The State of Coral Reef Ecosystems of the Northwestern Hawaiian Islands

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INTRODUCTION AND SETTING

Beginning at Nihoa and Necker Island (Mokumanamana; about 7 and 10 million years old, respectively) and extending to Midway and Kure Atolls (about 28 million years old), the NWHI represent the older portion of the emergent Hawaiian Archipelago (Grigg, 1988). The NWHI are set in a dynamic oceanographic and meteorological regime in the northern/central subtropical region of the Pacific Ocean (Figure 9.1). The boundary between the nutrient-poor surface waters of North Pacific Subtropical Gyre and the nutrient-rich surface waters of the North Pacific Subpolar Gyre frequently influence the NWHI region (Leonard et al., 2001; Polovina et al., 2001). This front shifts seasonally (Polovina et al., 2001) and migrates on interannual and decadal time scales, bringing colder and nutrient rich waters that are likely important to the productivity and ecology of the region.

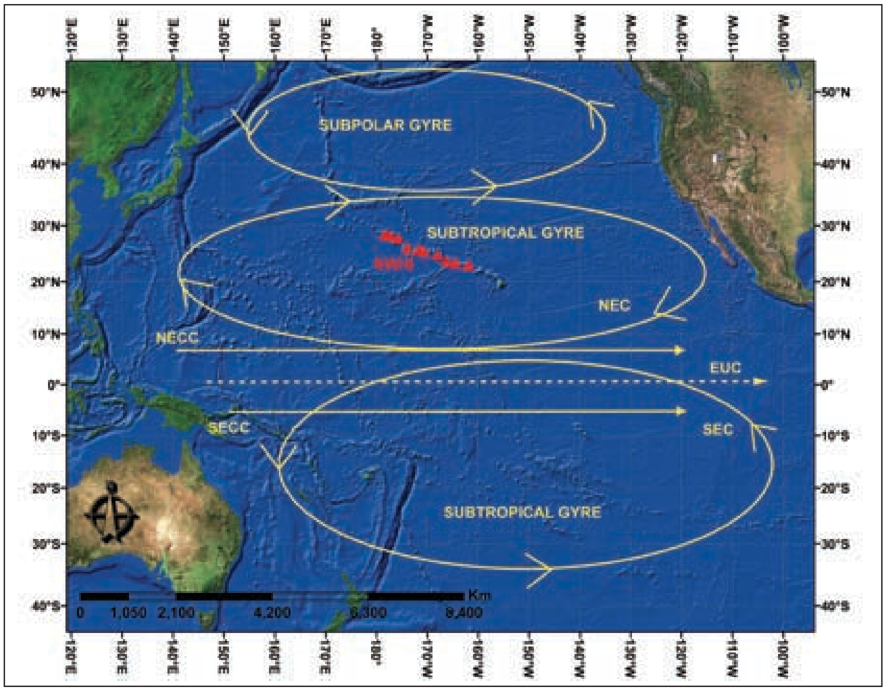

Figure 9.1. Topographic map showing location in Pacific Ocean of the NWHI and the major ocean currents in the region: North Equatorial Current (NEC), South Equatorial Current (SEC), North Equatorial Counter Current (NECC), South Equatorial Counter Current (SECC), Equatorial Under Current (EUC). Source: Pacific Islands Fishery Science Center-Coral Reef Ecosystem Division (PIFSC-CRED).

On June 15, 2006, President George W. Bush designated the Northwestern Hawaiian Islands (NWHI) as a Marine National Monument, one of the largest conservation areas on earth, through the signing of Presidential Proclamation 8031. The Monument encompasses nearly 362,600 km^2 (140,000 mi^2) of ocean and includes all the islands, atolls, shoals and banks from Nihoa Island to Kure Atoll (Figure 9.2). In March 2007, First Lady Laura Bush renamed the Monument the Papahanaumokuakea Marine National Monument (PMNM) on behalf of the President.

One of the most striking and unique components of the NWHI ecosystem is the abundance and dominance of large apex predators such as sharks and jacks (Friedlander and DeMartini, 2002), which exert a strong top-down control on the ecosystem (DeMartini et al., 2005; DeMartini and Friedlander, 2006) and have been depleted in most other locations around the world (Meyer and Worm, 2003, 2005). The geographic isolation of the Hawaiian Islands has resulted in some of the highest endemism of any tropical marine ecosystem on earth (Kay and Palumbi, 1987; Jokiel, 1987; Randall, 2007). Some of these endemic species are a dominant component of the community, resulting in a unique ecosystem that has extremely high conservation value and identifies Hawaii as an important global biodiversity hotspot (DeMartini and Friedlander, 2004; Maragos et al., 2004; Roberts et al., 2002; Allen, 2002). The few alien species known from the NWHI are restricted to islands with anthropogenic impacts such as Midway Atoll and French Frigate Shoals (Friedlander et al., 2005; Godwin et al., 2006). Disease levels in corals in the NWHI are much lower than those reported from other locations in the Indo-Pacific (Aeby, 2006).

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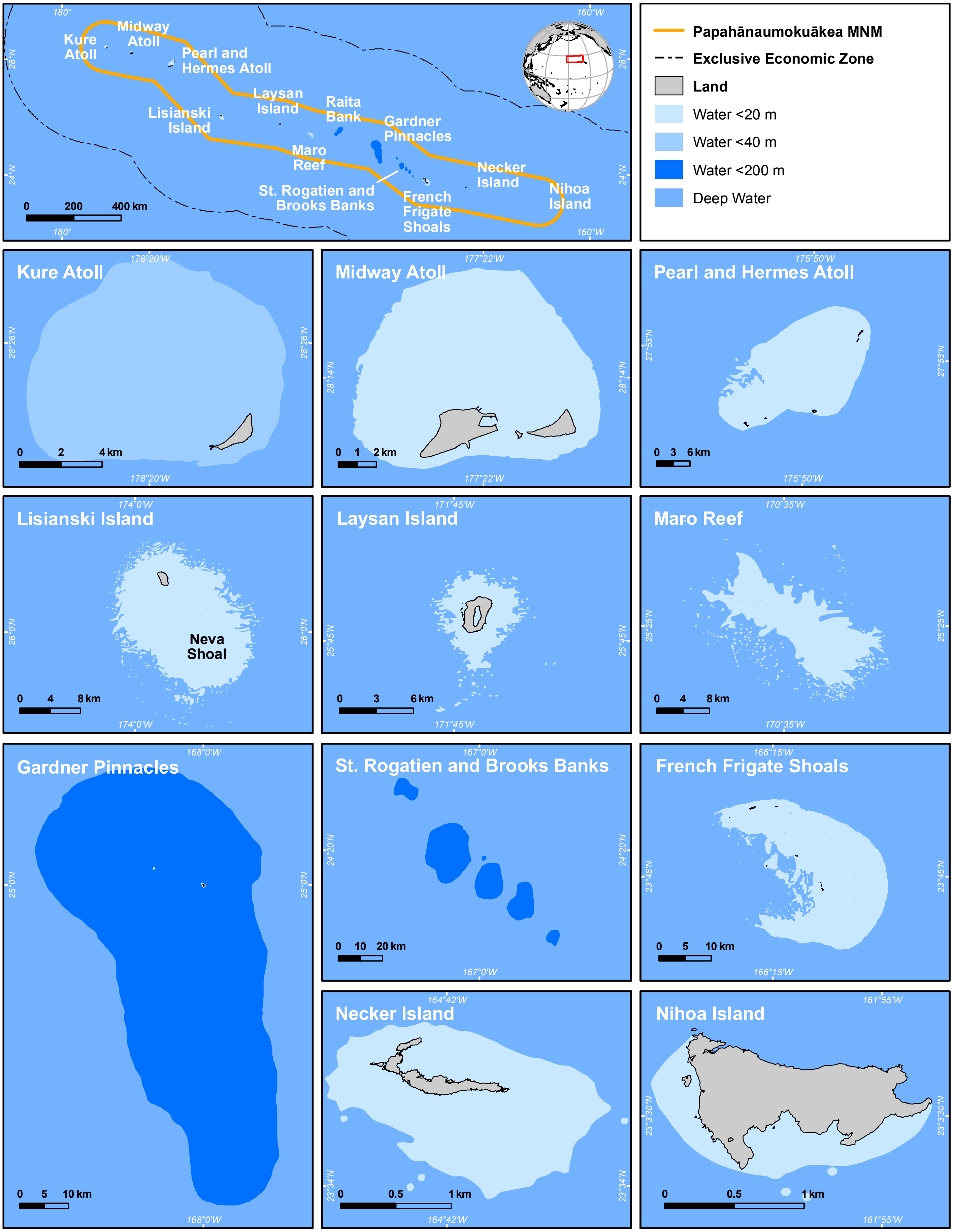

Figure 9.2. Locator map of the Northwestern Hawaiian Islands. ***NOTE:*** *Island abbreviations in figures and tables are as follows: Kure Atoll=KUR; Midway Atoll=MID; Pearl and Hermes Atoll=PHR; Lisianski Island=LIS; Laysan Island=LAY; Maro Reef=MAR; French Frigate Shoals=FFS; Gardner Pinnacles=GAR; Necker Island=NEC; Nihoa Island=NIH and RAI=Raita Bank. Map: K. Buja.*

The NWHI represent important habitat for a number of threatened and endangered species. The Hawaiian monk seal (*Monachus schauinslandi*) is one of the most critically endangered marine mammals in the U.S. (about 1,200 individuals) and depends almost entirely on the islands of the NWHI for breeding and the surrounding reefs for sustenance (Antonelis et al., 2006). Over 90% of all sub-adult and adult Hawaiian green sea turtles (*Chelonia mydas*) found throughout Hawaii inhabit the NWHI (Balazs et al., 2006). Additionally, seabird colonies in the NWHI constitute one of the largest and most important assemblages of seabirds in the world (USFWS, 2005). The remoteness and limited fishing and other human activities that have occurred in the NWHI have resulted in minimal anthropogenic impacts (Friedlander et al., 2005), therefore providing a unique opportunity to assess how a "natural" coral reef ecosystem functions in the absence of major localized human intervention and contrast these findings with the main Hawaiian Islands (MHI) and other ecosystems that experience high levels of anthropogenic influence (Grigg et al., in press).

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Mass coral bleaching affected numerous shallow reefs throughout the NWHI in 2002 and 2004 (Figure 9.3). In both years, the incidence of bleaching was greater at the three northern atolls (Kure, Pearl and Hermes, Midway) than at Lisianski and locations further south. At the three northern atolls, bleaching was most severe in shallow back reef and lagoon habitats. In both years, colonies in the genera *Montipora* and *Pocillopora* sustained the highest levels of bleaching (Kenyon et al., 2006a; Kenyon and Brainard, 2006). Prolonged periods of elevated sea surface temperatures (SST) coinciding with anomalously light wind speeds are thought to be the cause (Figure 9.4; Hoeke et al., 2006). In comparison, only low levels of bleaching were observed during 2006 surveys (Figure 9.5), which were conducted at the same time of year (September) as those in 2002 and 2004. Colonies in the genus *Montipora* were again most affected by bleaching in 2006.

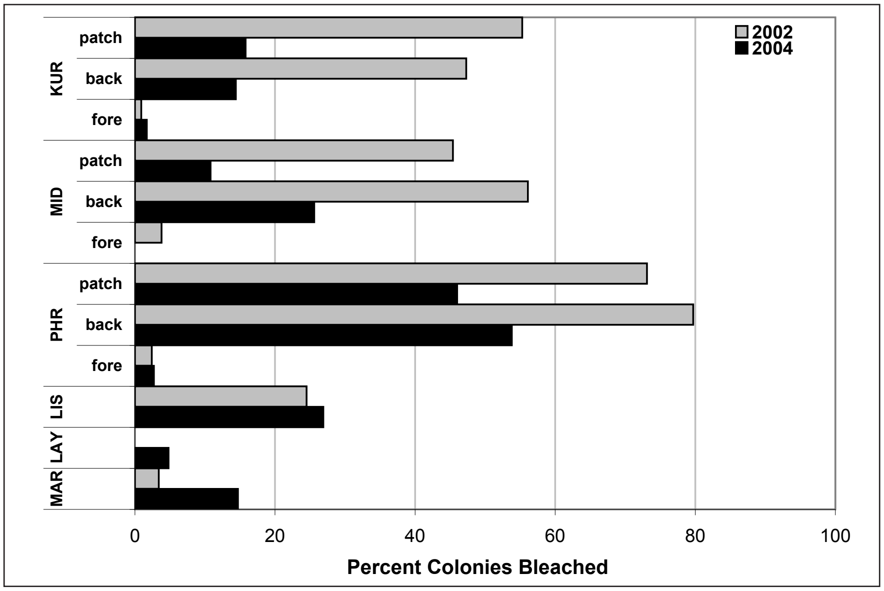

Figure 9.3. Mean percentage of colonies with bleached tissue in belt transects surveyed in 2002 and 2004 at Kure, Midway, Pearl and Hermes Reef, Lisianski Island/ Neva Shoal, Laysan Island and Maro Reef. Minimal bleaching was seen at Gardner Pinnacles and French Frigate Shoals (not shown). Source: Kenyon et al., 2006a.

In 2004, visual estimates of mortality and algal overgrowth of *Montipora capitata* and *M. turgescens* at back reef sites at the three northern atolls conservatively exceeded 50%, with nearly complete mortality of surface-facing portions of colonies at numerous sites. The shallow crest of a large central patch reef system at Kure Atoll, known previous to 2002 as "the coral gardens" due to its luxuriant growth of corals, was heavily bleached in 2002. In 2004 only a few branches of *Porites compressa* remained alive, and the dead coral skeletons were thickly covered in turf and macroalgae. Little change was observed in this reef's condition during 2006 surveys. A striking shift occurred at this location from a system dominated by coral in 2001 to a system dominated by algae in 2004 (Figure 9.6).

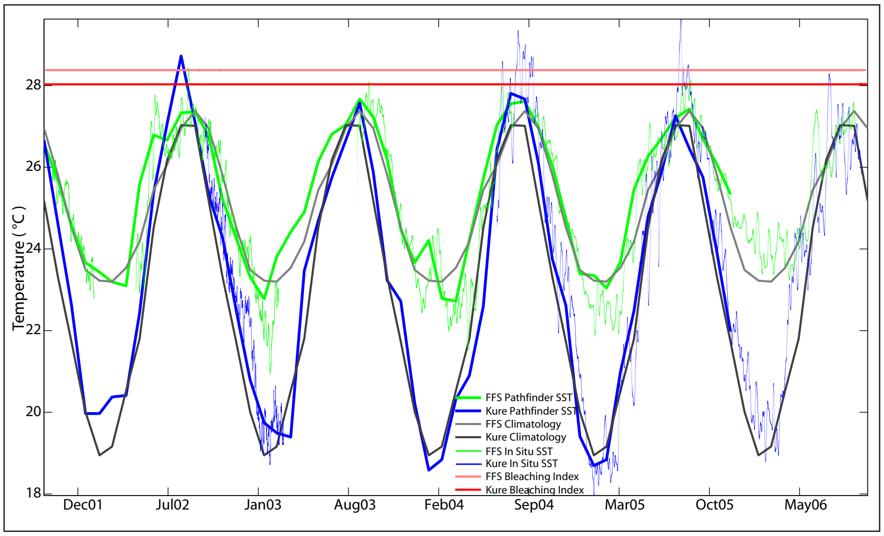

Figure 9.4. Time series observations of in situ *sea surface temperature (SST), Pathfinder SST, and Pathfinder SST Climatology from French Frigate Shoals and Kure Atoll. Coral Reef Watch bleaching threshold of maximum monthly mean SST plus 1°C are included for reference.* In situ *and satellite data exhibit predominantly seasonal variability, however, the annual range in temperatures is significantly greater at Kure (8-11°C) than at French Frigate Shoals (about 4-5°C).* In situ *observations indicate that temperatures exceeded the bleaching threshold at Kure in 2004, 2005 and 2006. There were no* in situ *observations of temperature during the 2002 bleaching event at Kure. Source: Brainard et al., in prep.*

The increase in water temperatures associated with global warming (1-2°C per century) and the regionally specific El Niño-Southern Oscillation (ENSO) events are causing a breakdown in the coral-algal symbiotic relationship, which is critical to the nutrient recycling that is thought to explain the high productivity of coral reefs (Hoegh-Guldberg, 2004). Although recent research has shown that algal-dominated areas occur naturally on many healthy Pacific reefs systems (Vroom et al., 2006), macroalgal overgrowth of coral-dominated areas as the result of anthropogenically derived activities indicate decreased ecosystem health, and may result in decreased accumulation of calcium carbonate, and impacts to the reef fauna that depend on the structural complexity provided by corals. Increasing temperatures associated with climate change are likely to increase the frequency and magnitude of coral bleaching events.

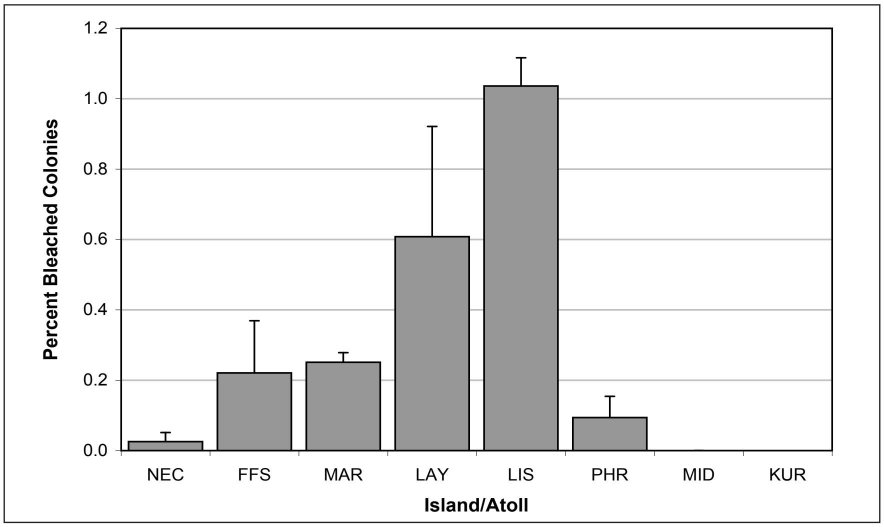

Figure 9.5. Mean percentage (±SE) of colonies with bleached tissue on belt transects surveyed in 2006. Source: PIFSC-CRED unpub. data; Brainard et al., in prep.

Figure 9.6. Phase shift on a patch reef at Kure Atoll from a benthos dominated by coral to one dominated by algae after a bleaching event in 2002. From left to right: 2001, bleaching in 2002 and 2004. Photos: J. Kenyon.

Diseases

In 2003, baseline coral disease surveys were conducted at 73 permanent monitoring sites throughout the NWHI and these sites have since been surveyed annually. Ten disease states have now been documented in the four major genera of coral (*Porites*, *Montipora*, *Pocillopora*, *Acropora*) on the reefs of the NWHI with *Porites* trematodiasis being the most commonly found disease (Aeby, 2006; Figure 9.7). Levels of disease appear stable through time with the exception of *Acropora* white syndrome (AWS) at French Frigate Shoals. This disease was first discovered at one reef in 2003 (Aeby, 2005) and has now spread to numerous reefs within French Frigate Shoals. Ongoing studies have found the disease to be lethal to *Acropora*. Analysis of 41 marked colonies having AWS revealed partial to total mortality in 97.6% of the colonies after one year (Figure 9.8; Aeby and Work, in prep).

Acropora growth anomaly (AGA) is another disease of concern that is being investigated at French Frigate Shoals. AGA is a progressive and lethal disease. After one year, five of eight marked colonies (62.5%) showed an increased number of growth anomalies and 57.1% of the colonies showed tissue death over the growth anomalies, indicating the lethal effects of this disease. It was also found that this disease significantly reduces the reproductive output of coral colonies (Aeby and Work, in prep.).

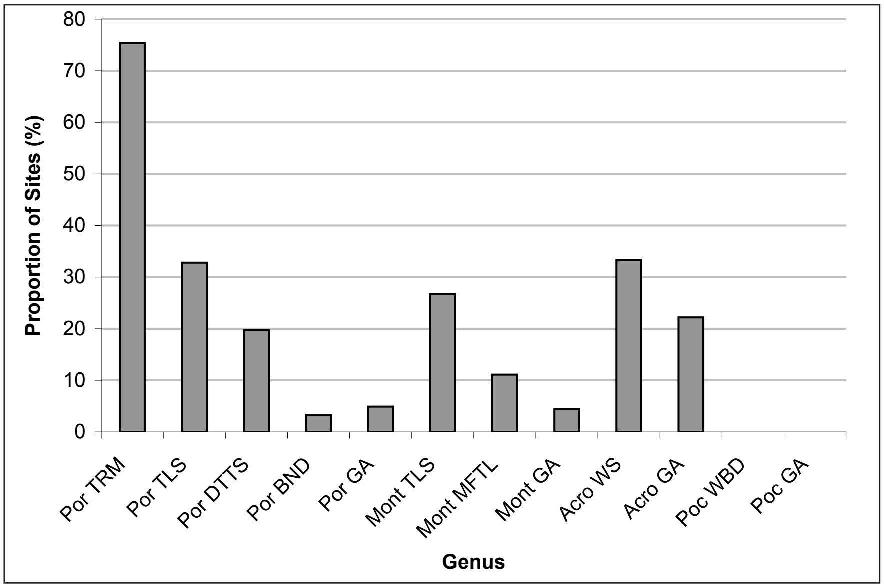

Figure 9.7. Frequency of occurrence of different coral diseases within the NWHI. Por=Porites, *Mont*=Montipora, *Acro*=Acropora, *Poc*=Pocillopora, *TRM= trematodiasis, TLS=tissue loss syndrome, DTTS=discolored tissue thinning syndrome, BND=brown necrotizing disease, GA=growth anomaly, MFTL=multifocal tissue loss, WS=white syndrome, WBD=white band disease. Source: G. Aeby, unpub. data.*

Diseases in marine ecosystems are not only limited to corals. In September 2005, two cases of Coralline Lethal Orange Disease (CLOD) were discovered at Maro Reef (Figure 9.9; Aeby, 2007). This disease is caused by a bright orange bacterium, which kills crustose coralline algae (CCA; Littler and Littler, 1997). It is found predominantly in the South Pacific, and this first report of CLOD in the Hawaiian Islands represents a range extension for this disease. CCA are an important component of the shallow coral reef environment because they act as binding agents that fortify the structural integrity of reefs. Hence, spread of CLOD within the NWHI will be carefully monitored.

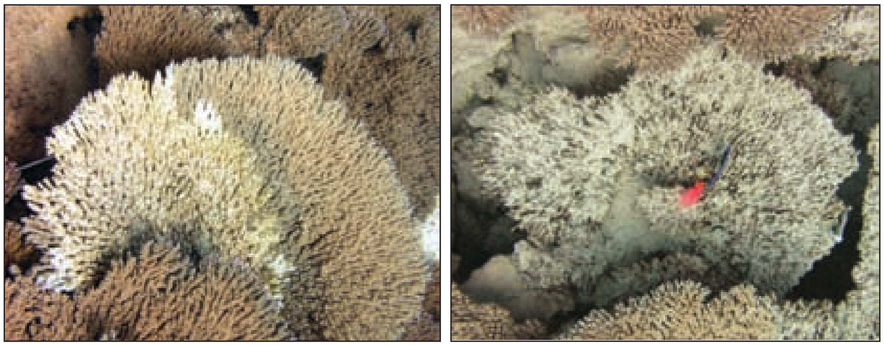

Figure 9.8. The left photo shows Acropora cytherea *with* Acropora *white syndrome in May 2005, and the right photo shows the same colony with complete mortality in May 2006. Photo: G. Aeby.*

Figure 9.9. Coralline lethal orange disease was discovered in the NWHI in September 2005 (left). Photo: G. Aeby. Goldring surgeonfish (Ctenochaetus strigosus) *with skin disease (right). Note difference in body color and condition in diseased fish (top) and healthy fish (bottom). Photos: G. Aeby.*

A number of diseases of reef fish have now been found in the MHI (Work et al., 2003; Work and Aeby, unpub. data) and recent studies examined whether those diseases also occur in fish in the NWHI. Butterflyfishes (*Chaetodon* spp.) with skin tumors have been found in the MHI (Okihiro, 1988; Work and Aeby, unpub. data) but have yet to be documented in the NWHI (n=336 butterflyfishes examined). It has been suggested this disease is associated with poor water quality (Okihiro, 1988), which may explain its absence in the NWHI.

Other studies have examined the possibility of disease transmission between the introduced blue-lined snapper, *Lutjanus kasmira* (ta'ape), and co-occurring native goatfish species (*Mulloidichthys* spp.). *L. kasmira* were introduced into Hawaii in the 1950s (Randall, 1987) and spread all the way to Midway Atoll. *L. kasmira* are closely associated with certain native goatfish (Friedlander et al., 2002), potentially facilitating disease transmission between the native and introduced fish species. Goatfish from the MHI are infected with some of the same diseases as *L. kasmira* including protozoal and bacterial diseases in the kidney and spleen and nematode infection in the gut (Work et al., unpub. data). These same diseases were found in fish in the NWHI, but at a lower prevalence.

Goldring surgeonfish (*Ctenochaetus strigosus*) in the NWHI were observed with an obvious skin discoloration (Figure 9.9). Upon external examination, these fish were found to be in poor body condition and had fins with ragged edges. The most significant histological finding in fish with pigment anomalies was excessive growth of skin cells, suggestive of cancerous lesions (Work and Aeby, in prep.).

Coral Endosymbiont Symbiodinium and Disease Susceptibility

Dinoflagellates from the genus *Symbiodinium* form mutualistic associations with coral (Muscatine and Porter, 1977). The genus *Symbiodinium* contains a diverse number of genetic varieties or clades which have been shown to affect the biology of the coral host, including growth rate and tolerance to elevated SSTs (Little et al., 2004; Rowan, 2004). Genetic tests were used to determine which clade of *Symbiodinium* was present in coral hosts (Figure 9.10). At French Frigate Shoals, a significant association was found between the clade of *Symbiodinium* and the health state of coral, with corals harboring clade A showing a higher incidence of disease (Stat et al., in prep.). Clade C was primarily found in healthy *A. cytherea* colonies. Cloned and sequenced ITS2 regions from *Symbiodinium* showed that *A. cytherea* harbors *Symbiodinium* subclade A1. This is the first report of A1 being found within coral from the Pacific. Interestingly, the upside down jellyfish, *Cassiopea* sp., which is an introduced species to Hawaii from the Atlantic/ Caribbean (Holland et al., 2004) also harbors A1. It is likely that the clade *A Symbiodinium* found in health-compromised *A. cytherea* in the NWHI is an introduced species that accompanied *Cassiopea* sp. (Stat and Gates, 2007).

Tropical Storms

The NWHI are rarely exposed to tropical storms and hurricanes (Figure 9.11), but are frequently impacted by large wave events, arguably among the highest of any tropical or subtropical island archipelago (Figure 9.12). During the winter months, the NWHI experience large waves exceeding 6 m, with associated wave periods as long as 25 seconds but typically closer to 8-18 seconds. These episodic events are generated from two atmospheric low pressure systems: Aleutian Lows, which are mid-latitude cyclones spawned as waves on the polar front (Graham and Diaz, 2001; Bromirski et al., 2005); and occasionally from subtropical cyclones known as Kona Lows, which generally form in the vicinity of the NWHI themselves (Caruso and Businger, 2006). Waves associated with the Aleutian Low tend to be long period swells from the northwest while the Kona Low generates extreme waves much less frequently, tending to be of shorter period from a more westerly or south-westerly direction. The vast majority of extreme wave events associated with these weather systems occur during the winter season between October and April. Between these episodic events, easterly trade winds associated with the North Pacific Subtropical High atmospheric pressure system tend to dominate the wave conditions of the NWHI, particularly during the summer months. Trade wind conditions typically bring waves with 1-3 m wave heights and 7-11 second periods from the east. During the summer season, the North Pacific High typically lies just north of the NWHI leading to weaker pressure gradients and lighter winds in the northern portions of the archipelago and stronger pressure gradients and associated trade winds in the southern portions. Long period swell generated during the summer months from southern-hemisphere storms generally decrease in energy from the MHI to the northwest along the archipelago (Rooney et al., in press).

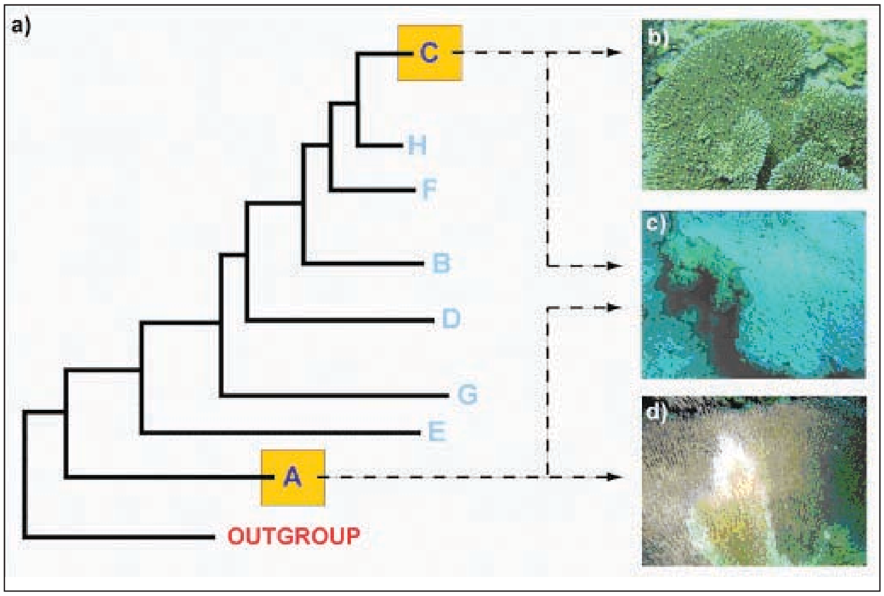

Figure 9.10. A) Phylogeny of Symbiodinium*, B) healthy* A. cytherea*, C)* A. cytherea *with abnormal phenotype and blue pigmentation, and D)* A. cytherea *with active tissue loss. Source: Stat and Gates, unpub. data.*

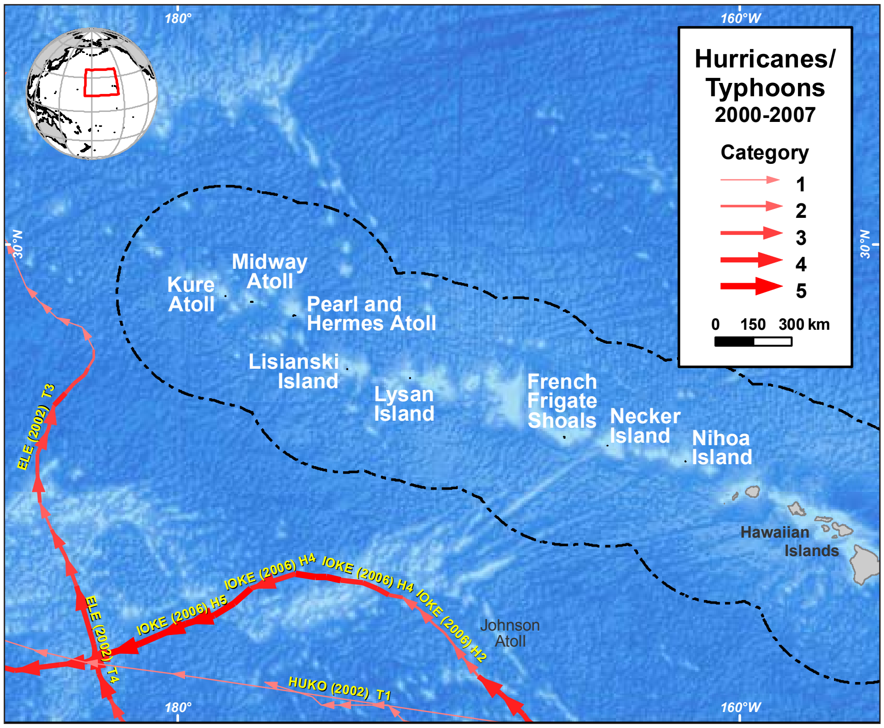

Figure 9.11. Path and intensity of tropical cyclones passing near the Hawaiian Archipelago from 2000-2007. Storm name and year are labeled on each track. Map: K. Buja. Source: http://weather.unisys.com/hurricane/.

ENSO/El Niño

ENSO is an interannual (about 2–8 years) global climate phenomenon that results from the large-scale coupling of atmospheric and oceanic processes which creates significant temperature fluctuations in the tropical surface waters of the Pacific and other oceans. The two distinct ENSO signatures in the Pacific Ocean are known as El Niño and La Niña.

During El Niño events, the Aleutian Low pressure system tends to be more intense and extend further to the south (closer to the NWHI), thereby producing stronger winds, larger waves and cooler water temperatures in the NWHI (Bromirski et al., 2005). Positive ENSO signatures appear to correlate with southern extensions of the North Pacific subtropical front (Leonard et al., 2001; Rooney et al., in press; Figure 9.13).

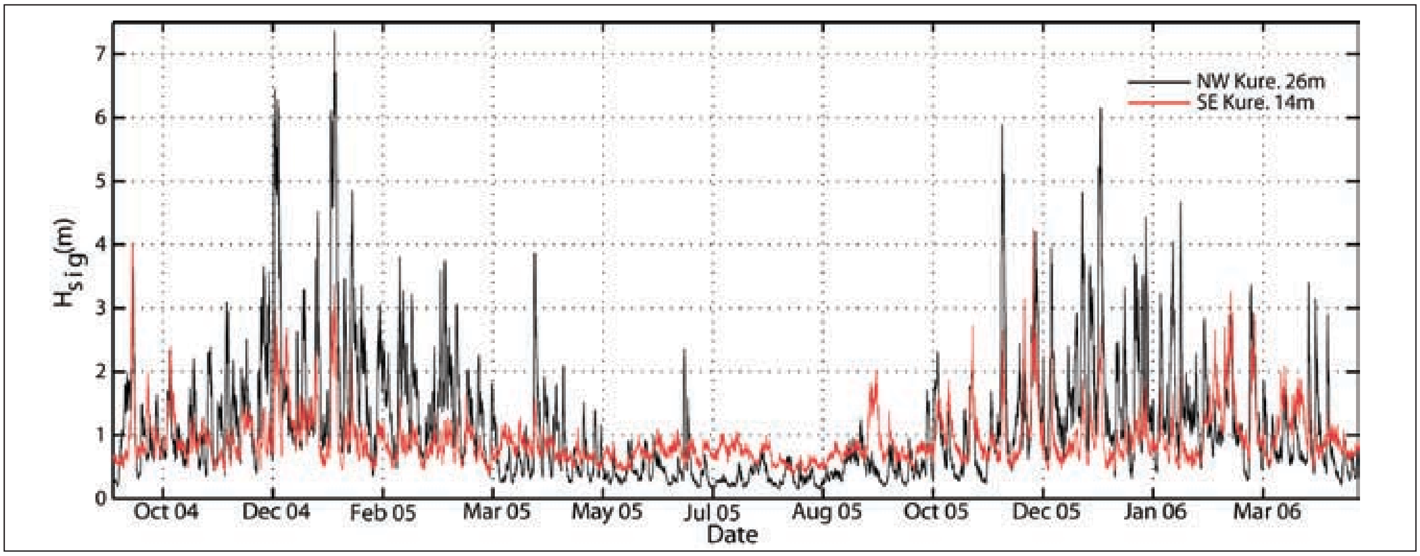

Figure 9.12. In situ *wave data from September 2004 to May 2006 from the northwest (black) and southeast (red) sides of Kure Atoll. Data shows significant increases in wave heights during the winter months, especially on the northwestern facing side of the atoll. Source: PIFSC-CRED, Brainard et al., in prep.*

Coastal Development and Runoff

A century ago, coastal development in the NWHI consisted of guano mining at Laysan Island and the establishment of the Commercial Pacific Cable Company at Midway. The Navy occupied Midway, French Frigate Shoals, and to a lesser degree Pearl and Hermes during the first half of the 20th century. The U.S. Coast Guard (USCG) also constructed Long-Range Aid to Navigation (LORAN) stations after World War II at Kure and French Frigate Shoals and operated them for several decades. Since the closure of Navy and USCG facilities, coastal development activities have been limited to small-scale conversion of abandoned USCG buildings on Tern Island (French Frigate Shoals) and Green Island (Kure) to biological field stations.

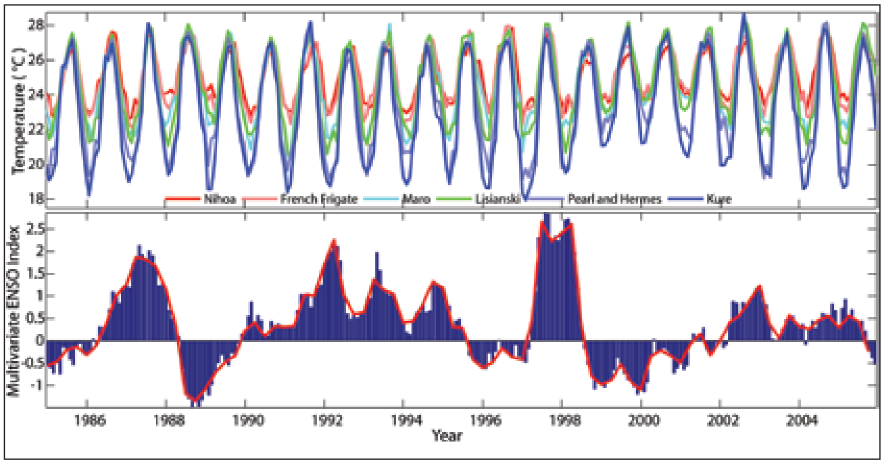

Figure 9.13. Relationship between NOAA Pathfinder SST at Nihoa, French Frigate Shoals, Maro Reef, Lisianski, Pearl and Hermes, and Kure (top) and the Multivariate ENSO Index (MEI; bottom) from 1985-2006. Positive/negative values of the MEI indicate El Niño/La Niña conditions, respectively. Source: Brainard et al., in prep.

The only recent coastal construction has been the repair of the seawall protecting Tern Island's small runway and buildings, and construction of a small boat ramp at French Frigate Shoals in 2004. This construction was needed to halt the erosion of the island and to eliminate the risk of injury and death to endangered monk seals, threatened green sea turtles and migratory seabirds. Current human population levels are limited to a few agency staff, volunteers and maintenance contractors at field stations operated at Laysan, French Frigate Shoals and Midway year round and at Kure, Lisianski, and Pearl and Hermes, seasonally.

Coastal Pollution

Past uses of the NWHI have left a legacy of modification and contamination on French Frigate Shoals, Midway Atoll, Pearl and Hermes Atoll and Kure Atoll from human activities including guano mining, fishing camps, USCG LORAN stations, U.S. Navy bases and various military missions. Contamination at all of these sites includes offshore and onshore contaminated debris, such as batteries (lead and mercury), transformers with polychlorinated biphenyls (PCBs), capacitors and barrels.

Uncharacterized, unlined landfills remain at some islands. Kure Atoll and French Frigate Shoals have point sources of PCBs due to former LORAN stations. While the USCG has undertaken cleanup actions at both sites, elevated levels of contamination remain in soils, nearshore sediment and biota (USCG, 2003). Due to the potential interaction with monk seals and turtles, the U.S. Environmental Protection Agency (EPA) and the U.S. Fish and Wildlife Service (USFWS) are working to identify resources to reduce or eliminate the remaining contamination on Tern Island (French Frigate Shoals). Studies conducted by the USFWS, USCG, U.S. Navy and the University of Hawaii have documented contamination in soil, sediment, and biota at French Frigate Shoals, Kure and Midway. Direct impacts to Black-footed albatrosses (*Phoe-*

bastria nigripes) in the form of reduced hatching success have been linked to high organochlorine levels (Ludwig et al., 1997). Finkelstein et al. (2007) found a correlation between elevated levels of organochlorines and mercury and impaired immune function in Black-footed albatrosses, a species that is currently the subject of a petition to be listed as endangered or threatened under the U.S. Endangered Species Act, as amended (72 FR 57278).

Pollution generated by past and present human activities, from sea-based and land-based sources, continues to stress the NWHI ecosystem. Emergency response mechanisms and ongoing cleanup and restoration activities must be maintained and enhanced to address these issues.

Tourism and Recreation

Recreational activities in the PMNM are limited to the Midway Atoll Special Management Area (SMA). Since 1995, USFWS has been strongly committed to welcoming visitors to Midway Atoll. This is the first and only remote island national wildlife refuge in the Pacific to provide the general public with an opportunity to learn about and experience these unique ecosystems. With the establishment of the PMNM, Midway Atoll National Wildlife Refuge (NWR) will allow visitors to learn about and enjoy a small portion of the largest fully protected marine managed area in the world.

A regularly scheduled visitor program operated on Midway Atoll until early in 2002, but ended when the concessionaire left the atoll. Between 2005 and 2007, minimal tourism and recreational activities occurred at Midway due to a lack of viable visitor access and limited ability to host visitors on-site. A limited number of tourists visited Midway Atoll NWR and the Battle of Midway War Memorial aboard small cruise ships that stopped at the atoll for less than a 24-hour period en route to other destinations. Visitors were provided guided tours of the NWR resources and the Battle of Midway Memorial, located on Eastern Island. In June 2007, Midway celebrated the 64th anniversary of the Battle of Midway with limited visits by chartered plane and a small cruise ship.

The USFWS recently completed an Interim Visitor Services Plan for Midway Atoll. For the next four years (2008-2011) visitor programs will operate from November through July, which coincides with the albatross season on Midway. The months of August through October are reserved primarily for planned construction and major maintenance activities. Plans are to slowly expand the visitor services over the next five years with accommodations limited to no more than 30 visitors at a time in the next three years and the ability to accommodate no more than 50 visitors at a time within the next five years. A range of options for visitor activities (such as wildlife viewing and snorkeling excursions) is being considered but must be compatible with maintaining wildlife health. Based on the results of the evaluation required in the Monument Management Plan's Midway Atoll Visitor Services Action Plan, other operational designs may be instituted in the longer term.

Fishing

In recent years, fishing and other resource extraction in the NWHI have been mostly limited to two commercial fisheries: the ongoing NWHI bottomfish fishery, and the now-closed NWHI lobster trap fishery. The bottomfish fishery has targeted about a half-dozen species of deep-slope (generally >140 m) Eteline snappers (family Lutjanidae) and one endemic species of grouper (family Serranidae) out of a total of a dozen common Bottomfish Management Unit Species (BMUS; WPFMC, 2004).

The bottomfish fishery is divided into two management zones (Mau, Hoomalu), partly in order to distinguish between short- and long-duration fishing trips (Figure 9.14). Between 1996 and 2004, the Mau zone bottomfish catch was dominated by shallow-water species such as uku (jobfish, *Aprion virescens*, 39%), butaguchi (thicklipped jack, *Pseudocaranx dentex*, 14%), but also included the deepwater species opakapaka (pink snapper, *Pristipomoides filamentosus*, 13%), hapuupuu (*Epinephelus quernus*, 13%), and onaga (red snapper, *Etelis coruscans*, 8%). The deepwater species, onaga and opakapaka, accounted for 53% of the Hoomalu catch, followed by hapuupuu (15%; Figure 9.15).

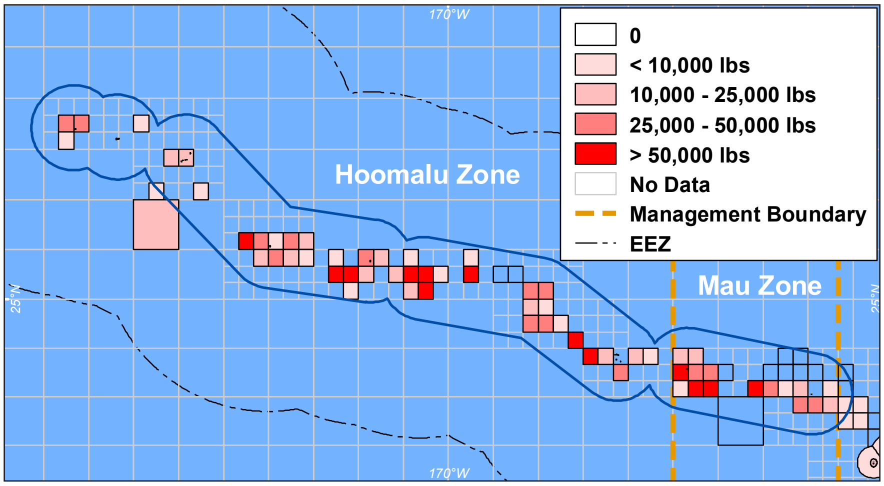

Figure 9.14. Total commercial bottomfish landings from 1996 to 2002. Data in several cells can not be shown due to confidentiality concerns. Data: DAR; Ehler, 2004.

The average annual reported landings of bottomfish in the NWHI between 1984 and 2003 were 336,000 lbs (±235,500 SD; NOAA, 2006). Of this, the Mau zone averaged 107,130 lbs (±53,890 SD) or 32% while the average catch in the Hoomalu zone averaged 228,730 lbs (±63,030 SD) or 68% (Figure 9.14). Landings are concentrated at a small number of locations in the Mau and Hoomalu zones (Figure 9.14). In 2003, the gross reported revenues for the Mau zone were $611,000 and $674,000 for the Hoomalu zone (Ehler, 2004). In 2003, the number of vessels participating in the two zones remained the same from the previous year, but there were substantial changes in the number of fishing trips (NOAA, 2006). In 2003, Mau zone trips decreased by 51% resulting in a 29% drop in landings from the previous year. The number of trips in the Hoomalu zone increased by 50% in 2003, resulting in a 29% increase in landings.

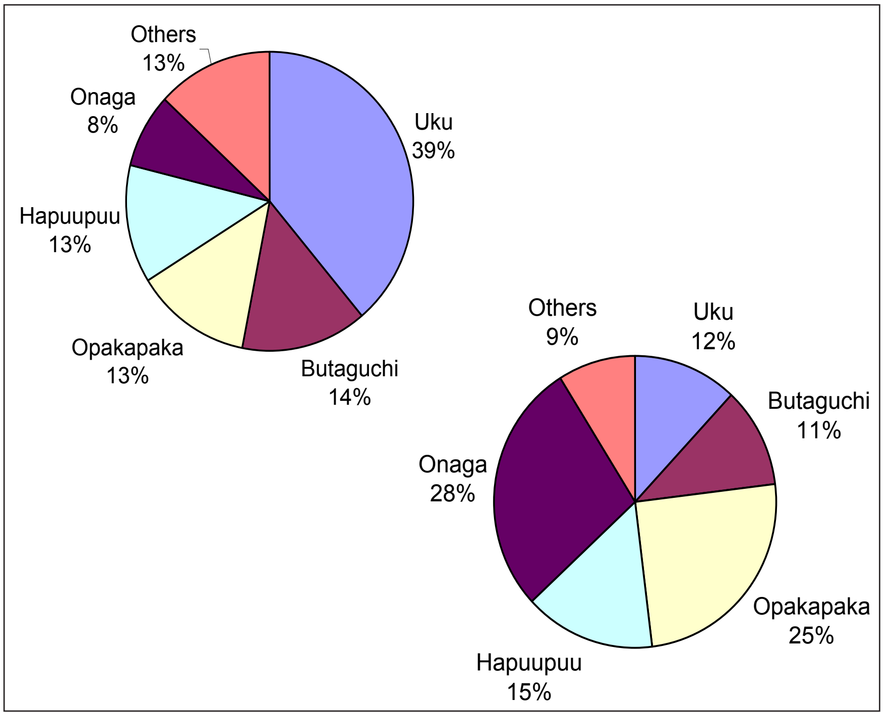

Figure 9.15. Average species composition (1996-2004) of bottomfish catches from the Mau (top left) and Hoomalu zones (bottom right) in the NWHI. Source: Kawamoto and Gonzales, 2005; WPRFMC, 2005. **NOTE:** *see text for scientific and common names.*

With the initial designation of the NWHI Coral Reef Ecosystem Reserve in 2000 and now PMNM, fishing activity in the NWHI has been on the decline. Proclamation 8031 allows commercial fishing by federally permitted bottomfish fishery participants that have valid permits until mid-2011 (FR 36443, June 26, 2006), which amounts to a maximum of eight vessels that are currently permitted to fish within the monument. Significant work was undertaken prior to the designation of the monument in response to previously issued Executive Orders that created the reserve in 2000. This fishery operates according to the management regime specified in the Fishery Management Plan for Bottomfish and Seamount Groundfish Fisheries in the Western Pacific Region. The management regime includes several precautionary measures that minimize potential effects of this fishery. The bottomfishery participants do not operate in the presence of the Hawaiian monk seals, and the annual harvest limit for the eight vessels is 300,000 lbs.

A multiyear project was designed to assess the impacts of commercial bottomfishing in the Raita and West St. Rogatien (e.g., first bank west of St. Rogatien) Reserve Preservation Areas (RPAs), based on the 2000 Executive Order which stipulated that after five years, bottomfishing will only be allowed in these two RPAs, "if it is determined that continuation of such activities will have no adverse impact on the resources of these banks." In 2001, known fishing sites in each RPA were surveyed using the *Pisces V* submersible and the RCV-150 remotely operated vehicle (ROV) operated by the Hawaii Undersea Research Laboratory (Kelley and Moffitt, 2004). During 2002 and 2003, a set of three submersible dives were conducted on each study site to obtain data on: the abundance and size of bottomfish targeted by fishermen; amount of fishing debris present at the sites; and the types and abundance of benthic invertebrates and other fish species that could be impacted by fishing activities. The data obtained during this study indicate that impacts resulting from bycatch, lost fishing gear, discarded trash and damage to benthic invertebrates such as attached cnidarians, were relatively low (Kelley and Moffitt, 2004). Removal of one of the two primary target species, the onaga (red snapper, *Etelis coruscans*) could be effecting the population at Raita Bank, although previous estimates of maximum sustainable yield indicate that the number being taken is sustainable. However, due to problems with interpreting the catch data, changes in the rules and data reporting methods are recommended for these and other RPAs.

The number of fishers actively working the banks is relatively low (four to five boats) and the amount of gear and debris discarded on the banks is also low. The substrate on each of the banks is relatively barren, with tops being primarily covered with rhodoliths while the slopes are mostly featureless carbonate rock and sediment. Based on limited exploratory surveys, reef-building corals were not found at bottomfishing depths, and other types of cnidarians, as well as sponges, urchins and sea stars were in low abundance. In general, there appears to have been very little collateral damage caused by bottomfishing at either Raita Bank or West St. Rogatien Bank (Kelley and Moffitt, 2004; Table 9.1).

Table 9.1. Impact of bottomfishing on the Raita and West St. Rogatien Reserve Preservation Areas in the NWHI Monument. Source: Kelley and Moffitt, 2004.

	IMPACT
Target Species Removal	Low ---------------------------♦-------High
Bycatch Species Removal	Low ----♦------------------------------High
Fishing Debris Addition	Low ----♦------------------------------High
Trash Addition	Low ----♦------------------------------High
Cnidarian Alteration	Low ----♦------------------------------High
Other Invertebrate Alteration	Low ----♦------------------------------High
Competitor Alteration	Low ----♦?----------------------------High
Prey Alteration	Low ----♦?----------------------------High

With the exception of Brooks Bank, bottomfishing impacts have not been investigated on any other sites in the monument. Brooks Bank was found to have a relatively extensive bed of black coral (*Antipathes ulex*) within bottomfishing depths and black corals and large anemones (e.g., *Telmatactis* sp.), were observed in abundance on the top of Bank 66 east of French Frigate Shoals during a single submersible dive and several ROV dives on that location in 2002 (Kelley et al., unpub.). In 2003, unusual stylasterid hydrozoans were also recorded in bottomfish depths during dives investigating deepwater corals on NWHI seamounts (Baco-Taylor, unpub.). Based on these observations, it is unknown but likely that deepwater coral beds are present on other bottomfishing sites in NWHI.

Trade in Coral and Live Reef Species

No trade in coral and live fish is permitted in the PMNM.

Ships, Boats and Groundings

A number of factors have contributed to vessel groundings and cargo loss in the NWHI, including human error, lack of appropriate navigational practices, inaccurate nautical charts and treacherous conditions due to low lying islands, atolls, and shallow pinnacles and banks. When the 85-foot longliner *Swordman I*, carrying more than 6,000 gallons of diesel fuel and hydraulic oil, ran aground at Pearl and Hermes in 2000, vessel monitoring system technology allowed agents to track the disaster and quickly respond. Cleanup costs, which were recovered from the owner in court, exceeded $300,000.

In July 2005, the NOAA-chartered marine debris cleanup vessel M/V *Casitas* (Figure 9.16) ran aground at Pearl and Hermes Atoll. Following the removal of 33,000 gallons of fuel and oil, the 145-foot motor vessel was successfully extracted from the reef and entombed northwest of the atoll in approximately 2,200 m of water. However, the crew fleeing the sinking vessel was forced to camp on a quarantine island without "clean gear." It has yet to be determined if any invasive species came ashore with the shipwecked crew. Unified Command representatives from the USCG, state of Hawaii and Northwind Inc. (owner of the *Casitas*), in cooperation with the federal trustees USFWS and NOAA, oversaw the operation to prevent further damage to the coral reef ecosystem and islands. The preliminary injury assessment resulted in an estimate of total damaged area of reef as 1,810 m^2, of which 508 m^2 was estimated to be coral. A full injury assessment may be conducted in the near future, depending upon the outcome of negotiations between the trustees and the responsible party.

Figure 9.16. Charter vessel M/V Casitas *aground at Pearl and Hermes Atoll, July 2005. Photo: USFWS.*

Most vessel activity in the NWHI occurs in corridors along the island chain and across the chain between Pearl and Hermes Atoll and Lisianski Island (Franklin, in press). The vessels transiting across the chain are primarily large (about183 m), foreign-flagged commercial freighters and tankers traveling to or from major Asian and U.S. ports (Figure 9.17). Vessels traveling along the chain are primarily either commercial fishing vessels or research vessels originating from the MHI. Commercial fishing vessels from the MHI spend the most cumulative time of any vessel type in the PMNM.

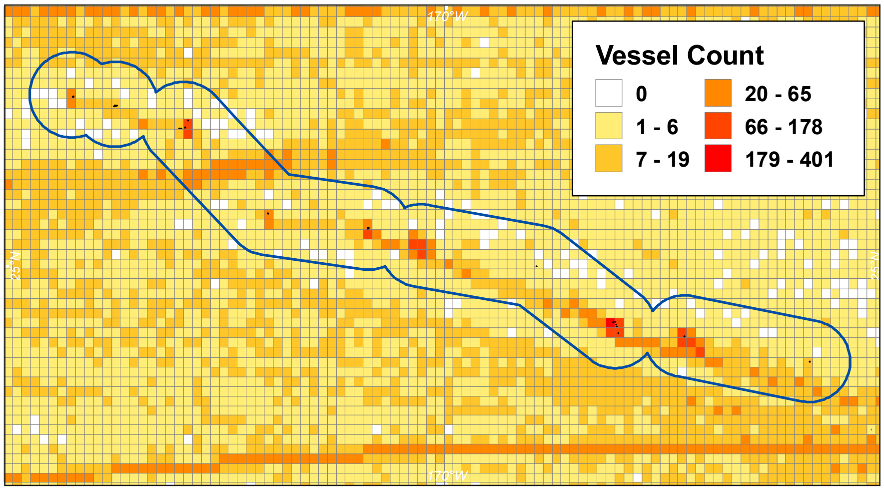

Figure 9.17. Spatial distribution of vessels reported near and within the current boundaries of the PMNM from 1994 to 2004. Source: Franklin, in press.

Marine Debris

Derelict fishing gear and other marine debris threaten the near-pristine coral reef ecosystems of the NWHI, which are prone to the accumulation of floating debris due to their location in the Subtropical and Subpolar North Pacific gyres. Most of the debris consists of derelict fishing gear that can entangle and kill endangered Hawaiian monk seals, threatened green sea turtles and other wildlife. Debris can also cause physical damage to sensitive reef habitats, including corals and other benthic flora and fauna, present a hazard to navigation and may accelerate the introduction of non-native species. In an effort to reduce entanglements of Hawaiian monk seals, NOAA's Pacific Island Fisheries Science Center (PIFSC) began removing marine debris from the beaches of the NWHI in 1982. Following pilot surveys of debris in the surrounding coral reefs in 1996, PIFSC-Coral Reef Ecosystem Division (PIFSC-CRED) has led the removal of over 511 metric tons of marine debris from the reefs and beaches through a collaborative effort with other federal, state and local partners, including the PMNM, state of Hawaii, USFWS, USCG, Schnitzer Steel Hawaii, Covanta Energy and the University of Hawaii (Table 9.2, Figure 9.18). A five-year, intensive removal effort (2001–2005) supported by NOAA's Coral Reef Conservation Program (CRCP) and NOAA's Marine Debris Program enabled the PIFSC and its partners to remove a large percentage of the historical debris from the reefs of the NWHI.

Table 9.2. Annual and cumulative amounts (kg) of derelict fishing gear and other marine debris removed from the islands and atolls of the NWHI by the multi-agency marine debris team lead by NOAA Fisheries PIFSC-CRED since 1996. Source: PIFSC-CRED.

YEAR	PHR	MARO	FFS	KURE	MIDWAY	LISIANSKI	LAYSAN	TOTAL
1996/1997	2,223	0	2,145	0	0	0	0	4,368
1998	0	0	7,500	0	0	0	0	7,500
1999	8,676	0	2,145	0	9,091	5,444	0	25,356
2000	9,866	0	0	3,069	7,457	2,035	0	22,427
2001	30,501	0	5,625	23,516	0	830	1,075	61,547
2002	92,955	0	432	1,567	0	1,087	1,231	97,272
2003	79,572	0	2,245	1,217	18,694	3,588	2,154	107,470
2004	56,668	46,740	1,402	3,284	0	2,799	3,040	113,933
2005	14,281	10,361	17,793	2,219	4,899	1,170	1,084	51,807
2006	4,228	0	1,028	9,142	2,680	368	1,549	18,995
TOTAL	**298,970**	**57,101**	**40,315**	**44,014**	**42,821**	**17,321**	**10,133**	**510,675**

Figure 9.18. Divers cutting away nets from the reef in the NWHI (left). Marine debris being loaded aboard the NOAA ship Oscar Elton Sette *(right). Photos: PIFSC-CRED.*

In 2006, a maintenance level effort was initiated to investigate the annual accumulation rates of debris at targeted atolls. During the first year of maintenance mode, the PIFSC and its partners removed 19 metric tons of derelict fishing gear from the NWHI. Debris was observed to accumulate in greater abundance in low energy lagoonal habitats (Figure 9.19). A newly released study estimates that the annual accumulation rate is over 52 tons, which is greater than originally anticipated (Dameron et al., 2007). This indicates that the current level of effort is not sufficient to keep up with the annual rate of accumulation, and future efforts need to focus on bridging this gap. In addition, ongoing efforts to develop at-sea debris detection and mitigation technologies aimed at removing derelict fishing gear from the open ocean before it can impact coral reef ecosystems are continuing. Finally, efforts in outreach, education and partnership-building need to be increased to address this issue locally as well as with Pacific Rim communities that share the responsibility for this marine debris.

Morishige et al. (2007) documented a significantly higher amount of marine debris coming ashore in the NWHI during El Niño periods compared with La Niña conditions over a 16-year period (Figure 9.20). Volunteers with the USFWS tabulated, collected and removed more than 52,000 pieces of debris since 1990 from the shores of the Hawaiian Islands National Wildlife Refuge's Tern Island station, located at French Frigate Shoals. More than 70% of the debris removed was made of plastic and included buoys, bottles and cigarette lighters. Evidence suggests that the increase in marine debris on the shores of the NWHI is a result of the southward movement of the Subtropical Convergence Zone, which tends to concentrate marine debris in the NWHI, particularly during El Niño periods.

Aquatic Invasive Species

In sharp contrast to the MHI, which harbors at least 287 introduced and cryptogenic (unknown origin) invertebrate species, only five introduced invertebrates have become established and two more have been recorded but do not appear to be established in the NWHI (Godwin et al., 2006; Friedlander et al., 2005; Eldredge, 2005). Not surprisingly, the majority of invertebrate introductions are found at Midway Atoll and French Frigate Shoals, which have long histories of anthropogenic activity. At Midway, the four invertebrate introductions include the hydroid, *Pennaria disticha*, two bryozoans, *Amathia distans* and *Schizoporella errata*, and the barnacle, *Chthamalus proteus* (Figure 9.21). Only two introduced species, the hydroid *Pennaria disticha* and the snapper, *Lutjanus kasmira*, are found throughout the NWHI archipelago (Godwin et al., 2006).

Populations of non-indigenous marine species that have already colonized areas of the MHI represent the most likely source of invasive species in the NWHI based on the proximity and pattern of ship movements associated with the MHI (Godwin et al., 2006). Marine debris has been shown to have the ability to transport non-indigenous species to the NWHI (Godwin et al., 2006). Modes of transport such as derelict fishing nets are problematic to manage but the impact of other debris, such as Fish Attraction Devices (FAD) deployed by the state of Hawaii, can be minimized (Godwin et al., 2006).

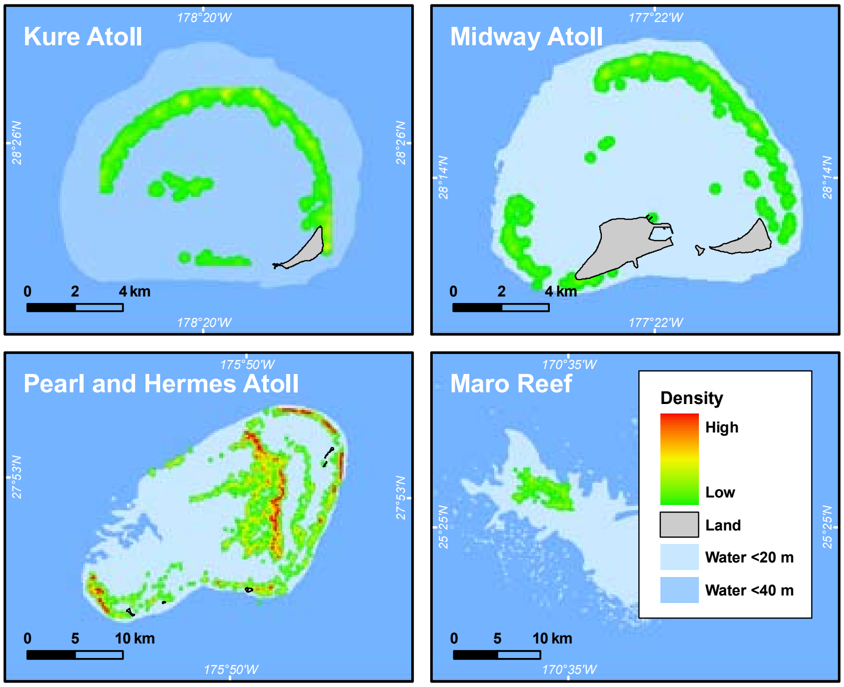

Figure 9.19. Maps depicting numerical densities of debris sites marked by GPS following discovery. Dark red in the monochromatic color ramp represents the highest debris densities. Buffered survey areas are shown for each location with green lines. Data source: Dameron et al., 2007; map: K. Buja.

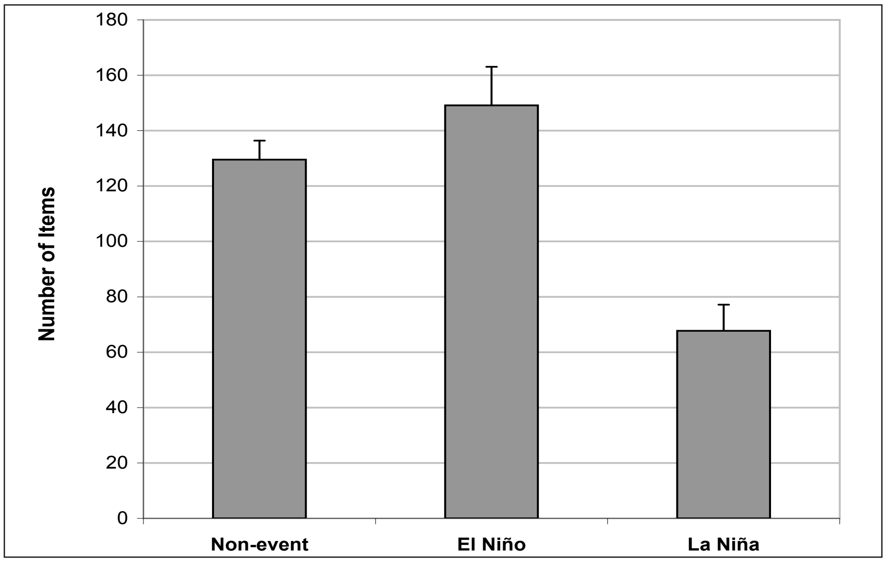

Figure 9.20. Mean number of items (±SE) deposited on beaches surveyed on Tern Island, French Frigate Shoals during El Niño (n=92), La Niña (n=33) and non-events (n=258) from 1990-2006. Debris deposition during La Niña events was significantly less than in El Niño and non-events (p<0.05). Source: Morishige et al., 2007.

Since 2000, annual NWHI Reef Assessment and Monitoring Program (RAMP) cruises have conducted species level Rapid Ecological Assessment (REA) surveys to characterize the marine flora and fauna of the NWHI, including examination of the presence or absence of alien species. Additionally, NOAA's PIFSC-CRED have used towed-diver methodologies on a biennial basis to survey benthic composition and abundance and distribution of large fishes (>50 cm total length) and key macroinvertebrates over large stretches of shallow water marine ecosystems. These surveys also help document outbreaks of alien and native invasive species. Of the nine currently established marine alien species in the NWHI (one alga, five invertebrates and three fishes), the population ranges for all except the hydroid, *P. disticha*, have remained static from 2005 to present (Friedlander et al., 2005; Godwin et al., 2006). *P. disticha* has now been recorded from Nihoa to Kure Atoll (S. Godwin, pers. obs.).

In 2005, international press coverage caused a minor panic over the potential spread of the red, invasive alga, *Hypnea musciformis* to the NWHI. The species was first recorded from deep water (>30 m) at Mokumanamana (Necker Island) in 2002, and one small individual was found as part of a drift assemblage at Maro Reef. From 2002 through 2004, small sprigs of the alga were commonly recorded on lobster traps at Mokumanamana brought up from depths of 30-90 m, but caused no immediate concern among algal biologists working in the NWHI. Suddenly, in spring to early summer of 2005, pounds of *H. musciformis* (Figure 9.22) began to appear on lobster traps at Mokumanamana, fostering concern about a large-scale epidemic of this nuisance alga. The algal bloom received international attention through numerous media outlets, and a special cruise was organized in autumn 2005 by PMNM to investigate the problem. Interestingly, no *H. musciformis* was discovered at Mokumanamana during the cruise, and continued investigations of algae associated with lobster traps in 2006 have failed to find any significant population blooms other than a few small individuals similar to those documented in 2002 through 2004. During annual NWHI RAMP cruises between the years 2000-2006, *H. musciformis* was not observed in shallow water reef environments anywhere in the NWHI, suggesting that the species currently appears to be restricted to deeper water habitats beyond the range of divers at Mokumanamana. No other alien or invasive algae have been reported from the NWHI.

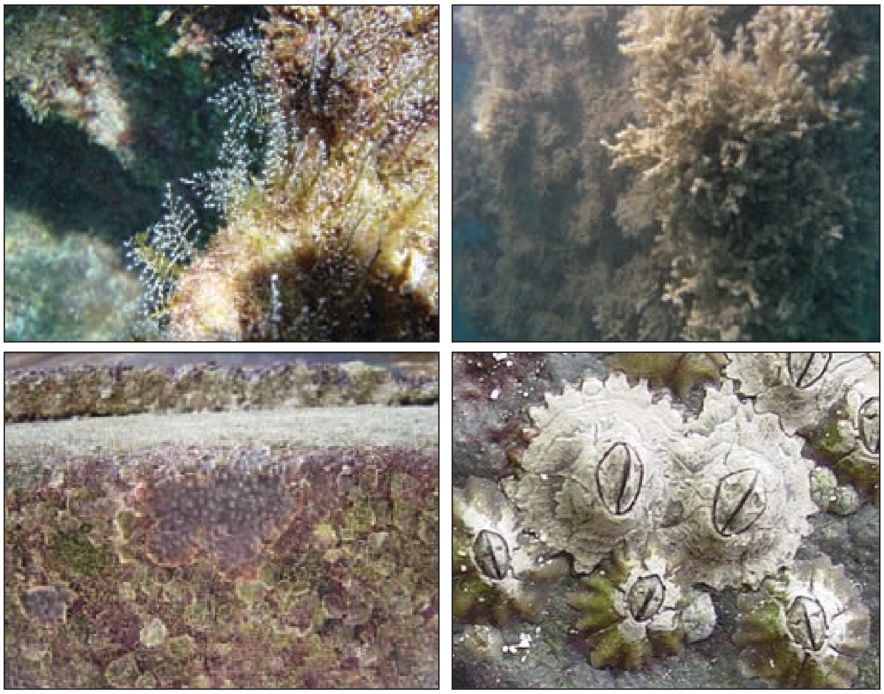

Figure 9.21. Top left to bottom right, introduced invertebrates at Midway include a hydroid, Pennaria disticha*, two bryozoans,* Amathia distans *and* Schizoporella errata*, and a barnacle,* Chthamalus proteus. *Photos: S. Godwin, J. Leonard, C. Zabin.*

The green alga *Caulerpa taxifolia* is a native organism to waters of the Hawaiian Archipelago and has never shown invasive tendencies in any environment in the NWHI. Despite the concerns caused by *C. taxifolia* in areas of accidental introduction (Australia, California and the Mediterranean Sea) where it can rapidly overgrow miles of coastline, individuals of native *C. taxifolia* in the NWHI usually grow in discrete patches under overhanging carbonate ledges and have never been observed to overgrow coral species or other biological organisms.

Security Training Activities

No military security training activities occur in the PMNM.

Offshore Oil and Gas Exploration

No offshore oil and gas exploration occurs in Hawaiian waters.

Others

Coral Predators: Crown-of-thorns Sea Star (Acanthaster planci) and Drupella

The crown-of-thorns sea star (COTS; Figure 9.22) and *Drupella* spp. snails are both corallivores that have caused significant coral damage in areas of the Indo-Pacific. They are being monitored on the reefs of the NWHI during REA and towed-diver surveys. Towed-diver surveys report COTS to be present on the reefs of the NWHI but to occur at relatively low levels (average=0.65 COTS/km; PIFSC-CRED, unpub. data;). During annual benthic monitoring surveys it was found that the frequency of occurrence (number of sites with animals or feeding scars/total sites surveyed) for *Drupella* was low (3% in 2004, 15.4% in 2005; Aeby, unpub. data). *Drupella* were usually found feeding at the base of branches of *Pocillopora meandrina*. For COTS, frequency of occurrence was also moderately low with reports of COTS observed at 4.5% of the REA monitoring sites in 2004, and 28.2% in 2005 (Aeby, unpub. data). COTS were usually found as single animals and not in aggregations.

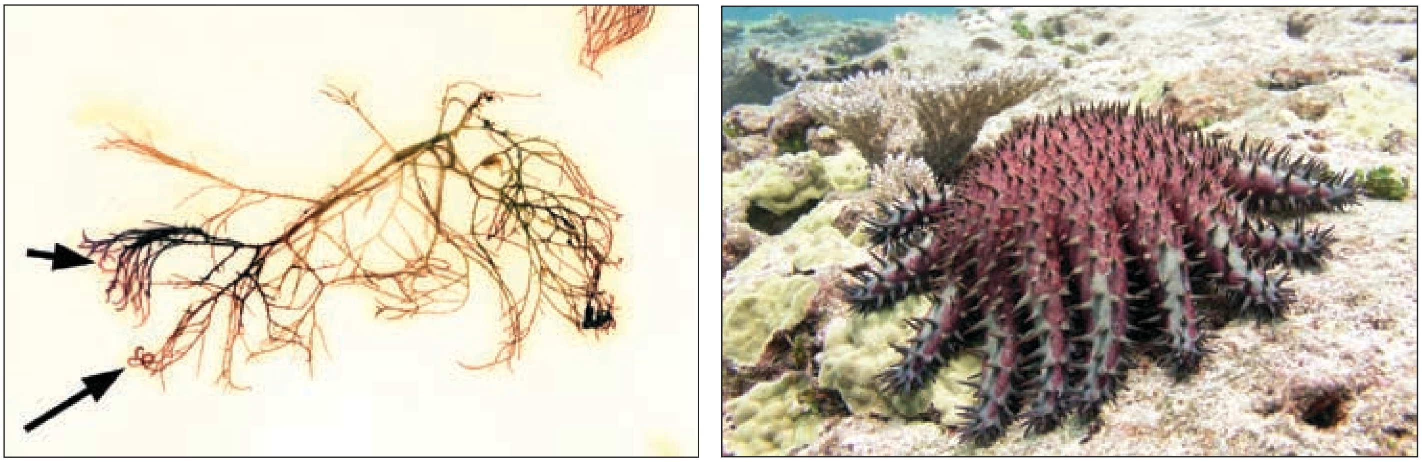

Figure 9.22. Left panel shows H. musciformis, *with arrows pointing out the distinctive "hooks" characteristic of this species. Right panel shows a COTS at French Frigate Shoals. Photos: P. Vroom and J. Kenyon.*

CORAL REEF ECOSYSTEM—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

The monitoring programs that are currently collecting data in the NWHI are listed in Table 9.3. Many locations where monitoring has recently occurred are shown in Figure 9.23.

Table 9.3. Long-term monitoring programs in the NWHI. Source: PIFSC-CRED.

MONITORING PROGRAM	OBJECTIVES	YEAR EST.	FUNDING	AGENCIES
Fishery monitoring and economics program	Fisheries catch and effort statistics	1948	NOAA	PIFSC, DAR
Marine turtle research program	Monitor selected sea turtle breeding sites	1973	NOAA, FWS	FWS, PIFSC
Seabird monitoring	Monitoring selected nesting seabird species	1978	FWS	USFWS, PIFSC
Fishery independent lobster monitoring	Monitor lobster using fisheries-independent sampling	1983	NOAA	PIFSC
Marine mammal research program	Monitor and assess subpopulations	1985	NOAA	PIFSC, FWS
Marine debris program	Rates of marine debris accumulation	1996	NOAA	PIFSC-CRED, UH, FWS, DAR, USGS
Reef assessment and monitoring program	Monitor and assess reef communities via integrated ecosystem science	2000	CRCP	PIFSC-CRED, FWS, numerous collaborators
Oceanography and water quality program	Spatial and temporal observations of physical and chemical oceanographic conditions and processes influencing reef health.	2000	NOAA	PIFSC-CRED, UH
Coral monitoring	Monitoring corals at permanent sites	2000	HCRI, FWS	FWS, PIFSC-CRED, CRCP
Connectivity and ecosystem health	Examine connectivity, ecosystem health and genetic structure	2005	NMSP	HIMB

CRCP – NOAA's Coral Reef Conservation Program
PIFSC-CRED - Coral Reef Ecosystem Division
DAR - Hawaii DLNR, Division of Aquatic Resources
FWS - U.S. Fish and Wildlife Service
HCRI - Hawaii Coral Reef Initiative
HIMB - Hawaii Institute of Marine Biology
NMSP - National Marine Sanctuary Program
NOAA - National Oceanic and Atmospheric Administration
NOS - National Ocean Service
PIFSC - Pacific Islands Fisheries Science Center
UH - University of Hawaii
USGS – U.S. Geological Survey

WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

The health, functioning and biogeography of the coral reef ecosystems of the NWHI are primarily controlled by the oceanographic processes and conditions, both physical and chemical, to which they are exposed. The broad and diverse biological communities comprising these ecosystems, including fishes, corals and other invertebrates, algae, turtles, seabirds and marine mammals, is significantly influenced by spatially and temporally-varying ocean currents, waves, temperature, salinity, turbidity, nutrients, and other measures of water quality and oceanographic conditions. As these conditions change, so do the condition, distribution, abundance and species diversity of reef communities. Though these processes vary over a diverse range of time scales, from seconds (individual waves), to tidal and diurnal, to seasonal, to interannual (multiple years), to decadal, to long-term climate changes, the biogeography of the reef communities has generally evolved to accommodate all of the shorter-term scales. Longer-term changes, particularly those related to climate, are of particular concern since the reef ecosystems of the NWHI may not have encountered such conditions for hundreds, thousands or even millions of years. Table 9.4 presents long-term oceanographic monitoring methods and equipment used in the NWHI since 1999.

The NWHI cover such a large geographical area that the entire archipelago is not exposed to the same oceanographic and meteorological conditions. As an example, Figure 9.24 illustrates the variability in wind strength and direction between French Frigate Shoals in the southern portion of the NWHI and Kure Atoll in the northern portion of the NWHI. At French Frigate Shoals, trade winds from the northeast quadrant clearly dominate the wind field, whereas at Kure Atoll, winds are much more variable with clear signatures of easterly trade winds and westerly winds associated with the passage of low pressure systems. Firing and Brainard (2006) also reported significant variability in surface ocean currents across the archipelago.

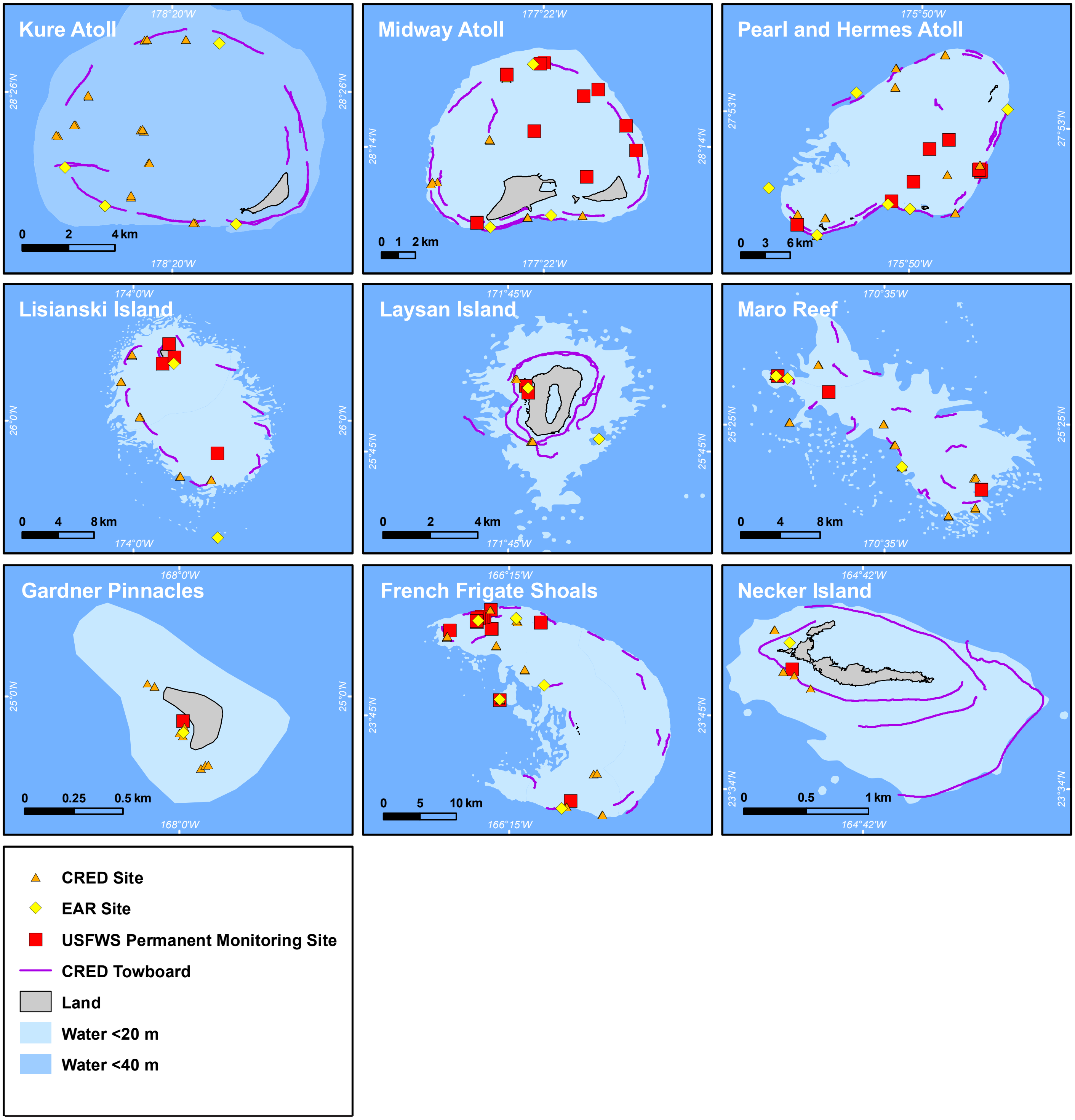

Figure 9.23. Monitoring locations in the NWHI. Map: K. Buja.

The NWHI are exposed to large seasonal temperature fluctuations, especially in the northern portions of the archipelago. Temperatures in the summer months across most of the archipelago are typically warm due to high insolation, and ocean waters are generally well-mixed in the upper 30 m of the water column due to steady trade winds and well-stratified below the mixed layer (Figure 9.25). In the winter, the northern portions of the archipelago experience much cooler SSTs relative to the rest of the NWHI as the subtropical front migrates southward and produces vigorous mixing of surface waters due to the combined effects of winds associated with low pressure storm systems and surface cooling associated with cooler air temperatures (Figure 9.25).

Table 9.4. Oceanographic monitoring systems in the NWHI by PIFSC-CRED. Source: PIFSC-CRED.

SYSTEM	VARIABLES MONITORED	DATES	AGENCY
Deepwater CTDs* at select locations near the islands	Conductivity (salinity), temperature, depth, dissolved oxygen and chlorophyll to a depth of 500 m	February 1999-present	PIFSC-CRED
Shallow-water CTDs* - multiple sites each island/atoll	Temperature, salinity, turbidity	February 2000-present	PIFSC-CRED
Water Samples	chlorophyll and nutrients (nitrate, nitrite, silicate, phosphate) collected concurrently with CTDs at select depths	September 2004-present	PIFSC-CRED
Coral Reef Early Warning Buoys - 3 Standard (Kure, Maro, Pearl & Hermes), 1 Enhanced (French Frigate Shoals)	Standard: temperature (1 m), conductivity (salinity), wind, atmospheric pressure. Enhanced: standard plus: ultraviolet radiation, photosynthetically available radiation	February 2002-present	PIFSC-CRED
Sea Surface Temperature (SST) Buoys - 5 (Kure, Laysan, Lisianski, Midway, Necker)	Temperature at 0.5 m	February 2002-present	PIFSC-CRED
Subsurface Temperature Recorders - 43 (all islands)	Temperature at depths between 0.5 m and 30 m	February 2002-present	PIFSC-CRED
Ocean Data Platforms (ODP) - 3 (Midway, Necker, Pearl & Hermes)	Temperature, conductivity (salinity), spectral waves, current profiles	October 2002-present	PIFSC-CRED
Wave and Tide Recorders (WTR) - 4 (Kure 2, Lisianski 2)	Wave and tidal heights	July 2003-present	PIFSC-CRED
Ecological Acoustic Recorder (EAR) - 4 (French Frigate Shoals, Kure, Pearl & Hermes)	Ambient sounds up to 12.5 kHz and vessel generated sounds	September 2006-present	PIFSC-CRED

*CTD = conductivity, temperature and depth.

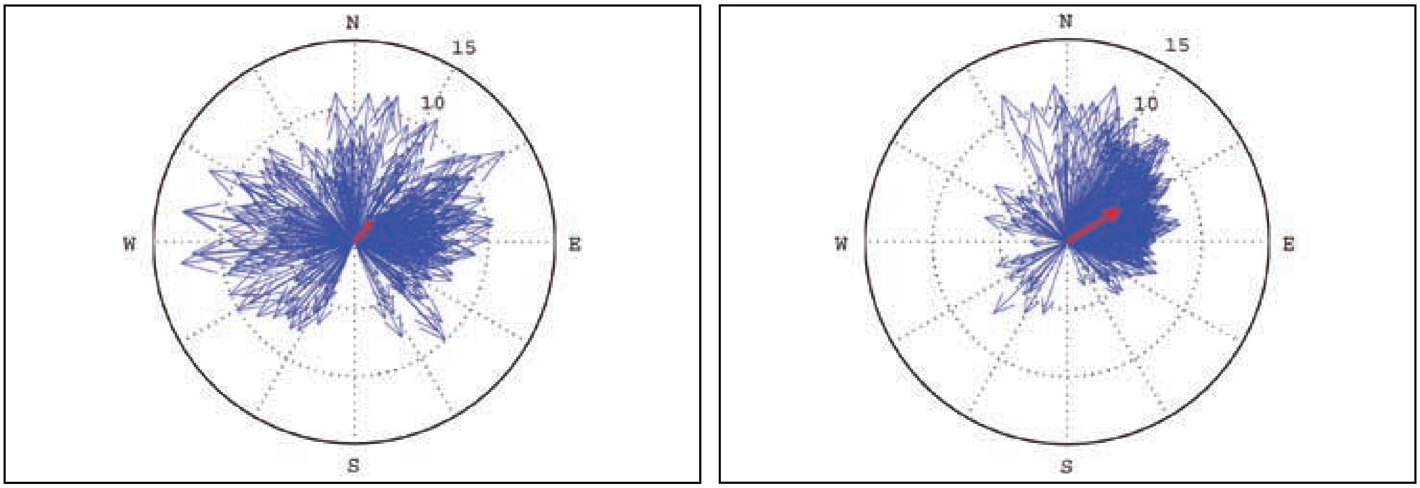

Figure 9.24. Coral Reef Early Warning System buoy data for surface (2 m) wind observations at Kure Atoll (left) from October 5, 2004 to January 13, 2006 and French Frigate Shoals (right) from April 11, 2005 to September 4, 2006. Blue arrows are daily averaged wind direction and speed (from 0-15 m/s) and red arrows are average for the entire period, depicting the prevailing north-northeasterly winds. Wind vectors point to the direction of wind origin. Data points more than 3 SD were excluded. Source: PIFSC-CRED, unpubl. data..

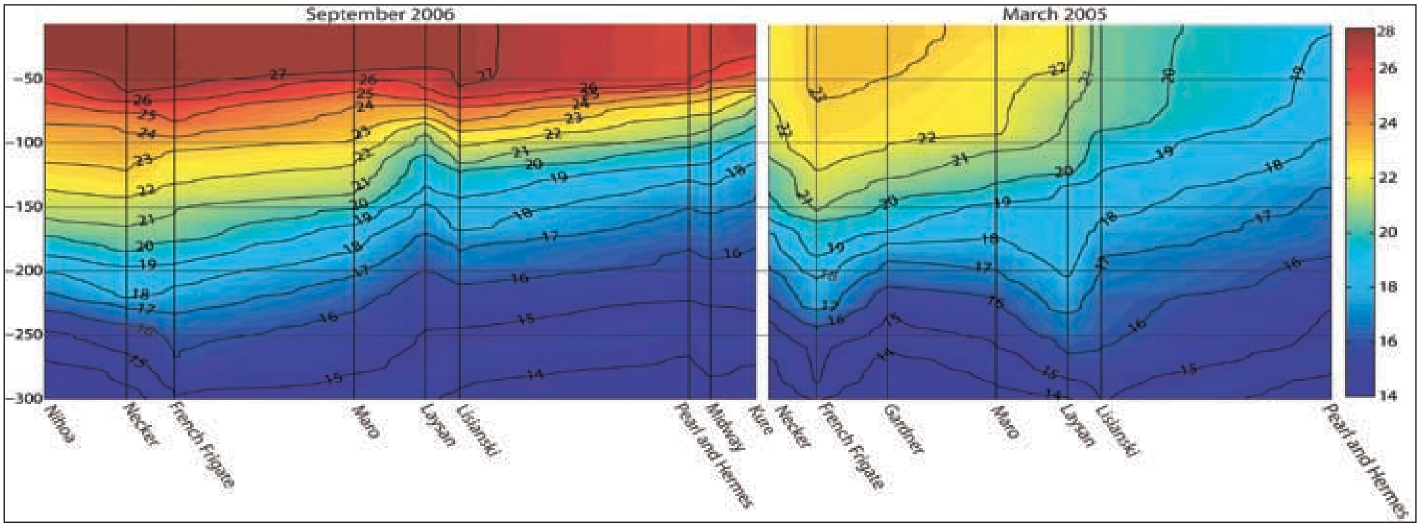

Figure 9.25. Vertical temperature profiles along the NWHI obtained from shipboard conductivity, temperature and depth (CTD) casts during September 2006 (left panel) representing late summer conditions and March 2005 (right panel) conditions representing winter. Depths (y-axis) are in meters and temperature color bar is in °C. Source: PIFSC-CRED, unpub. data.

BENTHIC HABITATS

Corals

Range Extensions and Possible New Coral Species

Recent scientific expeditions in the NWHI have yielded many new records and possibly undescribed species of stony coral since the last compilation by Maragos et al. (2004). One of the most exciting discoveries was of the table coral (*Acropora* spp.) off the spur-and-groove habitat on the southwest side of Pearl and Hermes Atoll and off the shallow southeast fore reef at Neva Shoal. Additional dives confirmed the presence of *Acropora cytherea* and *A. cerealis-valida* at Pearl and Hermes, and *A. valida* at Neva Shoal, which led to other discoveries at Neva, a second *Acropora* species and three *Montipora* species that are all likely new to science.

Figure 9.26. Two potential new species of Acropora *including the colony on the left and a possible* cf *austera hybrid form (right) from French Frigate Shoals from the CoML* cruise *in October 2006 (right). Photos: J. Maragos.*

The Census of Marine Life (CoML) cruise to French Frigate Shoals in October 2006, added additional sightings of rare species including *Diaseris distorta*, *Cycloseris tenuis*, *Leptastrea scabra*, and *Acropora* sp.1. Another rare species, resembling *Leptoseris papyracea,* was previously known only from dredge hauls by Maragos in the MHI, and was reported for the first time in the NWHI off the south east fore reef of French Frigate Shoals during the CoML cruise. An unidentified species, *Porites* sp.15, was reported on a pinnacle on the southwest side of French Frigate Shoals, and the first record of *Porites lutea* in the NWHI was reported from the north reef crest. Other unidentified species reported during the CoML cruise include those pictured in Figures 9.26 and 9.27. The combined 2006 investigations yielded up to 11 new records for the NWHI. Scientists conducting towed-diver surveys contributed directly or indirectly to several of the new records and species, with exploratory dives in new habitats and at new sites contributing the rest (Table 9.5).

Figure 9.27. Unidentified new species of coral from French Frigate Shoals. Photo: J. Maragos.

The most exciting coral discovery was of an unknown species that has not yet been identified to the genus or family level (Figure 9.27). This coral may be a relic that was once common in the past that subsequently died out elsewhere but survived in Hawaii. The other possibility is that the coral may be a type previously restricted to deep water that subsequently evolved and adapted itself to shallow water habitats. Randall (2007) makes note of two fishes that he characterized as relics. Likewise, it may also be possible for relict corals to have survived in Hawaii to this day. It will be necessary to collect this and other corals in order to determine their likely phylogenetic origin. So far there has been no consensus among coral experts looking at the photographs of the coral as to which family it belongs. Marine life in the NWHI evolved for many millions of years in isolation from neighboring archipelagos and islands, and it is plausible that this and perhaps other species were able to survive and thrive without the threat of newer species displacing them as likely occurred in other archipelagos.

The choice of French Frigate Shoals as the target for the first CoML was an excellent one from the standpoint of yielding probable new species and extending the range of many other species. Eight more species of cnidarians were reported from the atoll, further cementing the atoll's status as the most diverse island or atoll for corals in Hawaii. The atoll is the closest site within the Hawaiian chain to Johnston Atoll, which lies 830 km to the southwest, and Johnston may serve as a "stepping stone" for the dispersal of species to Hawaii from the Line Islands and other neighboring archipelagos south of Hawaii (Grigg, 1981; Maragos and Jokiel, 1986; Maragos et al., 2004; Kobayashi, 2006). This connection would explain why French Frigate Shoals has so many *Acropora* species which flourish at Johnston and why French Frigate Shoals has higher numbers of coral species compared to any of the other Hawaiian Islands.

Table 9.5. A listing of all coral and anemone species reported in the NWHI as of October 2006. Larger atolls with diverse habitats and shelter from large northwestern swells support the greatest number of species. Additional dives to 30 m should fill the void of deeper water species records and yield a more informed assessment of coral and anemone biodiversity. Source: J. Maragos, unpub. data.

ISLAND	NIH	NEC	FFS	GAR	MAR	LAY	LIS	PHR	MID	KUR	RAI	NO. OF ISLANDS
Stony Corals *(*)=undescribed or undetermined species and new records reported from the CoML cruise; cf=unknown, but similar to.*												
*coral unid., seen first by J. Starmer, sp.18			x									1
Acropora cerealis			x	x	x							3
A. cytherea		x	x	x	x	x		x				6
A. gemmifera			x	x								2
A. humilis			x	x	x							3
A. nasuta			x		x	x						3
A. paniculata			x									1
*A. sp.1 (prostrate)			x				x					2
*A. sp.28 cf. *retusa*			x									1
A. valida			x		x	x	x	x				5
*A. sp.29 (table)			x									1
*A. sp.30 cf. *palmerae*			x									1
A. sp. 20 (neoplasia/tumor?)			x									1
A. sp.26 cf. *loripes*			x									1
Montipora capitata	x	x	x	x	x	x	x	x	x	x	x	11
M. flabellata		x	x	x	x	x	x	x	x	x		9
M. patula	x	x	x	x	x	x	x	x	x	x		10
*M. sp.4 cf. incrassata		x	x		x					x		4
M. dilatata						x	x					2
*M. sp.6 cf. dilatata					x							1
*M. sp.7 (foliaceous)			x				x	x	x			3
*M. sp.2 (ridges)								x		x		2
*M. sp.5 (branching)												1
*M. sp.14 (nodular) first seen by *B. Vargas-Angel*								x				1
M. tuberculosa			x		x	x	x	x	x	x		7
*M. sp.24 (irregular)			x									1
*M. sp.3 cf. *turgescens*					x	x	x	x	x	x		6
M. verrilli			x		x	x	x	x	x	x		7
Gardineroseris planulata									x			1
Leptoseris hawaiiensis			x			x						1
L. incrustans			x					x	x	x		4
*L. sp.22 cf. *incrustans*			x									1
L. mycetoseroides			x									1
*L. cf. *papyracea* sp19			x									1
*L. cf. *scabra* sp17			x				x					2
Pavona clavus								x	x	x		3
P. duerdeni	x	x	x	x	x	x	x	x	x	x		10
P.maldivensis			x		x		x	x	x	x		6
P. varians	x	x	x	x	x	x	x	x	x	x		10
**Balanophyllia sp.* (pink)			x		x					x		3
Cladopsammia eguchii			x	x	x	x		x	x	x		7
Tubastraea coccinea	x		x	x	x	x		x	x	x	x	9
Cyphastrea ocellina	x	x	x	x	x	x	x	x	x	x		10
Leptastrea agassizi			x		x				x			3
L. bewickensis			x				x	x				3
L. purpurea	x	x	x	x	x	x		x	x	x		10

ISLAND	**NIH**	**NEC**	**FFS**	**GAR**	**MAR**	**LAY**	**LIS**	**PHR**	**MID**	**KUR**	**RAI**	**NO. OF ISLANDS**
L. pruinosa		x	x	x	x							4
*L. sp.8 cf. *F. hawaiiensis*		x	x		x		x			x		5
**Cycloseris tenuis*			x	x			x	x				3
**C. vaughani*			x				x	x	x			3
Diaseris distorta			x				x					2
Fungia scutaria	x		x	x	x	x	x	x	x	x		9
F. granulosa					x	x		x				3
Pocillopora damicornis			x		x	x	x	x	x	x	x	8
P. eydouxi	x	x	x	x	x	x	x	x	x			9
P. sp.10 cf. *laysanensis*			x			x				x	x	4
P. ligulata	x	x	x	x	x	x	x	x	x	x	x	11
P. meandrina	x	x	x	x	x	x	x	x	x	x		10
P. molokensis	x		x	x	x	x	x	x		x	x	9
P. sp.32 cf. *verrucosa*			x				x	x				3
P. sp.33 cf. zelli			x									1
*P. sp.11 cf. capitata			x		x	x	x	x	x	x	x	8
**Porites* sp.12 cf. annae							x	x		x		3
*P. sp. 15 (paliform lobes)			x									1
Porites brighami	x	x	x	x	x	x	x	x		x		9
P. compressa	x	x	x	x	x	x	x	x	x	x	x	11
*P. sp.23 (arthritic fingers)			x									1
P. duerdeni		x	x	x	x			x		x		6
P. evermanni	x	x	x	x	x	x	x	x	x	x		10
P. hawaiiensis		x	x		x	x	x	x	x	x		9
P. lobata	x	x	x	x	x	x	x	x	x	x		10
*P. sp. 21 cf. *lobata*			x									1
**P. sp.16 cf. lutea*			x									1
P. rus					x							1
*P. sp.27 (columns)			x									1
*P. sp.13 cf. *solida*			x	x		x		x	x	x		5
Psammocora explanulata				x								1
P. nierstraszi		x	x	x	x	x	x	x	x			8
P. stellata	x		x	x	x	x	x	x	x	x	x	10
P. verrilli								x	x	x		3
NON-STONY CORALS & ANEMONES *(*)=undescribed or undetermined species and new records reported during the CoML cruise.*												
Palythoa tuberculosa	x	x	x	x	x	x	x	x	x	x		10
P. sp.			x									1
Zoanthus pacificus			x		x			x		x		4
Zoanthus sp (Kure)										x		1
Zoanthus sp ("B")	x	x	x		x		x					5
**Sinularia* sp (yellow)	x	x	x	x			x					5
**Sinularia* (purple)				x						x		2
**Sinularia* (brown)			x									1
**Sinularia* (pink)								x				1
Acabaria bicolor			x							x		2
Cirrhipathes sp	x		x									1
Heteractis malu			x	x	x	x				x		5
TOTAL SPECIES PER ISLAND	**21**	**24**	**75**	**33**	**44**	**35**	**41**	**46**	**34**	**42**	**9**	
Total Species of Stony Corals: 80												
Total For All Cnidarians: 89												

Assessment and Monitoring Sites

In 2003, 73 REA sites were chosen as long-term monitoring sites from more than 500 sites assessed during NWHI RAMP surveys between 2000 and 2002. The sites were selected to represent a diversity of habitats at each island/atoll within constraints imposed by prevailing weather conditions and shipboard operational logistics. At each site, REA coral survey protocols built upon quantitative methods that were initiated in 2002 to compute several parameters that collectively describe community structure: coral percent cover, richness, relative abundance, colony density and size-frequency distribution. Surveys were conducted along two 25 m transects at each site, and included video records of benthic substrate and condition. The line-intercept method at 0.5 m intervals was introduced as a standard part of the survey protocol in 2004 to more efficiently quantify substrate composition (Figure 9.28). Directed observations on coral disease, predation and bleaching were conducted along the same transect lines. Surveys using the same methods were conducted in 2004, 2005 and 2006, with only minor modifications to the suite of sites chosen for long-term monitoring. Not all sites were surveyed in all years, due to factors including sea conditions and available ship time.

Figure 9.28. A diver uses the line-intercept method to document benthic composition at 0.5 m intervals along transects. Photo: J. Kenyon.

Coral distribution, abundance, and condition were assessed on larger spatial scales using towed–diver surveys (Kenyon et al., 2006b). As field efforts in 2003 transitioned from reef assessment to reef monitoring, specific track lines were chosen as targets for resurveys in 2003, 2004 and 2006.

Coral Percent Cover and Relative Abundance from REAs

Coral REA surveys were conducted at 70 sites in 2004, 37 sites in 2005 and 64 sites in 2006 (Table 9.6). As with percent cover data from 2002 surveys (which were calculated from size frequency data of colony counts within transects), line-intercept data from surveys during all three years indicated that coral cover varied greatly across the NWHI (Figure 9.29). Most locations had low coral cover (<20%), with higher values at Maro, Lisianski and French Frigate Shoals. Coral cover values determined from 2002 surveys also showed the highest coral cover values at Maro and Lisianski (Friedlander et al., 2005), though their magnitude (more than 60%) was greater than the values derived from the line-intercept method in 2004-2006. At each island/atoll, mean coral cover values from different survey years (2004, 2005 and 2006) were similar, indicating relatively little change overall at each location.

Table 9.6. Number of REA and towed-diver surveys (TDS) conducted by PIFSC-CRED (2004 and 2006) and PMNM (2005). Source: PIFSC-CRED, unpubl. data.

ISLAND	**2004**		**2005**		**2006**	
	REA	**TDS**	**REA**	**TDS**	**REA**	**TDS**
Necker	3	0	3	0	2	4
FFS	11	17	6	0	10	19
Gardner	3	2	0	0	0	0
Maro	9	12	7	0	9	13
Laysan	3	5	0	0	3	6
Lisianski	9	12	0	0	9	12
PHR	14	21	9	0	13	26
Midway	9	15	6	0	9	15
Kure	9	13	6	0	9	13

Relative abundance of cnidarians was assessed by computing the proportion of colonies, by taxon, that occurred within belt transects (Table 9.7). These data, from 2006 surveys, exemplify some general patterns seen during all years. The relative abundance of corals varied among locations, though *Porites lobata* composed a majority of the fauna at numerous locations and was an important component of the fauna at all locations. *Acropora*, particularly *A. cytherea*, was an important component of the coral fauna at French Frigate Shoals, but less so at other locations where it occurred (Necker

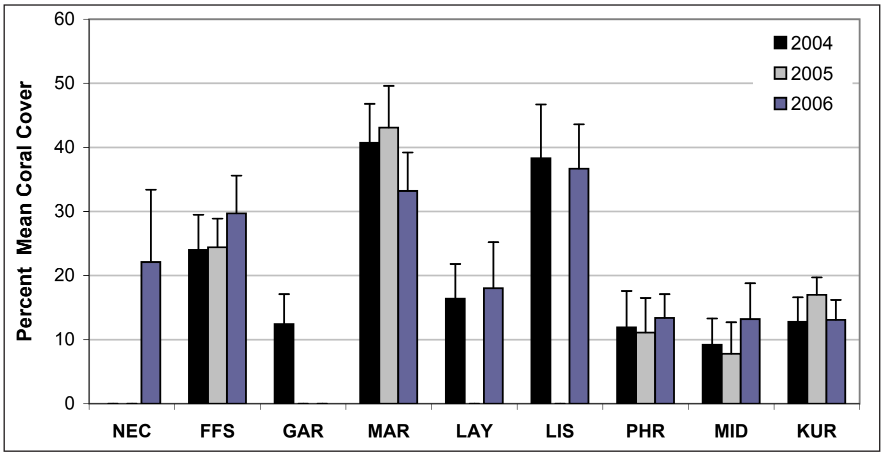

Figure 9.29. Mean coral cover (±SE) at locations in the NWHI. Not all locations were surveyed in all three years. Coral cover was calculated from the line-intercept method at 0.5 m intervals. Source: PIFSC-CRED, unpub. data.

Table 9.7. Relative abundance of cnidarian colonies in the NWHI based on REA surveys at 64 sites conducted by PIFSC-CRED in 2006. All cnidarian species for which at least one colony was tallied in at least one location are listed. Those contributing >10% of the coral fauna at each location are highlighted in bold. Source:PIFSC-CRED.

SPECIES	**PERCENT OF CNIDARIAN FAUNA**							
	NECKER	**FFS**	**MARO**	**LAYSAN**	**LISIANSKI**	**PHR**	**MIDWAY**	**KURE**
Acropora cytherea	0.0%	**10.7%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Acropora valida	0.0%	5.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Acropora humilis	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Montipora capitata	2.8%	2.6%	**15.1%**	9.4%	**17.7%**	6.3%	1.1%	2.7%
Montipora patula	2.5%	2.5%	5.2%	1.6%	6.8%	1.0%	0.1%	0.0%
Montipora flabellata	0.0%	0.0%	0.7%	0.0%	0.0%	0.5%	**13.6%**	1.9%
Montipora incrassata	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pavona duerdeni	1.9%	2.5%	2.5%	3.8%	2.1%	0.3%	0.0%	0.0%
Pavona varians	0.1%	0.0%	0.0%	2.1%	0.1%	0.3%	0.4%	0.2%
Pavona maldivensis	0.0%	0.0%	0.0%	0.0%	1.1%	0.2%	0.0%	0.0%
Cyphastrea ocellina	0.0%	7.6%	4.8%	4.5%	**18.8%**	1.5%	0.9%	1.5%
Leptastrea purpurea	0.6%	1.0%	0.2%	0.2%	0.3%	7.3%	1.1%	3.6%
Fungia scutaria	0.0%	0.0%	0.5%	0.0%	0.9%	2.4%	0.0%	0.0%
Leptoseris incrustans	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
Pocillopora damicornis	0.0%	6.9%	0.7%	0.0%	6.4%	2.6%	8.5%	**13.4%**
Pocillopora eydouxi	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pocillopora ligulata	0.7%	0.4%	1.2%	0.0%	0.6%	0.1%	0.2%	0.5%
Pocillopora meandrina	**28.9%**	8.1%	6.5%	**17.4%**	1.1%	**26.2%**	**11.3%**	**52.4%**
Porites brighami	0.6%	1.1%	0.3%	3.8%	0.6%	0.0%	0.0%	0.0%
Porites compressa	3.8%	**15.9%**	**39.8%**	1.9%	9.7%	8.5%	6.3%	5.4%
*Porites evermanni**	2.0%	1.5%	1.3%	0.2%	**11.9%**	0.0%	0.1%	0.1%
Porites lobata	**55.3%**	**32.2%**	**20.1%**	**54.9%**	**20.6%**	**37.1%**	**55.9%**	**16.3%**
Psammocora nierstraszi	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Psammocora stellata	0.0%	0.1%	0.0%	0.2%	1.3%	3.3%	0.2%	1.1%
Palythoa sp.	0.6%	1.3%	1.0%	0.0%	0.0%	2.3%	0.1%	0.8%
Total cnidarians counted	689	2,408	2,443	426	1,920	2,319	1,158	1,929
Area surveyed (m^2)	100	500	450	100	450	650	425	450

*** Note:** *Porites evermanni* is considered to be *P. lutea* by *Fenner 2005.*

to Pearl and Hermes, inclusive). *Pocillopora meandrina* and *Montipora capitata* were both abundant at some locations but less common at others. Numerous taxa were represented throughout the NWHI at very low levels of abundance; although 57 species of stony corals have been documented in the NWHI (Maragos et al., 2004), many species occur at such low frequencies that they were not encountered within survey transect belts. Thus, relatively few coral species numerically dominate throughout the NWHI. When species are pooled by genus, *Porites*, *Pocillopora*, and *Montipora* collectively emerged as the numerically dominant genera throughout the NWHI though their relative abundance varied by location (Figure 9.30).

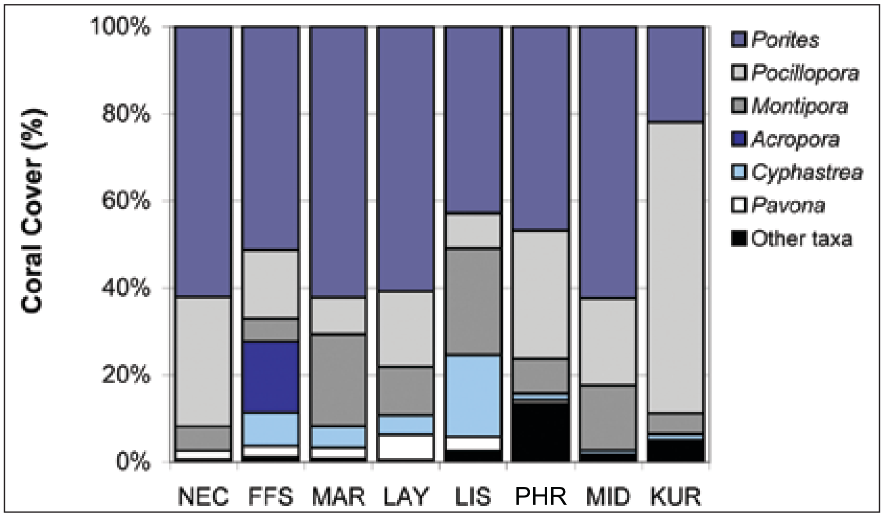

Figure 9.30. Relative abundance of coral genera in the NWHI. Data are derived from colony counts within belt transects during 2006 surveys. Source: PIFSC-CRED.

Coral colony size-frequency distributions can reveal important characteristics of reef communities, and can be used as a tool to estimate the response of coral populations to the environment. The size-frequency distributions of all cnidarians enumerated in belt transects throughout the NWHI in 2003, 2004 and 2006 indicate generally similar distributions in all three survey years, which in turn suggests stability in the complexity of the structural framework that provides shelter to numerous species of reef inhabitants.

Monitoring Corals at Permanent Transect Sites in the Northwestern Hawaiian Islands 2001-2006

This section focuses on the results of monitoring coral communities at 27 permanently marked transects established at seven NWHI reefs from 2001-2002 and resurveyed in September 2006. Friedlander et al., (2005) provides background information on the procedures used to establish permanent transects and the status of the communities at all 42 permanent transects from 2000-2002. Fifteen of the sites could not be resurveyed in 2006 due to time and logistical constraints.

Methods

Data collected during the surveys were used to compute the number of coral genera per transect, coral densities (number per m^2), mean diameter (cm), percent coral cover and size/population frequency distribution of corals and anemones reported on transects. The original surveys relied on post-hoc analysis of quadrat photos that had been scanned into a computer, however, surveys at the sites in 2006 relied on *in situ* censuses of corals, initially following the protocols described in Maragos et al. (2004) with subsequent modifications. Corals were censused within a meter-wide belt along the transect lines at all 27 permanent transects in 2006. Each coral whose center fell within one-half meter of either side of the transect line was assigned to a genus and one of seven size classes (1-5 cm, 6-10 cm, 11-20 cm, 21-40 cm, 41-80 cm, 81-160 cm and >160 cm) based upon the visually estimated length of each colony's longest diameter. Notes and digital photographs were also collected on and off transect to gain information on coral species diversity, disease, predation, etc.

Calculated estimates of coral cover at both REA and permanent transect sites using length-to-area conversions of size class data was proposed by Maragos et al. (2004). Percent coral cover data collected at 48 transects in the NWHI in 2000-2002 were used to calibrate an accurate length-to-area conversion based on measurements (to the nearest cm) of the colony's longest diameter collected from the same scanned photos. As with the *in situ* surveys, each coral in the quadrat photos was assigned to one of the seven classes and evaluated against the estimates using smaller length-to-area conversions. The calibrations resulted in the development of correction factors for length-to-area conversions by size class. These corrections and conversions are summarized in Table 9.8 and were applied to all permanent transect data from 2000-2006 to insure the consistency afforded by the use of a single technique. Figure 9.31 is a scatter diagram of the conversions in relation to the scanned estimates of percent coral cover.

Table 9.8. Size classes, mean diameter, and length-to-area conversions used for all coral NWHI permanent transects. The conversions are also used in the Pacific Remote Island Areas and Rose Atoll coral sections of this report. Source: J. Maragos.

SIZE CLASS	MEAN DIAMETER	AREA FORMULA		AREA/ CORAL
	$D=(n^{max} + n^{min})/2$	$A= (\pi r^2)/2$	$A'=(A^{max}+ A^{min})/2$[1]	
1-5 cm	3 cm	(1.5x1.5x3.14)/2	N/A	3.55 cm^2
6-10 cm	8 cm	(4x4x3.14)/2	N/A	25.1 cm^2
11-20 cm	15.5 cm	(7.75x7.75x3.14)/2	N/A	88.5 cm^2
21-40 cm	30.5 cm	(15x15x3.14)/2	N/A	353 cm^2
41-80m	60.5 cm	(30x30x3.14)/2	N/A	1,413 cm^2
81-160 cm	120.5 cm	(60x60x3.14)/2	(5,652+1,413)/2	3,532 cm^2
>160 cm	180 cm	(120x120x3.14)/2	(10,000+10,000)/2	10,000 cm^2

[1] Applies only to two largest size classes.

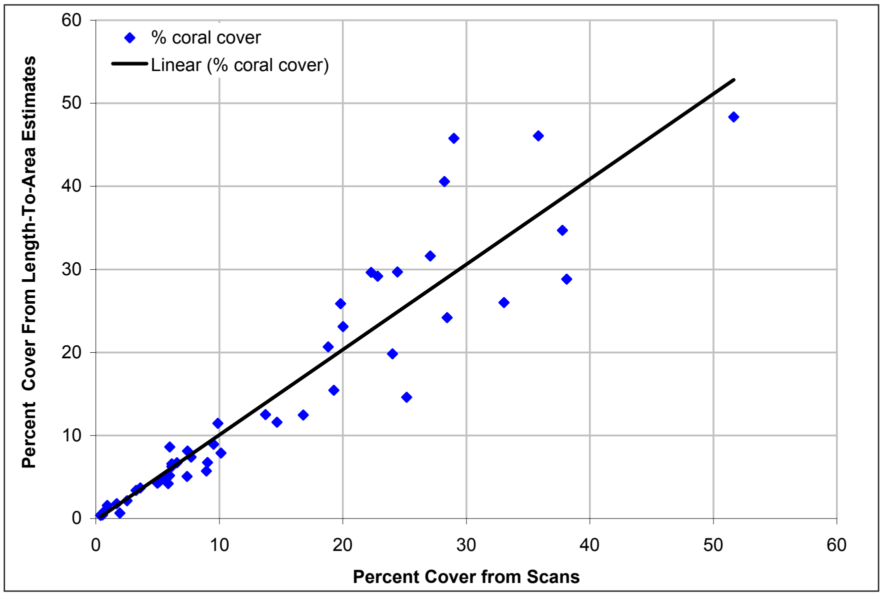

Figure 9.31. Scatter diagram of percent coral cover per site estimated from the sum of all coral areas inside all 2000-2002 NWHI photoquadrats using Sigma Scan™ software (x-axis), compared to estimates based upon assigning all scanned coral long diameters to the appropriate size classes and using the sum of length-to-area conversions in Table 9.9 to calculate percent cover for corals whose centers fell inside the quadrat frame (y-axis). N=48 transects, 1,937 m^2 and 9,264 corals. Source: Maragos, 2007.

Results and Discussion

Changes in percent coral cover, mean diameter, number of coral genera and the density of all corals per transect were compared between 2001-2002 and 2006 at permanent transects (Table 9.9; Figure 9.32). Mean coral cover declined by 2% from 2001-2002 to 2006 but was not significantly different (W=53, p=0.51). The mean colony diameter declined significantly (-15%) from 2001-2002 to 2006, while the mean number of coral genera (+46%) and density (+58%) both increased significantly over that same time period (W=236, p=0.004; t=2.26, p=0.03, respectively). Changes in the survey techniques between the two sets of surveys explain some of these patterns. For one, comparison of *in situ* census of corals in 2006 with analysis of photos would likely lead to the detection of more small coral genera, leading to lower mean diameter values. However, the analysis of the individual sites over time reveals that some of these trends can only be explained by changes in the coral populations.

Table 9.9. Percent coral cover, mean diameter, number of genera and frequency of all corals at each of 27 permanent transect sites surveyed in 2001-2002 and 2006. Bold numbers are the higher of two (earlier or later) values at each site. The asterisk (*) indicates that 2006 data not available at this site and the most current data collected in 2002 are instead provided. Source: Maragos, 2007.

SITE NUMBER	HABITAT	LOCALE	DATE	PERCENT CORAL COVER		MEAN DIAMETER CM		NUMBER GENERA/SITE		DENSITY (#/m^2)	
				2001-2002	2006	2001-2002	2006	2001-2002	2006	2001-2002	2006
FFS- 5P	fore reef	NW	7/17/2001	**19.4**	16.8	11.6	**13.3**	**4**	3	**14.2**	11.7
FFS 3P	lagoon basalt	N cen.	7/16/2001	27.7	**28.8**	**19.9**	17.8	5	5	8.5	**11.5**
FFS 16P	Lagoon	N	9/15/2001	4.8	**9.5**	12.3	**15.1**	**5**	4	4.6	**7.8**
FFS 2P	reef crest	S	7/15/2001	27.2	**33.5**	**26.2**	20.1	**7**	6	5.3	**9.4**
FFS 11P	back reef	N	10/30/2002	**39.1**	22	**76.2**	21.3	3	**4**	1.6	**5.9**
LAY 1P	channel	S	9/17/2001	**5.9**	5.1	7.7	**10.9**	3	**6**	**9.5**	4.9
LAY 5P	reef pool	SE	9/18/2002	7.7	**8.7**	11	**14.6**	3	**4**	**5.6**	4.8
LIS 1P	reef crest	S cen.	9/30/2002	**5.3**	0.43	**14.5**	4.6	2	**4**	**3.8**	0.36
LIS 9P	pinnacle	E	10/2/2002	19.2	**24.9**	**22.9**	16.3	2	**4**	5.1	**9.8**
LIS 6P	fore reef	N	10/1/2002	27.9	**46.8**	**57.4**	40.6	1	**3**	1.8	**4**
MAR 4P	back reef	NW	9/16/2002	**52**	34.4	**36.4**	20.6	3	**7**	6.4	**11.4**
MAR 5P	Lagoon	center	9/21/2001	4.2	**5.9**	**10.9**	10.3	2	**5**	3.8	**5.1**
MAR 1P	fore reef	SE	9/15/2002	**32.4**	7.9	**29.6**	9.3	3	**7**	4.6	**8.2**
MID 7P	Lagoon	E	9/23/2002	**50**	1.1	**25**	7.6	4	4	nd.	3.2*
MID 16P	back reef	N	12/3/2002	24.3	**36**	**46.7**	29.7	3	3	2.1	**5.8**
MID 14P	lagoon pinnacle	center	9/24/2002	4.7	**12.2**	8	**12**	2	**3**	**12.2**	9.5
MID 18P	back reef	NE	12/4/2002	0.7	**1.3**	6.8	**7.4**	4	**5**	2.5	**3.5**
MID 19P	lagoon pinnacle	SW	12/5/2002	**5.1**	0.9	**14.7**	13.1	2	**3**	**2.77**	1.02
MID 20P	back reef	NW	12/6/2002	**22.3**	19.2	**48.7**	31	**3**	2	1.46	**2.7**
MID 1Pa	reef crest	E	12/3/2002	**3.3**	1.04	**17.6**	11.7	2	**4**	1.73	**2.46**
MID 2P	back reef	NE	9/21/2002	13.8	13.8	**22.6**	21.3	4	4	2.8	2.8
MID 17P	back reef	E	12/4/2002	**9**	3.5	10.4	**20**	2	**4**	**4.6**	1
NEC 1P	basalt fore reef	S	9/9/2002	6	**14.6**	8.4	**10.6**	2	**4**	9.1	**18.4**
P&H 6P	lagoon pinnacle	S	9/19/2002	**2.53**	1.53	**11.7**	7.6	2	**4**	1.8	**4.8**
P&H 7P	lagoon patch reef	center	9/27/2002	**24**	20.7	**25.6**	10.1	1	**3**	**4.64**	19.8
P&H 9P	Pass	S	9/28/2002	**1.69**	0.23	**14.4**	9.5	2	**4**	**1.07**	0.4
P&H 12P	fore reef	SW	9/29/2002	**8.95**	7.11	**15.5**	11.1	3	**6**	3.15	**6.48**
TOTALS	**27**		**MEANS**	**16.64**	14	**22.69**	15.46	2.9	**4.3**	4.8	**6.7**

The 27 permanent transects resurveyed in 2006 represent two-thirds of the total established from 2000-2002 and accounts for only a small subset of the coral reef habitat in the NWHI. Consequently, a generalization on the overall status of the archipelago's reefs is not possible. The PIFSC- CRED program established an additional 60 permanent transects in 2006, and the results of the REA surveys are presented in the previous section. More than 100 total permanent transects will continue to be monitored in future years to better assess the status of the reefs within the newly established PMNM.

Towed-Diver Surveys

More than 200 towed-diver surveys were conducted throughout the NWHI during the period 2004-2006 (Table 9.6). Towed-diver surveys conducted in 2003, 2004 and 2006 replicated specific track lines surveyed in previous years as field efforts shifted from assessment to monitoring (Figure 9.33).

Detailed analysis of imagery recorded during 2003 throughout the NWHI has been completed, using a point-count methodology (Kohler and Gill, 2006) for images recorded at 30-second intervals (about 20 m distance). Percent coral cover estimates derived from these analyses (Figure 9.34) compare favorably with the relative ranking of regions as determined from estimates derived from REA surveys at fixed sites (Figure 9.29). Both methods indicate that Lisianski and Maro had the highest coral cover, with French Frigate Shoals ranking third. However, the magnitude of the estimates derived from the two methods differs, with towed-diver surveys yielding lower percent cover values than REA surveys. This difference is expected since towed-diver surveys assess all habitat types along a survey track, including soft bottom habitats, whereas REA surveys target only hard bottom communities.

At Pearl and Hermes Atoll, where benthic imagery recorded during surveys conducted in 2000 and 2002 has received detailed analysis (Kenyon et al., 2007), three genera – *Porites*, *Montipora* and *Pocillopora* – accounted for 97% of the coral cover throughout the atoll, though their relative abundances varied considerably according to habitat and geographic sector within habitats (Kenyon et al., 2007). Fore reef communities were dominated by massive and encrusting *Porites*, while the back reef was dominated by *Montipora* and the lagoon by *Porites compressa* (Figure 9.35). The relative abundance of dominant coral taxa at Pearl and Hermes differed considerably from coral dominance patterns at French Frigate Shoals (Kenyon et al., 2006c), particularly in back reef and lagoon habitats.

Algae

Quantitative algal monitoring continued during 2005-2006, with 39 sites visited by the PMNM in 2005 and 67 sites visited by the PIFSC-CRED in 2006. Continued use of the algal monitoring protocol developed in 2002 (Preskitt et al., 2004) assured uniformity of data for statistical temporal analyses. Qualitative assessment of study areas completed in conjunction with quantitative surveys allowed for the discovery of one species of red algae new to science, *Dasya atropurpurea* (Figure 9.36; Vroom, 2005).

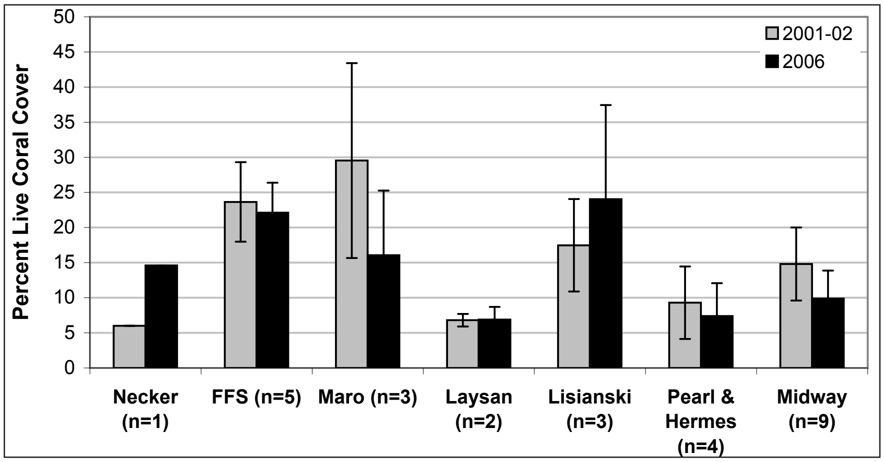

Figure 9.32. Mean (± SE) coral cover at permanent transects for seven reefs and atolls in the NWHI conducted in 2001-2002 and again in 2006. Numbers presented beside location names are the number of transects sampled at the site during each time period (n= 27). Source: Maragos and Veit, USFWS unpub. data.

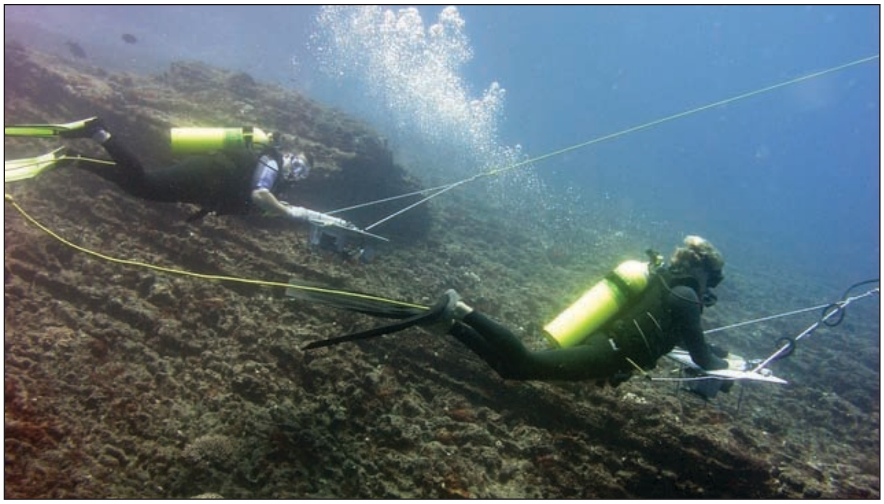

Figure 9.33. Divers survey a reef while being towed by a boat. Photo: J. Kenyon.

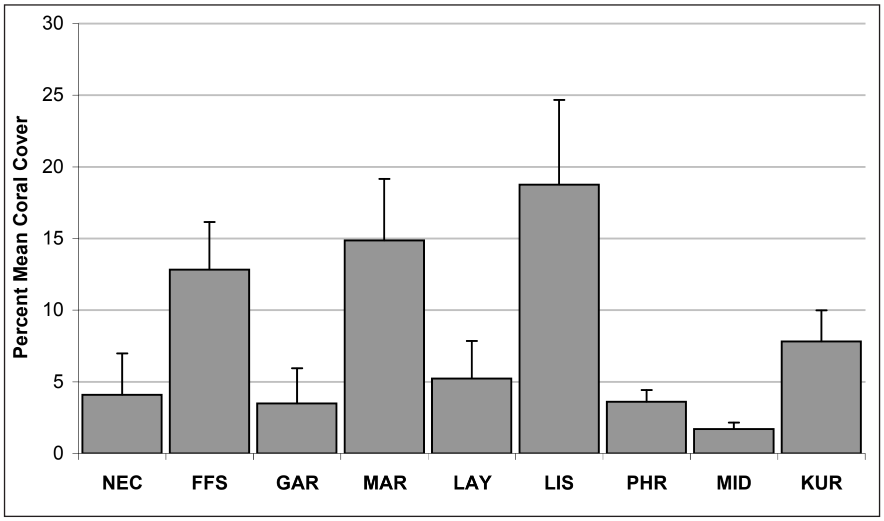

Figure 9.34. Mean coral cover (± SE) among locations in the NWHI. Coral cover was calculated from analysis of imagery recorded at 30-second intervals during towed-diver surveys conducted in 2003. Source: PIFSC-CRED, unpub. data.

Although the NWHI represent a relatively intact tropical reef ecosystem, macroalgal community dynamics of the 10 atolls, islands, and reefs situated in the PMNM remain poorly understood. A study published in conjunction with the Third Northwestern Hawaiian Islands Scientific Symposium (Vroom and Page, 2006) was the first to provide distributional maps of common algal species, statistically compare sites from differing habitats and islands based on relative abundance of macroalgae, and identify temporal differences in macroalgal populations. Findings revealed that the abundance of most macroalgal genera was low across the archipelago, but that members of certain green algal genera including *Halimeda* and *Microdictyon* can be abundant and in some cases form dense monotypic meadows on the reef, especially in fore reef areas (*Microdictyon*) and lagoons (*Halimeda*). Other genera, such as the brown algae *Stypopodium* and *Lobophora*, and the red alga *Laurencia*, became increasingly prevalent in the three northernmost atolls of the Hawaiian Archipelago (Kure, Midway, and Pearl and Hermes). Relative abundance of macroalgae across the NWHI as a whole remained relatively static for the years surveyed; however, slight changes occurred at Kure and Midway atolls, where coral bleaching events were documented in 2002 and 2004. Distributional maps of percent occurrence of 10 macroalgal genera spanning the years 2002 through 2006 are currently in production and will form part of PIFSC-CRED *Coral Reef Ecosystem Monitoring Report for the Hawaiian Archipelago: 2000-2007*.

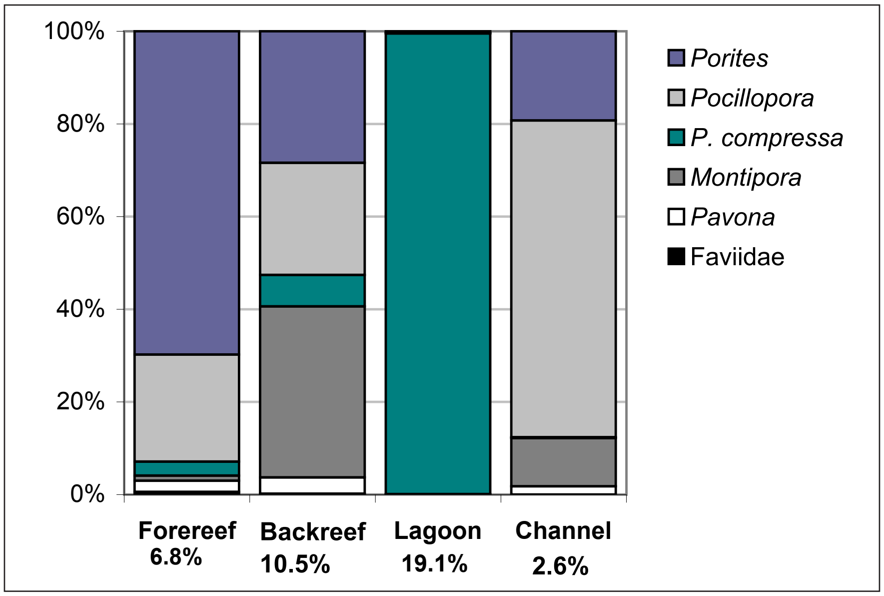

Figure 9.35. Relative abundance of primary coral taxa by habitat at Pearl and Hermes Atoll, NWHI, derived from towed-diver surveys conducted in 2000 and 2002. Values below habitat labels are total coral percent cover within each habitat. Porites *= massive and encrusting* Porites*;* P. compressa = Porites compressa. *Source: PIFSC-CRED, Kenyon et al., 2007.*

A study recently completed at Pearl and Hermes Atoll (Page, 2006) used detailed species-level percent cover analyses coupled with environmental variables to better understand the mechanisms that determine distributional patterns of organisms, particularly algae. Benthic community composition was examined along a wave exposure gradient using multivariate statistical analyses with the expectation that sites with similar levels of wave exposure would exhibit similar benthic communities. Species richness of coral and macroalgae were also compared to determine if sites with intermediate levels of wave exposure would contain the highest diversity of these benthic organisms. To test these hypotheses, percent cover of sessile benthic organisms was determined at 34 sites in four wave exposure categories: high, intermediate-high, intermediate-low and low. Multivariate statistical analyses revealed that sites from each wave exposure category differed significantly, and a non-metric multi-dimensional scaling ordination (nMDS) and cluster diagram grouped sites from low, high and intermediate-high wave disturbance areas into three relatively discrete clusters. However, sites experiencing intermediate-low wave exposure did not group together in the nMDS ordination or cluster diagram, suggesting variability in benthic composition among these sites. Coral and macroalgal species richness was significantly higher at sites with intermediate-high and intermediate-low levels of wave exposure than at sites with low wave exposure, although not significantly higher than sites with high wave exposure.

Figure 9.36. Recent surveys have found one species of red algae new to science, Dasya atropurpurea. *Photo: P. Vroom.*

Vroom et al. (2006) compared percent cover of macroalgal, turf algal, crustose coralline algal and coral populations at eight islands across the Pacific Basin, including two from the NWHI. The NWHI were documented to contain the highest percent cover of algal species when compared to other geographic locations, and the lowest percent cover of living coral. This is likely due to the subtropical location of the NWHI, which exposes reef communities to cool SSTs and relatively frequent extreme high wave energy events during winter months. Despite high algal populations, the NWHI remain healthy and thriving marine ecosystems that are dominated by top predators and high fish populations.

Habitat Mapping

In support of the U.S. Coral Reef Task Force's mission to produce comprehensive digital maps of all shallow (<30 m depth) coral reef ecosystems in the United States and characterize priority moderate-depth (20-200 m) reef systems, NOAA has undertaken a comprehensive and collaborative mapping effort in the Pacific Islands Region. As key products of these efforts, NOAA's Center for Coastal Monitoring and Assessment, Biogeography Branch (CCMA-BB) produced a draft of the *Atlas of the Shallow-Water Benthic Habitats of the Northwestern Hawaiian Islands* (NOAA, 2003; Figure 9.37) and continues to provide public access to imagery, digital data, map products and estimated water depths for shallow-wa-

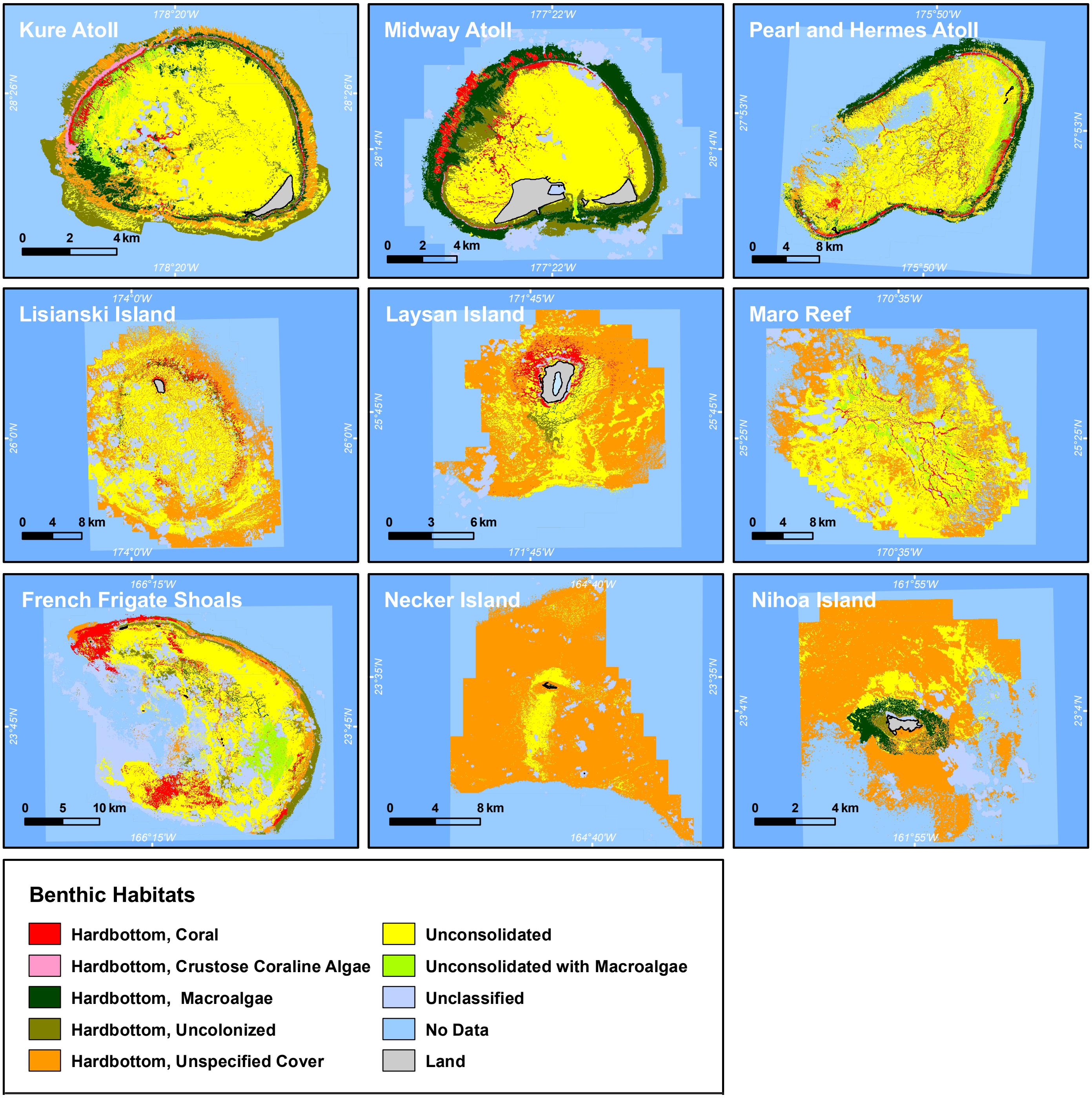

Figure 9.37. Benthic habitats in the NWHI by major habitat type. Data source: NOAA, 2003. Map: K. Buja.

ter areas derived from IKONOS imagery by Stumpf et al. (2003). In a complementary effort, PIFSC-CRED produced *The Bathymetric Atlas of the Northwestern Hawaiian Islands* (Miller et al., 2003), which focuses on moderate-depth areas. Bathymetric data from 2003-2006 collected during NOAA Ship *Hiialakai* and R/V *Acoustic Habitat Investigator* surveys add to previously published reports. Table 9.10 presents the current status of multibeam bathymetric mapping in the NWHI.

Table 9.10. NWHI Multibeam mapping statistics and estimates. Source: PIBHMC.

	MAPPING COMPLETED 2002-2006		ESTIMATE TO COMPLETE
	km^2	Days	Days
Deep (100-5000 m)	38,367	25	70
Mid-Depth (10-100 m)	3,709	124	285
Totals	42,076	149	355

Bathymetric grids at various resolutions are updated annually by the Pacific Islands Benthic Habitat Mapping Center (PIBHMC) and published at http://www.soest.hawaii.edu/pibhmc. Some bathymetric data have been collected and processed around each of the islands and banks in the NWHI in water depths ranging from 3-1000 m, with almost complete coverage around Kure, Midway, Pearl and Hermes, Brooks Banks, and French Frigate Shoals, and partial coverage at other locations. High resolution bathymetric surveys provide baseline depth data, as well as visual indications of the composition and features of the seafloor. The large bank on the southwest side of French Frigate Shoals, which lies in water depths between 15 and 100 m, was the first area to be thoroughly mapped in early 2005 and is used here to illustrate the various benthic habitat mapping products, their potential uses, and interpretation (Figure 9.38). Similar products for other banks are regularly added to the Web site as mapping, data processing, product and metadata generation, and interpretation are completed. As shown in Figure 9.38, the multibeam bathymetric data show complex patterns of sand waves, ridges and other bathymetric features, some of which are interpreted as coral patch reefs and confirmed with sparse optical validation observations. Bathymetric and optical validation data at French Frigate Shoals indicate the widespread presence of coral habitats in water depths as great as 40 m. Bathymetric and optical validation data from other NWHI banks and atolls also show a varying amount of complex hard substrate in these depths that may indicate coral presence.

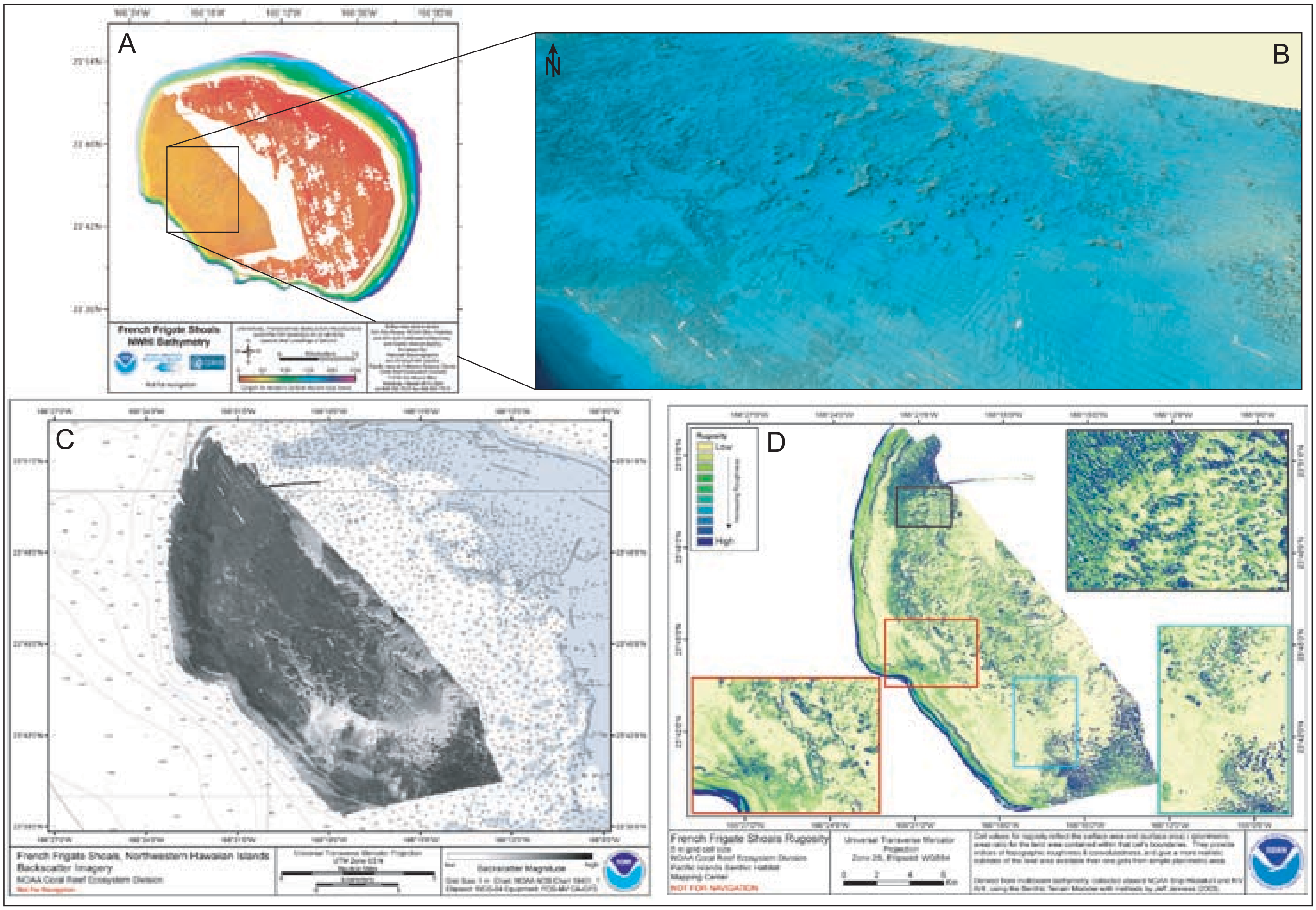

Figure 9.38. Multibeam bathymetric data at French Frigate Shoals show complex seafloor features including sand, waves and coral heads and ridges. Box outlined in panel A indicates location of detailed bathymetric image in panel B. Panel C shows multibeam backscatter data, which provide additional information about the hardness and roughness of the seafloor. High backscatter returns (dark) indicate hard substrate (e.g., pavement or coral), while lower returns (light) indicate softer substrate (e.g. sand). Panel D shows derivative data products (e.g., slope, rugosity and Bathymetric Position Index) which help identify geomorphological characteristics that may determine benthic habitat utilization. French Frigate Shoals shows high rugosity in many areas of the bank top, corresponding to areas of high bathymetric complexity and possible coral presence. Source: PIBHMC.

Optical validation data (Figure 9.39) that have been collected since 2001 at French Frigate Shoals aid scientists in interpretation of seafloor characteristics. Video and still photographic data are interpreted according to a benthic habitat classification scheme that was designed to include indications of substrate, living cover, coral type and other factors that may influence habitat utilization, as documented at ftp://ftp.soest.hawaii.edu/pibhmc/website/webdocs/webtext&figures/bh_class_codes.htm. While the individual data products, such as multibeam bathymetry, backscatter, geomorphological derivatives, and optical validation, are useful individually, combining the different data types allows interpretation of seafloor characteristics and creation of seafloor characterization maps, such as in Figure 9.40. This interpretation of soft and hard substrate results from concurrent analysis of bathymetric, backscatter and optical validation data.

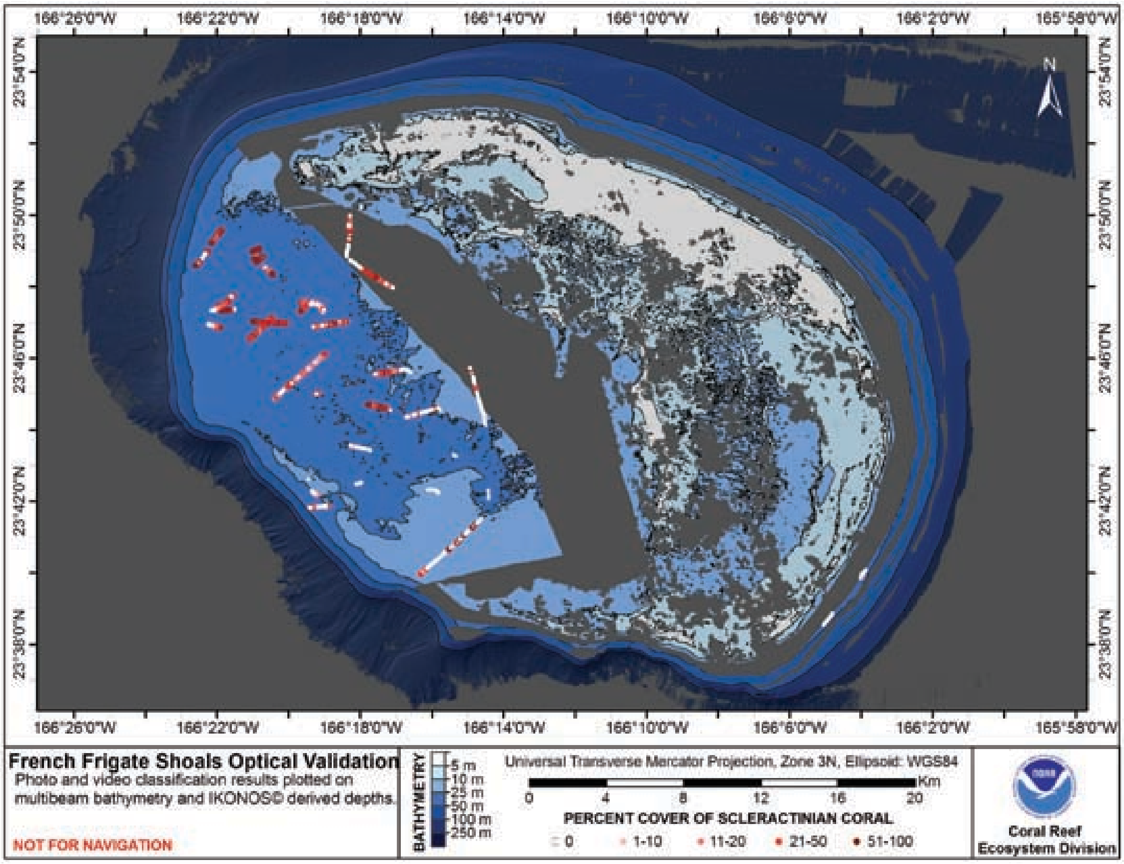

Figure 9.39. Percent coral cover as interpreted from optical validation data collected at French Frigate Shoals. Source: PIFSC-CRED.

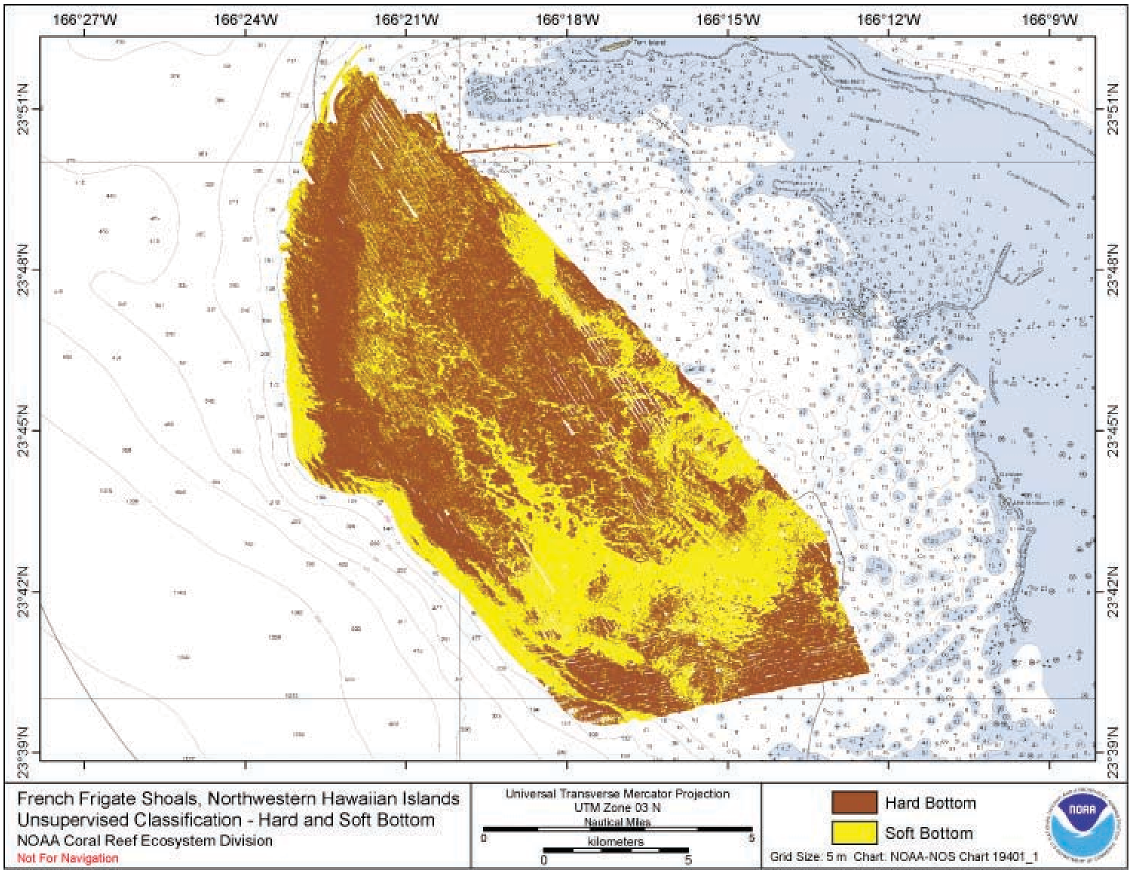

Figure 9.40. Preliminary hard and soft seafloor substrate map derived from an unsupervised classification of multibeam backscatter and bathymetry derivatives at FFS. Initial supervised classifications of backscatter data into hard and soft areas based on photographs were used to define the unsupervised class types and to evaluate map accuracy. Derivatives such as these are being used to improve sampling techniques for long-term ecosystem monitoring, to guide future groundtruthing operations, and to identify coral-rich and species specific environments in the NWHI. Source: PIFSC-CRED.

ASSOCIATED BIOLOGICAL COMMUNITIES

FISHES

Fish Assemblage Structure

The similarity of fish assemblages among reefs in the NWHI was compared based on numerical abundance of each species at each reef (Figure 9.41). The three true atolls (Kure, Midway, and Pearl and Hermes) and the one partial atoll (French Frigate Shoals) had high concordance and formed a distinct cluster in ordination space. The three basalt pinnacles (Nihoa, Necker and Gardner) were also similar in their fish assemblages (based on numerical density) but differed from each other more so than did the three atolls, resulting in lower spatial concordance. Maro Reef and Lisianski Island-Neva Shoal had similar fish assemblages and clustered together in a distinct grouping. Laysan Island is the only coral cay in the NWHI and had a somewhat unique fish assemblage.

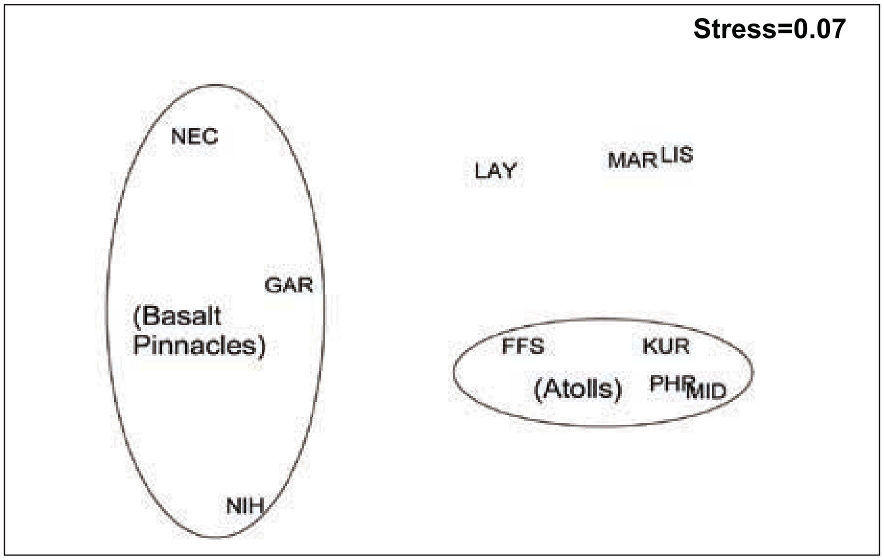

Figure 9.41. Non-metric multi-dimensional scaling plot of reef similarities derived from numerical abundance of fish species. Similarities based on Bray-Curtis Similarity Index. Numerical abundance values are square root transformed. Source: Friedlander and DeMartini, in prep.

Species Richness Patterns of Reef Fishes

A total of 612 reef and shore fishes have recently been reported from the MHI (Randall, 2007) while 258 are documented from Midway Atoll in the NWHI (Randall et al., 1993). Despite these differences, the total number of species observed on quantitative transects in the NWHI (n=210) was similar to the 215 species reported in a recent comprehensive quantitative study around the MHI (Friedlander et al., 2005, 2007). The lowest overall fish species richness in the NWHI occurs at the small basalt islands (Nihoa, Necker and Gardner) and is highest at French Frigate Shoals and Pearl and Hermes. The values at French Frigate Shoals may be related to the higher coral richness and greater diversity of habitats (Maragos et al., 2004) while high values at Pearl and Hermes is likely related to the atoll's large size, habitat diversity and presence of subtropical and temperate species which occur at greater depths southward.

Total species richness observed on surveys showed a positive and linear relationship with the total area of reef in waters <18 m (ln(x+1); Figure 9.42). This relationship is consistent with most theories of island biogeography and likely reflects the greater diversity of habitats at larger islands.

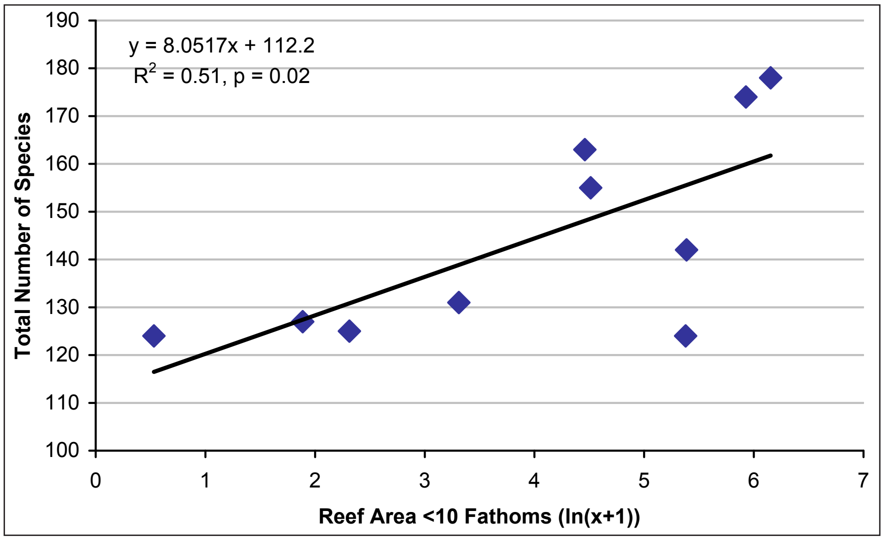

Figure 9.42. Relationship between number of fish species at each reef and total reef area <18 m (10 fathoms). Source: Friedlander and DeMartini, in prep.

Biogeographic Patterns Based on Latitude

A total of 30 species showed a significant positive correlation (Spearman Rank Correlation, $p<0.05$) with latitude based on numerical density from Northwestern Hawaiian Resource Assessment and Monitoring Program (NOWRAMP) quantitative fish surveys between 2000 and 2002. Of these, 17 (57%) were endemics. Wrasses (Labridae) had the greatest number of species (eight) that exhibited a higher latitude bias, followed by damselfishes (Pomacentridae) with four species. Several other species such as knifejaws (*Oplegnathus* spp.) and boarfish (*Evistias acutirostris*), were more abundant at higher latitudes but the low numbers of these species recorded during surveys made statistical results inconclusive.

Over 63% of the total numerical abundance of fishes at Kure Atoll was composed of species with a high latitude correlation (Figure 9.43). The percentage of high latitude biased individuals was also substantial at Midway Atoll (56%), Pearl and Hermes Atoll (52%), and Lisianski Island-Neva Shoals (53%). A major faunal break seems to occur between Maro Reef and Gardner Pinnacles with the numerical abundance of high latitude bias species dropping from 52% to 25% between these two locations. The lowest percentage of high latitude biased individuals was observed at Nihoa Island (13%). According to this analysis, another less dramatic faunal break seems to be present between Nihoa (13%) and Mokumanamana (Necker Island; 28%).

Of the 30 species analyzed, 21 were significantly and positively correlated ($p<0.05$) with low latitudes based on numerical density from NWHI RAMP quantitative fish surveys between 2000 and 2002. Only two of these species (9%) were endemics in contrast to the species with high latitude bias, where 54% were endemic. Based on total numerical abundance, the highest percentage of low latitude species was observed at Mokumanamana (28%) and Nihoa (14%; Figure 9.43). Less than 1% of the numerical density of fishes at Midway consisted of species with a low latitude preference. Similarly, Kure Atoll (1.2%), Pearl and Hermes Atoll (2.0%) and Lisianski Island-Neva Shoals (3.2%) had low numbers of more tropical fish species.

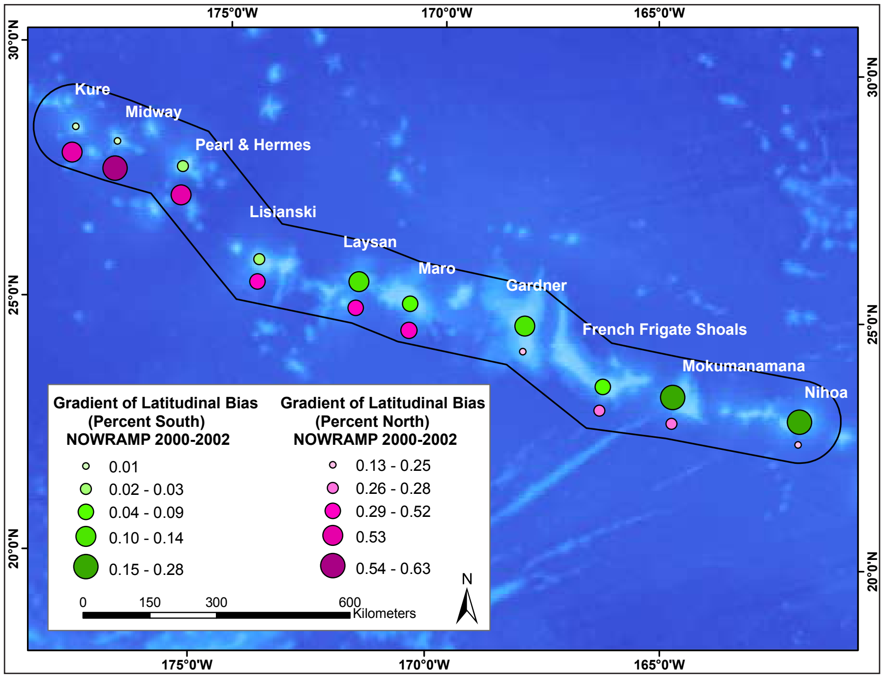

Figure 9.43. Latitudinal bias of reef fishes in the NWHI. Green circles are percentages of species that have a significant tropical bias. Pink circles are percentages of species that have a significant temperate bias. Source: Friedlander and DeMartini, in prep.

Temporal Trends in Fish Assemblages 2000-2005

Fish assemblage structure in the NWHI was examined for temporal trends between 2000 and 2005. Analysis was limited to only those reefs and stations that were initially sampled during the 2000-2002 assessment phase and then sampled again in subsequent years. Under these criteria, reefs examined included Maro, French Frigate Shoals, Pearl and Hermes, Kure and Midway. At each of these reefs, stations were only included that were sampled initially (2000-2002) and again in all subsequent years (2003, 2004 and 2005).

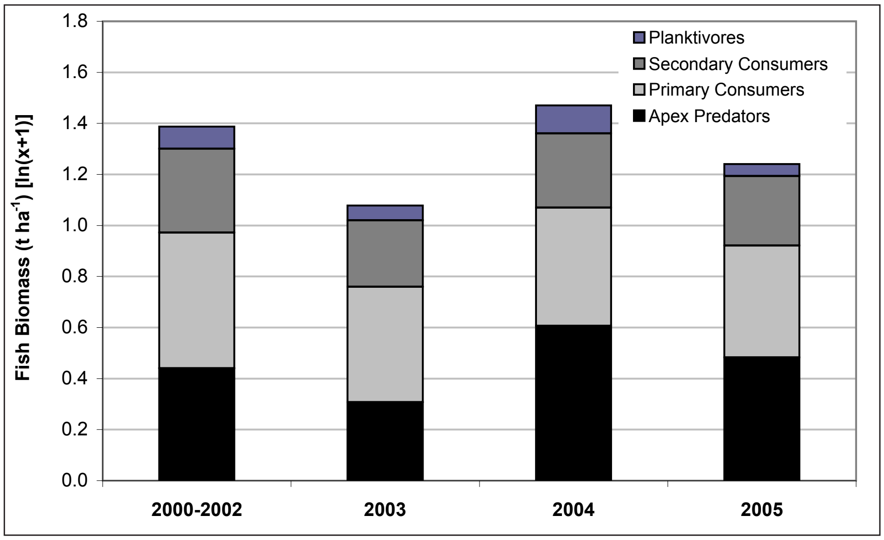

Figure 9.44. Fish biomass and trophic guilds from 2000-2005. Analysis limited to locations initially sampled during the 2000-2002 assessment phase and sampled again in subsequent years. Source: PIFSC-CRED, unpub. data.

Overall, apex predators accounted for 35% of the total biomass at long-term sites sampled in all years (Figure 9.44). Many of the sites visited consistently were lagoon and back reef locations in addition to some fore reef sites. Protection from surf meant that these sites could be sampled on a more regular basis than some of the fore reef locations, which were exposed and inaccessible during certain years. Apex predators account for over 55% of the total biomass on the fore reef (Friedlander and DeMartini, 2002) and the lower values observed in sheltered sites reflect a greater sampling effort in habitats that normally harbor fewer predators. Primary consumers comprised 38% of the total biomass across all monitoring sites in this analysis and is likely related to the higher abundance of macroalgae cover and hence increased food availability in these sheltered habitats. Overall abundance of planktivores (6%) is lower in sheltered habitats where plankton availability is lower.

There were no significant differences in the biomass among years for apex predators ($F_{3,215}=2.48$, $p=0.06$), planktivores ($F_{3,215}=2.29$, $p=0.08$), primary consumers ($F_{3,215}=0.92$, $p=0.43$), or secondary consumers ($F_{3,215}=1.25$, $p=0.29$). However, total biomass among years was marginally significantly different ($F_{3,215}=2.81$, $p=0.04$) but the only significant pair-wise difference was between 2004 and 2003 (2004>2003, $p<0.05$). This difference was driven mainly by lower apex predator biomass values recorded in 2003.

Movement Patterns of Top Predators

In 2005 and 2006, 122 top predators of seven species with surgically-implanted acoustic transmitters were monitored for movement using 17 underwater receivers stationed on the seabed at five atolls within the PMNM. In 2006, nine sharks (five tiger sharks and four Galapagos sharks) were equipped with satellite transmitters to monitor their movements in locations not equipped with acoustic receivers. Using these technologies, tiger sharks were found to routinely swim between atolls, range along the entire Hawaiian archipelago and venture hundreds of kilometers beyond PMNM boundaries into open ocean. The first empirical evidence of gray reef sharks swimming across open ocean between atolls was also documented.

Other top predator species appeared to be site-attached to individual atolls, but wide-ranging within their "home" atoll (Meyer et al., 2007a,b). Ulua (giant trevally, *Caranx ignobilis*) and uku (jobfish, *Aprion virescens*) had predictable patterns of movement, including diel habitat shifts and tidal and lunar rhythmicity (Figure 9.45; Meyer et al., 2007a). During summer full moons, ulua from all over French Frigate Shoals converge on one particular location, where they form large spawning aggregations (Figure 9.46, Meyer et al., 2007a).

Recruitment

Planktonic dispersal of reef fishes is an important process linked to the persistence of benthic reef populations. Recruitment of reef fishes increased with latitude, and was especially pronounced at the four northernmost reefs, which had a larger proportion of young-of-year (YOY) recruits (DeMartini and Friedlander, 2004). During 2000-2002, recruit fish densities were somewhat greater to the northwest portion of the archipelago compared to the southeast, and a larger number of endemic (versus non-endemic) species recruited to a greater extent in the northwest portion of the NWHI (Figure 9.47; DeMartini and Friedlander, 2004). This was first indicated by survey data collected during the 1990s at French Frigate Shoals and Midway (DeMartini et al., 2002; DeMartini, 2004), where consistently higher recruitment of YOY life stages of fishes occurred at Midway Atoll, despite the generally greater densities of older-stage fishes at French Frigate Shoals.

Disproportionate recruitment at higher-latitude reefs may be related to higher levels of within-reef and regional reseeding at higher latitudes. Ecologically significant levels of dispersal have been documented to be on the scale of 50 to 100 km for most species with a relatively high rate of local retention or recruitment from adjacent locations (Cowen et al., 2006). Hence, based on the genetic evidence, current patterns and scales of ecological connectivity, the NWHI are not likely a sufficient or consistent source to replenish stocks in the MHI, although sporadic contributions are possible and need to be investigated more thoroughly (Grigg et al., 2008).

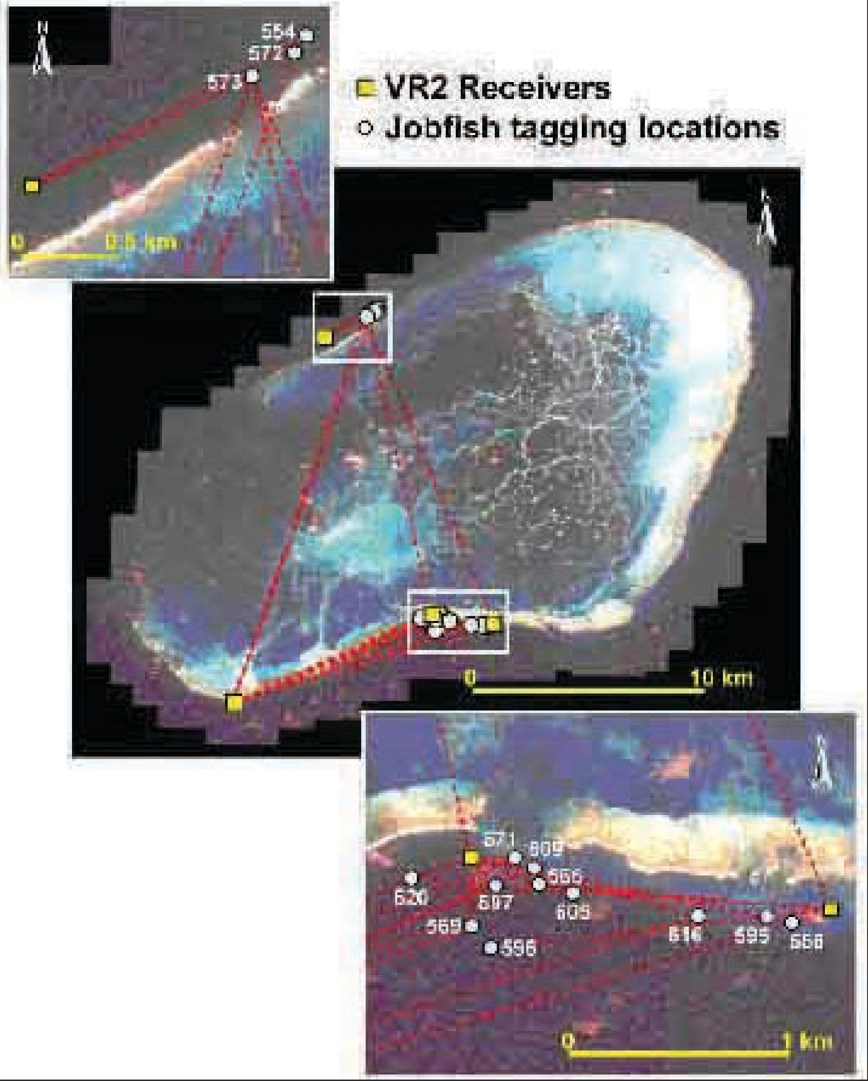

Figure 9.45. Trans-atoll movements of uku (green jobfish, Aprion virescens*) at Pearl and Hermes Reef. Yellow squares indicate locations of VR2 acoustic receivers, white circles indicate uku capture sites. Insets show enlarged view of capture areas with white numbers indicating the transmitter code of each uku. Dashed red lines indicate most direct route between uku release and detection locations. Source: Meyer et al., 2007b.*

*Figure 9.46. Spawning aggregation of giant trevally (*Caranx ignobilis*) at French Frigate Shoals, May 23, 2006. Photo: Jill Zamzow.*

Connectivity Studies

Molecular genetic markers are currently being examined to resolve population and evolutionary partitions of fishes and invertebrates in the NWHI. Preliminary results indicate large differences among taxa in their degree of genetic connectivity throughout the archipelago. Some species appear to move around the archipelago with relative ease and show no significant genetic population structure in the NWHI and MHI (e.g., reef fish–Schultz et al., 2007; Craig et al., 2007). Other species show strong population structure, including the endemic Hawaiian grouper (Rivera et al., 2004) and spinner dolphins (Andrews et al., 2006).

Opihi, the endemic Hawaiian limpets (*Cellana exarata*, *C. sandwicensis* and *C. talcosa*) show striking population differentiation between the MHI and NWHI (Bird et al., 2007; Figure 9.48). For all three species, significant differentiation of populations occurs across the Hawaiian Archipelago, but the spatial scales, patterns and magnitudes of partitioning differ by almost an order of magnitude among species. Preliminary data from hermit crabs (Baums et al., unpub. data) indicate variable genetic connectivity in this group as well. In terms of management implications, there is significant population differentiation between the MHI and NWHI for all three species of opihi, and estimates of dispersal (migrants per generation ≤3) are too low to augment depleted MHI populations. Within the MHI, one species (*C. talcosa*) shows such strong population differentiation that if the Kauai population were depleted, the species could not likely recover within our lifetime (Bird et al., 2007).

Johnston Atoll, about 1,300 km southwest of Oahu, shows a strong biodiversity linkage with the Hawaiian Archipelago (Figure 9.49). Kobayashi (2006) used a computer simulation to infer patterns of larval dispersal between Johnston and the Hawaiian Archipelago, identifying a "northern corridor" which connects Johnston and the central portion of the NWHI and a "southern corridor" which connects Johnston to the MHI. Preliminary genetic data for the sea cucumber *Holothuria atra* showed that connectivity is very low between Oahu and French Frigate Shoals and between Oahu and Johnston. (Skillings et al., in prep.). In contrast, there was no significant difference between samples from French Frigate Shoals and Johnston. This supports the northern corridor theory of dispersal and a hypothesis first advanced by Grigg (1981) that Johnston is a potential gateway for enhancing biodiversity in the NWHI.

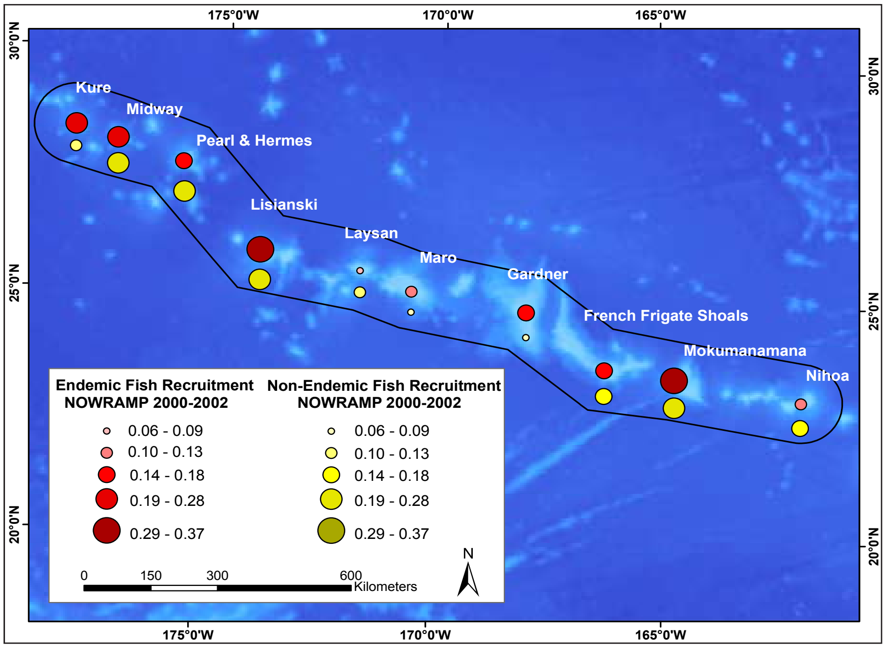

Figure 9.47. Geographic patterns of the Recruit Index (ratio of YOY sized to larger individuals) for all pooled major species of endemic and non-endemic reef fishes. Source: DeMartini and Friedlander, 2004.

*Figure 9.48. A yellowfoot opihi (*Cellana sandwicensis*) at Kauai. All Hawaiian *Cellana* spp. are endemic to the archipelago (left). Photo: C. E. Bird. Tinker's butterflyfish (*Chaetodon tinkeri*) at Johnston Island (right). This species is endemic to Johnston and the Hawaiian Islands, illustrating the biodiversity links between the two regions. Photo: L.A. Rocha, HIMB.*

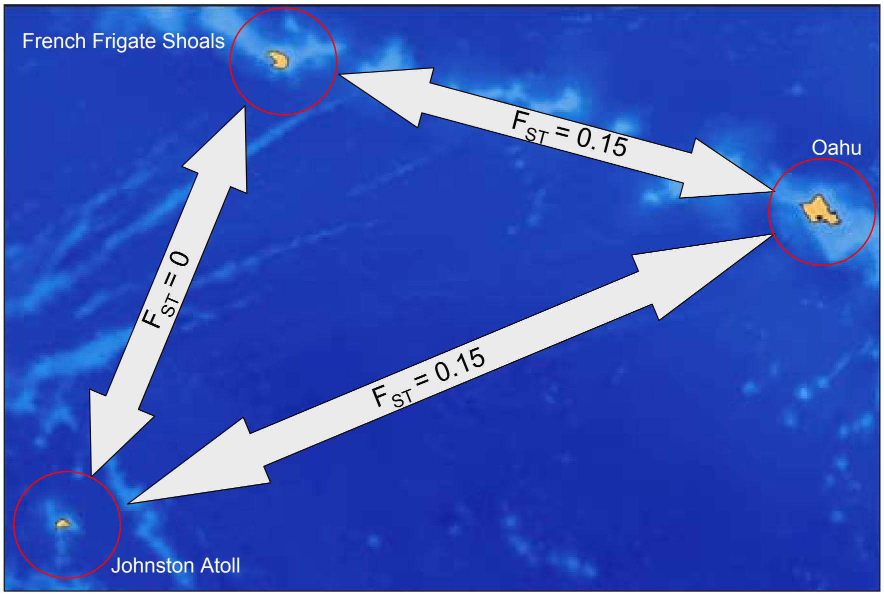

Figure 9.49. F-statistics demonstrate population genetic separations between the Oahu (MHI) and French Frigate Shoals (NWHI), and between the MHI and Johnston, but high connectivity between Johnston and French Frigate Shoals. Source: Skillings et al., in prep.

Results thus far indicate that population structure across the Hawaiian Archipelago does not fit a simple isolation-by-distance model, and generalizations based on average (geostrophic) oceanographic currents may not be warranted. Closely-related species with similar ecology and reproductive biology (such as opihi and hermit crabs) can have dramatically different patterns of genetic connectivity (Bird et al., 2007; Rocha et al., 2007). Together, these results necessitate that a suite of invertebrates and fishes be surveyed to resolve general trends, and to provide connectivity information pertinent to management of the PMNM (Figure 9.48).

Coral Ecosystem Health and Value

An evaluation of the “health” and “value” of the reefs of the PMNM was conducted using previously published data on reef fish biomass, reef fish endemism, total living coral cover, numbers of the endangered Hawaiian monk seal (*Monachus schauinslandi*), and number of female green sea turtles (*Chelonia mydas*) nesting annually on each island as metrics (Jokiel and Rodgers, 2007). These data sets were used to construct an integrated scoring and ranking scheme for all islands. Results show that French Frigate Shoals had the highest score among all NWHI reefs, followed by Pearl and Hermes Atoll and Lisianski/Neva Shoal (Figure 9.50). These locations possess the largest reef area within the Monument and also contain a wide diversity of habitats including sheltered lagoons, sandy beaches and patch reefs. The two basalt islands of Nihoa and Necker had the lowest scores due to the limited nesting habitat available to turtles and seals, the small amount of shallow reef habitat and a lack of sheltered areas.

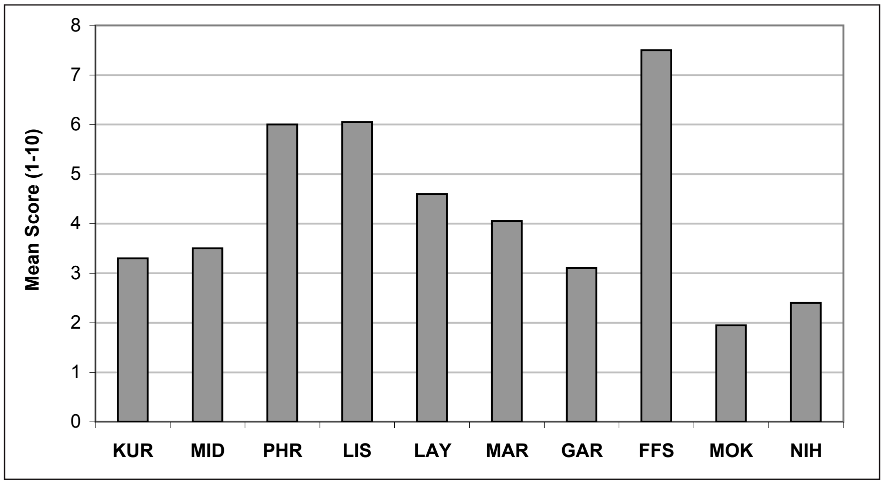

Figure 9.50. Island ranking in the PMNM. Mean score based on scale of 0-10. Source: Jokiel and Rodgers, 2007.

NON-CORAL INVERTEBRATES

Recent efforts to quantify the non-coral invertebrate populations in the NWHI included two broad-scale towed-diver surveys conducted in 2004 and 2006 and a REA survey conducted in 2005. Surveys were focused on collecting information on three target classes of invertebrates: Echinoidea (sea urchins), Holothuroidea (sea cucumbers) and Asteroidea (sea stars). Towed-diver surveys found densities of echinoids and holothuroids to be highest at the northernmost islands/atolls. Sea urchins were the most common invertebrate observed during these surveys, with Kure (2004 and 2006) and Midway (2006) reporting the highest densities in the island chain (>1,600 urchins/hectare; Figure 9.51). Sea cucumbers were present at all islands but in low densities, with the exception of the northern atolls. The highest sea cucumber density was recorded at Kure in 2006 (Figure 9.51). Crown-of-thorns sea stars (COTS), were in relatively low abundance throughout the archipelago with the highest density recorded in 2004 at Pearl and Hermes (Figure 9.51). Though abundance of COTS was relatively low in comparison with reported infestation levels in areas of high coral cover such as the Great Barrier Reef, the impact of even low numbers of COTS in the NWHI could be significant given the relatively low coral cover found throughout the NWHI.

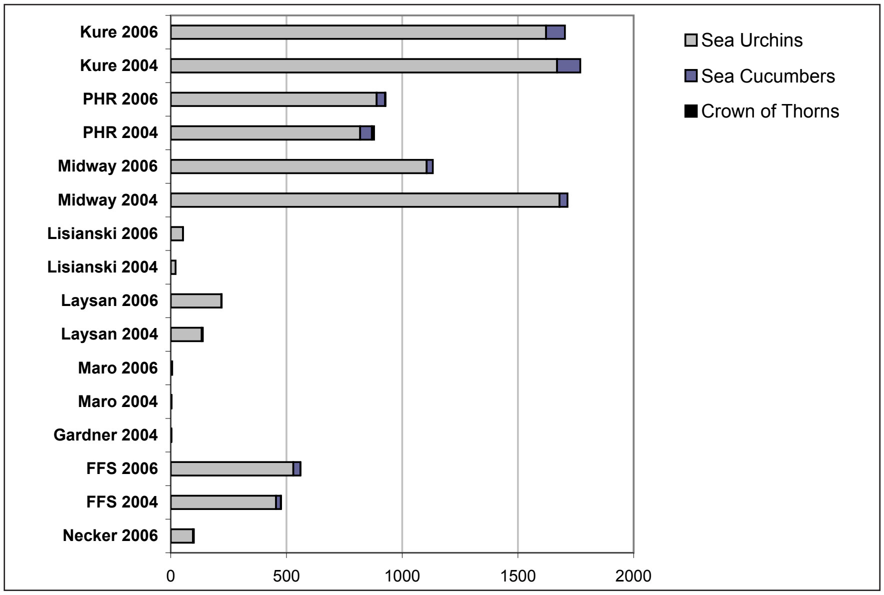

Figure 9.51. Mean number of echinoids, holothuroids, and asteriods per m^2 in the NWHI from towed-diver surveys. Source: PIFSC-CRED, unpub. data.

Data collected during REA surveys included species level information on the three target classes of invertebrates and followed the general patterns of the towed-diver data (Figure 9.52). The most common echinoid throughout the NWHI was the burrowing sea urchin, *Echinostrephus* sp., with the highest densities recorded at Midway and Kure (>12 individuals/m^2; Figure 9.52). As in towed-diver surveys, sea cucumbers were present at all islands/atolls but in low densities. The most common sea cucumber was *Actinopyga obesa*, with a density of 0.03 individuals/m^2 at Kure. The most common sea star was *Linckia multifora*.

Census of Marine Life (CoML)

The international CoML is a global effort to assess the diversity, distribution, and abundance of ocean life and explain how it changes over time. Over 1,700 scientists from 73 countries are pooling their findings to create a comprehensive and authoritative portrait of life in the oceans today, yesterday and tomorrow. As one of 17 projects of the CoML, the goals of the Census of Coral Reef Ecosystems (CReefs) are to increase tropical taxonomic expertise, conduct a taxonomically-diversified global census of coral reef ecosystems and unify and improve access to coral reef ecosystem information scattered throughout the world. As part of the CReefs effort, PIFSC-CRED led a multi-institutional team of international taxonomists on a 23-day research expedition in October 2006 to explore the biodiversity of small, understudied, or lesser known invertebrate, algal and microbial species at French Frigate Shoals. In an effort to maximize the ability to document biodiversity, surveys were conducted at over 50 sites representing 14 habitat types using 12 sampling methods, including baited traps, rubble brushing, rubble extraction, underwater vacuuming, plankton tows, light traps, sediment and water sampling and other methods specifically designed to minimize habitat impacts while maximizing the number of ecological niches sampled.

Although thorough taxonomic identifications and molecular analyses of the samples collected will take many years to complete, preliminary findings suggested that approximately 2,300 unique morphospecies were collected and photographed during the 16 days of sampling (Figure 9.53). To improve the long-term ability to monitor biodiversity, tissue samples for molecular barcoding were collected from about 60% of the unique morphospecies. An estimated 30-50 collected specimens are thought to be new species to science, including new species of crabs, corals, sea cucumbers, sea quirts, worms, sea stars, snails and clams. From this expedition, well over a hundred new species records, including sponges, corals, anemones, flatworms, segmented worms, hermit crabs, crabs, sea slugs, bivalves, gastropods, octopus, sea cucumbers, sea stars and sea squirts, will likely be identified for FFS. The highest sampled diversity at FFS was within the phyla Anthropoda and Mollusca. By habitat type, lagoon patch reefs, La Perouse Pinnacle (basalt), back reef and deep fore reefs had the highest diversity. Due to the high level of taxonomic expertise, hand collection was the most effective sampling methodology, following by rubble extraction, rubble brushing and use of baited traps.

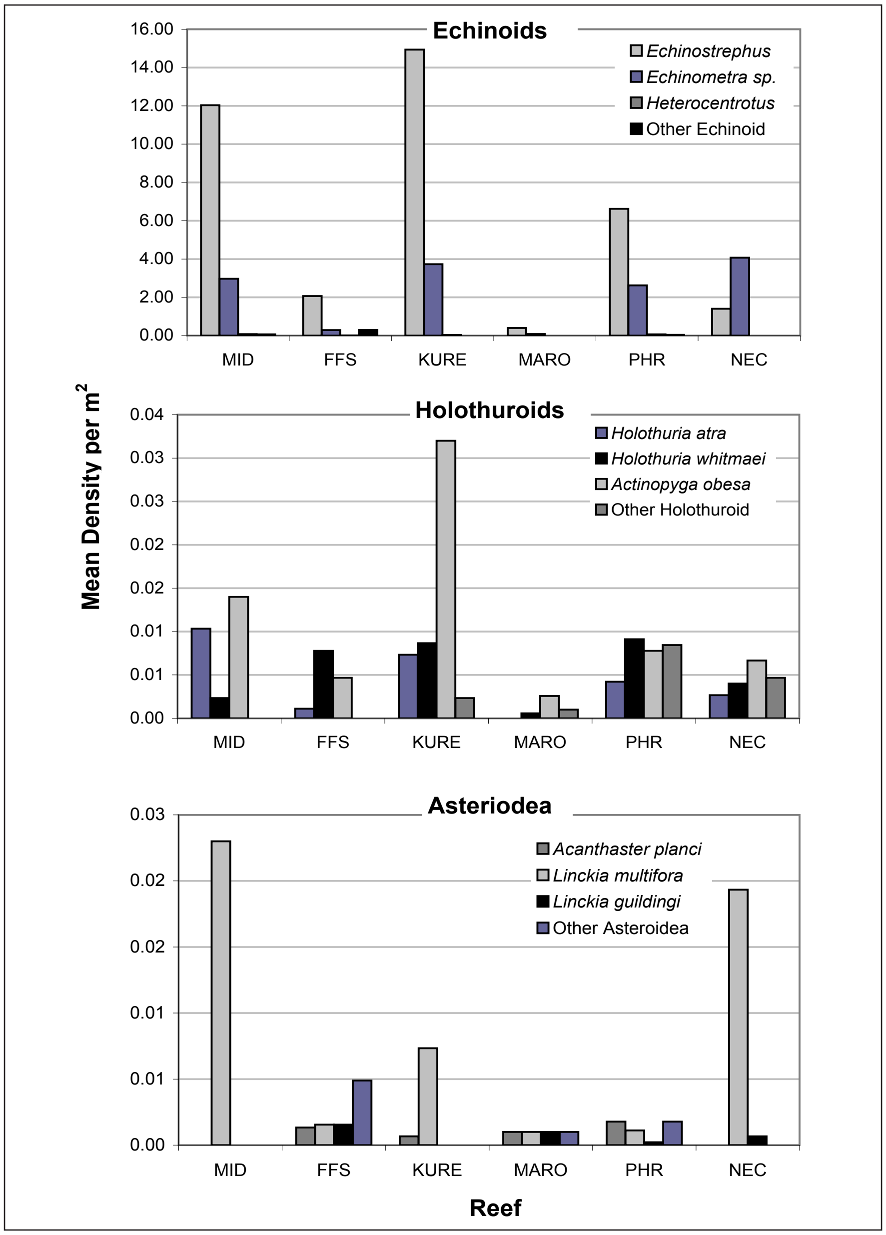

Figure 9.52. Mean density of echinoids, holothuroids and asteriods per m² in the NWHI. Source: PIFSC-CRED, unpub. data..

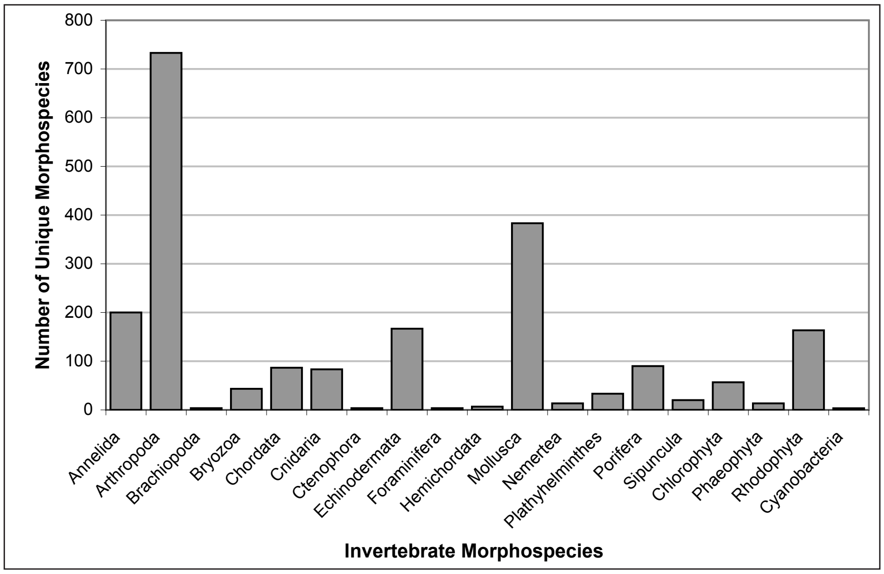

Figure 9.53. Number of unique morphospecies collected at French Frigate Shoals by phylum from CReefs cruise. Source: COML, unpub. data.

Though relatively high diversity was found for sponges, bryozoans, eulimid gastropods, hermit crabs, echinoderms and ascidians, other invertebrates, including corallimorph anemones, galatheid squat lobsters, porcellanid crabs, pea crabs, and coral barnacles, had strikingly low diversity or were absent. Interestingly, about one third of all invertebrate morphospecies collected were either found only once or found at only one site. A possible new ascidian of the family Mogulidae was collected, and a new species of coral that could not even be identified to family was found and photographed, though the permit did not allow sample collection. An estimated 48 new species records of opisthobranch molluscs for the French Frigate Shoals were collected, 27 of which appear to be new records for the NWHI. Of 366 algal specimens catalogued and preserved for molecular and taxonomic analysis, preliminary results suggest at least 160 unique morphospecies, with at least seven new records for algal species at French Frigate Shoals.

SEABIRDS

Seabird colonies in the NWHI constitute one of the largest and most important assemblages of seabirds in the world, with approximately 14 million birds representing 21 species (Naughton and Flint, 2004). Greater than 95% of the world's Laysan (*Phoebastria immutabilis*) and Black-footed albatross (*P. nigripes*) nest in the NWHI (USFWS, 2005). For several other species such as Bonin petrel (*Pterodroma hypoleuca*), Christmas shearwater (*Puffinus nativitatis*), Tristram's storm-petrel (*Oceanodrama tristrami*) and Grey-backed tern (*Sterna lunata*), the NWHI supports colonies of global significance. The most numerous breeders are the Sooty Terns (*Sterna fuscata*), accounting for half of the total seabird numbers, followed by Laysan albatross with over 1 million breeders (Table 9.11; Figure 9.54). Five other species have annual breeding populations in excess of 100,000 birds.

The last complete inventory of breeding populations in the NWHI was done between 1979 and 1984. Population trends since then were derived from more intensive monitoring at three islands in the chain (French Frigate Shoals, Midway and Kure) and opportunistic sampling at other locations (Table 9.12). Population trends are stable or increasing for most species but there is concern for a few, especially the albatross. As part of North American Waterbird Conservation planning efforts, teams of ornithologists classified seabirds by levels of conservation concern using six ranking factors. Eleven of 21 species were ranked as either highly imperiled or of high conservation concern. When ranked regionally, Hawaiian seabird populations were healthier than conspecifics elsewhere; only six species were considered highly imperiled or of high conservation concern: Laysan, Black-footed and Short-tailed albatross, Christmas shearwater, Tristram storm-petrel and Blue noddy.

Table 9.11. Estimated number of breeding seabirds and percentage of total in the NWHI. Source: FWS, unpub. data.

SPECIES	NUMBER	PERCENTAGE
Sooty tern	3,000,000	50.25
Laysan albatross	1,234,000	20.67
Bonin petrel	630,000	10.55
Wedge-tailed shearwater	450,000	7.54
Bulwer's petrel	180,000	3.02
Brown noddy	150,000	2.51
Black-footed albatross	111,800	1.87
Gray-backed tern	86,000	1.44
Black noddy	26,000	0.44
White tern	22,000	0.37
Great frigatebird	19,800	0.33
Red-tailed tropicbird	18,400	0.31
Red-footed booby	15,800	0.26
Tristram's storm-petrel	11,000	0.18
Blue noddy	7,000	0.12
Christmas shearwater	5,400	0.09
Masked booby	3,400	0.06
Brown booby	800	0.01
White-tailed tropicbird	8	<0.01
Little tern	<20	<0.01
TOTAL	**5,970,000**	**100.00**

Figure 9.54. Adult Laysan albatross (Phoebastria immutabilis) *at Midway Atoll National Wildlife Refuge. Photo: A. Friedlander.*

The greatest threats to seabirds in the NWHI are introduced mammals and other invasive species, fishery interactions, contaminants, oil pollution and climate changes with associated sea level rise. Over the past 20 years, active management for seabirds in the NWRs and State Seabird Sanctuary has included the eradication of black rats (*Rattus rattus*) at Midway Atoll and Pacific or Polynesian rats (*Rattus exulans)* at Kure Atoll; the eradication and control of invasive plants; coordination among NOAA Fisheries, the Western Pacific Fisheries Management Council, industry and conservation organizations to reduce fishing impacts; and the clean-up of contaminants and removal of obstructions at former military sites. The NWHI is unique in being one of the largest

Table 9.12. Overview of seabird monitoring efforts and findings since the last assessment in the NWHI. Gray boxes indicate species and sites that have not been surveyed since 1984. Pink boxes indicate an apparent increase of greater than 25% since 1984 and green a greater than 25% apparent decrease. Blue indicates little change and purple represent new records for that species at that location. White boxes indicate that the species was not found at that location. Source: USFWS, unpub.data.

SPECIES	KUR	MID	PHR	LIS	LAY	GAR	FFS	NEC	NIH
Black-footed albatross	+	+	-	=	=		=	-	-
Laysan albatross	+	+	-	▨	=	▨	+	=	-
Bonin petrel	=	+	-	▨	▨		=		
Bulwer's petrel	+		=	▨	▨	▨	=	▨	▨
Wedge-tailed shearwater	+	▨	-	▨	▨	▨	-	▨	▨
Christmas shearwater	+	+	-	▨	▨		-	▨	▨
Tristram's storm-petrel	▨		=	▨	▨		+	▨	▨
White-tailed tropicbird		+							
Red-tailed tropicbird	=	=	-	▨	▨	▨	=	▨	▨
Masked booby	-	-	-	▨	-	=	+	▨	▨
Brown booby	-	▨	=	▨	=	=	▨	▨	▨
Red-footed booby	+	+	-	▨	+		+	▨	▨
Great frigatebird	-	+	-	▨	+		=	▨	▨
Little tern		+	+						
Grey-backed tern	=	+	-	▨	▨	▨	-	▨	▨
Sooty tern	+	▨		▨	+	▨	=	▨	▨
Blue noddy						▨	+	▨	▨
Brown noddy	+	▨	▨	▨	▨	▨	+	▨	▨
Black noddy	+		-			▨	-	▨	▨
White tern	+	▨	=	▨	▨	▨	=	▨	▨

marine protected areas in the world and one of only a few places that has received protection for nearly 100 years, since establishment of the Hawaiian Islands National Wildlife Refuge in 1909 for the express purpose of protecting seabirds. Early protection and active management has resulted in large, diverse and relatively intact seabird populations.

MONK SEALS

The Hawaiian monk seal (*Monachus schauinslandi*) is the only endangered pinniped occurring entirely within U.S. waters. Its current population is estimated at 1,200 seals, a decrease of about 60% since the 1950s (Antonelis et al., 2006). Counts declined about 5% per year from 1985 to 1993, were relatively stable through 2000, and declined again in 2001. When compared historically, the monk seal beach count abundance index reached record lows in 2005 (Figure 9.55).

Population trends have been variable at the six main reproductive subpopulations in the NWHI (Baker and Thompson, 2006). In recent years overall pup production and juvenile survival have decreased at most sites (Figure 9.56). The largest subpopulation is at French Frigate Shoals where counts of non-pups have dropped by 60% since 1989, and the age distribution has become severely inverted due to high juvenile mortality over the last decade. Future abundance trends will likely depend upon whether predicted losses at French Frigate Shoals are countered by gains at other locations.

Monk seals occur throughout the Hawaiian Archipelago, and although most are found in the NWHI, a small but increasing number haul out and pup in the MHI. They commonly occur on isolated beaches for resting, molting, parturition and nursing offspring, but spend nearly two-thirds of their time in marine habitats. Monk seals are primarily

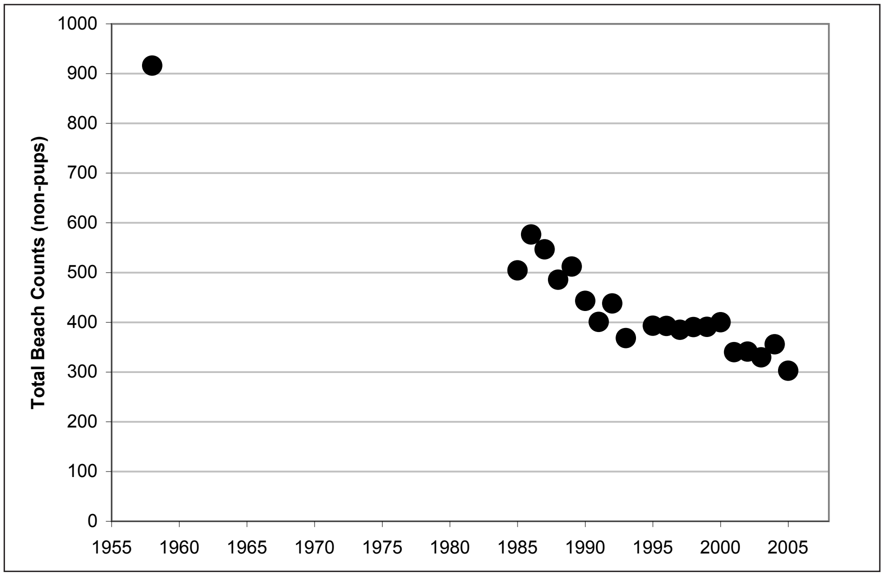

Figure 9.55. Historical trend in beach counts (non-pups) of Hawaiian monk seals at the six main reproductive subpopulations. Source: Antonelis et al., 2006; updated by Baker, PIFSC.

benthic foragers (Goodman-Lowe, 1998), and will search for food in waters up to 500 m and over different substrates (Parrish et al., 2006). Food availability in their marine habitat seems to be a limiting factor to population growth in the NWHI, with the greatest impact of food limitation being on the survival of juvenile and yearling seals, age of sexual maturity and fecundity. This has possibly resulted from a downward trend in ocean productivity in the NWHI in the past decade associated with the Pacific Inter-Decadal Oscillation, coupled with the erosion and loss of important pupping habitats (French Frigate Shoals), and entanglement by marine debris (Antonelis et al., 2006).

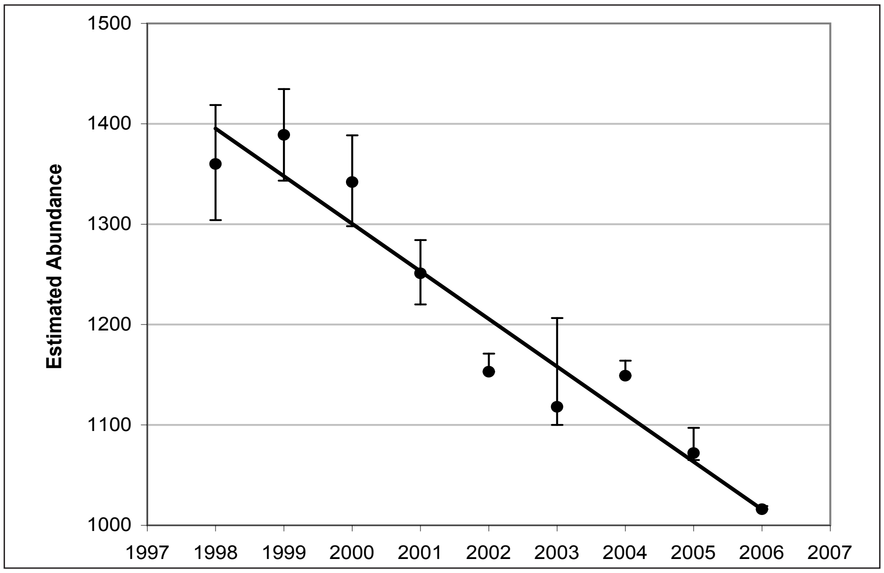

Figure 9.56. Estimated abundance of monk seals at six major reefs in the NWHI. Fewer seals are located on smaller islands in the NWHI and MHI. Source: PIFSC.

Past and present sources of anthropogenic and natural impacts to monk seals include: hunting during the 1880s; disturbance (e.g., active and post World War II military activities); entanglement in marine debris; direct fishery interactions prior to establishment of the 1991 Protected Species Zone in the NWHI; predation by sharks; aggression by adult male monk seals; and reduction of habitat and prey due to environmental change. Assessment and mitigation of factors limiting population growth are ongoing challenges and primary objectives of the monk seal recovery effort. The monk seal recovery plan may be found on the Internet at http://www.nmfs.noaa.gov/pr/pdfs/recovery/hawaiianmonkseal.pdf.

TURTLES

The green turtle (*Chelonia mydas*) is the most abundant, large marine herbivore and has a circumtropical distribution with distinct regional population structures. Globally, the green turtle has been subject to a long history of human exploitation with some stocks now extinct and others in decline. The Hawaiian green turtle, or honu, stock comprises a single closed genetic stock that is endemic to the Hawaiian Archipelago (Bowen et al., 1992) with numerous distinct foraging grounds within the 2,200 km span of the Hawaiian Archipelago. From the mid-1800s until about 1974, the Hawaiian stock was subject to human exploitation such as turtle harvesting at foraging grounds, harvesting of nesters and eggs and nesting habitat destruction. Turtles found at Midway have a significantly slower somatic growth rate and older age of maturity than turtles from MHI (Balazs and Chaloupka, 2004).

The principal rookery for the Hawaiian green sea turtle is located on sand islands at French Frigate Shoals and accounts for more than 90% of all nesting within the Hawaiian Archipelago (Balazs and Chaloupka, 2006). The main rookery island at French Frigate Shoals is East Island where at least 50% of all French Frigate Shoals nesting occurs. Nesting females exhibit strong island fidelity, and the Hawaiian green sea turtle stock has been continuously monitored for several decades. Annual surveys of the number of female green turtles coming ashore to nest each night have been conducted at East Island since 1973.

Green sea turtles in U.S. waters have been protected under the Federal Endangered Species Act since 1978. It was recently estimated that the Hawaiian green turtle stock was about 20% of pre-exploitation biomass when monitoring and protection began in the 1970s. The stock is estimated to be now about 83% of pre-exploitation biomass with an intrinsic growth rate of approximately 5.4% (Chaloupka and Balazs, 2006).

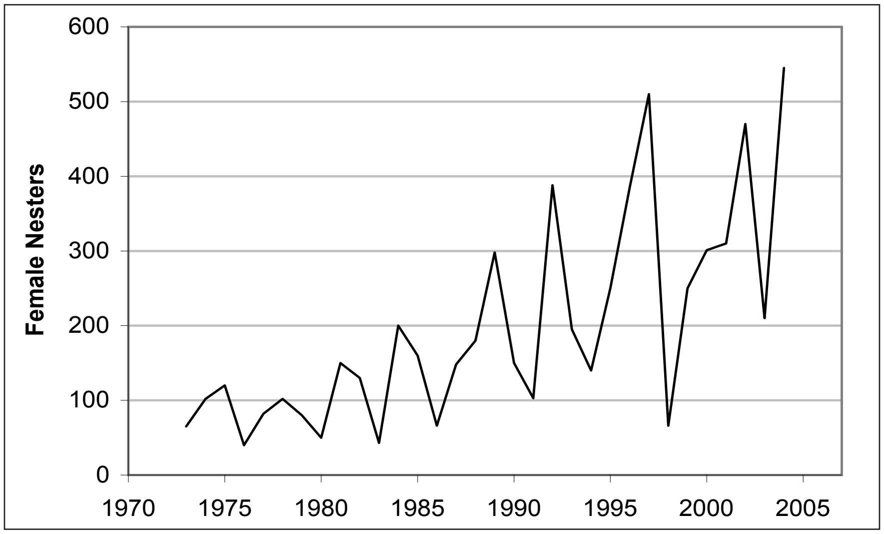

Figure 9.57. Nester abundance shown as the number of female green sea turtles nesting each year at East Island, French Frigate Shoals from 1973 to 2004. Source: Balazs and Chaloupka, 2006.

Long-term trends based on a population model for the East Island nester abundance illustrates two main features: a dramatic increase in abundance over the 30-year study and substantial fluctuations in the number of annual nesters (Figure 9.57). Such fluctuations are characteristic of green turtle nesting populations and reflect a variable proportion of females in the population that breed each year in response to spatially correlated ocean-climate variability. The Hawaiian green sea turtle stock is clearly recovering after more than 25 years of protection of their nesting and foraging habitats in the Hawaiian Archipelago.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Management of the PMNM is the responsibility of three co-trustee agencies: the state of Hawaii; the United States Department of the Interior, USFWS; and the Department of Commerce, NOAA. The co-trustees are committed to preserving the ecological integrity of the monument and perpetuation of NWHI ecosystems, Native Hawaiian culture and other historic resources. NOAA and USFWS promulgated final regulations for the monument under 50 CFR Part 404 on August 19, 2006. These regulations codify the scope and purpose, boundary, definitions, prohibitions and regulated activities for managing the monument. In addition, the co-trustees developed and signed a Memorandum of Agreement (MOA) on December 8, 2006, to establish roles and responsibilities, and coordination bodies and mechanisms for managing the monument.

In addition to the development of a management plan, the co-trustees are also developing a research plan that will provide the direction for research in the NWHI over the next several years. This plan will be based on a draft Hawaiian archipelago research plan that is currently being finalized, results of a NWHI research symposium held in 2004, and inputs from a workshop to gather research themes held in 2002 as a part of a NWHI Coral Reef Ecosystem Reserve effort. This plan will complement the objectives outlined in the management plan.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

The Papahanaumokuakea Marine National Monument (PMNM) is the largest fully protected marine conservation area in the world, and the unique predator-dominated trophic structure, the dominance by large numbers of endemic species, and the occurrence of a number of threatened and endangered species make it an important global biodiversity hotspot. Large numbers of seabirds are crucial components of the nutrient cycle in this ecosystem and suggest a strong connectivity between land and sea in this largely untouched environment. The NWHI are one of the few regions on earth where monitoring and research activities can be conducted in virtual absence of human presence. By comparison, most reef systems in the coastal regions of the world are adjacent to human population centers, where vessel traffic, overharvesting, sedimentation, habitat destruction and other human actions have altered the terrestrial and adjacent marine environments. The NWHI allow us to see what subtropical reefs looked like in the past and provide an opportunity to examine what could occur if larger more effective no-take marine reserves were to be established elsewhere.

Large unfished reference areas are extremely rare and valuable tools that can be used to establish baseline conditions and determine the current status of exploited areas using a space-for-time substitution. The NWHI provide a unique opportunity to compare the health of a nearly pristine ecosystem with the ecosystem of the human-impacted MHI (Friedlander and DeMartini, 2002; Sladek Nowlis et al., in review). Results have clearly shown that the coral reef ecosystem of the MHI is in very poor condition compared with the NWHI, and even small protected areas in the MHI do not adequately protect the full complement of species or interactions found in the NWHI (Friedlander et al., 2007). The limited deepwater bottomfish fishery in the NWHI is scheduled to close in 2011, and until that time, monitoring of this fishery can provide crucial information that can be applied to management across the archipelago.

Climate change may have a large impact on coral reef ecosystems and their management in the years to come. The PMNM provides a unique opportunity to examine the effects of climate change on a nearly intact large-scale marine ecosystem without direct and localized anthropogenic influences (Keller et al., in press). Sea level rise, coral bleaching, disease and ocean acidification are just a few of the potential impacts of climate change on coral reefs, and by understanding resilience and resistance to these stressors in a “natural” ecosystem, we can apply these findings to better inform decision making and management actions in the Hawaiian Archipelago and other coral reef ecosystems worldwide, where anthropogenic stressors are significantly greater.

An important future direction for biological research in the NWHI will be advancing our understanding of metapopulation dynamics and connectivity, especially for coral reef species. Demographic connectivity of coral reef organisms is typically on the order of 10s to 100s of km (Palumbi, 2004; Cowen et al., 2006), so many of the reefs in the NWHI may be isolated and therefore susceptible to localized extinction. Greater knowledge of recruitment variability, current patterns, larval retention, and genetic connectivity will be required to better understand the dynamics of population replenishment in this region.

By developing strong and lasting joint management initiatives and the framework for continued cooperation among the co-trustees and other partners, the PMNM can implement comprehensive and integrated management that is ecosystem-based and addresses the management needs of this valuable and irreplaceable ecosystem well into the future. Research results and management outcomes from the PMNM can also be used to inform management decisions throughout the Hawaiian Archipelago and coral reef ecosystems elsewhere.

An important step in this direction is the *Hawaiian Archipelago Marine Ecosystem Research Plan*, which strives to understand the archipelago's marine physical and biological environments, their dynamics and their interactions with human beings as a single connected system leading toward improved resource management. This ten-year, multi-agency, collaborative program is proposed to advance ecosystem science and resource management throughout the Hawaiian Archipelago. Few regions on the planet have the isolation, spatial structure and research history that are needed to evaluate ecosystem dynamics and function at this scale. This collaborative plan is designed to advance ecosystem science, develop new technologies and assist society in making the most of its resources while preserving them for future generations.

The millions of pounds of marine debris that have accumulated in the NWHI illustrate the global scale of the impacts that are occurring in the NWHI and constitute an urgent call for international cooperation on this and other large-scale stressors such as climate change. Due to the proliferation of distant-water fishing fleets, remote places like the NWHI are increasingly susceptible to poaching, and concerted efforts requiring improved surveillance technologies will be necessary to combat this threat. Increased threats from disease, ocean acidification, sea level rise and bleaching associated with climate change, are the most significant long-term threats to the NWHI.

Remote, uninhabited, and relatively pristine in comparison to other marine ecosystems of the world, the NWHI serve as a key sentinel for monitoring and deciphering short-term and long-term responses to local, regional, and global environmental and anthropogenic stressors. Ongoing research, monitoring, habitat restoration and conservation management of the insular and marine ecosystems in the NWHI will continue to provide significant insights that will benefit management interventions not only for the NWHI, but for insular and marine ecosystems around the world. Globally, the NWHI represent a natural and cultural treasure of high scientific, conservation and aesthetic value, and the wise stewardship of this unique ecosystem is the responsibility of us all.

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