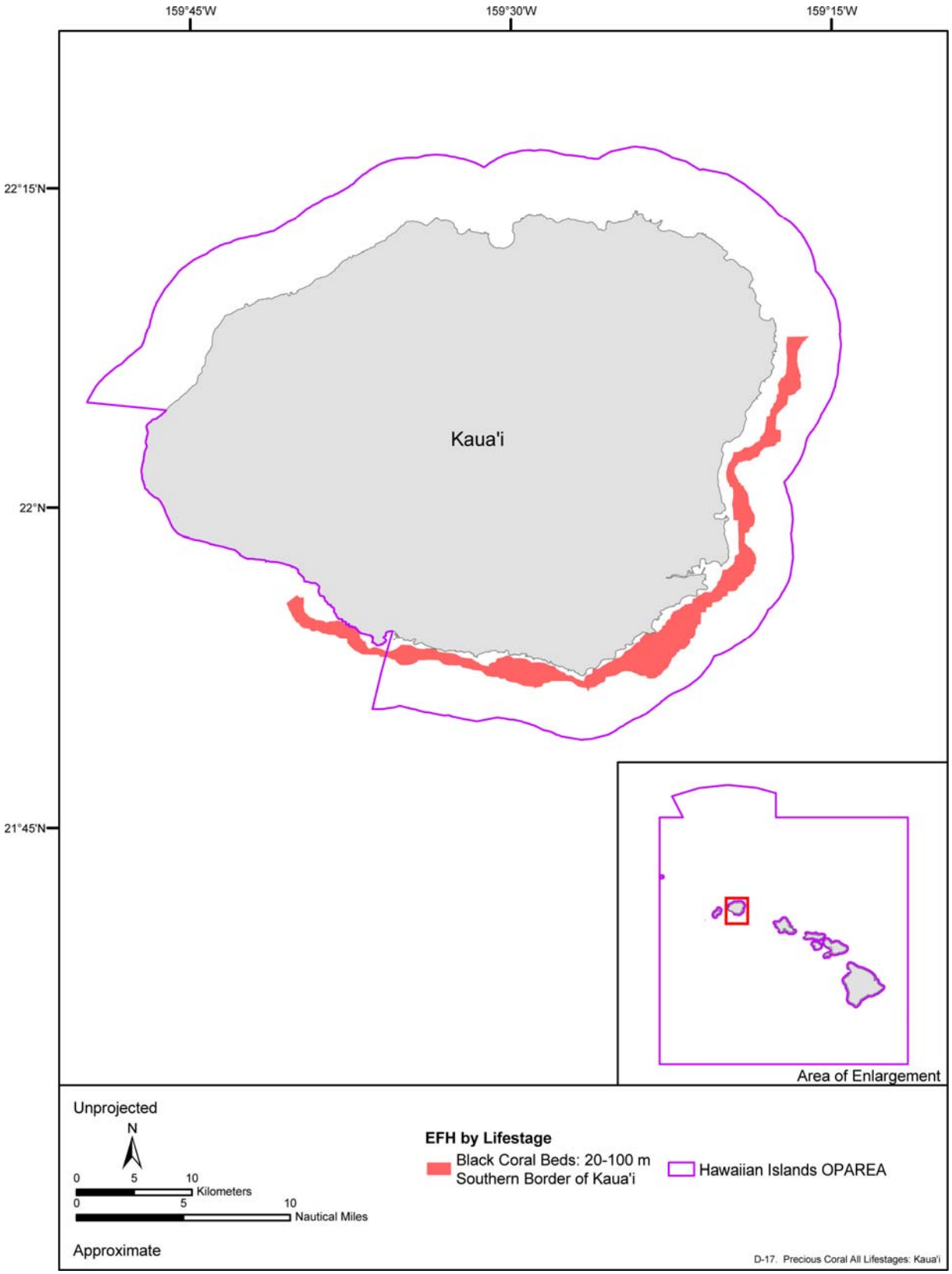

Figure D-17. EFH for all lifestages of precious corals beds designated on Kaua‘i in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (1998) and GDIAS (2004).

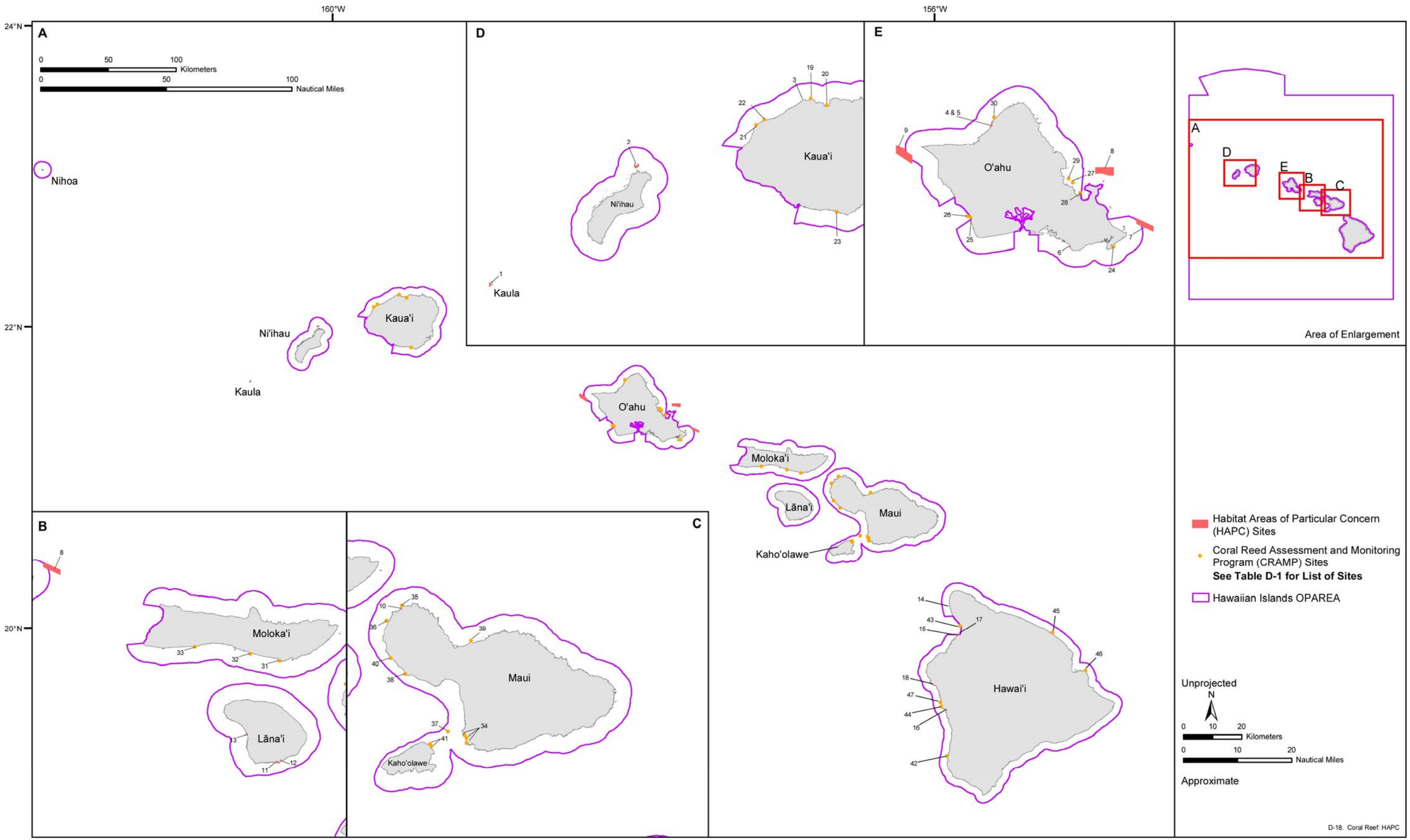

Figure D-18. HAPC for the CRE designated in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (2001a) and Jokiel and Freidlander (2005).

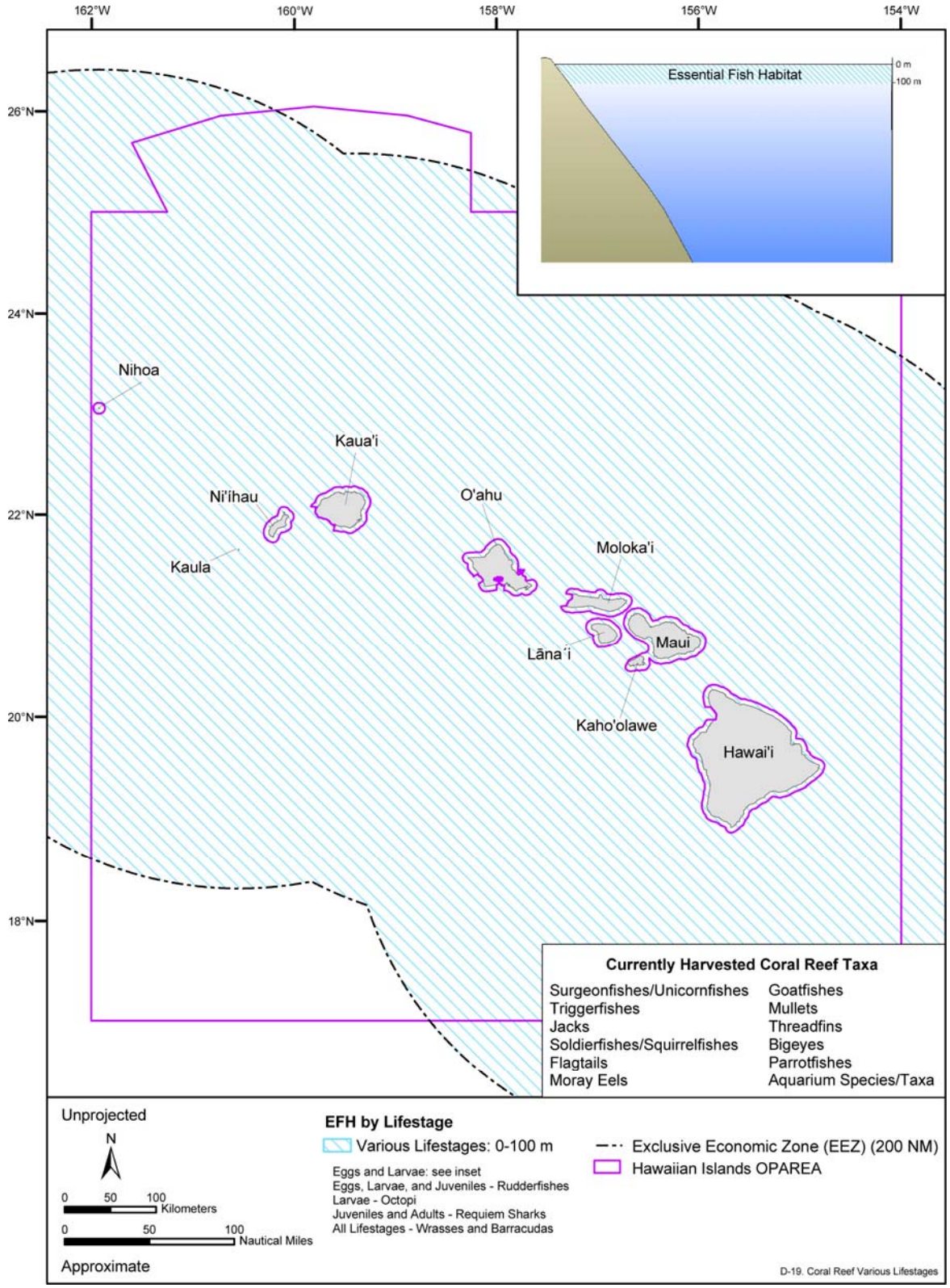

Figure D-19. EFH for various lifestages of the CHCRT-CRE and HAPC designated in the main Hawaiian Islands and on Nihoa in the Hawaiian Islands OPAREA. Depth ranges noted in legend apply from shoreline to the outer limits of EEZ. Map adapted from: WPRFMC (2001a) and GDIAS (2004).

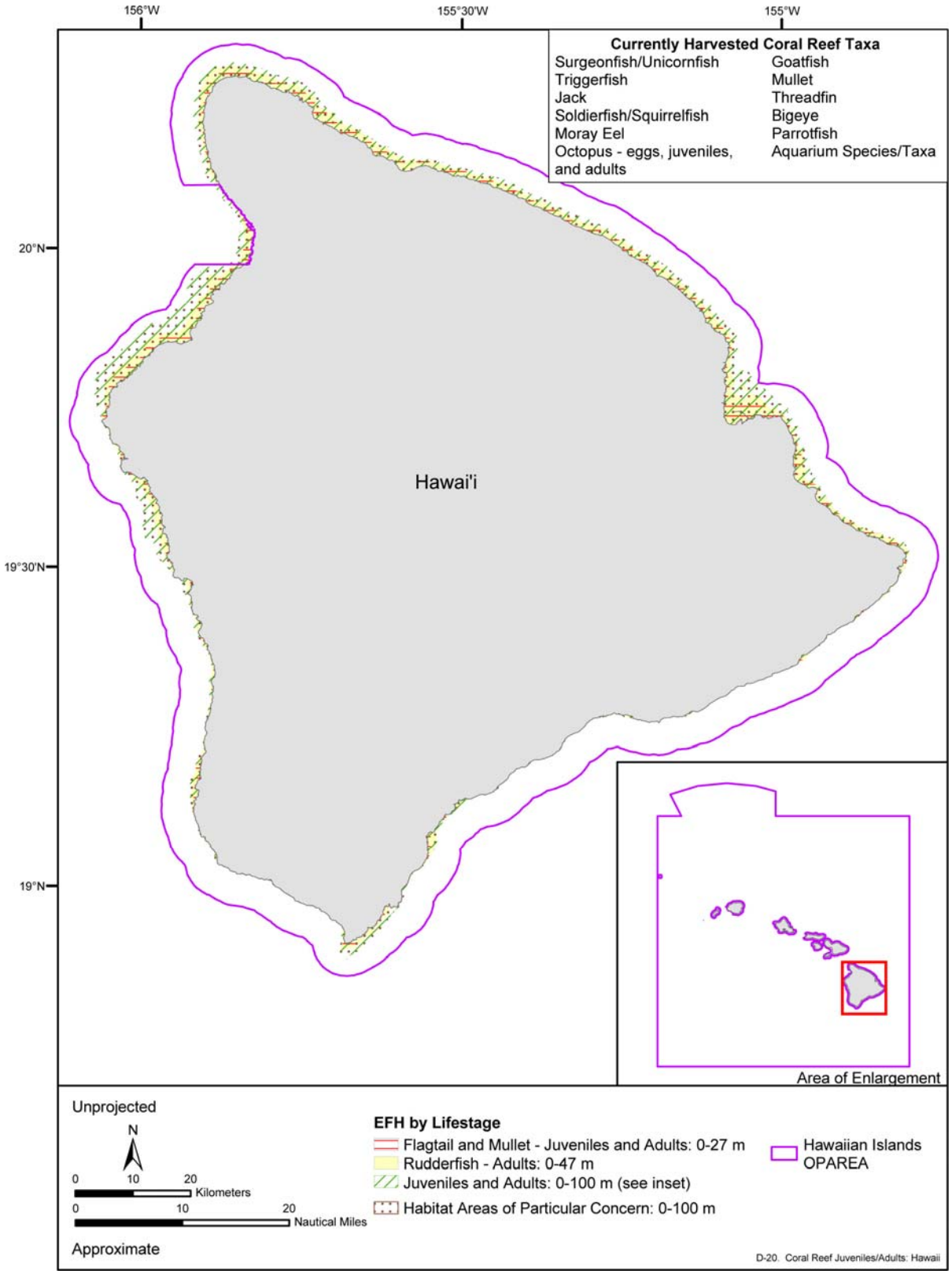

Figure D-20. EFH for all juvenile and adult lifestages of the CHCRT-coral reef ecosystem and HAPC designated in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (2001a) and GDIAS (2004).

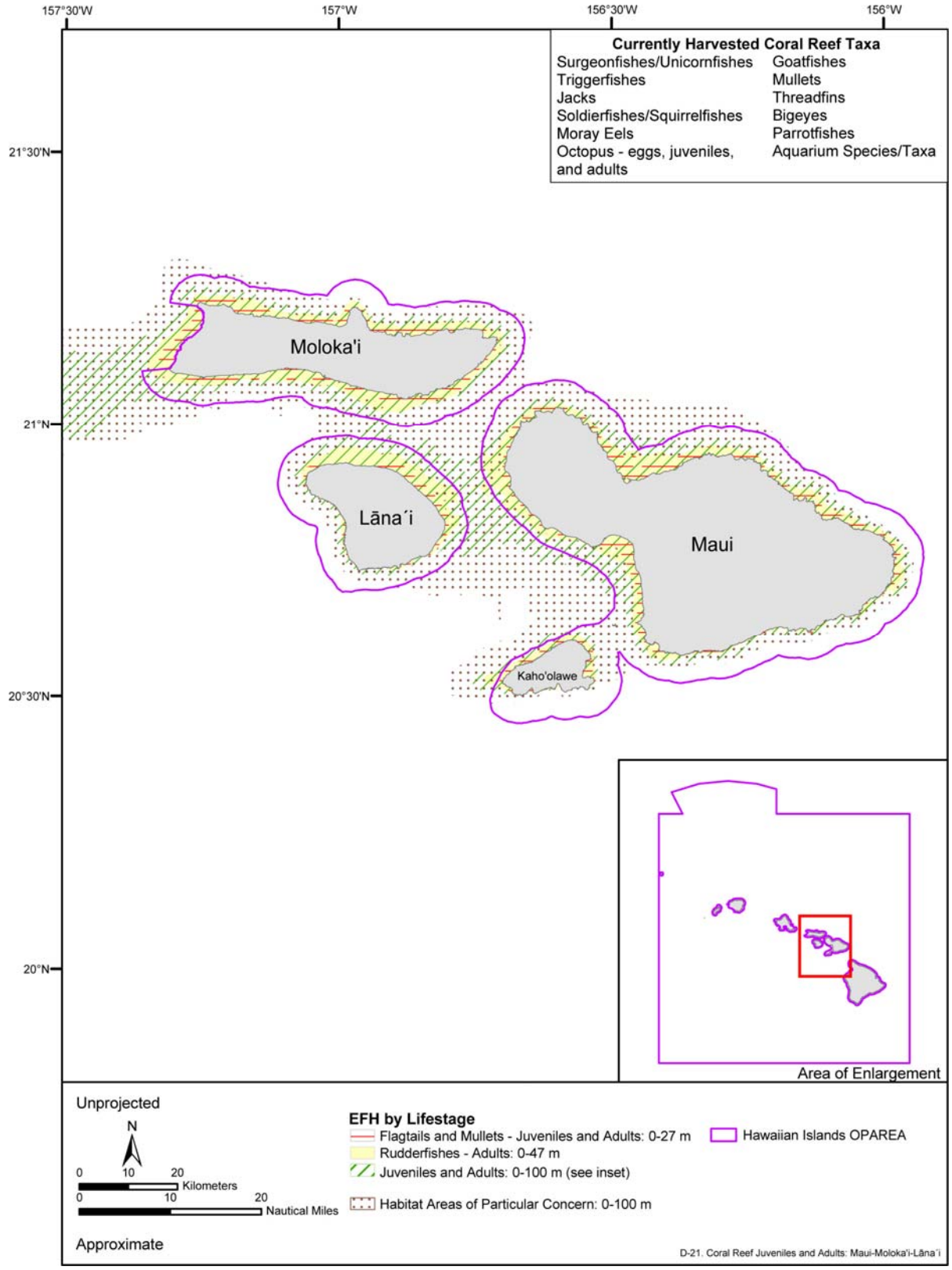

Figure D-21. EFH for all juvenile and adult lifestages of the CHCRT-coral reef ecosystem and HAPC designated on Mauʻi, Kahoʻolawe, Lānaʻi, and Molokaʻi in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (2001a) and GDIAS (2004).

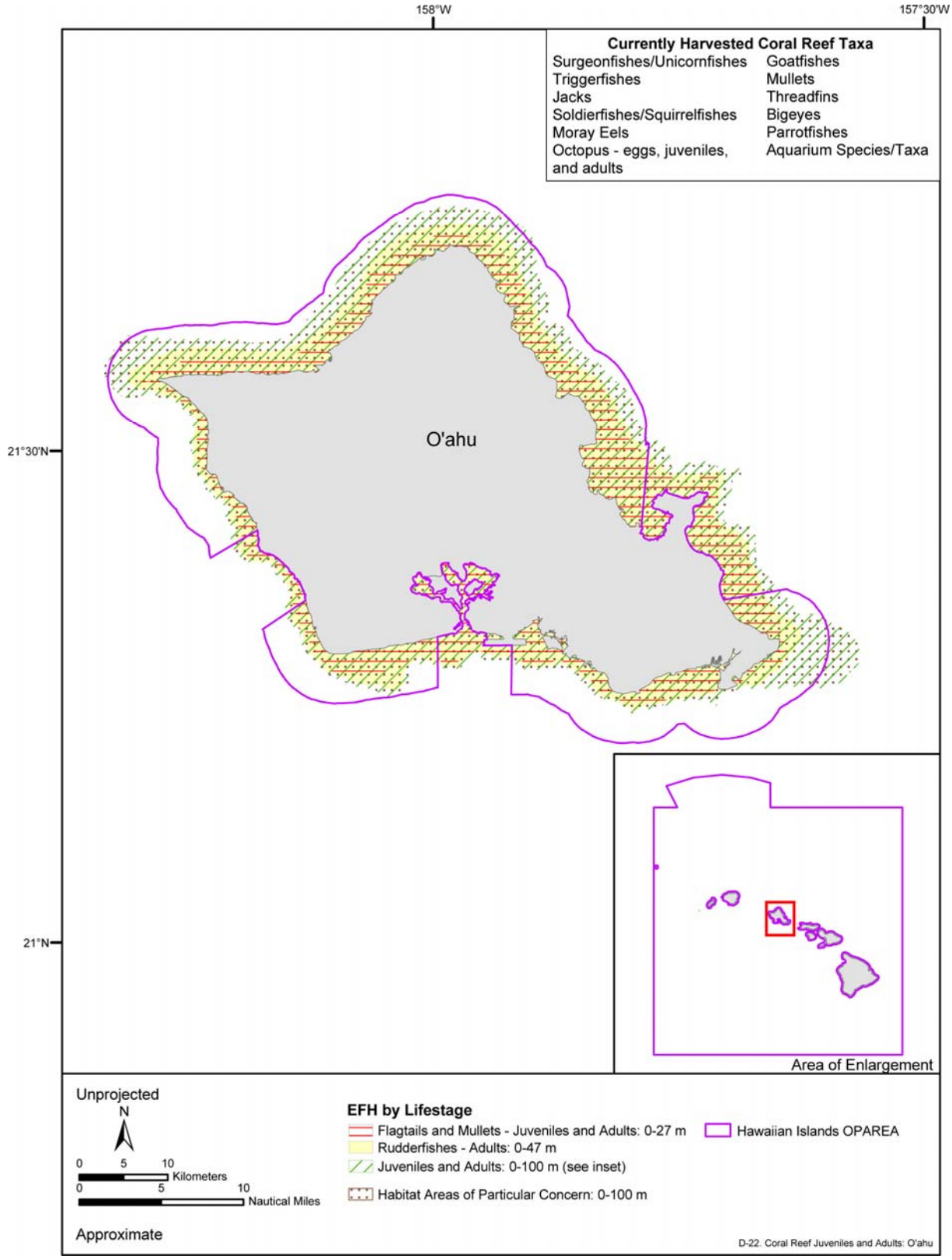

Figure D-22. EFH for all juvenile and adult lifestages of the CHCRT-coral reef ecosystem and HAPC designated on O‘ahu in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (2001a) and GDIAS (2004).

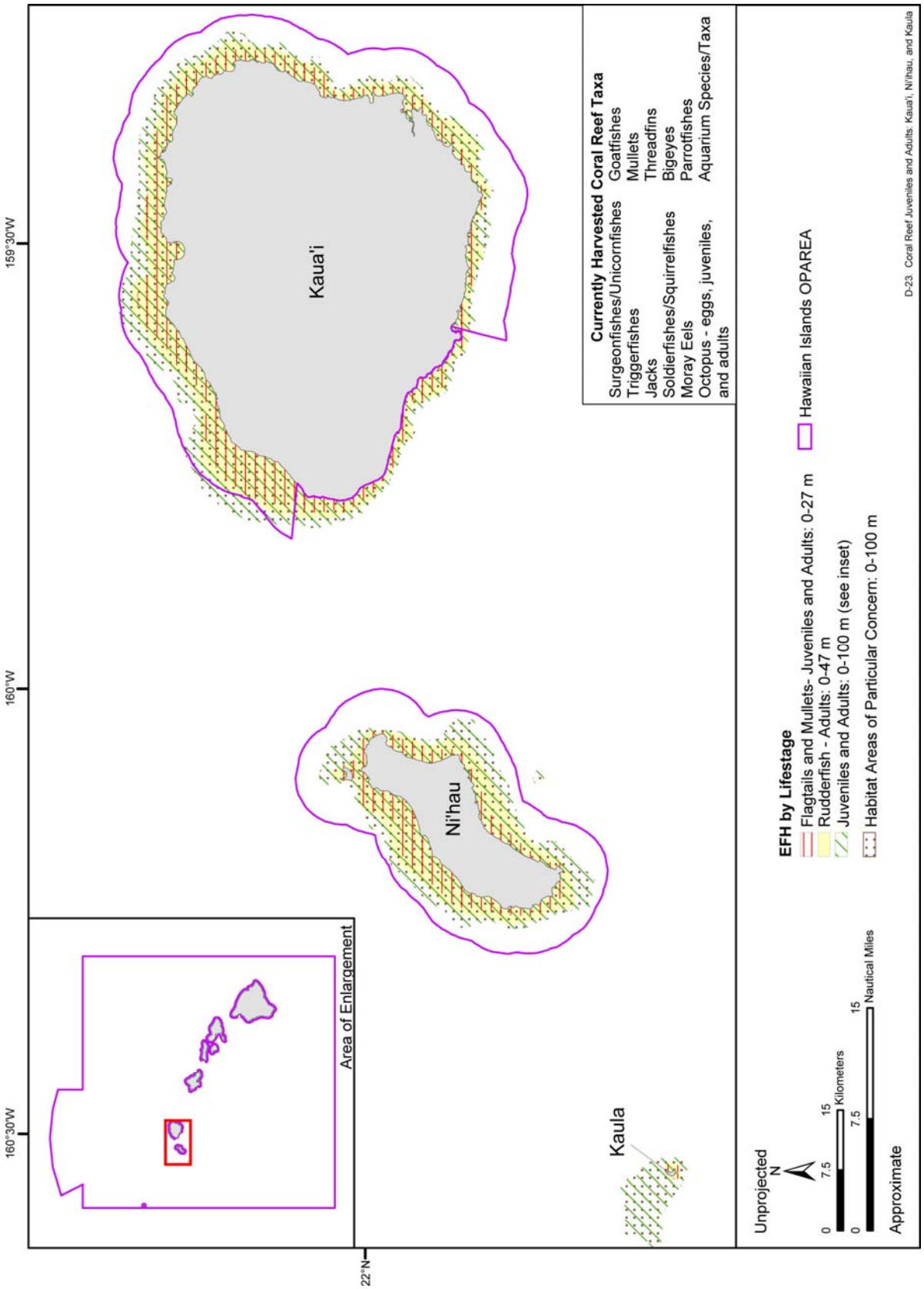

Figure D-23. EFH for all juvenile and adult lifestages of the CHCRT-coral reef ecosystem and HAPC designated on Kaua'i and Ni'hau in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (2001a) and GDIAS (2004).

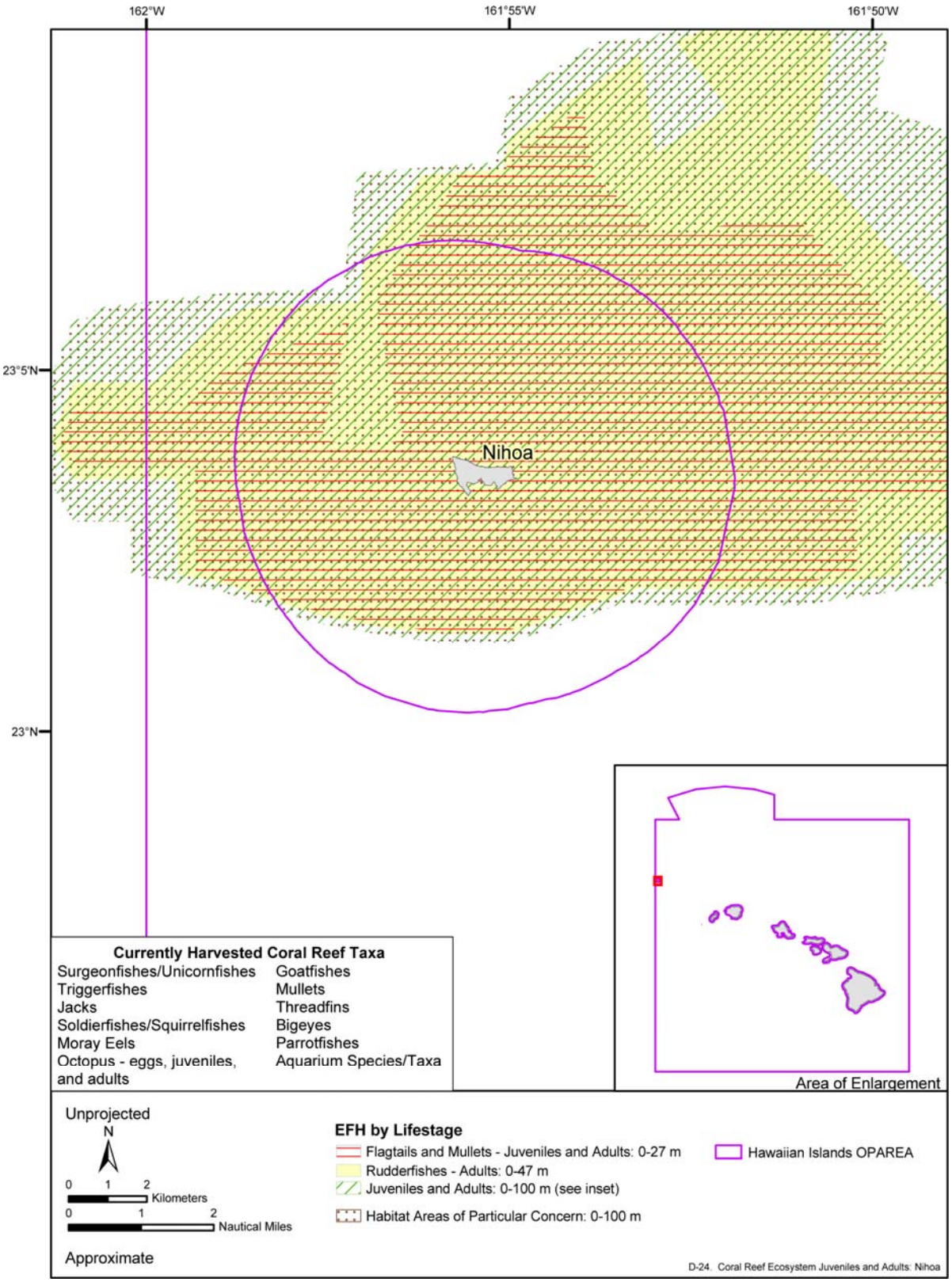

Figure D-24. EFH for all juvenile and adult lifestages of the CHCRT-coral reef ecosystem and HAPC designated on Nihoa in the Hawaiian Islands OPAREA. Map adapted from: WPRFMC (2001a) and GDIAS (2004).

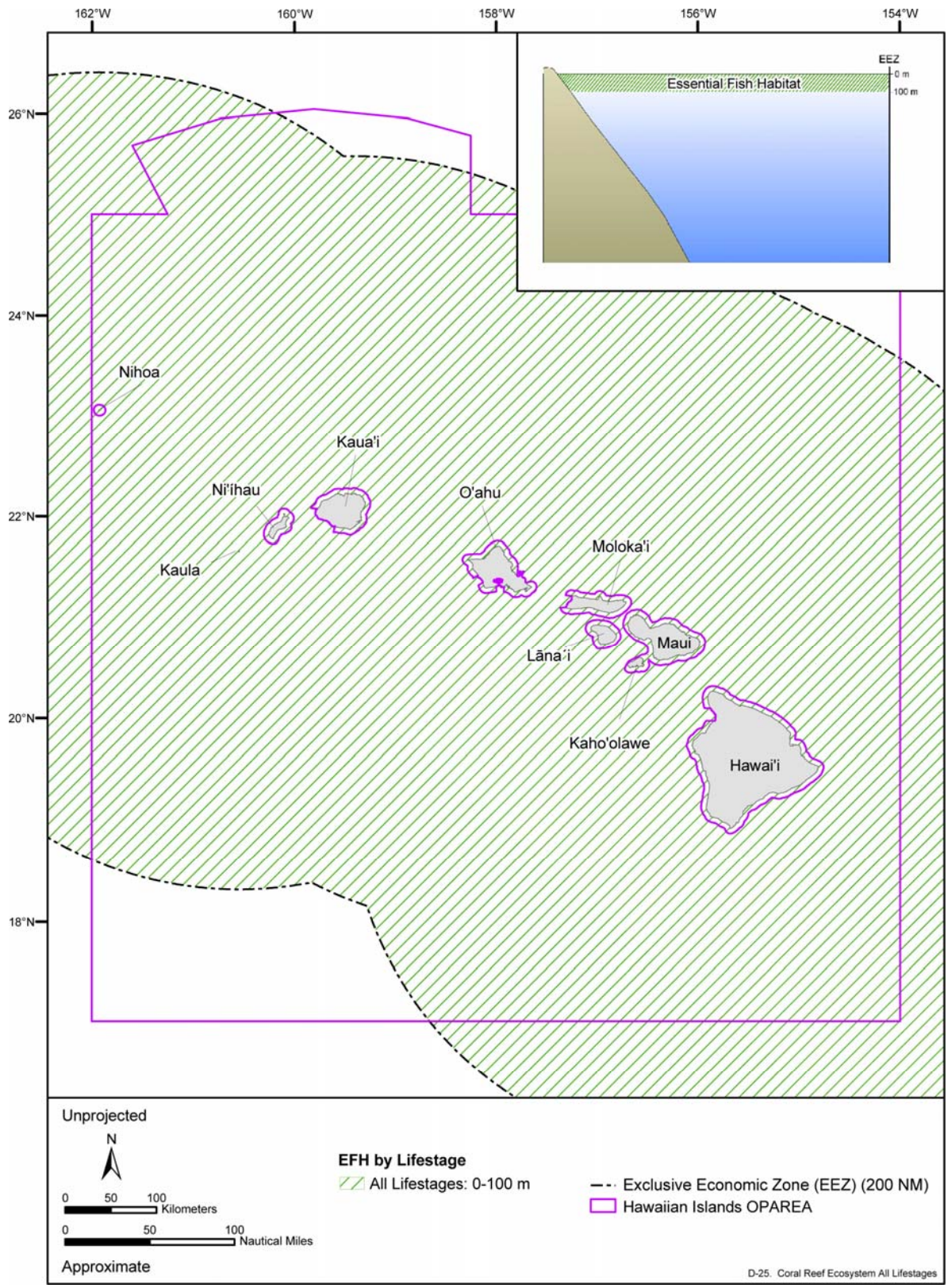

Figure D-25. EFH for all lifestages of the PHCRT-coral reef ecosystem and HAPC designated in the Hawaiian Islands OPAREA. Depth ranges noted in legend apply from the shoreline to the outer limit of the EEZ. Map adapted from: WPRFMC (2001a) and GDIAS (2004).