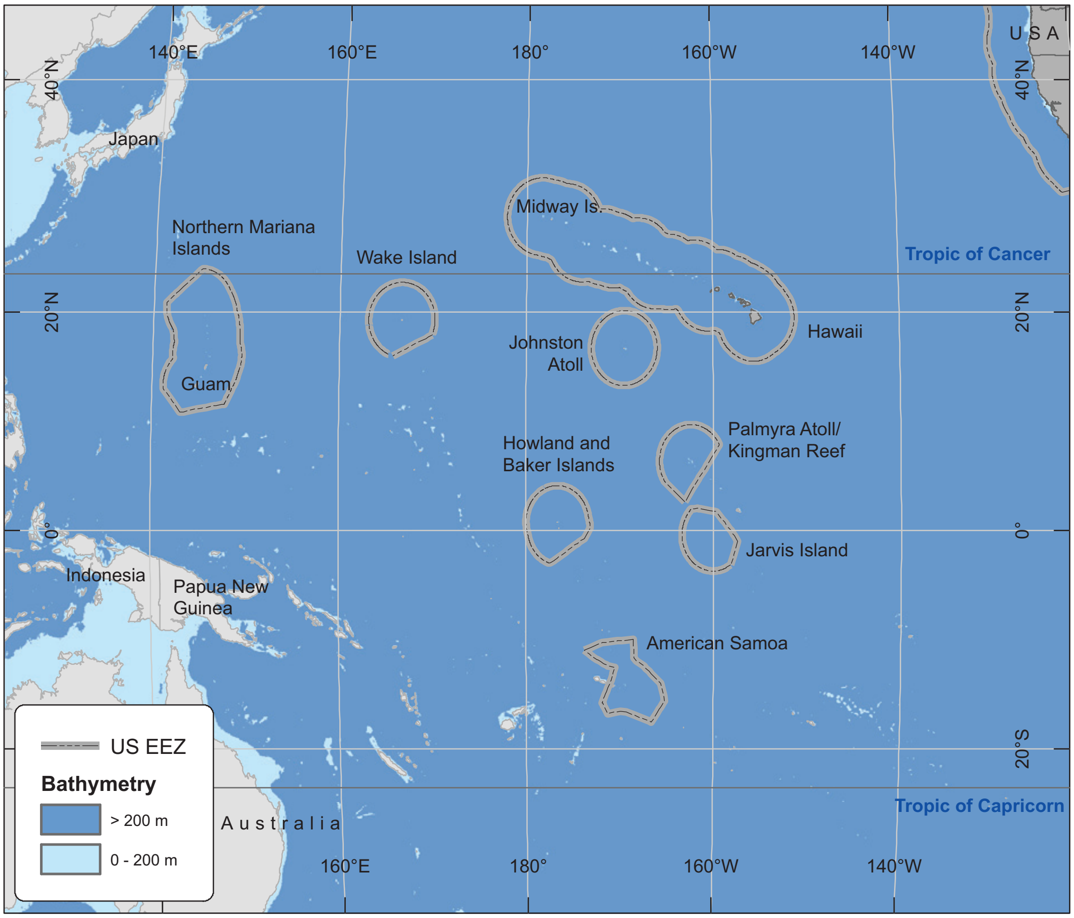
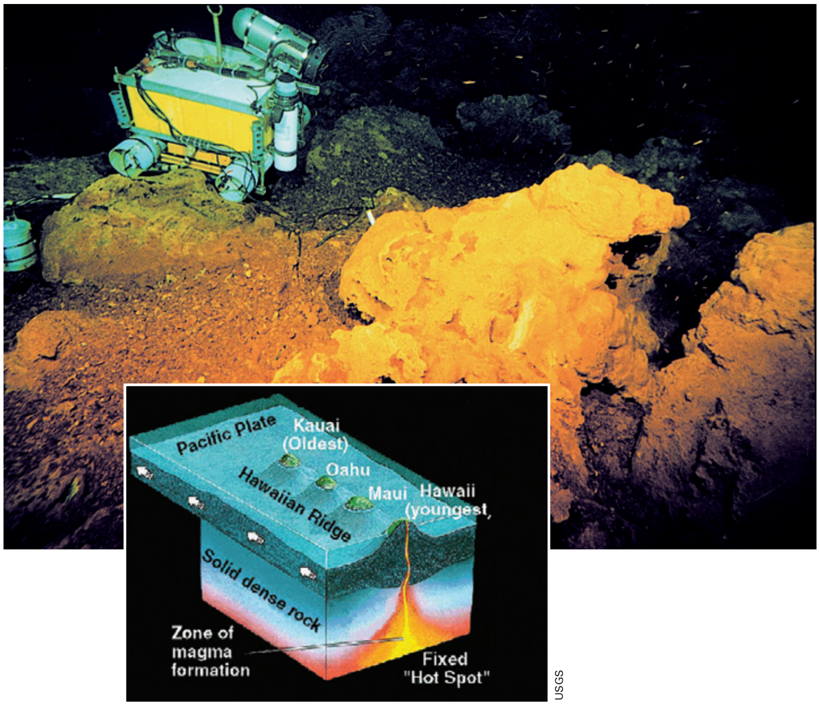
Pacific Islands Region



HABITAT AREAS

The United States has jurisdiction over about 50 Pacific Ocean islands, including two archipelagos (Hawaiian and Marianas), part of another archipelago (Samoan), and eight isolated atolls or low-lying islands (Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Howland Island, Baker Island, Swains Island, and Wake Atoll).[1] Created by volcanoes erupting from the seafloor, these islands are the summits of pinnacles that rise steeply from ocean depths of 4–7 km (2.5–4.35 mi). Although the land area (about 1,900 km^2; 734 mi^2) of the U.S. Pacific Islands Region is small when compared to North America, the total area of U.S. Exclusive Economic Zone (EEZ) waters included in the Pacific Islands Region is 5.751 million km^2 (1.677 million nmi^2), or almost 50% of the entire U.S. EEZ. This combination of geographically wide-spread holdings with small land areas and large marine EEZs creates a large region of predominantly marine biological resources. The indigenous societies of this region, Micronesian in the west and Polynesian in the center, relied on marine resources for food and cultural needs, creating the most maritime of civilizations, and this

[1]Kingman Reef, Palmyra Atoll, Jarvis Island are also part of an island chain known as the Line Islands.



A. Malahoff, OAR/NURP; Univ. Hawaii

USGS

Inset image: Illustration of magma rising to the surface and forming the Hawaiian Islands, and showing the relative age of each island in the chain.

Background image: Underwater equipment monitors Loihi, a volcano that is still underwater in the Hawaiian chain.

reliance continues today. Thus, the islands' marine resources often have a greater per capita value than those of industrialized fisheries, despite the lesser monetary value of island harvests.

The geomorphology of the islands varies and includes some of the youngest and oldest islands in the world. Mountainous "high" islands are found in areas of active volcanism, such as the Marianas and the southeastern end of the Main Hawaiian Islands (MHI), where the next island, called Loihi, which is still roughly 1,000 m (3,280 ft) underwater, is currently being formed. Atolls, or "low" islands, are the much older coral-encrusted remnants of high islands that have eroded to sea level with the passing millennia. The Line Islands (south of Hawaii, crossing the Equator) are estimated to be one of the oldest archipelagos. The Hawaiian Archipelago is an excellent example of the transition of young high islands to old low islands. Islands successively created as the Pacific Plate drifts northwest over a stationary hot spot erode from their initial state as high mountainous islands (e.g. Maui and Hawaii) to become low coral atolls at the opposite end of the chain (e.g. Midway, Kure). Finally, plate drift, subsidence, and sea level rise have drowned many of these low features, creating numerous submerged banks and seamounts.

The oceanography of the Pacific Islands Region is equally varied, with notable differences in effects from ocean currents. Many species at varying trophic levels, and particularly plankton (both holoplankton, which are plankton their entire life cycle, and meroplankton, which are plankton during only part of their life cycle, such as larval fish), are sometimes restricted to single water masses or currents; the endemism of these species indicates the limits of single biogeographic regions. Within the Pacific, these regions are the northern and southern central gyres,[2] the northern and southern currents that border the gyres (in regions called "transition zones"), the equatorial currents, and a fringe area referred to as the eastern tropical Pacific. Because of the pelagic environment's fluidity, the boundaries of these regions overlap, particularly in the western Pacific. As a consequence of this overlap, the environment's fluidity, and the biota's dispersal capability, most pelagic species have ranges that encompass two or more of these ecosystems. U.S. Pacific holdings lie within the following pelagic ecosystems: Midway, Kure, and the northern Hawaiian seamounts are in the north central gyre/northern transition zone ecotone (transitional area);[3] Hawaii and Wake are in the North Pacific central gyre; Johnston is in the central gyre/eastern tropical Pacific ecotone; Kingman and Palmyra are in the equatorial/eastern Pacific ecotone; Jarvis, Howland, and Baker are in the equatorial ecosystem; American Samoa is in the south central Pacific ecosystem; and the Mariana Islands are in an ocean complex with elements from the north central gyre, transition zone origin, and equatorial ecosystems.

Biological resources in the oceanic Pacific differ remarkably from those off the coast of North America. U.S. islands span the east–west extent of the tropical Pacific with its rich warm-water biota, and Hawaii extends from the subtropics northward into the south-temperate climes. An eastern Pacific expanse devoid of land separates the islands from the Americas, while archipelagos within less than 1,000 km (621 mi) of each other connect to the Pacific's western edge. The earth's highest marine biodiversity exists at the juncture of

[2]Gyres are large-scale circular features made up of ocean currents that travel clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.

[3]An ecotone is a transition area between habitats or environments.

the Indian and Pacific Oceans; the Pacific Islands Region connects most closely with this area, sharing many species with it. U.S. possessions, dispersed across a realm of great biological richness, therefore contain more marine species than all other U.S. marine regions. These biodiversity patterns in the oceanic Pacific have been shaped primarily by volcanism, tectonic plate movement, sea level change, island subsidence, ocean currents, and human-caused extinctions and species introductions. High and low islands have large ecological differences. Substantial human populations often live on high islands in urban centers that low atolls cannot support. High islands often have substantial rainfall, allowing forests, freshwater streams, and estuaries to exist. Most atolls are dry, lacking dense vegetation and estuaries. High islands have a greater diversity of aquatic habitats, including freshwater and estuarine areas necessary for the life histories of some species that are absent from low islands.

The Pacific Islands Region contains many diverse habitats including high islands, atolls, submerged banks, seamounts, and offshore oceanic habitat. Nearshore habitats with beaches are important terrestrial nesting sites critical to the survival of seabirds and sea turtles and as haul-out sites for Hawaiian monk seals. Shallow nearshore habitats include algal beds, seagrass beds, sand flats, rocky reefs, and rubble-covered bottom, but the most productive habitat of these Pacific islands is the coral reef.

Coral reef ecosystems are among the most diverse and biologically complex ecosystems found on earth, harboring a richness of algae, corals, reef invertebrates, fish, and a variety of other flora and fauna. They are found in the warm, clear, shallow waters of tropical oceans worldwide. Coral reefs and their associated habitats provide economic and environmental services such as shoreline protection, areas of natural beauty and recreation, and sources of food, chemicals, pharmaceuticals, jobs, and revenue. In addition, reef habitats play an important cultural role within the U.S. Pacific Islands Region, where community-based conservation, subsistence fisheries, and managed areas have been successfully implemented for generations. Coral reef ecosystems are deteriorating worldwide at alarming rates due to multiple stressors including climate change, coral bleaching, over-exploitation, coastal development, pollution, marine debris, habitat destruction, boat groundings, diseases, and invasive species. Some of the most serious threats posing extinction risk to corals are considered to be ocean warming, disease, and ocean acidification (Brainard et al., 2011). The rapid degradation of these diverse marine ecosystems is causing significant social, economic, and environmental damage to the Pacific Islands Region and around the world.


PIFSC, NMFS

A Pacific coral reef showing a wide diversity of coral and fishes.

The formation of a coral reef is a long and complex process. Generally, hard corals build coral reefs through the secretion of calcium carbonate by their polyps. Through their symbiosis with unicellular algae (zooxanthellae), reef-building hard corals are the source of primary production in reef communities. Wave action, boring organisms (e.g. sponges, worms, bivalves), and grazers (e.g. parrotfish, sea urchins) break down the coral skeletons into sediment that settles into the interstitial spaces in the reef. Coralline algae, encrusting bryozoans, and minerals then cement the eroded material and stabilize the reef structure. The prevailing theory of coral reef formation, first developed by Charles Darwin, recognizes three types of reefs: the fringing reef, the barrier reef, and the atoll.[4] Fringing reefs border the shorelines of continents and islands in tropical seas, and are commonly found in the South

[4]For more information on atolls, different types of reefs, and their formation, see http://oceanservice.noaa.gov/education/kits/corals/coral04_reefs.html (accessed March 2015).

NOAA

Yellow tangs swimming in coral reef habitat.

Pacific, Hawaiian Islands, and in some parts of the Caribbean. The barrier reef occurs farther offshore, forming when an associated land mass sinks, and fringing reefs become separated from shorelines by wide channels. Barrier reefs are common in the Caribbean and Indo-Pacific, with the Great Barrier Reef off the northeastern coast of Australia recognized as the largest barrier reef in the world, stretching more than 2,000 km (1,240 mi). If the land mass is a small island, it may eventually disappear below the ocean surface, and the reef then becomes an atoll. The result is usually several low coral islands that surround a central lagoon. Atolls commonly occur in the Indo-Pacific, and there are several in the Northwestern Hawaiian Islands (NWHI). The world's largest atoll, Kwajalein, is located 3,900 km (2,423 mi) southwest of Honolulu, Hawaii, and is part of the Republic of the Marshall Islands. Kwajalein Atoll surrounds a lagoon over 97 km (60 mi) long.

Reef-building corals, which thrive above depths of 50 m (164 ft), become rare below 150 m (492 ft), but many animals usually associated with reef habitat may be found to depths of 200–300 m (656–984 ft).

Reef habitats at central Pacific U.S. possessions encompass 15,852 km^2 (6,120 mi^2) divided among 50 islands from four distinct biogeographic regions and have more species than any other single island habitat type. Fishery Ecosystem Plans (FEP) for the Mariana Archipelago, American Samoa, Hawaii, and the Pacific Remote Island Areas list hundreds of currently harvested coral reef species and includes many more potentially harvestable species for a total of more than 2,000 species. But even this number does not adequately represent the high level of biodiversity present in many Pacific reef habitats.

Algal beds are another important habitat in the Pacific Islands Region. These beds are a nearshore habitat used by various organisms for food, shelter, and nursery grounds. Calcareous algae are a major source of sand, which in turn forms habitat for many other species. Subadult and adult green sea turtles, for example, forage primarily on algae and seagrasses.

Freshwater Habitat

There are few enclosed freshwater bodies in the Pacific Islands Region, and they tend to be small and vary widely in their morphology (Maciolek, 1969; Mink and Bauer, 1998). In Hawaii, where they are best described, they include man-made reservoirs, mountain ponds, and water-filled volcanic craters. All of these are isolated from the ocean. Most freshwater habitat in the Pacific Islands Region occurs in the form of streams that are exclusively found on the high islands. Some of these streams are ephemeral in nature, and others flow year-round. In Hawaii, more than 500 streams have been documented. Streams in the least-developed areas are the healthiest, because they have been subjected to fewer introduced species and less channelization. On islands with recent lava flows, fresh water travels underground through the porous crust to mix with salt water on the coast and form anchialine ponds, a unique habitat niche with its own community of animals. On the islands comprising American Samoa, Tutulia has at least 30 streams.

Generally, there is little information available regarding freshwater biodiversity and habitat use in this region (Ellison, 2009). The watershed of the Marianas has had some preliminary study of the fauna, but a complete inventory is needed, particularly in the remote Northern Islands (Concepcion and Nelson, 1999; Donaldson and Myers, 2002). Pacific streams and coastal ponds are habitat for species of freshwater fish, mollusks, and crustaceans that are a conservation concern (Englund, 1999, 2002; Yamamoto and Tagawa, 2000; Cook, 2004). A number of these species have a poorly understood oceanic larval component to their life history.

Estuarine Habitat

Estuaries are semi-enclosed bodies of water that are open at some location to the sea and have a freshwater inflow aside from rainfall. Estuaries and lagoons of Pacific tropical islands are usually small, in contrast to North American estuaries. All estuaries are found on the high islands. The estuaries range from large bays that are primarily salt water, to the mouths of rivers, which vary from salt to fresh water depending on the river flow and tidal phase. Estuaries are composed of mud bottoms, mangrove swamps, brackish marshes, man-made canals, and coral reefs. The Hawaiian Archipelago has 18 estuaries; American Samoa has 14; and the Marianas have 10. The species assemblage varies with each type of estuary. Only a few species are known to complete their entire life histories within certain types of estuaries. Many reef species are known to use brackish habitats as nursery grounds. Estuaries emptying into large saltwater embayments can support sizable adult reef fish communities. The importance of estuarine habitats is largely unknown for species under the jurisdiction of NOAA's National Marine Fisheries Service (NMFS), but indications are that, while some species may opportunistically use estuarine habitats, none of the NMFS species exclusively depend on estuaries for any portion of their life history (e.g. Smith and Parrish, 2002). However, estuarine habitats have been identified as a source of energy (e.g. detritus, meroplankton) that enhances adjacent offshore nursery grounds of deepwater snappers (Parrish et al., 1997).

Shallow Marine Habitat

Lacking a continental shelf, the shallow marine habitats of the Pacific Islands Region can be hard to delineate. This is further complicated by a long history of sea level change, which has created a series of guyots[5]—some connected to islands and reefs, and some located far from any coastal influence other than supporting a shallow (30 m [100 ft]) euphotic demersal[6] community. For the purposes of this description, we will define shallow marine habitats as those benthic habitats connected to the coast. Independent guyots, seamounts, and deep slope habitats will be addressed in the oceanic habitat category. Coastal shallow marine habitats in the Pacific Islands Region can be divided broadly into fringing reefs and atolls.

In Hawaii there are over a dozen fringing reef systems, half of which surround the high islands, and the other half of which skirt the small emergent basalt pinnacles dispersed in the lower half of the archipelago. Samoa supports five fringing reefs, and Guam and the Marianas have six. Fringing reefs are distinguished by their considerable exposure to storm conditions in the form of wave energy and runoff from the adjacent land. As a consequence, these reefs are primarily encrusting forms that can handle the stress of storms. In Hawaii, some of the main islands (Maui, Molokai, and Lanai) are interconnected by submerged land bridges that were drowned as the sea level rose. Currents race over these submerged platforms, providing excellent conditions for the largest known black coral bed in the Pacific Islands Region. In one area the platform extends 40 km (25 mi) seaward, forming a habitat feature referred to as Penguin Bank. In the NWHI, seven of the islands are bordered

An example of estuarine habitat in the Waimanu Valley on the Island of Hawaii.

[5]Guyots (also referred to as tablemounts) are submarine seamounts with flat tops.

[6]Demersal species are those that live on or near the seafloor.

Pelagic armorhead swim near soft coral habitat on Hancock Seamount, near Midway Island.

by extensive shelves radiating out at 30–40 m (100–130 ft) depths. Cumulatively, this shelf area represents nearly 4,000 km^2 (1,544 mi^2) of area, and its habitat and faunal assemblages are the same as oceanic tablemounts described in the oceanic section (Parrish and Boland, 2004).

Ten atolls in total are found within the U.S. Pacific Islands Region. Four, including the world's most northern atoll, are in the NWHI (Maragos and Gulko, 2002). Two atolls are in Samoa, two are in the Line Islands, and the last two are Johnston and Wake Atolls. Atolls are typically reefs that enclose a lagoon. The protected water conditions of the lagoon provide areas for recruitment of fragile branching corals and settling points for particulates. Features in lagoons can include extensive coral structure, rubble patches, mud plains, algal meadows, and sand. Biological activity largely depends on the degree of oceanic flushing. Residence time of lagoon waters can be many months, and the speed at which the water is replaced can shape the habitat and the faunal assemblage.

Oceanic Habitat

Because the islands in the Region rise abruptly from the ocean floor, most of the offshore area in the EEZ surrounding the islands is oceanic habitat. Traveling less than 5 km (3 mi) offshore from many of these islands usually places one over water deeper than 2,000 m (6,563 ft). Consequently, oceanic habitat can be divided into pelagic and benthic types. The pelagic habitat can be described in terms of its vertical structure and geographic boundaries. The benthic habitat includes an array of oceanic guyots and seamounts that are diverse in morphology but are all independent from coastal habitats. For this reason, this discussion refers to them all as seamounts.

The offshore oceanic waters typically have a vertical structure consisting of a homogeneous, photic, warm upper surface mixed layer of low nutrients above cold, nutrient-rich waters. The warm upper and cold lower waters are separated by a permanent thermocline that limits vertical enrichment of the euphotic zone throughout the year. The offshore oceanic habitat is often influenced by high-gradient dynamic features such as frontal meanders, eddies, and jets on spatial scales of 10–100 km (6–62 mi) (Pickard and Emery, 1990). These mesoscale features give rise to localized regions of higher productivity leading to aggregation of food items and development of a forage base, while physical gradients provide cues for pelagic predators to locate prey. Pelagic larvae and organisms may reside in surface waters, at depth, or migrate vertically to use both habitats. The magnitude and influence of these features are subject to variability in climate and short- and long-term cycles associated with the natural variability of the Pacific water masses within which the several groups of U.S. Pacific islands reside. Regionally important climate and oceanographic factors include wave strength, rainfall, surface winds, hurricanes, surface currents including eddy and meander formation, El Niño events, and climate regime shifts.

Seamounts, particularly those that rise to within a few hundred meters of the surface, can have a strong influence on adjacent open-ocean habitat in a variety of ways. Waters overlying seamounts are often characterized by high standing stocks of plankton, and at some locations they concentrate and transfer energy not only within the pelagic community, but also to the demersal community below (Uchida et al., 1986; Rogers, 1994). The Hawaiian Archipelago is known to contain more than 40 seamounts. They range from pinnacles with peaked summits at subphotic depths (>300 m [>984 ft]) to those with extensive tabletops at 40 m (131 ft) depths, comprising more than 800 km^2 (309 mi^2) of habitat. Eleven seamounts are found near American Samoa, 8 near Guam, and 34 in the Marianas. The habitat and faunal assemblages of these seamounts vary with their summit depth (Chave and Malahoff, 1998). The flat tops of the tablemounts support extensive algal meadows and impoverished reef fish communities. Deeper slopes support larger-bodied fish, including many commercially important species. At subphotic depths the habitat is carbonate, manganese/basalt, or sand. Patches of deep-sea corals, often called "beds," are found at sites with bottoms subject to high waterflow. The ecological role of these deep-sea corals is not well understood.

HABITAT USE

Until 2010, the Western Pacific Regional Fishery Management Council (WPRFMC) utilized five fishery management plans (FMPs). These included the Pelagics FMP, Bottomfish FMP, Crustaceans FMP, Precious Corals FMP, and Coral Reef Ecosystems FMP. Beginning in 2010, the WPRFMC adopted five new Fishery Ecosystem Plans (FEPs). The FEPs (Pelagics FEP, American Samoa FEP, Marianas FEP, Hawaii FEP, Pacific Islands Remote Area FEP) shifted management focus from species-based to place-based, and began the implementation of ecosystem-based approaches to fisheries management in the Pacific Islands. The adoption of these FEPs created the organizational structure to incorporate additional information, community input, and local knowledge into development of fishery ecosystem management (WPRFMC, 2009). Recent amendments to the FEPs have established fishery regulations, including annual catch limit procedures, and gear requirements for the American Samoa longline fishery to reduce sea turtle interactions. Additionally, longline area closures have been established in the Commonwealth of the Northern Mariana Islands, and fishing regulations have been created for the Pacific marine national monuments.

As such, the habitat relationships depicted in Table 16, which are listed by Management Unit Species (MUS) in each FEP, including crustaceans, bottomfishes, coral reef ecosystem species, pelagics, and precious corals, are still valid.

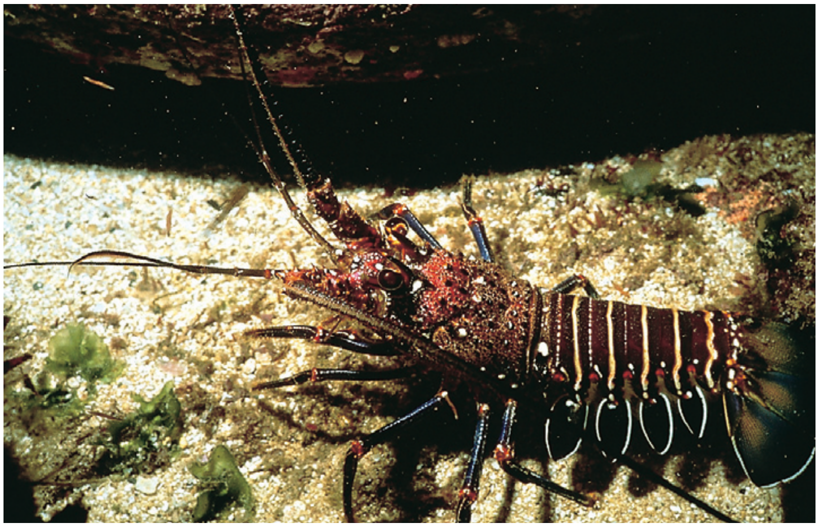
This section contains qualitative descriptions of habitat use for Pacific Islands FEP MUS and protected species groups (cetaceans, pinnipeds, and sea turtles) and to a smaller extent, state-managed and non-MUS species. Habitat use is only described once for each MUS group, but the

FEP management unit species [a]	Freshwater habitat	Estuarine habitat	Shallow marine habitat	Oceanic habitat
1. Bottomfishes	N	N	F	F
2. Coral Reef Ecosystem Species	N	O	F	F
3. Crustaceans	N	N	F	F
4. Pelagics	N	N	F	F
5. Precious Corals	N	N	F	F [b]
Total percentage of all Pacific Islands FEP management unit species that have one or more species that use each habitat type	0%	20%	100%	100%
Protected species groups [a]				
Cetaceans	N	N	F	F
Pinnipeds (monk seals)	N	N	F	F
Sea Turtles	O	O	F	F
Total percentage of all Pacific Islands cetacean, pinniped, and sea turtle groups that use each habitat type	33%	0%	100%	100%

[a] Appendix 3 lists official FEP titles. Appendix 5 lists the species.
[b] Note that pink and gold precious corals are typically found at depths greater than 200 m (656 ft) and on slopes or ridges associated with volcanic islands, atolls, and seamounts.

Table 16
Typical use of the four major habitat categories in the Pacific Islands Region, summarized by FEP and protected-species groups of cetaceans, pinnipeds, and sea turtles.

Habitat use key:
F = Frequent
O = Occasional
N = Never



A Hawaiian spiny lobster, Oahu, Hawaii.

information applies to each of the location-based FEPs. For example, the crustacean habitat-use description below applies to the crustacean MUS in the American Samoa, Marianas, Hawaii, and Pacific Islands Remote Area FEPs.

Table 16 provides a summary of typical habitat-use patterns in the Pacific Islands Region organized by FEP MUS and protected-species groups of cetaceans, pinnipeds, and sea turtles (managed by NMFS). The table shows typical patterns of use for one or more species within each group. However, it is important to recognize that these groups include many species, all of which have unique habitat requirements by life stage. Habitat information is lacking for many Pacific Islands species, particularly for the earlier life stages, and such critical information gaps are not captured in this table.

As the table shows, MUS in the Region do not typically use freshwater habitats, and most MUS do not use estuarine habitats. This may be due in part to the relative rarity of these types of habitats in the Pacific Islands, compared to their much greater availability on mainland North America. Shallow marine and oceanic areas are used by one or more species in all MUS groups. In regard to cetaceans, pinnipeds, and sea turtles in the Pacific Islands, one or more species in all three groups use shallow marine and oceanic habitats. Sea turtles are also known to use estuarine habitats occasionally for foraging and resting. Although freshwater habitat is not commonly used, some sea turtle species, like green turtles, travel up rivers in Hawaii and elsewhere.[7] Distribution (presence/absence) data is the most prevalent type of habitat information available for all harvested and protected marine species, while habitat-specific productivity information is not available for most harvested or protected species in any habitat.

Habitat Use by MUS Groups Within the FEPs

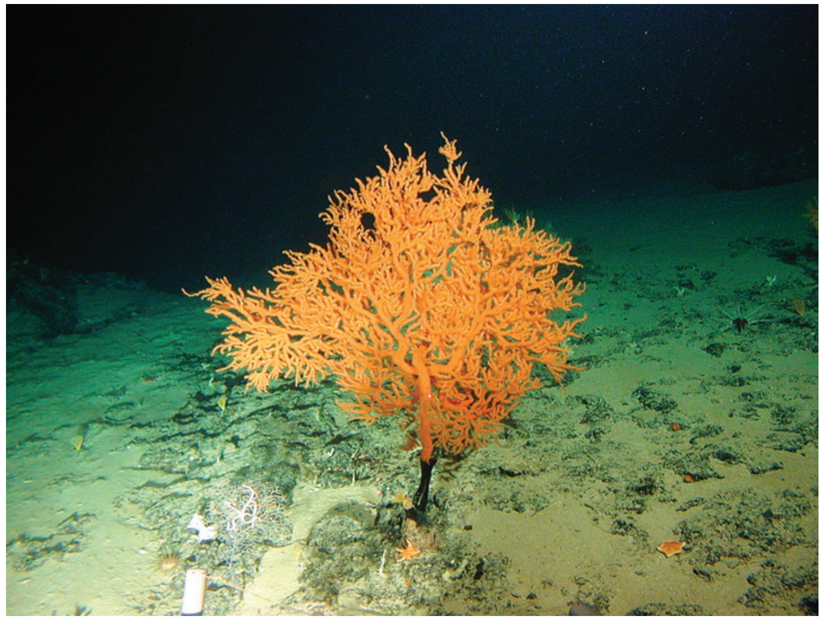
Crustaceans—The Crustacean MUS group involves several species of spiny and slipper lobsters, which have a pelagic larval stage ranging from 3 to 12 months. They use offshore oceanic habitat from the surface to 150 m (492 ft) depths in the water column during their larval period, and afterwards settle on benthic habitats. Adults inhabit reef or rubble habitat from the surge zone to 100 m (328 ft) depths or deeper, and they also inhabit offshore seamounts and banks. Habitats of new postlarval and early juvenile stages are not well known.

Bottomfishes—The Bottomfish MUS group includes a multispecies complex of snappers and groupers, which all have a pelagic larval stage that uses the water column of offshore oceanic habitat. After their larval period, most juveniles and adults use island and bank benthic habitats in 0–400 m (0–1,312 ft) depths. For most species the juvenile habitat is shallower than that for adults. Bottomfish habitat preferences vary by species and life stage. Some species, for example, show an affinity for rocky slopes (e.g. Ehu and Gindai), while other species prefer sandy bottoms (e.g. juvenile opakapaka) or areas with a diversity of features (e.g. adult opakapaka).

Coral Reef Ecosystem Species—The Coral Reef Ecosystem MUS group encompasses coral and all the species associated with coral reef habitat. By definition, the habitats most essential to the coral reef ecosystem species (over 2,000) have corals as part of the substrates, including not only coral reefs themselves, but also lagoons, surge zones, and deep-slope terraces. Benthic species are usually restricted to coral or rocky reefs as adults, but adults of many mobile reef-associated species can be found in all other demersal habitats.

[7]Kyle Van Houtan. NMFS, PIFSC, 1845 Wasp Blvd., Honolulu, HI 96818. Personal communication, January 2015.

Most reef organisms have pelagic larvae or eggs that drift in the mixed layer and upper water column, although there are numerous exceptions in all taxonomic groups. Behaviors of some larvae keep them very close to reefs, but other larvae, including those of some of the most visible reef fishes, drift great distances from their natal and settlement habitats. Juveniles of demersal reef species settle to reefs or immediately adjacent substrates, but what little information is available suggests that many of the more mobile species settle to transitional sediment, sand, rock, or rubble habitats. A few reef species, such as some jacks and barracudas, use mangroves and estuaries as juvenile habitat, and a very few, such as some mullets and flagtails, occur in freshwater directly connected to tidal water. For these reasons, important habitat for coral reef management species includes all waters from the shorelines to the offshore boundaries of the U.S. 370 km (200 nautical mile [nmi]) EEZs, from the surface to 90 m (300 ft).



NOAA Hawaiian Undersea Research Lab

Black coral in the waters of the Hawaiian Islands. The species is named for the black color of its skeleton, visible in this photograph where the specimen attaches to the sea floor; the living tissue is brightly colored, like this orange specimen.

Pelagics—The Pelagic MUS group is a multispecies complex that comprises tunas, billfishes, sharks, and associated pelagic species. The eggs and larvae of these species occur in the water column from the surface to 200 m (656 ft) depths, while juveniles and adults use shallow marine and oceanic habitat from the surface to 1,000 m (3,281 ft) depths and from the shoreline to the outer limit of the EEZ and beyond. All stages are often found associated with submerged banks and seamounts, and with oceanic features including eddies and fronts.

Precious Corals—The three primary targets of the precious coral fishery are black coral, pink coral, and gold coral. Each of these coral types occurs in patches that are referred to as beds. Their fixed attachment to the substrates and the vertical relief they create make these corals a significant component of habitat in regions where they occur. The locations and sizes of coral beds are poorly known, so the description of habitat uses and trends will be limited to the few known beds that have been identified in Hawaii. Black coral grows on current-swept bottom in the MHI between depths of 30 and 100 m (100–328 ft). Pink and gold corals are found on current-swept bottom depths of 300–500 m (984–1,640 ft). Black coral occurs primarily in the main islands (three significant beds) of the Hawaiian Archipelago, with none identified in the NWHI. Beds of pink and gold coral have been documented throughout the main islands at Cross Seamount and halfway up the Hawaiian Islands chain.

Habitat Use by Protected Species

Cetaceans—The Pacific Islands Region supports at least 24 species of cetaceans including sperm whales (3 species), beaked whales (3 species), baleen whales (6 species), and delphinids (12 species). The delphinids, which include dolphins and small species of toothed whales (such as melon-headed whales and false killer whales), include tropical and subtropical species that forage near islands (e.g. spinner dolphins, bottlenose dolphins) or in deeper offshore waters (e.g. spotted dolphins, pygmy killer whales). They forage on a variety of fish and invertebrates, such as squid. Most of the large whale species found within the Pacific Islands Region are migratory, ranging northward as far as Alaska. The central North Pacific stock of humpback whales, consisting of just over 10,000 animals, breeds in the Hawaiian Islands during winter and forages in Alaska waters during summer. Several large whale species, including blue, fin, humpback, and sperm whales, are listed as endangered under the Endangered Species Act (ESA)

Bruce Eilerts, USFWS

A Hawaiian monk seal hauled out on the beach and resting.

owing to historical over-exploitation by whaling operations in the North Pacific. Additionally, one species of dolphin, the Hawaiian Islands false killer whale, is listed under the ESA as a result of its low population abundance estimate, but the cause of its decline remains uncertain. Under the Marine Mammal Protection Act (MMPA), as amended in 1994, marine mammal stocks are further categorized as "strategic" stocks if either human-caused mortality exceeds the potential biological removal level, the stock is listed as endangered or threatened under the ESA, the stock is declining and likely to be listed as threatened under the ESA, and/or the stock is designated as depleted. In the Pacific Islands Region, all ESA-listed species are considered strategic, and the Hawaii pelagic stock of false killer whales is considered strategic due to interactions with longline fisheries in Hawaiian waters.

Pinnipeds—The Hawaiian monk seal is the only pinniped in the Pacific Islands Region. Monk seal colonies are found primarily around the atolls of the NWHI, where beaches and adjacent shallows are used for bearing and weaning pups. The seals' foraging activities are poorly known, but telemetry instruments carried by the seals suggest that they routinely travel between banks to forage, ranging more than 160 km (100 mi) from their colony. The bulk of feeding occurs between 30 and 200 m (100–656 ft) depths at the atolls and on the summits of neighboring banks. A small percentage of feeding effort has been documented at depths greater than 500 m (1,640 ft). Telemetry and scatological analysis indicate that all prey species are bottom-dwelling.

Sea Turtles—Green sea turtles within the EEZ of the Pacific Islands Region use a variety of habitats, including beaches for nesting, algal beds from the shoreline to 100 m (328 ft) depths for foraging, and underwater caves for resting. Other species of sea turtles including olive ridleys, leatherbacks, hawksbills, and loggerheads also migrate through the Region and forage largely at oceanic fronts and eddies or subsurface at the deep scattering layer. Hawksbill turtles are also known to nest and forage in coral reef habitats.

Habitat Use by State-Managed and Non-FMP Species

Most of the nearshore species managed under state jurisdictions also occur in federally managed habitat. The summits of shallow seamounts and habitat that extends outside the 5.5 km (3 nmi) state boundaries support reef communities that are addressed under the Coral Reef Ecosystem Species group.

HABITAT TRENDS

In most cases, a lack of habitat information for the Pacific Islands Region makes it difficult to detect trends. Little is known about natural changes in the habitat associated with prolonged cycles in temperature regimes (e.g. annual differences in foliation of algal beds on bank summits) or prevailing weather patterns (e.g. interannual differences in the erosion of sand islets). Prior studies have identified the ecological importance of various habitats, whereas future work should evaluate their natural dynamics and look for possible anthropogenic impacts. While a majority of the habitats are not near populated coastal areas, and thus are somewhat insulated from many of the typical anthropogenic stressors (runoff, pollution, etc.), valuable habitats such as fringing reefs are directly adjacent to populated islands and exposed to these stressors. Impacts from fishing, invasive species, and contaminants are anthropogenic stressors to marine habitats in the region, which require further study.

The Papahānaumokuākea Marine National Monument was created in June 2006, designating over 360,000 km^2 (140,000 mi^2) of islands, atolls, and ocean along the Northern Hawaiian Islands chain as a protected national monument. This is one of the largest protected marine areas in the world, and encompasses over 13,200 km^2 (5,100 mi^2) of coral reef habitat. The monument is home to approximately 80% of the Hawaiian monk seals and contains the breeding grounds for about 95% of the green sea turtles of the Hawaiian Islands. Conservation efforts in the monument include prohibiting unauthorized ship passage, unauthorized activities of a recreational or commercial nature, dumping waste, and extracting coral, wildlife, minerals, and other resources. Commercial fishing activities were phased out over a 5-year period. In addition, in January 2009 under the Antiquities Act President George W. Bush established three new national monuments (Marianas Trench, Pacific Remote Islands and Rose Atoll) in the tropical western Pacific, with a total area of over 490,000 km^2 (190,000 mi^2) (White House, 2009). Additionally, in September 2014 under the Antiquities Act President Obama designated expansion of the Pacific Remote Islands Marine Monument to 1,056,720 km^2 (408,000 mi^2) (White House, 2014). Protections for these areas include designated bans on commercial fishing (excluding the Volcanic and Trench Units of the Marianas Trench Marine National Monument) and mining for oil or gas, as well as restrictions on access and tourism. The largely uninhabited areas contain pristine coral reefs, volcanic ecosystems, and the Mariana Trench, which at approximately 11,000 m (36,000 ft) depth, is the deepest region of the oceans. Protections for these areas include designated bans on fishing and shipping.

The invasive algae *Cladophora* has overgrown and smothered the coral in this area off Maui, Hawaii.

Invasive Species

Species of fishes, crustaceans, invertebrates, and algae have been introduced to varying extents throughout the Pacific Islands Region, both intentionally and accidentally. Some of the intentional introductions were made in the 1950s as part of fishery enhancement efforts. Notable examples of this include the introduction of the blue-striped snapper, the blue-spotted grouper, the mud crab, and the algae *Kappaphycus striatum* in Hawaii. Species such as the algae *Hypnea musciformis* were intentionally introduced for aquaculture. Other species were introduced accidentally by transport on the hulls of ships or in their ballast water (e.g. snowflake coral and the algae *Gracilaria salicornia*). Some introduced fish species have been documented to spread from their point of introduction at the southern end of the Hawaiian Island chain up to the remote northwest end of the archipelago. Some algae known to ride on ship hulls have been identified in the remote NWHI. Another source of introduction has been through marine debris. Large pieces of debris from the 2011 Tohoku tsunami reached the continental U.S. western coast and Hawaiian Islands in 2012, some of them carrying non-native species of algae and invertebrates.

Of the introduced species, algae may have the greatest impacts to the habitat ecology. In Hawaii many have spread to become the dominant bottom cover in reef and coastal areas. Tons of algae are routinely removed from Hawaii's beaches, making invasive algae a public health and economic issue. Introduced species are poorly documented in American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands (CNMI), but, given the history of military and other vessel traffic, these regions are also likely to have impacts from invasive species.


NMFS

Removing marine debris (derelict fishing nets) in the NWHI.

Trends in MUS Species Habitat

Trends in Crustacean Habitat—Trends in habitat are unknown for many crustaceans in the Pacific Islands. Lobster habitats were inspected in the NWHI by diver and remote camera surveys in the early 1990s with some follow-up survey work in recent years, and algae was identified as the primary bottom cover. More information is still needed on the seasonal and interannual changes in the foliation of algal beds of bank summits and the associated ecological implications for lobsters and other species.

Trends in Bottomfish Habitat—Trends in bottomfish habitat are unknown. Juvenile habitats have been identified at shallower depths, including algal beds and sand terraces. These shallower habitats may be more subject to change than adult habitats, which are considerably deeper and thought to be more static environments. This is because the shallower areas are more likely to experience a higher flux in primary productivity and greater vulnerability to natural and anthropogenic disturbances.

Trends in Coral Reef Ecosystem Species Habitats—Data on U.S. Pacific Island coral reef ecosystem habitats is collected on a biennial basis to help determine the status of these vital areas and identify any trends. Three factors that can adversely impact these habitats and that are watched closely include marine debris, shoreline construction, and point and nonpoint source pollution.

- **Status of Baseline Data**
  The state of coral reef habitats in the U.S.-affiliated islands of the Pacific is being monitored on an annual basis (or on a triennial basis in different parts of the Pacific) with support from the NOAA Coral Reef Conservation Program. Coral reef monitoring and habitat mapping are routinely conducted on NOAA research cruises throughout the Hawaiian Archipelago; the Mariana Archipelago (including Guam); American Samoa; Johnston, Wake, and Palmyra Atolls; Howland, Baker, and Jarvis Islands; and Kingman Reef. These cruises are staffed by fish, coral, invertebrate, and algal taxonomists, and specialists in coral disease and water quality, as well as oceanographers and mapping specialists. Results show these habitats are generally in good condition, with some notable exceptions in areas where human impacts are concentrated, such as population centers or shipwreck sites.

- **Marine Debris**
  NMFS has been actively involved in marine debris removal from the NWHI since 1996. Over 750 metric tons (1.65 million lbs) of derelict fishing gear have been removed as part of a multiagency partnership supported by the NOAA Coral Reef Conservation Program, NOAA Marine Debris Program, Papahānaumokuākea Marine National Monument, and the NOAA Damage Assessment Remediation and Restoration Program. A 5-year (2001–05) intensive effort resulted in the removal of much of the historical debris on the coral reefs of the NWHI. NOAA removed over 16 metric tons (35,000 lbs) in 2006, the first year of the maintenance-level effort, which was aimed at keeping pace with new accumulation. However, a 2007 NMFS study estimated the accumulation rate to be approximately 52 metric tons (115,000 lbs) annually, which was higher than expected (Dameron et al., 2007). NMFS is also working with the NOAA Marine Debris Program, Office of National Marine Sanctuaries, and NOAA

Unmanned Aircraft Systems Program in looking at remote sensing technologies and their application for marine debris at sea. The goal is to detect and remove debris at sea before it damages reef ecosystems and impacts protected species in the nearshore area. The 11 March 2011 tsunami that struck Japan swept an estimated 5 million metric tons (11 billion lbs) of material into the ocean. About 70% of that is estimated to have sunk. A portion of the remaining debris was transported eastward, some of which reached the continental U.S. western coast and Hawaii in 2012. Based on ocean current models, more is expected in the coming years, but the magnitude, timing and impact of this debris are uncertain.

- **Shoreline Construction and Other Habitat Alteration**
  Shoreline construction and other habitat alteration have impacted reef habitats in the MHI, Guam, and to a lesser extent Tutuila, for over a century. Such alterations have resulted in loss of marine habitat, conversion of coral reefs to lesser-value habitat, and increased sedimentation rates along many of the Region's coastlines.

- **Point and Nonpoint Source Pollution**
  Awareness of environmental problems in populated areas of Hawaii, Guam, and Samoa has resulted in amelioration of point source and nonpoint source pollution degradation since the 1970s and 80s. Most notable in this regard are Oahu's Kaneohe Bay and American Samoa's Pago Pago Harbor. The more remote islands are still relatively pristine.

Trends in Pelagic Habitat—The oceanic central North Pacific region, including the Hawaiian Archipelago, exhibits a low-frequency oscillation between cooler and warmer phases, approximately on decadal time scales. This oscillation generally coheres with climate indices such as the Pacific Decadal Oscillation (PDO) index and sea level height data (Polovina and Howell, 2005). For example, during 1999 to 2002 there was an elevation in sea level height in the central North Pacific, resulting in increased vertical stratification and a decline in winter surface chlorophyll at the northern end of the Hawaiian Archipelago. In the pelagic environment, a better understanding of the impact of climate variability on key oceanic habitats (e.g. fronts, frontal systems) is still required. For example, variations in fronts and frontal systems (e.g. latitudinal position, degree of meandering), intensification of current flow fields, and coupled biological responses to the environment associated with changing regimes need to be addressed.

NMFS

Spinner dolphins resting in a sheltered, shallow water area.

Trends in Precious Corals Habitat—Over the last 30 years the biomass of the Auau Channel black coral population has decreased by 25% or more. Data collected during submersible dives also show a decline in recruitment. This decrease may be related to an increase in the abundance of snowflake coral, an alien hydroid, which has been identified as a risk to the black coral stocks. Black coral trees too deep for harvest by divers were thought to serve as a reserve to the fishery until recent surveys determined that deep colonies were fully encrusted with the hydroid (WPRFMC, 2008). Refining knowledge of the growth rate of gold coral and determining the importance of these corals as fish habitat are also the current foci of study. Recent research results indicate that gold corals (*Gerardia* sp.) are much older and have much slower growth rates than previously believed (Parrish and Roark, 2009).

Low, flat beaches, such as this Pacific atoll, are vital habitat for sea turtles and monk seals and would be affected greatly by sea level rise.

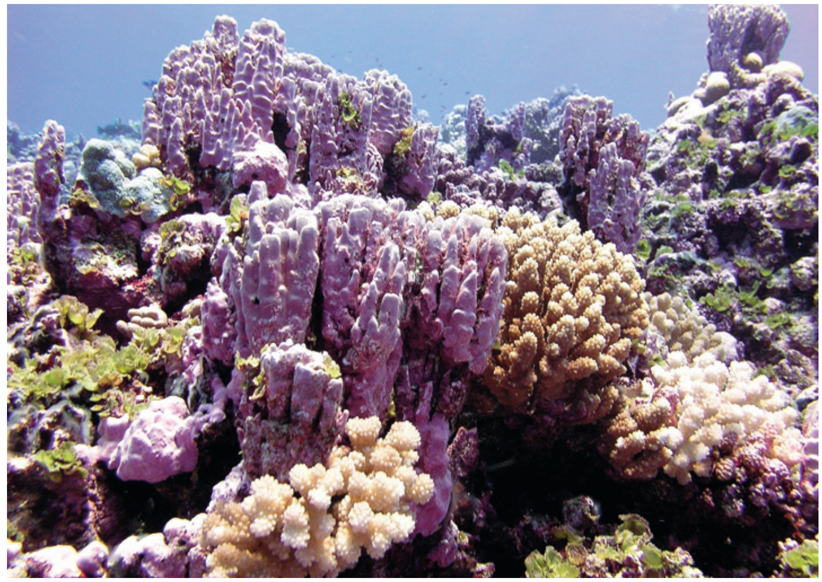
Trends in Protected Species Habitat

Trends in Cetacean Habitat—Pelagic cetacean habitat is affected by natural oceanographic variation that occurs over seasonal, interannual, and decadal time scales. These processes can change the distribution and intensity of marine productivity, which in turn may lead to variations in the amount of suitable habitat available for different cetacean species. In general, however, cetaceans have life-history traits that enable them to adapt to these natural variations. Anthropogenic impacts to cetacean habitats have also been documented in both nearshore and offshore areas. Near the shore, habitat quality may be affected by vessel traffic and an increased risk of vessel collisions with cetaceans. Disturbance of cetaceans by whale-watching boats and swim-with-dolphin programs is an increasing habitat concern in some areas, particularly for Hawaiian spinner dolphins, which come into shallow bays to rest during the daytime. Nearshore fisheries may also injure or kill marine mammals incidentally. In oceanic habitats, the primary threats to cetaceans and their habitats involve fisheries and anthropogenic underwater noise. Longlines and marine debris are known to cause incidental mortality and injury of cetaceans in many areas of the U.S. Pacific Islands region. Some interactions with cetaceans and gillnets have also have been observed as a result of small-scale nearshore fishing activities. In addition, a significant increase in the volume and extent of noise in the world's oceans has become a subject of increasing concern. High-intensity underwater sound production from a wide range of anthropogenic sources (e.g. industrial or military activities) can reach intensities of over 235 dB (as intense as an underwater earthquake) and may particularly affect susceptible cetacean species.

Trends in Hawaiian Monk Seal Habitat—Considerable loss of haul-out area due to current-swept beach erosion has impacted the reproductive success of ESA-listed Hawaiian monk seals at some locations in the NWHI (Antonelis et al., 2006). This phenomenon may be related to climate change, sea level rise, or changes in current patterns; and if this erosion continues at a rapid rate, it could represent a bottleneck in the population's recovery. Habitats important for seals' foraging and at-sea resting are only now being identified. In the MHI, monk seal sightings and observations have been steadily increasing, including at beaches utilized regularly in populated areas.

Trends in Sea Turtle Habitat—Sea level rise is a threat to critical sea turtle habitats. Nearly 95% of Hawaiian green sea turtle nesting occurs at French Frigate Shoals in the NWHI (Kittinger et al., 2013), and a recent study found that hawksbill sea turtles inhabit the NWHI and may have done so historically in greater numbers (Van Houtan et al., 2012). These low-lying islands are particularly vulnerable to sea level rise, putting protected species that rely on them at even further risk. Atolls, such as French Frigate Shoals, are less than 2 m (6.6 ft) above sea level, and topographic models predict that rising waters could significantly decrease available nesting habitat (Baker et al., 2006). Whale-Skate Island, located in the French Frigate Shoals, was once an important nesting site, but now is completely submerged.

The impacts of introduced algal species are also a concern in the Pacific Islands. Research has found that Hawaiian green sea turtles have expanded their foraging as introductions occur and three non-native species are now common in their diet (Russell and Balazs, 2009). There is compelling evidence that foraging on macroalgae in nutrient-elevated coastal areas in the MHI is promoting the tumor disease fibropapillomatosis in green turtles. Non-native, invasive species of macroalgae contain an amino acid that is known to promote tumor growth, making the spread of invasive algae an even greater concern (Van Houtan et al., 2010). Uninhabitated areas, such as the NWHI, are not impacted by nitrogen-rich agricultural runoff and sewage wastewaters known to elevate nutrient levels, but macroalgal communities should be continually monitored for the presence of invasive species that may promote this disease.


Jean Kenyon, NMFS

Coral and green algae in Rose Atoll, American Samoa.

RESEARCH NEEDS

In order to provide guidance to resource managers and officials charged with protecting habitat, information is needed on how species use habitat, where it exists, its condition, the best practices to conserve it, and how marine communities and, ultimately, sustainable fishery yields and conservation of protected species depend on the amount and condition of available habitat. Because the Pacific Islands Region is so vast and widely dispersed, there are large gaps in the basic knowledge of the fishery and protected species in the Region, the quantity and quality of available habitat, and how these species use the habitats.

The Pacific Islands Region is a research frontier, where leading-edge research conducted by NOAA scientists continues to advance the knowledge needed for resource management in a set of complex, interconnected marine systems. As a part of Coral Reef Conservation Program-sponsored research cruises to all of the islands in the Region, almost complete baseline bathymetric maps in water depths of 20–1,000 m (66–3,281 ft) are now available for CNMI, Guam, American Samoa, the Pacific Remote Island Areas, and the MHI. In the NWHI, where there are extensive submerged bank-top areas that provide habitat for many ecologically and commercially important species, as of 2012 only about 30% of these bank-top areas had been mapped within the top 100 fathoms (183 m).[8] Although bathymetric data are now readily accessible, considerable effort is still needed to analyze, interpret, and correlate the physical and biological data and produce benthic habitat maps for species of interest. Estuarine, shallow marine, and oceanic habitats all require extensive research, ranging from ecological assessment and life history studies to population dynamics and fishery impacts. Freshwater habitats, though rare, support a number of native and endemic species that rely on freshwater streams and marshes, including some endangered bird species. The geographic area of research requires expansion as well. Historically, most research has occurred in and around the Hawaiian Archipelago. Current NOAA efforts under the Coral Reef Initiative are doing a better job of conducting research at these remote locations. Table 17 presents an overview of habitat-specific research needs for the Pacific Islands Region, with more detailed information provided in the text that follows.

Fishery Species

All Fishes—Life history research is needed for many fish species, particularly on the habitat needs for early life stages of species such as juvenile tunas. There is also a great need to develop time-series observations on fish habitats of all types in the Pacific Islands Region to address emerging questions about the effects upon marine resources of such things as pollution at the urbanized islands, extraction of marine resources, introduced species impacts, and climate variability. Almost all research in the Pacific Islands Region has been directed at specific problems for short durations. The pri-

[8]J. Rooney, NMFS, PIFSC, 1845 Wasp Blvd., Honolulu, HI 96818. Personal communication, January 2013.

Table 17 Overview of research needs for Pacific Islands Region fishery and protected species.

Research Needs	Freshwater habitat	Estuarine habitat	Shallow marine habitat	Oceanic habitat
Collect life history information on fishery and protected species as related to habitat needs, particularly for the early life stages.[a]		x	x	x
Complete baseline descriptions of habitats for fishery and protected species and monitor these habitats over the long-term.	x	x	x	x
Delineate and map important fishery and protected species' habitats and complete high-resolution mapping of bottom topography, bathymetry, currents, algal beds, substrate types, and habitat relief.		x	x	x
Define cetacean spatial and temporal pelagic habitat use.			x	x
Characterize juvenile monk seal foraging habitat in the Hawaiian Archipelago.			x	x
Evaluate habitat loss at turtle nesting and monk seal pupping sites.			x	
Identify sea turtle nesting and foraging sites.			x	
Evaluate the ecological impact of invasive species colonizing native habitat.	x	x	x	x
Determine effects of natural and anthropogenic stresses to habitats.			x	x
Determine which islands and banks are sources or sinks for larvae and how widely separated island populations are connected by larval mixing and dispersal.		x	x	x
Initiate assessment and monitoring surveys following storm events to measure habitat impacts and recovery rates.			x	x
Monitor impacts of fisheries and marine debris and levels of anthropogenic sound.			x	x
Quantify habitat-related densities and growth, reproduction, and survival rates within habitats for all life-history stages of fishery species.[b]			x	x

[a]This includes information on species distribution, the environmental and biological features that determine suitable habitats, identification of foraging and spawning habitats, and understanding species metapopulation dynamics.

[b]This includes establishing baseline catch per unit effort for many coral reef ecosystem species.

mary exception at present is the NMFS Pacific Islands Fisheries Science Center (PIFSC) Coral Reef Ecosystems Division's monitoring program, which began time-series observations in 2000 at coral reef habitats at 0–30 m (0–100 ft) depths in the U.S. Pacific islands. Even this effort has acquired just over a decade of data at 1- to 3-year intervals for each major island group in the Region (i.e. the Hawaiian Islands; the Mariana Islands; and American Samoa; plus Johnston Atoll, Wake Atoll, the U.S. Line Islands, and the U.S. Phoenix Islands). Research programs establishing time-series observations in the other NMFS regions have been crucial to establishing an understanding of the role of habitat change in driving marine resource population fluctuations (Roemmich and McGowan, 1995; Brodeur et al., 2003). The California Cooperative Oceanic Fisheries Investigation,[9] in which the NMFS Southwest Fisheries Science Center (SWFSC) is a partner, is a well-known example of this type of program. Critical needs for similar habitat research in the Pacific Islands Region include, but are not limited to, obtaining time-series data by collecting micronekton and plankton at major oceanographic fronts and current boundaries in the Region in order to relate satellite observations of oceanography to real biological changes in pelagic habitats at trophic levels above primary production; conducting repeated multiyear observations of deepwater bottomfish and invertebrate habitats to track changes in benthic habitats below 30 m (100 ft) depth; and continuing the shallow-water coral reef and precious coral fishery species surveys. Habitat research is needed for all Pacific Island regional fishery species, including demersal and pelagic fishes, and deepwater bottomfishes.

- **Reef Fishes**

  The habitat requirements of most reef-associated fishes of the U.S. Pacific Islands Region are, in general, poorly known. Baseline catch per unit effort (CPUE)[10] data are needed for many species.

[9]For more information see http://www.calcofi.org (accessed March 2015).

[10]CPUE data is a measure of the density or population size of a species targeted by fishing.

The habitat relationships of fish species typically found in shallow (< 30 m [100 ft] depth) coral reefs (Friedlander and Parrish, 1998; DeMartini, 2004) are only marginally better documented than those of deep-slope bottomfishes (Kelley et al., 2006). Research priority should be given to documenting the essential fish habitat (EFH) requirements of functionally dominant piscivores and herbivores (keystone species) and other ecologically important species, as well as economically important reef fishes. These data are essential to effectively evaluate habitat when siting and designing the no-take Marine Protected Areas needed to manage and conserve fish stocks in the MHI and elsewhere. Special consideration should be given to factors that complicate species-level classifications; studies should focus on habitat areas of particular concern (HAPC), such as juvenile nursery and adult spawning habitats.

- **Aquaculture**

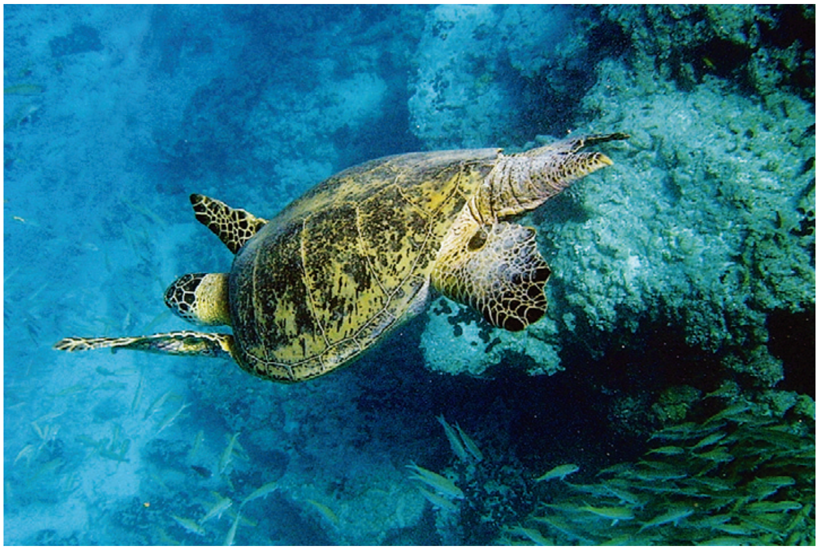
Research on the environmental interactions and mitigation of potential impacts of coastal and offshore cage aquaculture on island habitats are emerging study areas. While much information exists for temperate aquaculture, including best management practices designed to minimize impacts, less is understood for tropical environments. Impacts of finfish cage-culture and other aquaculture facilities upon marine resource habitats include direct physical modification of habitats from the facility structures; effects of nutrient discharges on surrounding marine habitats; pathogen and parasite transmittal to, from, and among cultured organisms; and the potential genetic effects on wild stocks of accidental escapes of aquaculture species (Stickney et al., 2006). Siting aquaculture facilities in locations that minimize the potential for adverse impacts, and monitoring for any environmental effects, such as checking for changes in nearby benthic communities, can help mitigate potential impacts of aquaculture operations. Over the past couple of decades, technologies have been developed to raise finfish and shellfish in offshore waters. Hawaii presently has one existing offshore commercial cage operation that has been the location of initial research on habitat effects from open ocean aquaculture.

A false killer whale leaping in the waters off Rota, in the Northern Mariana Islands.

Crustaceans—An important research need is to define early life-stage habitats for species of concern, particularly the settlement habitats of slipper and spiny lobsters. In addition, the seasonal and interannual changes in the foliation of algal beds of the bank summits and their ecological implications to lobster and other taxa should be a focus of future investigations.

Protected Species

Cetaceans—Relatively little is known about temporal and spatial habitat use of most cetacean species occurring in the Pacific Islands Region. Specifically, research is needed into the habitat used by the three stocks of false killer whales to refine knowledge of stock ranges and better understand the environmental factors that maintain separation of the existing stocks. Such information is critical for determining population impacts and the level of mitigation needed to reduce harmful fishing gear interactions. Characterization of nearshore, shallow marine habitat use by spinner dolphins is essential for defining the feeding and resting areas requiring protection from human interactions (e.g. swim-with-dolphin activities). Similarly, improved resolution of humpback whale habitat use is needed to address the increasing ship strikes on humpbacks, particularly calves, and to address the potential dangers of future high-speed ferry use in the MHI. Finally, increasing anthropogenic sound in the ocean environment is of concern. Additional research is needed on where and when such sounds occur and the degree to which they may impact various cetacean species in the Region.



A green sea turtle swimming near coral in the NWHI.

Hawaiian Monk Seals and Sea Turtles—Over 50% of the major Hawaiian monk seal pupping sites at French Frigate Shoals have been lost due to erosion over the last 40 years (Antonelis et al., 2006), and additional loss of habitat there and at other breeding sites in the NWHI will occur if sea level rise continues as predicted (Baker et al., 2006). Research is needed to better understand this problem throughout the NWHI, to assess the potential threats to the recovery of this ESA-listed species, and to evaluate possible methods of mitigation. Studies are also needed to more accurately define the foraging habitat of juvenile monk seals. Poor juvenile survival is the primary reason for the monk seal decline; therefore, foraging habitat is an essential factor that must be considered when identifying and protecting the prey resources on which they depend.

While much is known about the habitat use and population of the Hawaiian green sea turtle in the Hawaiian Archipelago, relatively little is known about the spatial and temporal use of habitat by green sea turtles in the rest of the Pacific Islands Region. Hence, more research is needed to obtain a better understanding of their nesting and foraging habitats throughout the Region. Similar studies are also needed for hawksbill sea turtles occurring in the Region. Research is needed to characterize the problem of loss of green sea turtle nesting habitat due to beach erosion, especially at French Frigate Shoals, and to determine the feasibility of mitigation. Additional research is needed to better understand the pelagic habitat needs of juvenile sea turtle species during the time between hatching and movement to coastal habitats for feeding and reproducing.

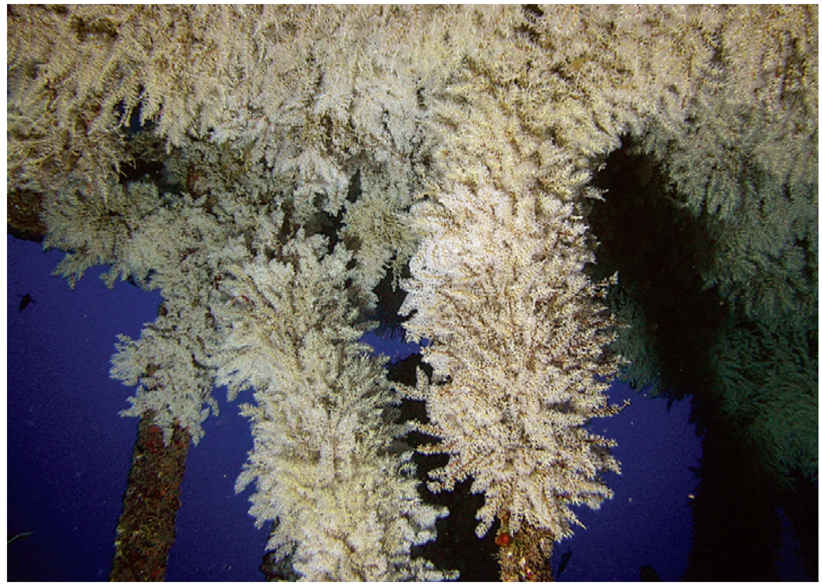
The issue of future sea level rise and its impacts to beach habitat used by Hawaiian monk seals, green sea turtles, and sea birds is an emerging research issue. An initial estimate of the impact of sea level rise on the islands in the NWHI concluded that, based on a median sea level rise scenario of 48 cm (19 in) by the year 2100, terrestrial habitat loss for nesting seabirds, sea turtles, and for monk seal pupping could be 3 to 65%, depending on factors such as each island's shore-slope angle and the percentage of land covered by low coastal fringes, etc. (Baker et al., 2006). However, further research is needed to monitor and understand beach habitat dynamics in the Insular Pacific.

Corals—The abundance and distribution of the major reef-building corals have been relatively well studied on shallow reefs of the NWHI. However, the recent listing of 15 Indo-Pacific coral species as threatened under the ESA will necessitate additional monitoring and research on coral recovery. In addition to these research needs, range extensions of known corals as well as probable new species have been discovered within the past few years, indicating that additional efforts aimed towards coral biodiversity studies may be warranted. The occurrence of two mass coral bleaching events since 2002 (Kenyon and Brainard, 2006) and the documentation of 10 coral diseases throughout the NWHI (Aeby, 2006) indicate that the health condition of reefs throughout the NWHI should be monitored on a regular basis and studied to prevent further declines in coral abundance, and especially those species listed under the ESA. Additionally, PIFSC Reef Assessment and Monitoring Program (RAMP) activities in all islands of the Pacific should be continued to provide on-going multidisciplinary information on the coral reef ecosystem.

Invasive Species

The habitat and ecological impacts of the invasive octocoral called snowflake coral is another research issue. Snowflake coral is a zooxanthellate, shade-loving, shallow water species (Bayer, 1961) that was introduced to the Island of Oahu in the mid-1960s. In the decades since, it has spread throughout the MHI, fouling the shaded areas under piers and reef ledges. Its most notable impact has been on the black coral community that lives in the dim depths below 70 m (230 ft; Grigg, 2003). Snowflake coral preferentially colonizes black coral trees, smothering the colonies completely. Surveys of the largest black coral bed located in the channel waters off Maui found 50% of the black coral colonies below 70 m (230 ft) were encrusted with snowflake coral (Kahng and Grigg, 2005). This finding prompted a reevaluation of the management strategy for the Hawaii black coral fishery (Grigg, 2004). However, the impacts of snowflake coral on other habitats and ecosystems are not well known.

Invasive algae are a major problem for habitat integrity of the coral reefs of the MHI (Smith et al., 2002), although they are not an issue in many of the other U.S. Pacific island groups. Even though much research has been completed on invasive algae in Hawaii, much more needs to be done to obtain an understanding of habitat impacts. For example, the impact that invasive algae have on fish communities is largely unexplored in Hawaii. The following are examples of the many questions that still need investigation: How do invasive algal species affect fish grazing behavior? Are the problems caused by invasive algae due to herbivorous fish not eating them? Do invasive algae overgrow preferred food sources of herbivorous fish, and if so, does this habitat alteration affect fish distributions or production? Does local fishing pressure and its effects on herbivore density affect the ability of invasive algae to compete with native coral species? What management efforts will be effective in restoring habitats damaged by invasive algae if those algae are removed? Are all reef habitats equally susceptible to algal invasions, and if not, why? What attributes of habitats and algal species promote algal invasions in reef habitats? What are the short-, medium-, and long-term impacts of large-scale algae removal efforts?



Invasive snowflake coral covering metal structures on a sunken ship off Oahu in the MHI.

REFERENCES CITED AND SOURCES OF ADDITIONAL INFORMATION

Aeby, G. S. 2006. Baseline levels of coral disease in the Northwestern Hawaiian Islands. Atoll Research Bulletin 543:471–488.

Antonelis, G. A., J. D. Baker, T. C. Johanos, and A. L. Hartig. 2006. Abundance of the Hawaiian monk seal (*Monachus schauinslandi*): status and conservation issues. Atoll Research Bulletin 543:75–101.

Baker, J. D., C. L. Littnan, and D. W. Johnston. 2006. Potential effects of sea level rise on the terrestrial habitats of endangered and endemic megafauna in the Northwestern Hawaiian Islands. Endangered Species Research 2:21–30.

Bayer, F. M. 1961. The shallow-water Octocorallia of the West Indian region: a manual for marine biologists. Martinus Nijhoff Publishers, The Hague, Netherlands, p. 39–42.

Brainard, R. E., C. Birkeland, C. M. Eakin, P. McElhany, M. W. Miller, M. Patterson, and G. A. Piniak. 2011. Status review report of 82 candidate coral species petitioned under the U.S. Endangered Species Act. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-PIFSC-27, 530 p. + appendix. Internet site—http://www.nmfs.noaa.gov/stories/2012/05/07_coral_documents_page.html (accessed May 2015).

Brodeur, R. D., W. D. Pearcy, and S. Ralston. 2003. Abundance and distribution patterns of nekton and micronekton in the northern California Current transition zone. Journal of Oceanography 59:515–535.

Chave, E. H., and A. Malahoff. 1998. In deeper waters. University of Hawaii Press, Honolulu, HI, 125 p.

Concepcion, G. B., and S. G. Nelson. 1999. Effects of a dam and reservoir on the distributions and densities of macrofauna in tropical streams of Guam (Mariana Islands). Journal of Freshwater Ecology 14(4):447–454.

Cook, R. P. 2004. Macrofauna of Laufuti Stream, Tau, American Samoa, and the role of physiography in its zonation. Pacific Science 58(1):7–21.

Dameron, O., M. Parke, M. Albins, and R. Brainard. 2007. Marine debris accumulation in the Northwestern Hawaiian Islands. An examination of rates and processes. Marine Pollution Bulletin 54:423–433.

DeMartini, E. E. 2004. Habitat and endemism of recruits to shallow reef fish populations: selection criteria for no-take MPAs in the NWHI Coral Reef Ecosystem Reserve. Bulletin of Marine Science 74:185–205.

Donaldson, T. J., and R. F. Myers. 2002. Insular freshwater fish faunas of Micronesia: patterns of species richness and similarity. Environmental Biology of Fishes 65(2):139–149.

Ellison, J. C. 2009. Wetlands of the Pacific Islands region. Wetlands Ecology and Management 17:169–206.

Englund, R. A. 1999. The impacts of introduced poeciliid fish and Odonata on endemic *Megalagrion* (Odonata) damselflies on Oahu Island, Hawaii. Journal of Insect Conservation 3:225–243.

Englund, R. A. 2002. The loss of native biodiversity and continuing nonindigenous species introductions in freshwater, estuarine, and wetland communities of Pearl Harbor, Oahu, Hawaiian Islands. Estuaries 25(3):418–430.

Frantzis, A. 1998. Does acoustic testing strand whales? Nature 39:29–30.

Friedlander, A. M., and J. D. Parrish. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. Journal of Experimental Marine Biology and Ecology 224:1–30.

Grigg, R. W., 2003. Invasion of a deep water coral bed by an alien species, *Carijoa riisei*, off Maui, Hawaii. Coral Reefs 22:121–122.

Grigg R. W. 2004. Harvesting impacts and invasion by an alien species decrease estimates of black coral yield off Maui, Hawaii. Pacific Science 58:1–16.

Kahng, S. E., and R. Grigg. 2005. Impact of an alien octocoral, *Carijoa riisei*, on black corals in Hawaii. Coral Reefs 24:556–562.

Kelley, C., R. Moffitt, and J. R. Smith. 2006. Mega- to micro-scale classification and description of bottom-fish essential fish habitat on four banks in the Northwestern Hawaiian Islands. Atoll Research Bulletin 543:319–332.

Kenyon, J. C., and R. E. Brainard. 2006. Second recorded episode of mass coral bleaching in the Northwestern Hawaiian Islands. Atoll Research Bulletin 543:505–523.

Kittinger, J., K. S. Van Houtan, L. McClenachan, and A. Lawrence. 2013. Using historical data to assess the biogeography of population recovery. Ecography 36(8):868–872.

Maciolek, J. A. 1969. Freshwater lakes in Hawaii. Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie (International Association of Theoretical and Applied Limnology) 17:386–391.

Maragos, J., and D. Gulko. 2002. Coral reef ecosystems of the Northwestern Hawaiian Islands: interim results emphasizing the 2000 surveys. U. S. Fish and Wildlife Service and Hawaii Department of Land and Natural Resources, Honolulu, HI, 46 p. Internet site—http://www.hawaiianatolls.org/research/NOW-RAMP_2000.pdf (accessed May 2015).

Mink, J., and G. Bauer. 1998. Water. *In*: S. P. Juvik and J. O. Juvik (editors), Atlas of Hawaii, Third edition, p. 87–91. University of Hawaii Press, Honolulu, HI.

Parrish, F. A., and R. C. Boland. 2004. Habitat and reef-fish assemblages of banks in the Northwestern Hawaiian Islands. Marine Biology 144:1065–1073.

Parrish, F. A., E. E. DeMartini, and D. M. Ellis. 1997. Nursery habitat in relation to production of juvenile pink snapper, *Pristipomoides filamentosus*, in the Hawaiian Archipelago. Fishery Bulletin 95:137–148.

Parrish, F. A., and B. Roark. 2009. Growth validation of gold coral *Gerardia* sp. in the Hawaiian Archipelago. Marine Ecology Progress Series 397:163–172.

Pickard, G. L., and W. J. Emery. 1990. Descriptive physical oceanography: an introduction. Pergamon Press, New York, NY, 320 p.

Polovina, J. J., and E. A. Howell. 2005. Ecosystem indicators derived from satellite-remotely sensed oceanographic data for the North Pacific. ICES Journal of Marine Science 62:319–327.

Richardson, W. J., C. R. Greene, Jr., C. I. Malme, and D. H. Thompson. 1995. Marine mammals and noise. Academic Press, San Diego, CA, 576 p.

Roemmich, D., and J. McGowan. 1995. Climatic warming and the decline of zooplankton in the California Current. Science 267:1324–1326.

Rogers, A. D. 1994. The biology of seamounts. Advances in Marine Biology 30:305–350.

Russel, D., and G. H. Balazs. 2009. Dietary shifts by green turtles (*Chelonia mydas*) in the Kāne'ohe Bay region of the Hawaiian Islands: a 28-year study. Pacific Science 63(2):181–192.

Smith, G. C., and J. D. Parrish. 2002. Estuaries as nurseries for the jacks *Caranx ignobilis* and *Caranx melampygus* (Carangidae) in Hawaii. Estuarine Coastal and Shelf Science 55:347–359.

Smith, J. E., C. L. Hunter, and C. M Smith. 2002. Distribution and reproductive characteristics of nonindigenous and invasive marine algae in the Hawaiian Islands. Pacific Science 56:299–315.

Stickney, R. R., B. Costa-Pierce, D. M. Baltz, M. Drawbridge, C. Grimes, S. Phillips, and D. L. Swann. 2006. Toward sustainable open ocean aquaculture in the United States. Fisheries 31:607–610.

Uchida, R. N., S. Hayashi, and G. W. Boehlert (Editors). 1986. Environment and resources of seamounts in the North Pacific. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 43, 105 p.

Van Houtan, K. S., S. K. Hargrove, and G. H. Balazs. 2010. Land use, macroalgae, and a tumor-forming disease in marine turtles. PLoS ONE 5, e12900, 9 p. Internet site—http://www.plosone.org/article/info:doi/10.1371/journal.pone.0012900 (accessed May 2015).

Van Houtan, K. S., J. N. Kittinger, A. L. Lawrence, C. Yoshinaga, R. Born, and A. Fox. 2012. Hawksbill sea turtles in the Northwestern Hawaiian Islands. Chelonian Conservation and Biology 11:117–121.

White House. 2009. Statement by the President on the occasion of the designation of the Marianas Trench Marine National Monument, Pacific Remote Islands Marine National Monument, and the Rose Atoll Marine National Monument. Internet site—http://georgewbush-whitehouse.archives.gov/news/releases/2009/01/20090106-9.html (accessed 2013).

White House. 2014. Presidential Proclamation—Pacific Remote Islands Marine National Monument Expansion. Internet site— http://www.whitehouse.gov/the-press-office/2014/09/25/presidential-proclamation-pacific-remote-islands-marine-national-monumen (accessed 2014).

WPFMC. 2008. Amendment 7 to the Fishery Management Plan for the Precious Corals Fisheries of the Western Pacific. Western Pacific Regional Fisheries Management Council, Honolulu, HI, 73p.

WPFMC. 2009a. Fishery Ecosystem Plan for the Hawaiian Archipelago. Western Pacific Regional Fisheries Management Council, Honolulu, HI, 249 p.

WPFMC. 2009b. Fishery Ecosystem Plan for Pelagic Fisheries of the Western Pacific Region. Western Pacific Regional Fisheries Management Council, Honolulu, HI, 249 p.

Yamamoto, M. N., and A. W. Tagawa. 2000. Hawaii's native and exotic freshwater animals. Mutual Publishing, Honolulu, HI, 200 p.