The State of Coral Reef Ecosystems of the Northwestern Hawaiian Islands

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INTRODUCTION AND SETTING

The Northwestern Hawaiian Islands (NWHI) consist of small islands, atolls, submerged banks, and reefs, and stretch for more than 2,000 km northwest of the high windward main Hawaiian Islands (MHI; Figures 10.1 and 10.2). From Nihoa and Necker Island (~7 and 10 million years old respectively) to Midway and Kure Atolls (~28 million years old), the NWHI represent the older portion of the emergent archipelago (Juvik and Juvik, 1998). The majority of the islets and shoals remain uninhabited, although Midway, Kure, Laysan Island, and French Frigate Shoals have all been occupied for extended periods over the last century by various government agencies.

The remoteness and limited reef fishing activities in the NWHI have resulted in minimal anthropogenic impacts. Large apex predators such as jacks and reef sharks are one of the most striking and unique components of the NWHI ecosystem. These top carnivores are no longer present in any abundance in the inhabited Hawaiian Islands. The NWHI flora and fauna include a large percentage of species that are endemic to the Hawaiian Islands, which are recognized for having some of the highest marine endemism in the world. The faunas of isolated oceanic archipelagos like the Hawaiian Islands represent species conservation hotspots that have become increasingly important due to the continual losses of biodiversity on coral reefs worldwide (DeMartini and Friedlander, 2004).

The NWHI represent important habitat for a number of threatened and endangered species. The Hawaiian monk seal is one of the most critically endangered marine mammals in the U.S. (1,400 individuals) and depends almost entirely on the islands of the NWHI for breeding and the surrounding reefs for sustenance. Over 90% of all sub-adult and adult Hawaiian green sea turtles found throughout Hawaii inhabit the NWHI. Seabird colonies in the NWHI constitute one of the largest and most important assemblages of seabirds in the world.

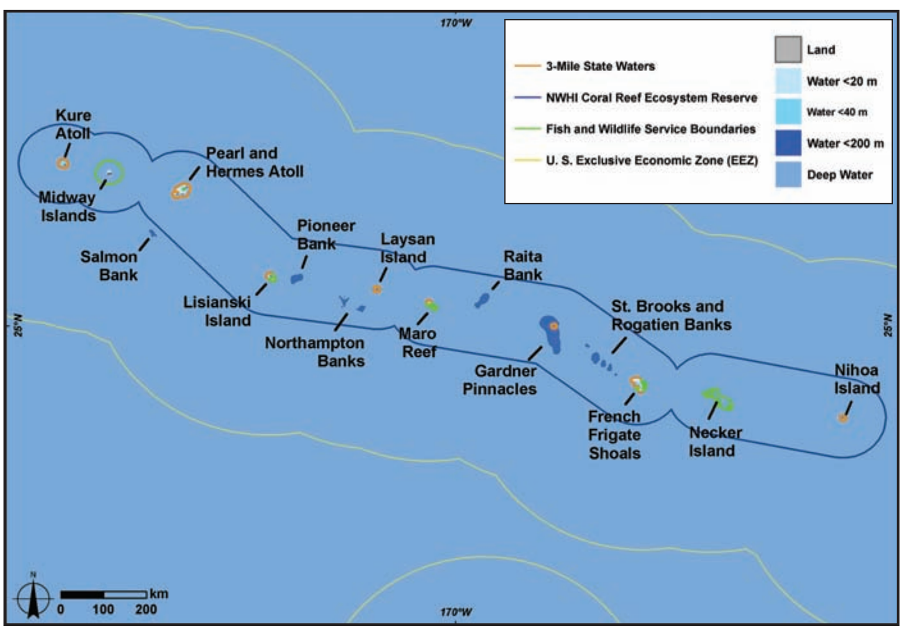

Figure 10.1. The Northwestern Hawaiian Islands, which extend across the north central Pacific, represent a vast, remote coral ecosystem that has been subjected to relatively minimal anthropogenic impacts. Map: A. Shapiro.

Despite their high latitude, similar numbers of coral species have been reported in the NWHI (57 spp.) compared to the MHI (59 spp.). Kure is the world's most northern atoll and is referred to as the Darwin Point, where coral growth and subsidence and erosion balance one another. Unlike the MHI where alien and invasive algae have overgrown many coral reefs, the reefs in the NWHI are free of alien algae and the high natural herbivory results in a pristine algal assemblage.

The reefs in the NWHI are among the few large-scale, intact, predator-

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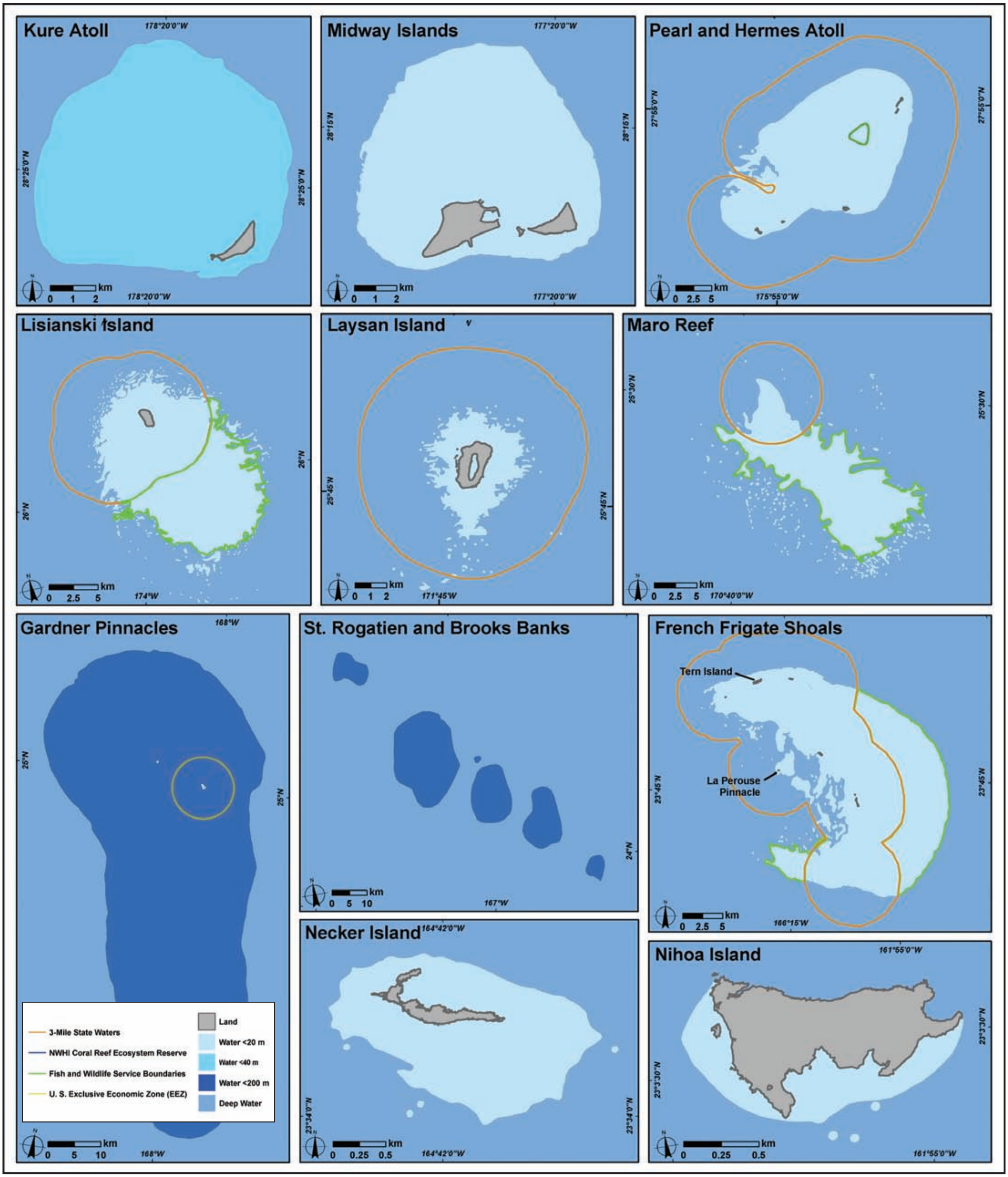


Figure 10.2. Locator map for the Northwestern Hawaiian Islands. Island abbreviations in figures and tables are as follows: Kure Atoll=KUR; Midway Atoll=MID, Pearl and Hermes Atoll=P&H; Lisianski Island=LIS; Laysan Island=LAY; Maro Reef=MAR; French Frigate Shoals=FFS; Gardner Pinnacles=GAR; Necker Island=NEC; Nihoa Island=NIH. Map: A. Shapiro.

dominated reef ecosystems remaining in the world and offer an opportunity to examine what could occur if larger more effective no-take marine reserves are established elsewhere (Friedlander and DeMartini, 2002). The nearly pristine condition of the NWHI allows scientists to study how unaltered ecosystems are structured, how they function, and how they can most effectively be preserved.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

The NWHI were impacted by mass coral bleaching during late summer 2002 (Aeby et al., 2003; Kenyon et al., in review). No records of mass coral bleaching in the NWHI exist before this time and it was previously thought that the NWHI was less susceptible to bleaching due to its high latitude location. The first documented bleaching event in the MHI was reported in 1996 (Jokiel and Brown, 2004). Bleaching was most severe at the three northern-most atolls (Pearl and Hermes, Midway, and Kure), with lesser incidences of bleaching at Lisianski Island and farther south in the NWHI. At the three northern atolls, bleaching was most severe on the backreef, moderate in the lagoon, and low on the deeper forereef (Table 10.1). Of the three coral genera that predominate at these atolls (*Porites, Montipora, Pocillopora*), *Montipora* and *Pocillopora* were most affected by bleaching (Figure 10.3), with lesser incidences observed in *Porites*. The average incidence of coral bleaching experienced in the backreef, forereef, lagoon, and channel closely corresponds to the composition of the dominant coral fauna in these zones coupled with its susceptibility to bleaching. Sea surface temperature (SST) data derived from both remotely sensed satellite observations as well as *in situ* buoys from the National Oceanic and Atmospherid Administration (NOAA) Coral Reef Early Warning System (CREWS) suggest that prolonged, elevated SST was a likely explanation for the bleaching response (Figure 10.4). This prolonged period of elevated SST coincided with a prolonged period of anomalously light wind speed, suggesting decreased wind and wave mixing of the upper ocean (Hoeke et al., 2004a, b). No significant bleaching was found the following year during surveys conducted in July 2003.

Table 10.1. Summary of towed-diver surveys conducted at the three northern-most atolls in the NWHI from September 20-28, 2002. NA=zone not surveyed at this atoll. Source: PIFSC-CRED, unpublished data.

	KURE	MIDWAY	P&H
Backreef (0.4 - 4.0 m depth)			
distance surveyed (km)	12.26	8.66	35.22
average % coral cover	10.19	11.26	10.20
average % coral bleached	64.09	77.41	66.14
Forereef *			
distance surveyed (km)	10.56	21.95	4.88
average % coral cover	6.72	1.59	5.89
average % coral bleached	14.35	15.04	75.38*
Central lagoon patch reefs (1.2 - 5.3 m depth)			
distance surveyed (km)	1.63	0	9.42
average % coral cover	18.57	NA	26.87
average % coral bleached	37.31	NA	36.81
Atoll barrier channel (6.5 - 15.8 m depth)			
distance surveyed (km)	0	6.58	2.65
average % coral cover	NA	1.46	5.16
average % coral bleached	NA	32.41	73.06
*Depth (m): 4.6-5.0 m at P&H; 9.0-16.5 m at MID and KUR			

Figure 10.3. Left panel shows *Montipora capitata* (bleached) and *Montipora turgescens* (lavender) on the northern backreef of Midway Atoll, September 2002. Right panel shows *Pocillopora meandrina* (bleached), with initial overgrowth by turf algae in the central patch reef of Kure Atoll, September 2002. Photos: J. Kenyon.

In late summer 2004, a second episode of mass coral bleaching was documented (Kenyon and Brainard, in review), as well as high mortality of *Montipora capitata* in backreef habitats at the three northern atolls. This second documented event, although milder in intensity than the 2002 event, shared numerous spatial and taxonomic patterns with the 2002 event. *In situ* temperature recorders that were deployed in July 2003 for 14 months showed that corals in shallow backreef and lagoon habitats experienced substantially more thermal stress during late summer 2004 than during 2003, exceeding local bleaching thresholds for as much as seven weeks. In both years, backreef sites at Pearl and Hermes Atoll experienced the highest incidences of bleaching.

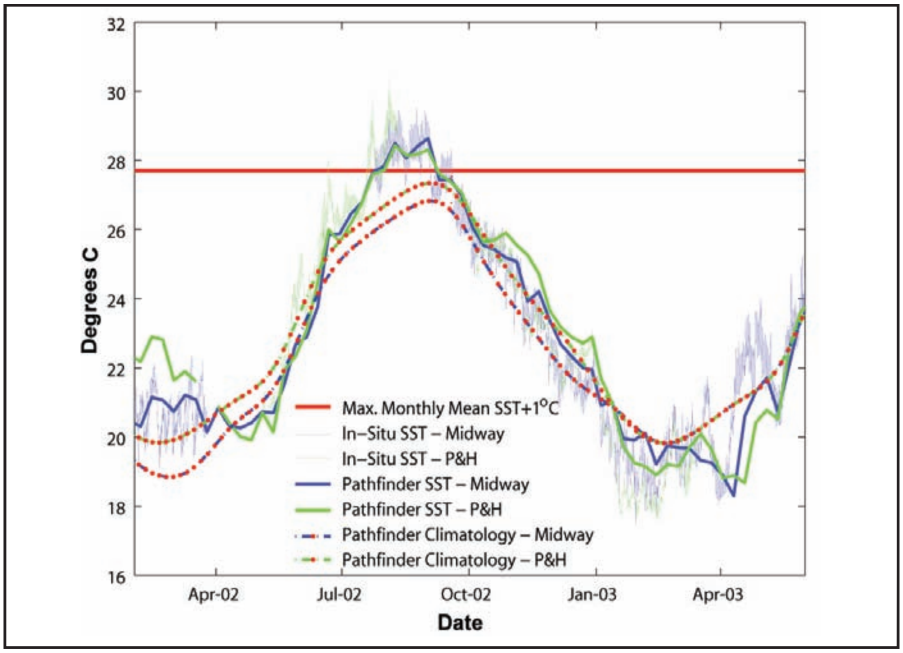


Figure 10.4. Satellite and *in situ* measurements at MID and P&H during 2002 and 2003, showing anomalously high SSTs at these northern atolls during the 2002 mass coral bleaching event. Both satellite Pathfinder SST and *in situ* SST at MID and P&H show values significantly exceeding long-term mean climatological values and the Coral Reef Watch bleaching threshold of maximum monthly mean SST plus 1° C. Source: Hoeke et al., 2004a, b.

Disease

There has been a worldwide increase in the reports of diseases affecting marine organisms. However, our ability to fully understand recent disease outbreaks is hampered by the paucity of baseline and epidemiological information on the normal disease levels in the ocean (Harvell et al., 1999). The NWHI is considered to be one of the last relatively pristine large coral reef ecosystems remaining in the world. As such, it provides the unique opportunity to document the normal levels of disease in a coral reef system exposed to limited human influence.

Little work had been done regarding coral disease in the NWHI with the exception of one study by Work et al. (2002) in which 16 sites were surveyed at French Frigate Shoals. They reported tumors on *Acropora* (Figure 10.5) as well as lesions associated with parasites, bacteria and fungi on a number of different coral species. During a multi-agency cruise conducted in September 2002, disease investigation was incorporated into the protocol and a characterization of coral disease was initiated. In July 2003, surveys were conducted, at 73

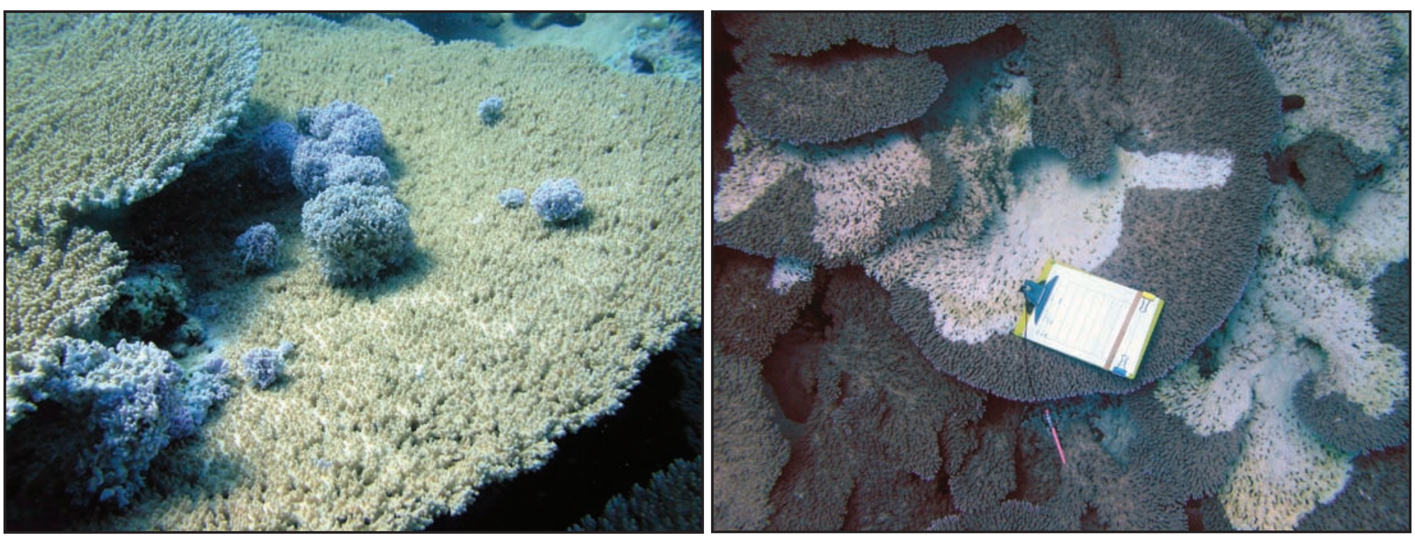


Figure 10.5. Two examples of disease in *Acropora cytherea* colonies in the NWHI. Left photo shows a colony of *A. cytherea* with tumors; the colony in the right photo shows signs of severe tissue loss in FFS. Photos: G. Aeby.

sites throughout the NWHI, to quantify and further characterize coral disease. During this survey, evidence of coral disease was found at very low levels at 68.5% of the sites across all regions. The most common disease was *Porites* trematodiasis caused by the digenetic trematode, *Podocotyloides stenometra* (Aeby, 1998). This disease was widespread (57.5% of the sites) and is known to exclusively affect *Porites* spp. coral. Numerous other conditions were also observed but at much lower frequency of occurrence (1.4%-16.4% of the sites). The majority of the observed disease signs were distinct from what has been previously described from other coral reef systems. Numbers of colonies affected by *Porites* trematodiasis were not enumerated but other types of conditions were found to be present at low levels. The overall average prevalence of disease (no. diseased colonies/total no. colonies) one site at French Frigate Shoals resulted in massive tissue on large acroporid table corals (Aeby, in review; Figure 10.5b).

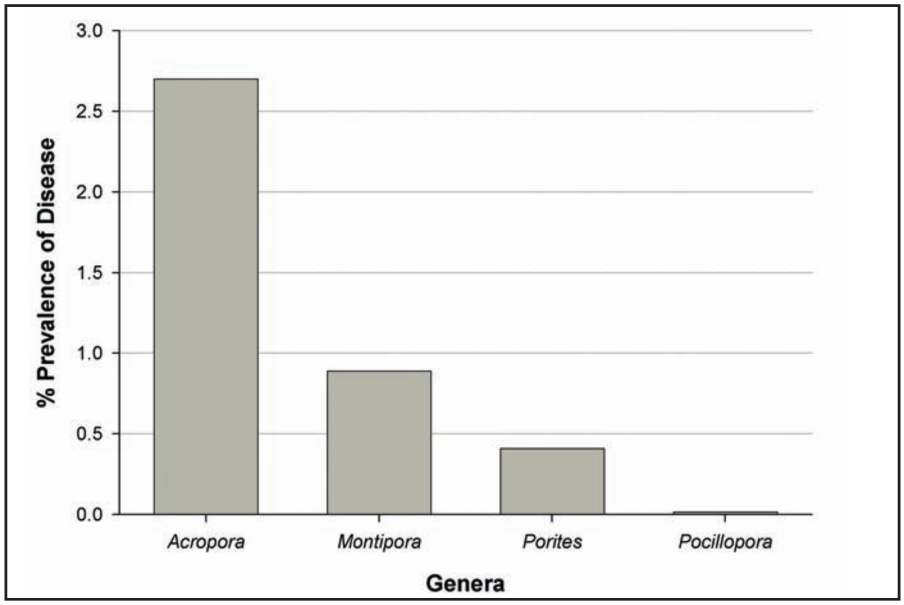


Figure 10.6. Differences in overall prevalence of disease among coral genera in the NWHI. Source: G. Aeby, unpublished data.

Coral genera were found to exhibit differences in types of conditions and prevalence of disease (Figure 10.6). Pocilloporids, which are one of the most common types of corals found on the reefs of the NWHI, seemed comparatively resistant to disease. Only a single colony of *Pocillopora* with disease signs was found out of more than 6,000 colonies searched (prevalence=0.016%). In contrast, Acroporids make up less than 5% of the coral community yet showed the greatest damage due to disease and the highest prevalence of disease (prevalence=2.7%). Studies are planned to further investigate and monitor the incidence of coral diseases in the NWHI.

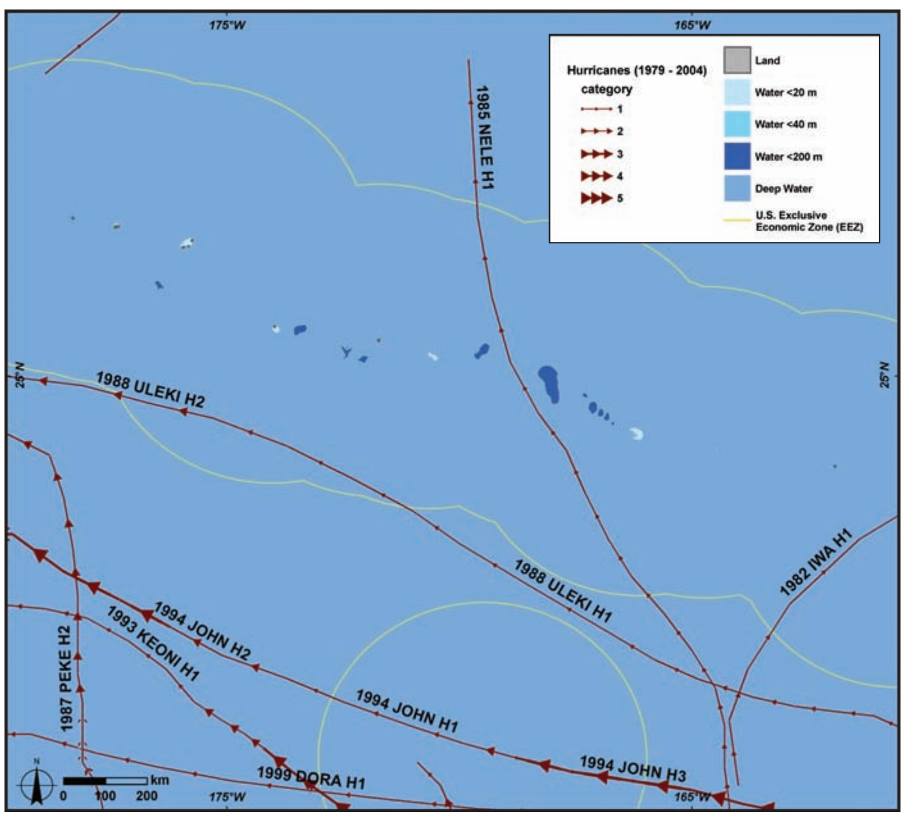


Figure 10.7. The path and magnitude of storms passing near the NWHI from 1979-2004. Year of storm, storm name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Data: NOAA Coastal Services Center.

Storm and Wave Events

Tropical Storms

The coral reef ecosystems of the NWHI are only rarely in the path of tropical storms and hurricanes. On average, between four and five tropical cyclones are observed annually in the Central Pacific. This has ranged from zero, most recently in 1979, to 11 in 1992 and 1994. Few tropical storms that develop in the region become hurricanes (Figure 10.7) and those that do tend to be relatively weak. Both of the hurricanes nearing the NWHI since 1979 were category 2 on the Saffir/Simpson scale (maximum windspeeds of 96-110 mph) or weaker. Hurricane Patsy (in 1959) was the strongest hurricane reported for the NWHI in the past 50 years, with wind speeds exceeding 100 knots as it approached and passed between Midway and Kure Atolls. None of the other hurricanes reported to have occurred in the NWHI have had winds exceeding 100 knots.

The impacts of these tropical storm events on the coral reef ecosystems of the NWHI are not documented. Though not observed, any damage to reef habitats associated with these storms would have been caused primarily by extreme wave energy events. No significant tropical storms have been observed in the NWHI since Hurricane Nele passed near Gardner Pinnacles in 1985. In summary, tropical storms represent a potential, but infrequent, threat to the coral reefs of the NWHI.

Extratropical Storms and Significant Wave Events

While the impacts of tropical storms on the coral reef ecosystems of the NWHI are relatively rare, the impacts of large wave events resulting from extratropical storms passing across the North Pacific each winter are thought to be significant. Most large (5-10+ m) wave events approach the islands and atolls of the NWHI from the west, northwest, north, and northeast, with the highest energy generally occurring from the northwest sector. The southern sides of most of the islands/atolls of the NWHI are exposed to fewer and weaker wave events. Average wave energy and wave power (energy transferred across a given area per unit time) is generally very high (~1.3 watts per meter, or W/m) between November and March and relatively low (~0.3 W/m) between May and September (Figure 10.8). October and April are generally transition months between the high energy winter months and the low energy summer months. In addition to mean wave power values increasing during the winter months, it is particularly noteworthy that the average maximum wave power during the winter months, associated with these storm events, is typically between 8 and 10 W/m. These extreme wave events (10+ m waves) subject the shallow water coral reef communities to at least one order of magnitude more energy than the typical winter waves. As such, these extreme wave events are believed to play a fundamental role in forming and maintaining biogeographic (spatial and vertical) distributions of corals, algae, and fishes of the coral reef ecosystems of the NWHI.

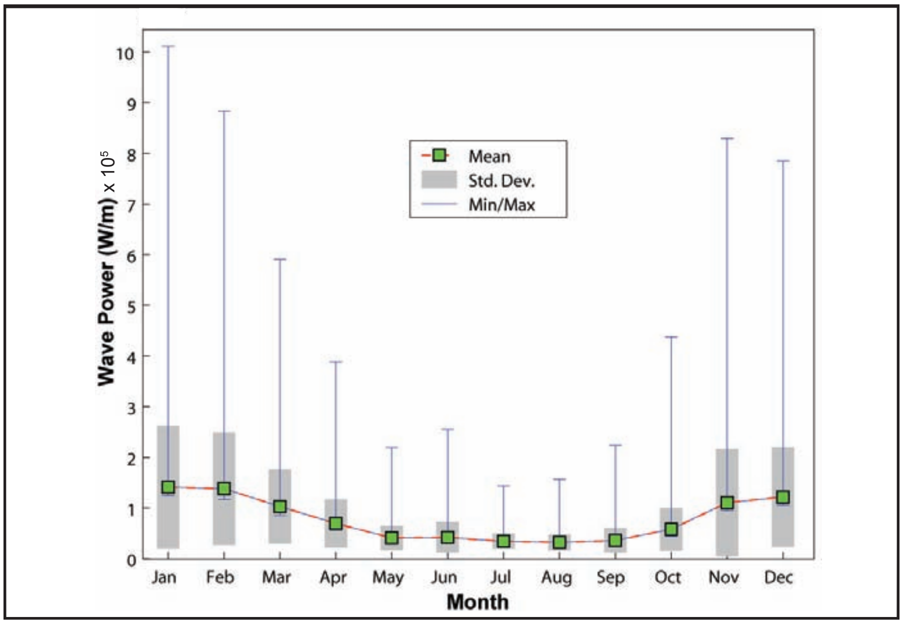


Figure 10.8. Climatological values of wave power (W/m) derived from NOAA buoy # 51001 located near NIH from 1981 to 2003. Green squares=monthly means; Shaded rectangles=standard deviation; Range bars=maximum and minimum monthly means. Data: NOAA National Data Buoy Center.

Coastal Development and Runoff

Previous land development and disturbance in the NWHI consisted of guano mining at Laysan Island a century ago, naval base construction at Midway and French Frigate Shoals during the first half of the 20th century, and U.S. Coast Guard (USCG) LORAN station construction and operation at Kure and French Frigate Shoals for several decades following World War II (WWII). The affected islands are coralline, small, porous, and generate little runoff and soil erosion. During recent decades there has been very little land development except small-scale conversion of abandoned USCG buildings on Tern Island at French Frigate Shoals and Green Island at Kure to wildlife research stations.

In-water development was limited to dredging of navigation channels for the naval bases at Midway and French Frigate Shoals during the middle of the 20th century. The only recent coastal construction at any of the NWHI 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 project is now completed and marine environments monitored before construction were re-monitored in late 2004. Construction impacts were minimal, and removal of derelict sheet piling in the area eliminated injury and death to endangered monk seals, threatened green sea turtles, and migratory seabirds that had previously become trapped.

The Midway Naval Air Station supported several hundred to several thousand soldiers and dependents during the pre- to post- WWII era before Midway was transferred to the U.S. Fish and Wildlife Service (USFWS) in 1996. Human population levels have been very small during the past several decades elsewhere in the NWHI, with only a few workers and volunteers now at the permanent wildlife stations at Laysan, French Frigate Shoals, and Midway, and the seasonal wildlife camps at Kure, Lisianski, and Pearl and Hermes. Due to the lack of any coastal development in the NWHI, runoff-induced impacts to nearshore reefs are non-existent.

Coastal Pollution

While no National Pollutant Discharge Elimination System (NPDES) permits or other industry permits were present in the NWHI, there has been a diverse history of use including: guano mining, fishing camps, USCG LORAN stations, U.S. Navy airfields and bases, and various Cold War missions. This history of use has left a legacy of contamination on many of the atolls. Contamination at all these sites includes offshore debris such as batteries (lead and mercury), transformers, capacitors, and barrels of chemical waste. Uncharacterized, unlined landfills remain on all of these islands. Specific known areas of contamination are the following:

Kure and French Frigate Shoals both have point sources of polychlorinated biphenyls (PCBs) due to former USCG LORAN stations. While the USCG has mounted cleanup actions at both sites, contamination remains and is found in island soils and in nearshore sediments and biota.

French Frigate Shoals and Pearl and Hermes were both used for WWII seaplane refueling. This activity is suspected to have been a source of petroleum contamination during operations.

Midway Atoll was the site of a U.S. Navy airfield. Before transfer to the U.S. Department of the Interior in 1996, the Naval installation was part of the Base Realignment and Closure (BRAC) that identified and cleaned up numerous contaminated sites throughout the Atoll. Contamination identified and remediated included petroleum in the groundwater and nearshore waters, pesticides (e.g., DDT) in the soil, PCBs in soil, groundwater, and nearshore sediments and biota, metals such as lead and arsenic in soil and nearshore waters, and unlined, uncharacterized landfills. See the BRAC documents for a complete inventory (http://www.defenselink.mil/brac/). While most of the known areas were remediated, several areas warrant continued monitoring for potential releases. Since closure, the Navy has returned on several occasions for further remediation.

Plutonium from the aboveground nuclear tests at Johnston Atoll in the 1960s has been detected in corals at French Frigate Shoals, 700 miles to the north. Finally, floating debris is a constant source of potential contamination to the islands and surrounding waters. A container of the pesticide carbofuran is suspected to have washed ashore at Laysan and killed many invertebrates. Named the 'Dead Zone', the area remained a hazard on the Island from 1987 until remediated by the USFWS in 2002. Debris continues to wash ashore on all of the islands and can cause localized adverse impacts. At Laysan, debris washed ashore or found in the surf over the last year has included unmarked bottles, military flares, a barrel marked diisocyanate (a carcinogen), and petroleum.

Tourism and Recreation

Tourism, sport fishing, recreational boating, and diving are not compatible with protection of fish and wildlife and their habitats in the Hawaiian Islands National Wildlife Refuge, and therefore are not permitted. Uses, such as research, that improve management of fish and wildlife are regulated through Special Use Permits issued by the USFWS. Midway Atoll National Wildlife Refuge (NWR) promotes visitor use including diving, snorkeling, beachgoing, nature photography, guided tours, birding, historical tours, and catch-and-release sport fishing. Visitor use in recent years, however, has been limited by the lack of routine, affordable air charter service to transport visitors to and from Midway Atoll NWR.

Fishing

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 several species of deepwater (generally >130-200 m) snappers (Lutjanidae) and one endemic species of epinepheline grouper (Serranidae) out of a total of a dozen common Bottomfish Management Unit Species (BMUS; WPFMC, 2004). This fishery is divided into two management zones: the Mau zone, which is closer to the MHI, and the more distant Hoomalu zone. The lobster trap fishery, which had historically targeted only the endemic Hawaiian spiny lobster, *Panulirus marginatus*, began targeting the non-endemic slipper lobster, *Scyllarides squammosus*, in 1998. The NWHI lobster trap fishery closed in 2000 because of growing uncertainty in the population models used to assess stock status (DeMartini et al., 2003).

Relatively few BMUS are conspicuous members of the shallow-reef ecosystem (<100 m) in the NWHI: amberjack (*Seriola dumerili*), although frequently caught while targeting other deep-slope species, are not retained; giant trevally (*Caranx ignobilis*), while the most abundant of the BMUS on shallow reefs (Friedlander and DeMartini, 2002), are neither caught nor sold in large numbers (WPFMC, 2004). Only two species, green jobfish (*Aprion virescens*) and the endemic Hawaiian grouper (*Epinephelus quernus*), occur in shallow reef habitats and also contribute substantively to NWHI Bottomfish landings (WPFMC, 2004), with jobfish by far the more abundant of these two species on shallow NWHI reefs (Friedlander and DeMartini, 2002). Existing time series data for Mau and Hoomalu Zone landings per trip (untargeted catch per unit effort [CPUE]) suggest no obvious pattern of temporal change for jobfish or for Hawaiian grouper in the Mau Zone, although there is a declining trend in CPUE for Hawaiian grouper in the Hoomalu Zone (Figure 10.9). A more accurate CPUE metric (targeted catch per unit of effort) is not available because species-specific effort data are lacking (R. Moffitt, pers. comm.).

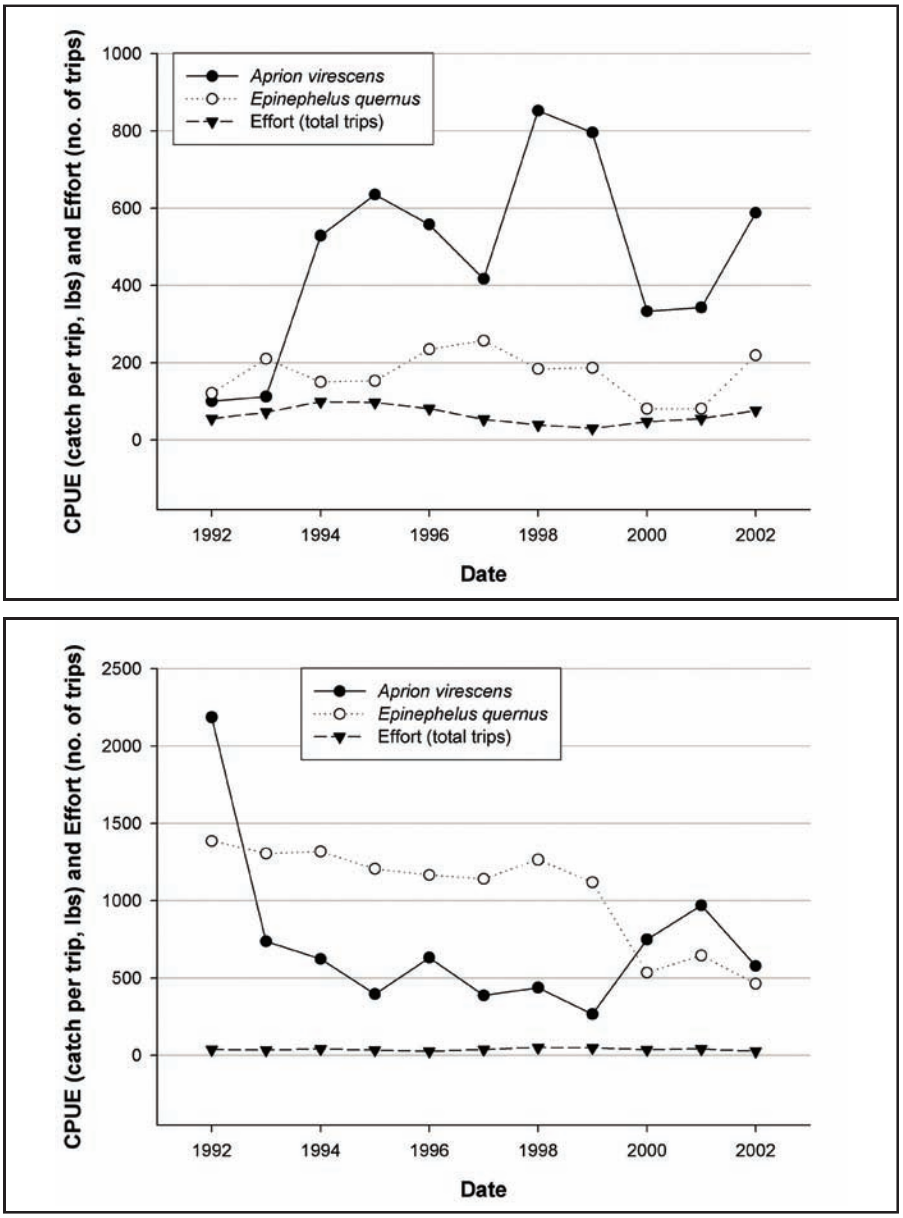


Figure 10.9. Time series of landings per trip in the Mau (upper panel) and Hoomalu (lower panel) zones for jobfish (*Aprion virescens*) and for Hawaiian grouper (*Epinephelus quernus*). Total (untargeted) effort (no. of trips) is also noted. Source: Western Pacific Fisheries Management Council, 2004.

CPUE data for the fishery-dependent NWHI lobster trap fishery and for fishery-independent lobster research surveys suggest successive half order of magnitude decreases in abundance between the early 1980s-early 1990s and between the early-to-late 1990s, respectively (Figure 10.10; DeMartini et al., 2003).

Other sources of resource extraction in the NWHI have been either nonexistent or brief, low impact, or both. There has never been a precious coral fishery in the NWHI (the fishery in the MHI has been inoperative since 2001). Small-scale (one boat), short-lived (single season) commercial fishing using bottom longlines to catch reef sharks was conducted at French Frigate Shoals and nearby banks in the year 2000. During one 21-day fishing trip, the vessel caught 990 sharks in the NWHI consisting mainly of sandbar shark, *Carcharhinus plumbeus* (69%), Galapagos shark, *Carcharhinus galapagensis* (18%), and tiger shark, *Galeocerdo cuvier* (10%) (Vatter, 2003). Extraction of shallow reef fishes in the NWHI for the ornamental trade has been almost non-existent due to their relatively inaccessible location and the establishment of the NWHI Coral Reef Ecosystem Reserve (CRER) in January 2001. Extraction of food and aquarium fish by recreational fishers has similarly been protected (and recently prohibited in Federal waters) and is currently being proposed for closure in State waters. Collections of voucher and other research specimens of shallow-water reef fishes, corals, other invertebrates, and algae in the NWHI has been periodic (typically late summer) and of trivial magnitude (less than several hundred pieces weighing less than a few tens of kilograms in aggregate, per year). All such activity continues to be regulated by NWR Special Use Permits, which are issued only to qualified researchers by the USFWS, and State of Hawaii Scientific Collecting Permits.

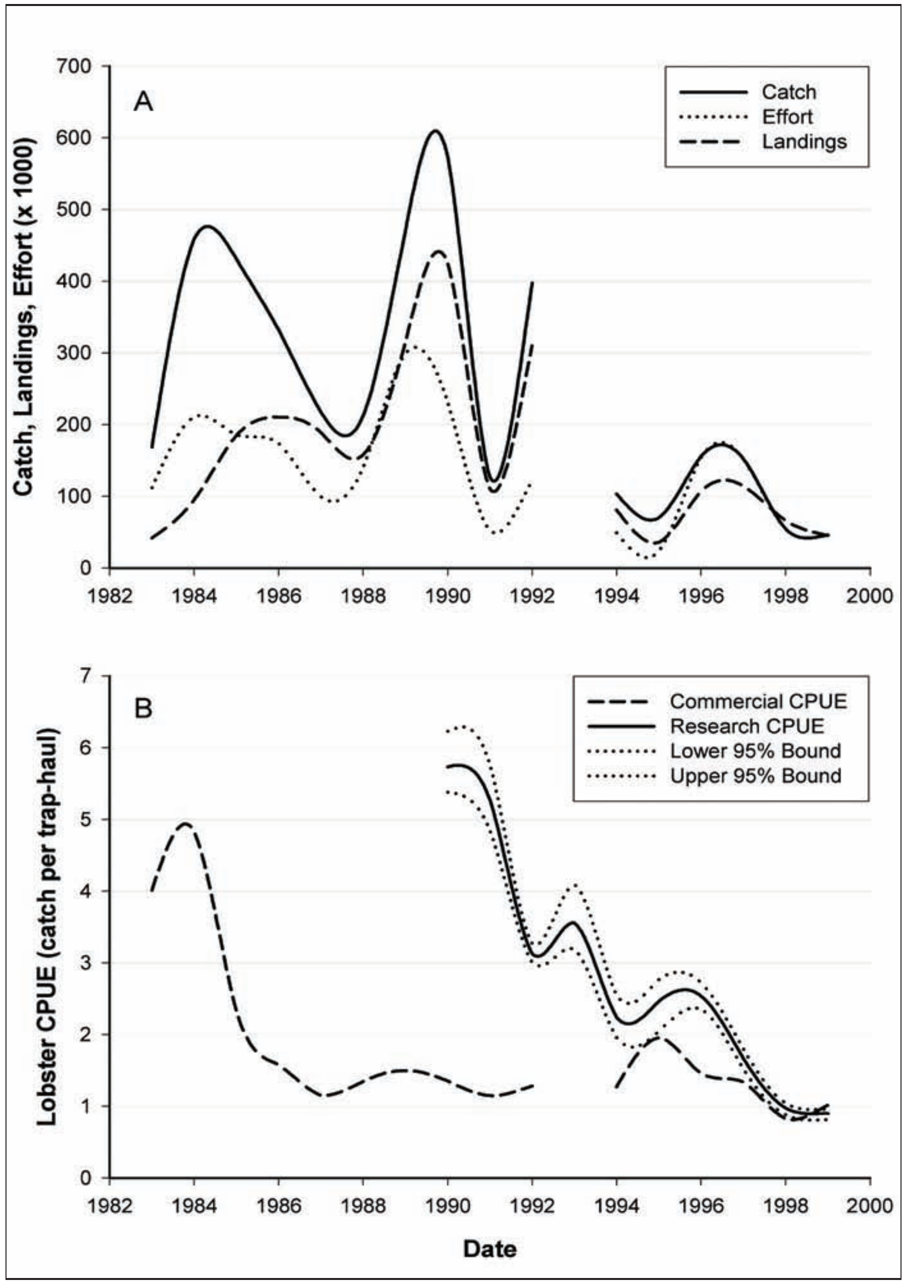


Figure 10.10. Time series plots of the NWHI commercial trap catch. Upper panel: Hawaiian spiny lobster landings (no. of lobsters x 1000), and effort (no. of trap-hauls x 1000); Lower panel: Total spiny lobster CPUE at Necker Bank, during the 1983-1999 comercial fishing seasons and as assessed on 1988-1999 lobster research cruises. Source: DeMartini et al., 2003.

Trade in Coral and Live Reef Species

Several species of reef fish found in the NWHI are highly desirable in the live aquarium fish trade. Of these, the endemic masked angelfish (*Genicanthus personatus*, Figure 10.11) is the most prized (R. Pyle, pers. comm.). Although two attempts have been made in recent years to access the NWHI to collect *Genicanthus* for the aquarium trade outside of Federally protected waters, the logistical and financial challenges of mounting such collecting trips and the difficulty of transporting live fish back to market in good condition have precluded any further efforts to obtain these fish.

Recently, the Waikiki Aquarium has spawned and reared masked angelfish in captivity (Debelius et al., 2003). With the feasibility of aquaculture of this species demonstrated, it is unlikely that a cost-effective commercial fishery for this species will ever exist in the NWHI. Other desirable aquarium species found in the NWHI, such as the Japanese angelfish (*Centropyge interrupta*, Figure 10.11) are not endemic, are available from more accessible localities for the aquarium trade, and have also been spawned and reared in captivity.

Figure 10.11. Left photo shows Endemic masked angel (*Genicanthus personatus*), and right photo shows Japanese angelfish (*Centropyge interrupta*). Both are valuable aquarium fish species. Photos: J. Watt.

Commercial harvesting of live coral for the aquarium trade is not known to have occurred in the NWHI and is now illegal or unauthorized within the NWHI CRER and the two NWRs and is also illegal within State waters. Table coral (*Acropora cytherea*) and several congeners are essentially absent in the MHI but are common at French Frigate Shoals and neighboring reefs in the NWHI (Grigg et al., 1981; Grigg, 1981; Maragos et al., 2004). However, *A. cytherea* is also common at many readily accessible locales throughout the Indo-Pacific region, and it is unlikely that an economically viable and legal fishery for live corals could exist in the remote NWHI. Still, one dead specimen of *A. cytherea* attributed to the NHWI was available for sale on eBay™ in 2002.

Ships, Boats, and Groundings

The NWHI region has a wide variety of submerged artificial structures including shipwrecks, aircraft wrecks, submerged landings, and unexploded ordinance. The systematic investigation of these objects in the NWHI began in 2002. Currently there are 52 known shipwrecks in the region, including rafts, whaling vessels, navy frigates, tankers, and modern fishing boats. Approximately 12 vessels have been located. In addition there are 67 known plane losses in the region, mainly naval aircraft from WWII, although only two have been located. Some of these ship and aircraft wreck sites fall into the category of war graves associated with major historic events. Unexploded ordinance and debris also exists in discrete locations.

Wrecks of historic sailing vessels in high energy environments are considered artifact "scatter sites", and do not pose an immediate or critical threat to their surroundings. The preservation and management of heritage resources are mandated by state and Federal laws. More modern shipwrecks, such as the fishing vessels *Hoei Maru #5* and *Paradise Queen II* at Kure, or the tanker *Mission San Miguel* lost at Maro Reef, are greater threats to reef ecosystems. NOAA's Damage Assessment Center maintains a list of sites for the NWHI. Mechanical damage from the initial grounding, subsequent re-deposition of wreck material by storm surge, fishing gear damage to reef and species, and fuel/oil or hazardous contents are all issues to be considered in protecting the integrity of the environment. Understanding the difference between historic wrecks and modern wrecks is crucial to proper (and legal) remediation and restoration efforts.

Marine Debris

Marine debris, mostly derelict fishing gear from distant fisheries around the Pacific Rim, is one of the greatest anthropogenic impacts to the reefs of the NWHI. These large nets damage corals and create an entanglement problem for monk seals, seabirds, and other marine organisms. Since 1996, the NOAA Fisheries Pacific Islands Fisheries Science Center (PIFSC), has led a highly successful multi-agency effort to remove and recycle over 329 metric tons of derelict fishing gear and other marine debris from the coral reef ecosystems of the NWHI (Table 10.2). The PIFSC Coral Reef Ecosystem Division (CRED) collaborates with NOAA's National Ocean Service, NWHI Ecological Reserve, State of Hawaii, City and County of Honolulu, USFWS, USCG, U.S.

Table 10.2. Marine debris collection (kg) in the NWHI since 1996. Source: PIFSC-CRED.

REEF	1996/1997	1998	1999	2000	2001	2002	2003	TOTAL
KUR				3,298	23,516	1,567	1,227	**29,608**
MID			9,091	7,457			18,620	**35,168**
P&H	2,223		8,676	9,866	30,501	92,955	83,030	**227,251**
LIS			5,444	2,035	830	1,087	3,589	**12,985**
LAY					1,075	1,231	2,155	**4,461**
FFS	2,145	7,500	2,145		5,625	432	2,246	**20,093**
Total	**4,368**	**7,500**	**25,356**	**22,656**	**61,547**	**97,272**	**110,867**	**329,566**

Navy, University of Hawaii, Sea Grant, Hawaii Metals and Recycling, Honolulu Waste Disposal, and other local agencies, businesses, and non-governmental partners. Additional shore- and land-based recovery of derelict fishing gear was conducted in cooperation with the NOAA monk seal field camp, State of Hawaii, and USFWS. The primary goals of these efforts have been to assess, document, and remove derelict fishing gear from the coral reef ecosystems of the NWHI. In addition, strategic research has been conducted to better understand the dynamics of marine debris, particularly accumulation rates and estimates for specific sites labeled High Entanglement Risk Zones (HERZ) for endangered Hawaiian monk seals (*Monachus schauninslandi*). Marine debris survey and collection activities have been conducted at Kure, Midway, Pearl and Hermes, Lisianski, Laysan and French Frigate Shoals.

The past and current marine debris removal operations have targeted the accumulation in the NWHI over the past several decades, with tremendous success in both the direct removal of debris from the ecosystem and increasing public awareness of the issue. Based on the amount removed to date, it is estimated that at most, 1,000 tons of debris have accumulated in the NWHI over the past several decades. Assuming accumulation rates have been relatively constant over the past four decades, long-term average accumulation rates are approximately 25 tons per year. At Kure, annual towboard surveys of the HERZ along the northeastern edge of Green Island elicited evidence of marine debris accumulation (2002: 63 nets/km^2; 2003: 73 nets/km^2).

Until substantial efforts are made to significantly reduce the sources of debris and until debris can be effectively removed at sea, similar amounts are expected to continue accumulating indefinitely in the reef ecosystems of the NWHI.

Aquatic Invasive Species

Aquatic invasive species in the NWHI have only recently become an issue of interest, which has been driven by survey efforts in the MHI. The status of the taxonomy of many non-coral marine invertebrate groups is not fully developed for the NWHI and this does not allow comprehensive species inventories to be produced, although efforts to correct this are presently underway. In addition, when large-scale faunal surveys began in shallow water coral reef habitats in the NWHI in 2000 only two expeditions with such a focus had ever been to the area during the previous 100 years.

The data concerning marine aquatic invasive species in the NWHI was collected from a single focused marine invasive species survey by the Bishop Museum at Midway and from multidiscipline efforts conducted under the auspices of the Northwestern Hawaiian Islands Rapid Assessment and Monitoring Program (NOWRAMP) in 2000 and 2002, and the PIFSC-CRED efforts in 2000, 2002, and 2003.

Results of these efforts have recorded a total of eleven aquatic invasive marine invertebrate, fish, and algal species in the NWHI. Table 10.3 shows the species, their native ranges, their present status in the NWHI, and the hypothesized or documented mechanism of their introduction. The magnitude of the problem of aquatic invasive species is far greater in the MHI than the NWHI. Efforts in the NWHI should be focused on minimizing the likelihood of these remote habitats being exposed to aquatic invasive species through anthropogenic means. This can be achieved by outreach and education directed towards all activities that have the potential for acting as mechanisms of transport.

Table 10.3. Marine invasive species in the NWHI. Sources: Zabin et al., 2003; Godwin, 2002; DeFelice et al., 2002; Godwin, 2000; DeFelice et al., 1998.

SPECIES	TAXA	NATIVE RANGE	PRESENT STATUS IN NWHI	MECHANISM OF INTRODUCTION
Hypnea musciformis	Algae	Unknown; Cosmopolitan	Not Established; in drift only (MAR)	Intentional introduction to MHI (documented)
Diadumene lineata	Anemone	Asia	Unknown; on derelict net only (P&H)	Derelict fishing net debris (documented)
Pennaria disticha	Hydroid	Unknown; Cosmopolitan	Established (P&H, LAY, LIS, KUR, MID)	Fouling on ship hulls (hypothesized)
Balanus reticulatus	Barnacle	Atlantic	Established (FFS)	Fouling on ship hulls (hypothesized)
Balanus venustus	Barnacle	Atlantic and Caribbean	Not Established; on vessel hull only (MID)	Fouling on ship hulls (documented)
Chthamalus proteus	Barnacle	Caribbean	Established (MID)	Fouling on ship hulls (hypothesized)
Amathia distans	Bryozoan	Unknown; Cosmopolitan	Established (MID)	Fouling on ship hulls (hypothesized)
Schizoporella errata	Bryozoan	Unknown; Cosmopolitan	Established (MID)	Fouling on ship hulls (hypothesized)
Lutjanus kasmira	Fish	Indo-Pacific	Established (NIH, NEC, FFS, MAR, LAY, and MID)	Intentional introduction to MHI (documented)
Cephalopholis argus	Fish	Indo-Pacific	Established (NIH, NEC, FFS)	Intentional introduction to MHI (documented)
Lutjanus fulvus	Fish	Indo-Pacific	Established (NIH and FFS)	Intentional introduction to MHI (documented)

Eleven species of shallow-water snapper (Lutjanidae) and grouper (Serranidae) were purposefully introduced to the main islands of the Hawaiian Archipelago in the late 1950s and early 1960s. Two snappers, the bluestripe snapper (*Lutjanus kasmira*) and the blacktail snapper (*L. fulvus*), and one grouper, the peacock grouper (*Cephalopholis argus*), are well-established and have documented patterns of colonization along the island chain (Randall, 1987).

Bluestripe snappers have been by far the most successful fish introduction to the Hawaiian coral reef ecosystem. From some 3,200 individuals introduced on the island of Oahu in the 1950s, the population has expanded its range widely and has been reported as far north as Midway in the NWHI (~2,400 km; Figure 10.12.). These records suggest a dispersal rate of about 33-130 km/yr. The other two species have only been recorded as far north as French Frigate Shoals and are present in much lower numbers than bluestripe snappers.

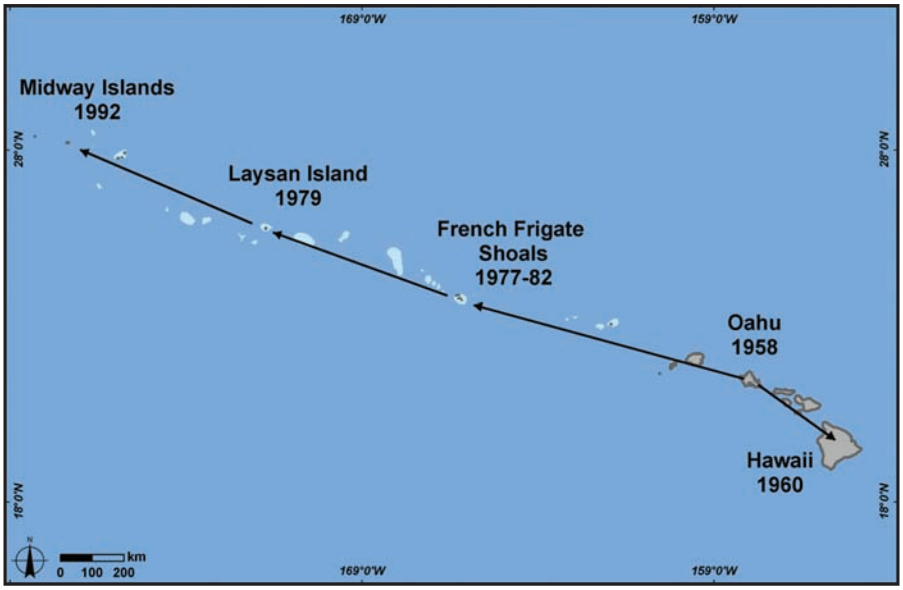


Figure 10.12. The spread of bluestripe snapper, *Lutjanus kasmira*, throughout the Hawaiian archipelago. Map: A. Shapiro. Source: Sladek-Nowlis and Friedlander, 2004.

Security Training Activities

Areas between Kauai and Nihoa are sometimes subjected to closure when missile tests are conducted at the Pacific Missile Testing Range on Kauai.

Offshore Oil and Gas Exploration

No offshore oil or gas exploration occurs in Hawaii.

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Description of Coral Reef Monitoring, Research and Assessment Activities

The monitoring programs that are currently collecting data in the NWHI are listed in Table 10.4. Many of the locations where monitoring has occurred recently are shown in Figure 10.13.

Table 10.4. Monitoring programs in the NWHI.

MONITORING PROGRAM	OBJECTIVES	YEAR EST.	FUNDING	AGENCIES
Northwestern Hawaiian Islands Reef Assessment and Monitoring Program	Monitor fishes, algae, coral and other invertebrates	2000	NOAA, USFWS, HCRI	PIFSC-CRED, DAR, USFWS, UH, NOS, numerous other institutions
Monk Seal Forage Base Study	Track the temporal dynamics of the shallow-reef fish forage base of monk seals	1992-2000	NOAA	PIFSC
Marine debris program	Oceanographic conditions and the rate of marine debris accumulation	1996	NOAA	PIFSC-CRED, UH, USFWS, DAR, USCG
Oceanography program	Water chemistry, circulation patterns	2000	NOAA	PIFSC-CRED, UH
Fishery independent lobster monitoring	Monitor lobster using fishery-independent sampling	1983	NOAA	PIFSC
Fishery Monitoring and Economics Program	Fisheries catch and effort statistics	1948	NOAA	PIFSC, DAR
Marine mammal research program	Monitor and assess reproductive subpopulations	1985	NOAA	PIFSC, USFWS
Marine turtle research program	Monitor selected sea turtle breeding sites	1973*	NOAA, USFWS	PIFSC, USFWS
Seabird monitoring	Monitor selected nesting seabird species	1978 (Albatross annually)	USFWS	USFWS
Coral monitoring	Monitoring of coral at permanent sites	2000	HCRI, USFWS	USFWS, PIFSC-CRED

PIFSC – Pacific Islands Fisheries Science Center
CRED – Coral Reef Ecosystem Division, PIFSC, NOAA Fisheries
DAR – Hawaii Division of Aquatic Resources, Department of Land and Natural Resources
USFWS – U.S. Fish and Wildlife Service
NOS – NOAA Ocean Service
UH – University of Hawaii
HICRI – Hawaii Coral Reef Initiative
*USFWS personnel stationed at French Frigate Shoals since 1978 to monitor turtle breeding sites.

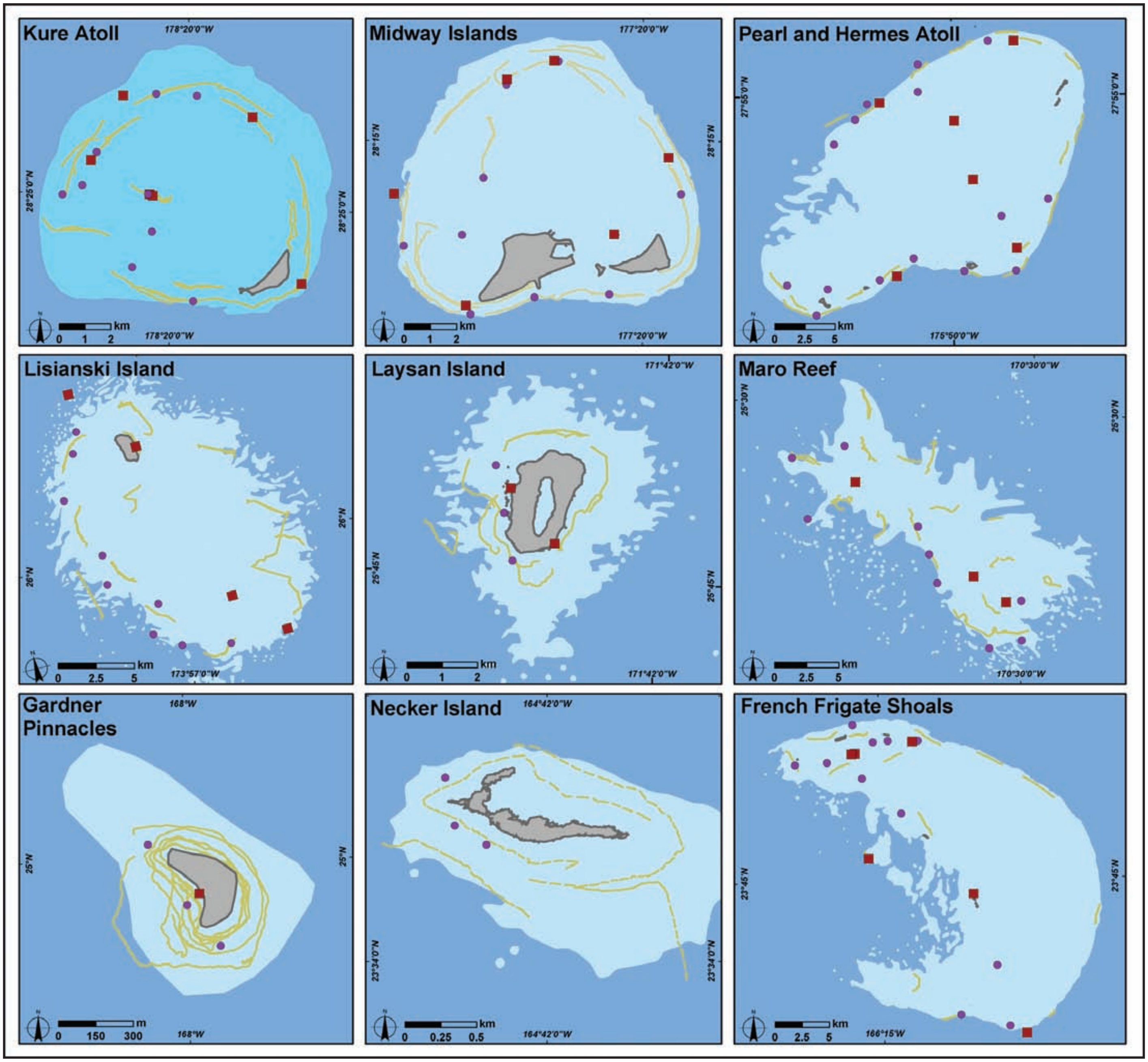
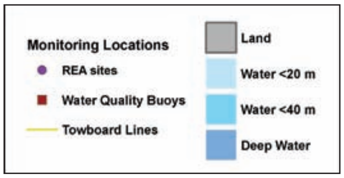


Figure 10.13. Monitoring locations in the NWHI. Map: A. Shapiro.



OCEANOGRAPHIC CONDITIONS AND WATER QUALITY

The health, functioning, and biogeography of the coral reef ecosystems of the NWHI are affected by the oceanographic conditions to which the fish, algae, corals, and other invertebrates of the ecosystem are exposed. These biological components depend on the time-varying ocean currents, waves, temperature, salinity, turbidity, nutrients, other measures of water quality, and other oceanographic conditions. As these conditions change, so do the health, distribution, and species diversity of each reef community. Table 10.5 provides a list of long-term oceanographic and water quality monitoring programs in place in the NWHI. Figure 10.14 shows the station locations of many of these monitoring systems.

Ocean Currents

Ocean currents transport and distribute larvae among and between different atolls, islands, and submerged banks of the NWHI, and also provide the mechanism by which species are distributed to and from the MHI, as well as far distant regions. The relatively low species diversity and high endemism of the NWHI are the result of the relative oceanographic isolation of the Hawaiian Archipelago. Ocean currents are measured and monitored in the NWHI in many different ways (Table 10.4). Since 1990, ocean current profiles along the Ha-

Table 10.5. Long-term oceanographic and water quality monitoring programs in the NWHI. Source: PIFSC-CRED.

SYSTEM	VARIABLES MONITORED	DATES	AGENCY
Deepwater CTD* - 10 sites (NIH, NEC, FFS, GAR, MAR, LAY, LIS, P&H, MID, KUR)	temperature, salinity, dissolved oxygen, and chlorophyll versus depth to a depth of 500 m	May 1998 - present	PIFSC-CRED
Shallow-water CTD* - multiple sites each island/atoll	temperature, salinity, turbidity	Sept. 2001 - present	PIFSC-CRED
Coral Reef Early Warning System (CREWS) Buoys - 4 Standard (P&H, MAR, KUR), 1 Enhanced – (FFS)	Standard: temperature (1 m), salinity, wind, atmospheric pressure, Enhanced: Std plus ultraviolet radiation, photosynthetic active radiation	Oct. 2001 - present	PIFSC-CRED
Sea Surface Temperature (SST) Buoys – 4 (NEC, LAY, LIS, MID)	Temperature at 0.5 m	Oct. 2001 - present	PIFSC-CRED
Subsurface Temperature Recorders (STR) – 22	Temperature at depths between 0.5 m and 5 m	Oct. 2002 - present	PIFSC-CRED
Ocean Data Platforms (ODP) – 2 (NEC, MID)	temperature, salinity, spectral directional wave motion, current profiles	Oct. 2002 - present	PIFSC-CRED
Wave and Tide Recorders (WTR) – 4 (P&H, KUR)	spectral wave motion, tides, temperature	July 2003 - present	PIFSC-CRED
Drifter Buoys	temperature, surface circulation (location)	2001 (6), 2002 (10), 2003 (8)	PIFSC-CRED
Autonomous Profiling Explorer (APEX) Floats	temperature, surface circulation (location)	2002 (6)	PIFSC-CRED
Tide Gauges	tidal fluctuations, sea level	FFS=1974-present, MID=1947-present	UH Sea Level Center
Wave Monitoring Buoys	wave height & period, wind speed & direction, atmospheric pressure, temperature	1980 - present	NOAA National Weather Service, National Data Buoy Center
Satellite Remote Sensing	sea surface temperature, winds, sea surface height, ocean color	SST -1981 SSH – 1992 Wind – 1995 Ocean Color - 1994	NOAA Satellites and Information, Hawaii Coastwatch
Model Fields	waves / surface circulation		NOAA National Weather Service, Wave Watch 3 Naval Research Laboratory, Navy Coastal Ocean Model

* CTD: Conductivity, Temperature and Depth

waiian Archipelago have been measured using acoustic Doppler current profilers (ADCP) aboard the NOAA ships *Townsend Cromwell* (1990 to 2002) and *Oscar Elton Sette* (2003 to present) during routine transects along the archipelago to support an array of scientific cruises for PIFSC. Based on 10 years of ADCP data during the period 1990 to 2000, Firing et al. (2004a) demonstrate that upper ocean currents in the NWHI are highly variable in both speed and direction, being dominated by eddy variability. Averaged over time, the resultant mean flow of the surface waters tend to flow predominantly from east to west in response to the prevailing northeast tradewinds (Figure 10.15). The lack of coral reef ecosystems to the east, or upstream, of the Hawaiian Archipelago and the generally low biodiversity to the east explains the low species richness and high endemism. Surface Velocity Program (SVP) current drifters and autonomous profiling explorer (APEX) drifters have also been deployed in the NWHI by PIFSC annually since 2001. These SVP and APEX drifters provide indications of the Lagrangian (or water-following) flow, thereby representing potential larval pathways. Similar to the ADCP measurements, the drifters show significant eddy variability and a general surface flow from east to southwest (in 2001-2002) and northwest (in 2003) (Figure 10.16). Interestingly, two of the six APEX drifters deployed near Nihoa and Necker in 2001 were advected close to Johnston and then moved back northward toward the NWHI, suggesting the larval link between Johnston and the NWHI (Firing et al., 2004a). Spatial maps of ocean currents in the vicinity of the NWHI are also computed from satellite observations of sea surface height from the TOPEX Poseidon and JASON altimetric satellites (Polovina et al., 1995). In recent years, the PIFSC has also deployed ADCP moorings at Southeast Brooks Bank (1998-1999), Necker (2003-2004) and Midway (2003-2004) to look more closely at temporal variability of ocean currents over submerged banks and reef habitats in the NWHI.

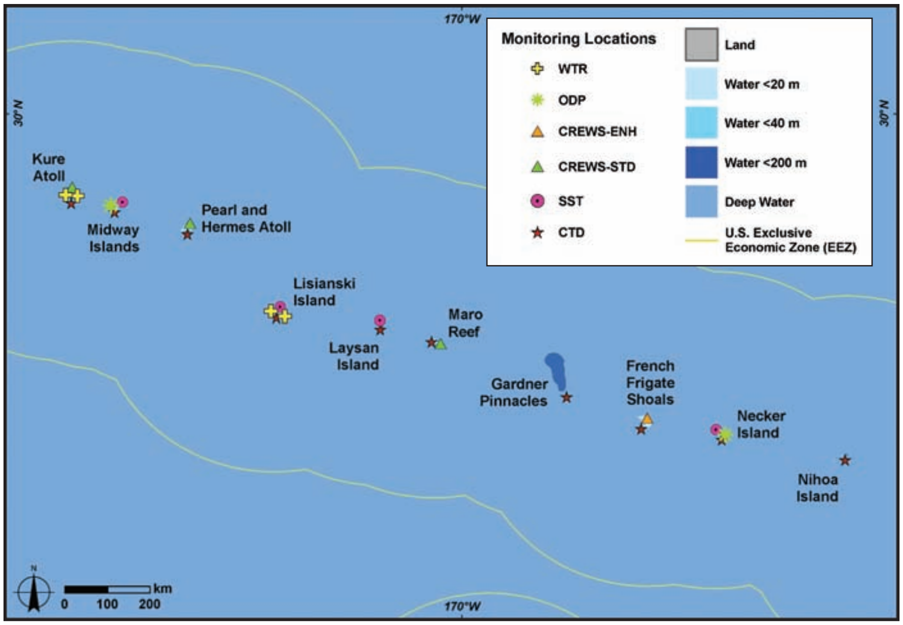


Figure 10.14. Long-term oceanographic monitoring stations in the NWHI. Wave and Tide Recorder (WTR) stations are indicated by yellow crosses. Ocean Data Platform (ODP) locations are indicated by green asterisks. Enhanced CREWS stations are indicated by orange triangles. Standard CREWS stations are indicated by green triangles. SST buoys are indicated by purple circles. Permanent deepwater CTD stations are indicated by red stars. Source: Hoeke et al., 2004a, b.

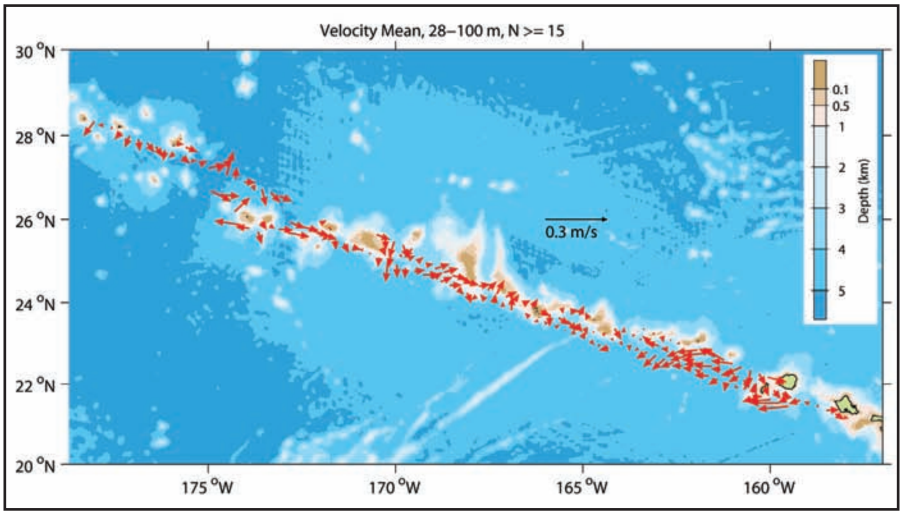


Figure 10.15. ADCP data from 1990 to 2000 averaged over time. The upper ocean currents in the NWHI are highly variable in both speed and direction, being dominated by eddy variability. The resultant mean flow of the surface waters tends to flow predominantly from east to west in response to the prevailing northeast tradewinds. Source: Firing et al., 2004a.

Ocean Waves

Among each of the islands, atolls, and submerged banks of the NWHI, the distributions of species of corals and algae, and their associated fish and invertebrate assemblages are often determined not only by the ocean currents, but also by the exposure to ocean waves. Many species of corals and algae can survive in sheltered

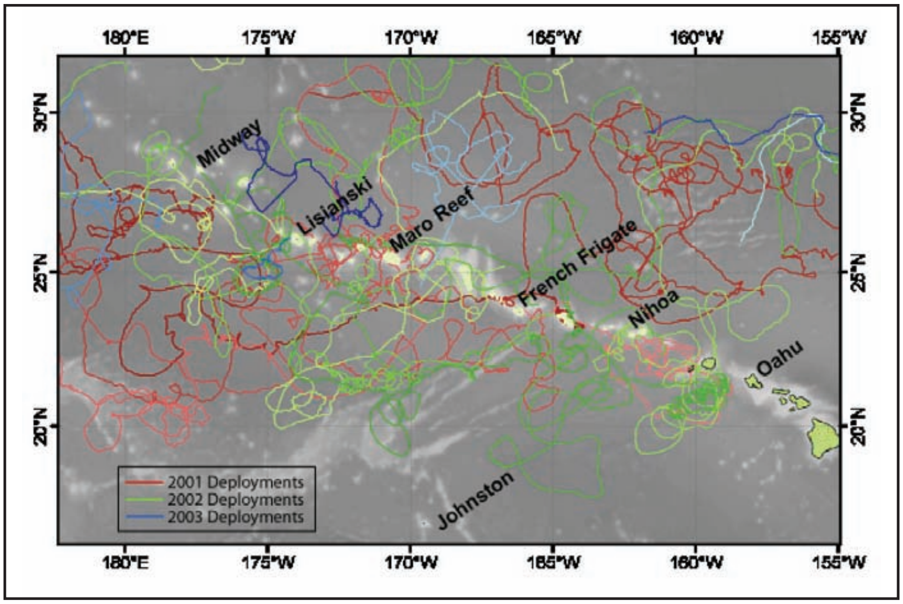


Figure 10.16. Satellite-tracked drifter tracks from SVP drifters deployed along the NWHI in 2001 (reds), 2002 (greens), and 2003 (blues). Source: Firing et al., 2004b.

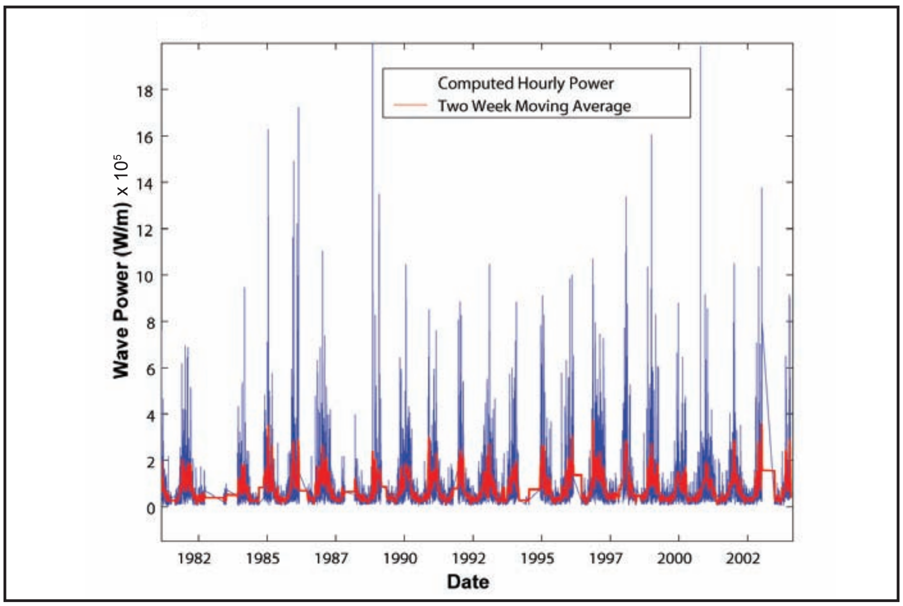


Figure 10.17. Time series of wave power computed from wave data from NOAA Buoy #51001 located near Nihoa Island in the NWHI. Data courtesy of NOAA Data Buoy Center. Source: Brainard et al., 2004.

or quiescent habitats. Other species can survive or even thrive in the high-energy habitats of the surf zones on the northwestern facing reefs that are exposed to tremendous waves caused by winter storms across the North Pacific. The less hardy species cannot survive the pounding by these large winter waves.

Significant wave events vary over interannual (between year) and decadal time scales (Figure 10.17). Interannually, some years experience greater or lesser amounts of cumulative wave energy or numbers of extreme wave events than other years. This temporal variability of wave power allows expansions and retractions of the spatial and vertical ranges of the some species during relatively quiescent and turbulent years, respectively. Over the past 20 years, wave measurements at NOAA buoy 51001 (near Nihoa Island in the NWHI) show a pattern of anomalously high numbers of extreme wave events during the periods 1985-1989 and 1998-2002 and anomalously low numbers of extreme wave events in the early 1980s and the period 1990-1996. This apparent decadal variability of wave power is possibly related to well-documented Pacific Decadal Oscillation (PDO) events, which are a mode of North Pacific climate variability at multi-decadal time scales that has widespread climate and ecosystem impacts (Mantua et al., 1997). Studies have shown decadal oscillations of various components of NWHI ecosystems (lobsters, monk seals, seabirds, etc.) relate to larger scale climate shifts across the North Pacific (Polovina et al., 1995).

Ocean temperatures

While coral bleaching can be caused by a wide range of environmental variables acting alone or in combination (Jokiel and Brown, 2004), the predominant cause of increasing incidences of coral bleaching globally is believed to be anomalously warm water temperatures (Jokiel and Coles, 1990; Kenyon et al., in review). Because of the significant influence of temperature on coral reef ecosystem health, observations of temperature in the NWHI are collected by a wide array of instruments and platforms, including satellite remote sensing of SST using Advanced Very High Resolution Radiometer (AVHRR), moored surface buoys and subsurface temperature recorders, closely-spaced conductivity-temperature-depth profiles (CTD casts) in shallow water/nearshore reef habitats, broadly-spaced shipboard deep water CTD casts to depths of 500 m, and satellite-tracked SVP drifters (Table 10.5).

The coral reefs of the NWHI are exposed to large seasonal temperature fluctuations, particularly Kure, Midway, and Pearl and Hermes Atolls at the northwestern end of the archipelago. SSTs at these northerly atolls range from less than 18°C in late winter of some years (17°C in 1997) to highs exceeding 28°C in the late summer months of some years (29°C in 2002) (Figure 10.18). Compared with most reef ecosystems around the globe, the annual fluctuations of SST of about 10°C at these northerly atolls is extremely high. While the summer temperatures are generally similar along the entire NWHI, the warmest summer temperatures tend to occur at the three northernmost atolls, presumably caused by reduced mixing due to weaker winds (situated closer to the center of the North Pacific high pressure ridge) and decreased circulation due to large shallow water lagoons (Brainard et al., 2004; Hoeke et al., 2004a, b). The winter temperatures tend to be 3-7°C cooler at the northerly atolls than at the southerly islands and banks as the subtropical front migrates southward. These cooler winter temperatures are thought to reduce coral growth rates.

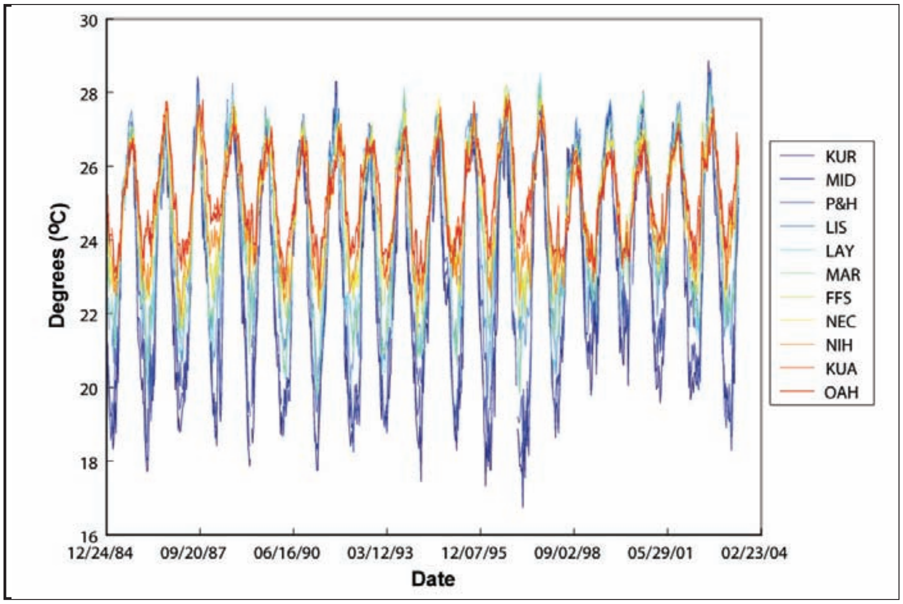


Figure 10.18. Time series of Pathfinder SST at key islands and atolls of the NWHI from KUR to Oahu (OAH) between 1984 and 2004. Blue colors=northerly atolls and red colors=Kauai (KUA) and OAH in the Main Hawaiian Islands. Data provided by NOAA Satellites and Information, Hawaii CoastWatch. Source: Hoeke et al., 2004b.

In addition to the strong annual cycle, SST observations show significant interannual and decadal variability (Figure 10.18). The highest summer maximum SSTs at the northern atolls occurred during the summers of 1987, 1991, and 2002, possibly suggesting a teleconnection with El Niño Southern Oscillation (ENSO) events. Winter minimum temperatures at the northern atolls appear to oscillate over a longer time period, as indicated by a significant warming of winter SSTs beginning in 1999 and lasting for several years (Brainard et al., 2004).

During the period between July and September 2002, ocean temperatures along the Hawaiian Archipelago were anomalously warm (Figure 10.19). According to NOAA's Coral Reef Watch Program, temperatures exceeded the coral bleaching threshold for four consecutive Degree Heating Weeks. As discussed elsewhere in this report, this resulted in widespread mass coral bleaching of many species of coral in shallow water habitats, particularly at the three northernmost atolls. While warming is common during the late summer months, this extreme warming event, and the resulting coral bleaching is believed to have been caused by anomalously low wind speeds during the period (Hoeke et al., 2004a, b).

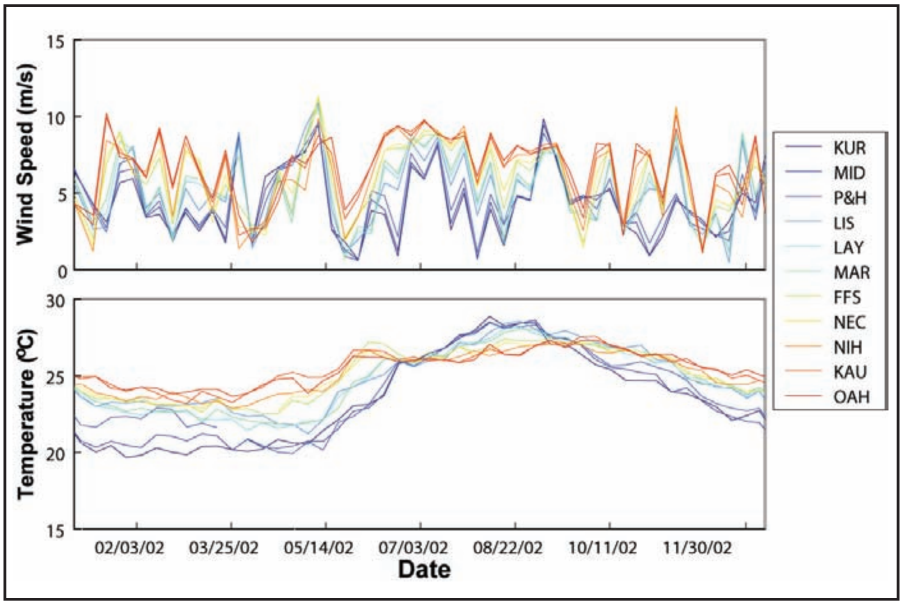


Figure 10.19. Satellite-derived wind speed and SST along Hawaiian Archipelago from Oahu (OAH) to KUR during 2002. The warming event associated with the 2002 coral bleaching followed periods of light winds at the northernmost atolls. Source: Hoeke et al., 2004a, b.

Nutrients

Satellite observations of ocean color from the National Aeronautics and Space Administration's (NASA) Sea-viewing Wide Field-of-view Sensor (SeaWiFS) reveal a significant chlorophyll front associated with the subtropical front, with high chlorophyll north of the front and low oligotrophic waters south of the front. These observations reveal significant seasonal and interannual migrations of the front northward during the summer months and southward during the winter months (Seki et al., 2002). The southward migration of the subtropical front generally brings these high chlorophyll waters to intersect the northern portions of the NWHI. During some years, these winter migrations of the subtropical front extend southward to include the southern end of the NWHI. Additional evidence suggests decadal scale movements in the southward extent of the subtropical front. During periods when high chlorophyll waters intersect the NWHI, overall productivity of the effected reef ecosystems is expected to be elevated. Changes across many trophic levels of the NWHI ecosystem are believed to be associated with these migrations (Polovina et al., 1995).

BENTHIC HABITATS

CORAL

Coral abundance, distribution, condition, biodiversity, and population structure in the NWHI were surveyed at more than 536 sites between 2000 and 2003. Several techniques were used: towed diver video surveys each averaging approximately 2 km in length, rapid ecological assessments (REA) each covering between 1000-5000 m^2 per site, photo-quadrat/video surveys at permanently marked 50-100 m transects, settlement and recruitment studies at six of the NWHI, and directed observations on coral disease, predation, and bleaching at all of the NWHI except Nihoa. Initially, the REA protocols focused on video-taping two 25 m transects at each site and visually inventorying species and estimating their relative abundance in broader surrounding areas. In 2002, the protocols were revised to shift towards *in situ* quantitative coral population data collection along the first two 25 m transects. The revised REA protocols are described in Maragos et al. (2004) and were used during the 2002 and 2003 surveys.

Coral species inventories and distribution from REAs

REA surveys at 465 discreet sites on 11 reefs in the NWHI inventoried coral species, their relative abundances, and their distributions during 2000-2002. Surveys (462) around the 10 islands were in depths of ≤20 m, and three surveys on the submerged Raita Bank were in depths of 30-35 m. Results include 11 first records for stony coral species in the Hawaiian Archipelago, and 29 species range extensions to the NWHI. Several species may be new to science. There are now 57 stony coral species known in the shallow subtropical waters of the NWHI (Table 10.6), similar to the 59 shallow and deepwater species known in the better-studied and more tropical MHI. Coral endemism is high in the NWHI: 17 endemic species (30%) account for 37-53% of the relative abundance of stony corals visually estimated on each reef of the NWHI. Three genera (*Montipora, Porites, Pocillopora*) account for 15 of the 17 endemic species and most of the endemic abundance. Seven *Acropora* species (Figure 10.20) are now known from the central NWHI despite their near absence from the MHI. Coral abundance and diversity are highest at the large open atolls of the central NWHI (French Frigate, Maro, Lisianski/Neva Shoal) and decline gradually through the remaining atolls to the northwest (Pearl and Hermes, Midway and Kure). Stony corals are also less abundant and diverse off the exposed basalt islands to the southeast (Nihoa, Necker, La Perouse, Gardner), where soft corals (*Sinularia, Palythoa*) are more abundant. Exposure to severe wave action appears to limit coral development off these small islands and surrounding deep platforms. Temperature extremes and natural accumulation of lagoon sediments may contribute to decline of coral species and abundance at the northwestern end of the chain, based on the REA survey results.

Table 10.6. Checklist of stony corals reported from the NWHI, including 2000-2002 REA surveys. Source: Maragos et al. 2004.

ACROPORIDAE	
++ j	*Acropora cerealis* (Dana, 1846)
J	*A. cytherea* (Dana, 1846)
++ j	*A. gemmifera* (Brook, 1892)
J	*A. humilis* (Dana, 1846)
++ j	*A. nasuta* (Dana, 1846)
+ j	*A. paniculata* (Verrill, 1902)
j	*A. valida* (Dana, 1846)
*? j	*Montipora capitata* (Dana, 1846)
* v	*M. dilatata* (Studer, 1901)
* ++	*M.* cf. *dilatata* (Studer, 1901)
*	*M. flabellata* (Studer, 1901)
* j	*M. patula* (Verrill, 1864)
* + j	*M.* cf. *incrassata* (Dana, 1846)
++ j	*M. tuberculosa* (Lamarck, 1816)
* +	*M. turgescens* (Bernard, 1897)
	M. verrilli (Vaughan, 1907)
AGARICIIDAE	
	Pavona clavus (Dana, 1846)
*? j	*P. duerdeni* (Vaughan, 1907)
j	*P. maldivensis* (Gardiner, 1905)
j	*P. varians* (Verrill, 1864)
v j	*Leptoseris hawaiiensis* (Vaughan, 1907)
j	*L. incrustans* (Quelch, 1886)
+ j	*L. scabra* (Vaughan, 1907)
+	*Gardineroseris planulata* (Dana, 1846)
BALANOPHYLLIIDAE	
+	*Balanophyllia* sp.
+	*Cladospammia* cf. *eguchii* (Wells, 1982)
DENDROPHYLLIIDAE	
+	*Tubastraea coccinea* (Lesson, 1829)
FAVIIDAE	
+	*Leptastrea agassizi* (Vaughan, 1907)
++	*L. bewickensis* (Veron & Pichon, 1977)
* ++	*L.* cf. *Favia hawaiiensis* (Vaughan 1907)
++	*L.* cf. *pruinosa* (Crossland, 1952)
j	*L. purpurea* (Dana, 1846)
j	*Cyphastrea ocellina* (Dana, 1846)
FUNGIIDAE	
j	*Fungia scutaria* (Lamarck, 1801)
++	*F. granulosa* (Klunzinger, 1879)
+ j	*Cycloseris vaughani* (Boschma, 1923)
POCILLOPORIDAE	
* r	*Pocillopora* cf. *cespitosa* var. *laysanensis* (Vaughan,1907)
j	*P. damicornis* (Linnaeus, 1758)
j	*P. eydouxi* (Edwards & Haime, 1860)
	P. ligulata (Dana, 1846)
j	*P. meandrina* (Dana, 1846)
* +	*P. molokensis* (Vaughan, 1907)
* ++	*P.* cf. *capitata* (Verrill, 1864)
PORITIDAE	
*	*Porites brighami* (Vaughan, 1907)
*	*P. compressa* (Dana, 1846)
* +	*P. duerdeni* (Vaughan, 1907)
* +	*P. evermanni* (Vaughan, 1907)
j	*P. lobata* (Dana, 1846)
*	*P. rus* (Forskal, 1775)
* ++	*P. hawaiiensis* (Vaughan, 1907)
+	*P.* cf. *annae* (Crossland, 1952)
	P. cf. *solida* (Forskål, 1775)
SIDERASTREIDAE	
+	*Psammocora explanulata* (Horst, 1921)
+ j	*P. nierstraszi* (Horst, 1921)
+ j	*P. stellata* (Verrill, 1864)
* +	*P. verrilli* (Vaughan, 1907)

Notes:
+ New range record for the NWHI (previously known in main Hawaiian Islands).
++ New range record for Hawaii as a whole.
j Hawaiian species also reported at Johnston Atoll.
r reported only at Raita Bank and now considered endemic at the species level.
v reported by Vaughan (1907) at Laysan but not during present study.
* species endemic to Hawai'i and northern but Line Islands (including Johnston).
*? considered endemic to Hawai'i and Line Islands here and by Maragos (1995), not by Veron (2000).

Northwestern Hawaiian Islands

Figure 10.20. A large table coral, *Acropora cytherea*, thrives near a permanent monitoring site at French Frigate Shoals. Photo: J. Watt.

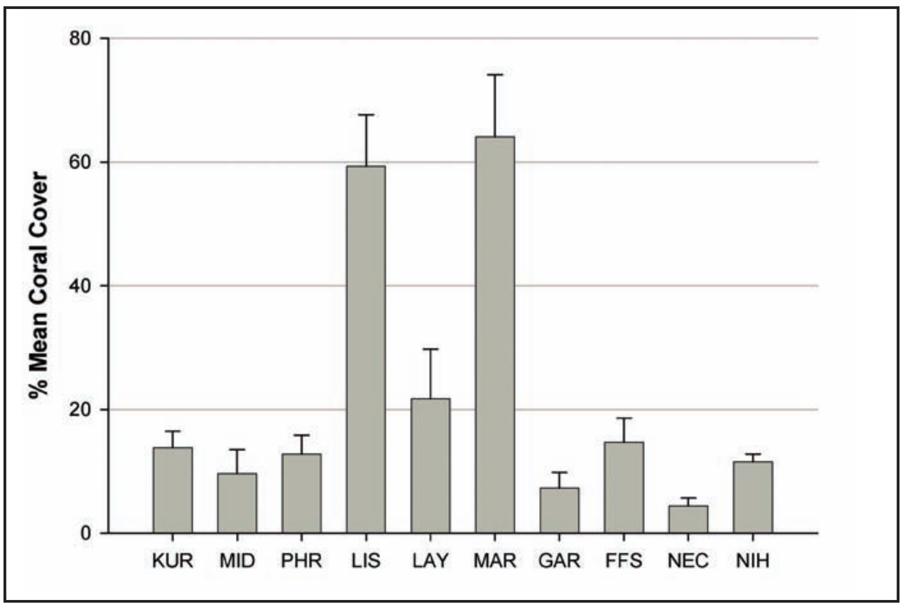


Figure 10.21. Differences in coral cover among regions within the NWHI. REA surveys were conducted at 173 sites in 2002. Coral cover was calculated from size frequency data of colony counts within transects. Data are mean and standard error. Source: PIFSC-CRED, unpublished data.

Coral Community Structure

REA surveys were conducted at 173 sites across the NWHI in 2002. Based upon these surveys it was found that coral cover varies greatly across the NWHI. Most regions have low coral cover while Maro Reef and Lisianski having comparatively high coral cover (Figure 10.21). Grigg (1983) reported similar results with the exception of higher coral cover reported from French Frigate Shoals. However, his study was based on a much smaller and spatially limited number of sites. It was also found that coral cover varied among reef zones (Table 10.7), thus estimates of coral cover would vary greatly depending on where the surveys were conducted. The reef zone with the highest coral cover varied among regions with no consistent pattern emerging. Coral community structure also differed across the regions (Table 10.8) but overall *Porites, Pocillopora,* and *Montipora* were the dominant genera.

Coral monitoring at permanent transects

Methods

Permanent monitoring sites were selected to cover representative shallow-water (<20 m) coral reef habitats. With only an hour of ship's time every other year devoted to each survey, it was important that sites be conveniently located and safely approached from offshore. Several sites at Pearl and Hermes and French Frigate Shoals were installed to monitor the effects of a ship grounding and a future sea wall construction project, respectively. A total of 11 transects were established at French Frigate Shoals, 10 at Midway Atoll, eight at P&H, three each at Maro Reef and Lisanski/ Neva Shoal, two each at Laysan and Nihoa, and one each at Gardner Pinnacles and Necker. The availability of small skiffs at the permanently occupied field stations at Midway and French Frigate Shoals contributed to the greater number of transects there.

At each site, photoquadrats were taken along 50 m or 100 m transects. To date 1,938 photoquadrats at 48 transects have been collected and partially analyzed. Digital video was also taken along most transects.

Results and Discussion

Monitoring of corals was established at 41 permanently marked transects at nine of the NWHI (except Kure) from 2000-2002, supplementing 2002-2003 monitoring efforts at REA sites. Six of the sites at French Frigate Shoals and two at Midway were resurveyed in 2002. Repetitive surveys at the same reefs using the same methods allows more precise detection of changes in coral and macroinvertebrate populations over time. The principal advantage of fixed sites is reduced spatial variability relative to temporal variability, provided that the original transects are precisely relocated and resurveyed. The principal disadvantage is the extra time required for installing permanent markers during the initial survey and relocating, repairing, or replacing lost markers during subsequent surveys. Permanently marked transects are particularly useful for tracking changes in sessile benthos such as individual coral colonies over many years. Analyses are still in progress and discussion here is limited to the results of initial baseline surveys.

Table 10.7. Differences in coral cover within different reef zones in the NWHI. Numbers represent the average coral cover (%) + standard error. Coral cover calculated from size frequency data of colonies within transects. Data based on REA surveys in 2002. NS=not sampled. Source: PIFSC-CRED, unpublished data.

	REEF ZONE			
	SHELF	**FOREREEF**	**BACKREEF**	**LAGOON**
NIH	11.5 (1.3)	NS	NS	NS
NEC	4.4 ± 1.3	NS	NS	NS
FFS	8.2 ± 6.6	7.6 ± 3.2	12.0 ± 3.5	24.1 ± 9.7
GAR	7.3 ± 2.5	NS	NS	NS
MAR	NS	64.1 ± 10.0	NS	NS
LAY	21.7 ± 8.0	NS	NS	NS
LIS	50.0 ± 12.1	73.2 ± 11.2	NS	24.5±
P&H	NS	13.3 ± 3.1	5.0 ± 2.7	20.7 ± 11.0
MID	2.7 ± 2.2	2.1 ± 0.63	30.6 ± 12.1	0.98 ± 0.41
KUR	20.2 ± 11.7	8.9 ± 2.0	12.3 ± 3.6	19.9 ± 5.3
mean	**15.8 (5.5)**	**28.2 (12.9)**	**14.9 (5.4)**	**18.0 (4.4)**

Table 10.8. Coral community structure within the NWHI. Numbers represent the average composition (%) by genera based on colony counts within belt transects conducted in 2002. The three most abundant genera are highlighted (bold type) within each region. Source: PIFSC-CRED, unpublished data.

	NWHI	KUR	MID	P&H	LIS	LAY	MAR	GAR	FFS	NEC	NIH
	# REA SITES PER ISLAND	21	31	32	22	10	14	6	29	6	2
CORAL GENERA	*Acropora*	0	0	0	0.4	0	2.6	0.06	**8.8**	0	0
	Cyphastrea/Leptastrea	**3.2**	3.3	**13**	**12**	8.5	4.2	**2.5**	3.2	0.4	1.1
	Fungia/Cycloceris	0.1	0.15	0.4	7.2	0	0.5	0	0.2	0	0
	Montipora	1.8	**15**	3.2	**35**	**14**	**18**	1.1	3.3	**4.3**	**4.8**
	Pocillopora	**41**	**27**	**28**	3.5	**12**	**9.9**	**11**	**19**	**28**	**34**
	Porites	**54**	**53**	**52**	**41**	**65**	**54**	**81**	**63**	**68**	**60**
	Pavona	0.2	0.43	1.9	3.5	0.9	5.7	1.9	1.9	0	0
	Psammocora	0	0.38	0.9	1	0	0.1	0.45	0.1	0	0
	Other stony coral	0	0	0	0	0	0	0	0.1	0	0
	Soft coral/anemones	0	0.92	1	0	0.3	4.9	1.94	2.5	0	0

Live coral cover was quite variable ranging from 0.37% to 48.34% at the monitoring transects (Table 10.9). The highest values were concentrated at ocean reef sites sheltered from heavy tradewinds and large winter swell from the Northwest Pacific and at most lagoon sites, except the low values at sites near Tern Island at French Frigate Shoals which have a history of chronic disturbance from dredging filling, fuel spills, and other contamination since WWII. The lowest live coral values were concentrated at ocean facing reefs off Nihoa, Necker, Gardner, and Laysan Islands, which are more exposed to large waves and swells from any direction. Lisianki Island is protected by Neva Shoal, which might explain the higher coral cover there.

Moreover, sites with large mean coral diameters positively correlated with those of high coral cover. However, sites with large frequencies (numbers of corals per square meter) did not correlate with high coral cover. Sites with the highest diversity of corals (numbers of coral types per transect) showed no strong correlations with other parameters. Many of these sites were situated where there was greater habitat variety and some shelter from heavy swells and wave action.

Table 10.9. Summary of NWHI coral monitoring data at permanently marked sites. C=central, N=north, S=south, E=east, W=west, lag=lagoon, tip=end of perimeter reef. Source: Maragos and Veit, 2004.

ATOLL/ ISLAND	# OF SITES	REEF LOCALE	YEAR	# CORAL TYPES/ TRANSECT	TRANSECT AREA (m^2)	% CORAL COVER	CORAL FREQ. #/m^2	CORAL MEAN DIAM.-cm
FFS	1	N tip	2001	5	25	20.7	2.8	25
FFS	2	N tip	2002	5-8	72	11.5-23.1	2.3-7.7	19-23
FFS	1	NE lag	2001	4	35	25.9	3.4	42.4
FFS	2	NE lag	2002	3-4	73	29.1-34.7	1.6-2.9	32.6-76.2
FFS	3	N lag	2002	3-4	119	0.4-1.6	1.5-1.9	5.3-8.7
FFS	1	N ocean	2001	4	38	11.6	14.2	11.6
FFS	1	N ocean	2002	3	51	12.5	11.7	13.3
FFS	1	NC lag	2001	6	36	8.6	4.6	12.3
FFS	1	NC lag	2002	3	45	6.7	8	9.3
FFS	1	central lag	2001	5	33	24.1	8.5	19.9
FFS	2	central lag	2002	2-4	69	14.6-28.8	6.2-7.1	16.1-30.3
FFS	1	S tip	2001	8	36	31.6	5.1	25.5
FFS	1	S tip	2002	2	16	46.1	3.3	43.6
GAR	1	W side	2002	3	20	4.3	10	8.9
LAY	2	W lag	2002	4	62	4.2-7.4	5.6-9.5	7.7-11.0
LIS	1	S fringing	2002	2	51	4.8	1,0	14.5
LIS	1	E ocean	2002	1	51	45.8	1.8	57.4
LIS	1	N fringing	2002	2	51	15.5	5.1	22.9
MAR	1	W lag	2001	3	34	3.7	3.8	10.9
MAR	1	SE ocean	2002	3	17	26	4.6	29.6
MAR	1	NW tip	2002	3	24	48.3	6.4	36.4
MID	3	N&W lag	2002	2-3	154	29.6-40.6	1.5-2.0	46.6-53.2
MID	5	E lag	2002	2-4	152	0.49-12.5	1.4-4.5	6.8-22.6
MID	2	S lag	2002	2	80	4.4-5.1	2.8-12.2	8.0-14.7
NEC	1	S ocean	2002	2	57	5.2	9.1	8.4
NIH	2	S&W side	2002	2-4	57	0.6-7.9	3.2-4.3	2.4-18.0
P&H	4	SE ocean	2000	2-5	271	6.2-8.9	3.0-7.7	11.0-21.1
P&H	1	W ocean	2002	4	62	5.7	3.2	15.5
P&H	1	S pass	2002	3	54	1.8	1.1	14.4
P&H	1	S lag	2002	3	37	2.1	1.8	11.7
P&H	1	C lag	2002	2	55	19.8	4.6	25.65

Towed-diver surveys

Since 2000, 333 towed-diver surveys have been conducted in the NWHI by PIFSC-CRED (Kenyon et al., 2004; Figure 10.22). During each survey, two divers maneuver separate boards that are equipped with digital video or still camera, as well as temperature and depth recorders, while being towed behind a small boat. The tow path is concurrently recorded by a global positioning system (GPS) receiver onboard the boat, to which a layback model is applied to more accurately map the position of the recorded imagery. Percent cover of salient benthic categories is quantified by whole-image analysis of still frames sampled at 30-second intervals. Towed-diver surveys bridge a gap between large-scale mapping efforts using satellite data and small-scale traditional belt transects or roving diver assessments, providing a mesoscale spatial assessment of reef habitats.

Towboard results

At French Frigate Shoals, where the greatest quantity of towed-diver survey benthic imagery has been analysed to date, three coral genera – *Porites, Pocillopora,* and *Acropora* – account for more than 93% of total coral cover throughout the atoll, while their relative percent cover, densities, and size distributions vary according to geomorphic and geographic location within the atoll system. Preliminary results from other atoll systems in the NWHI (Pearl and Hermes, Midway, and Kure) similarly reveal differences in total coral cover and the relative abundance of coral genera based upon zone (forereef, backreef, or lagoon) and geographic location. *Porites* and *Pocillopora* dominate the coral cover at these three northern atolls, with *Montipora* frequently co-dominating in the relatively protected backreef zone.

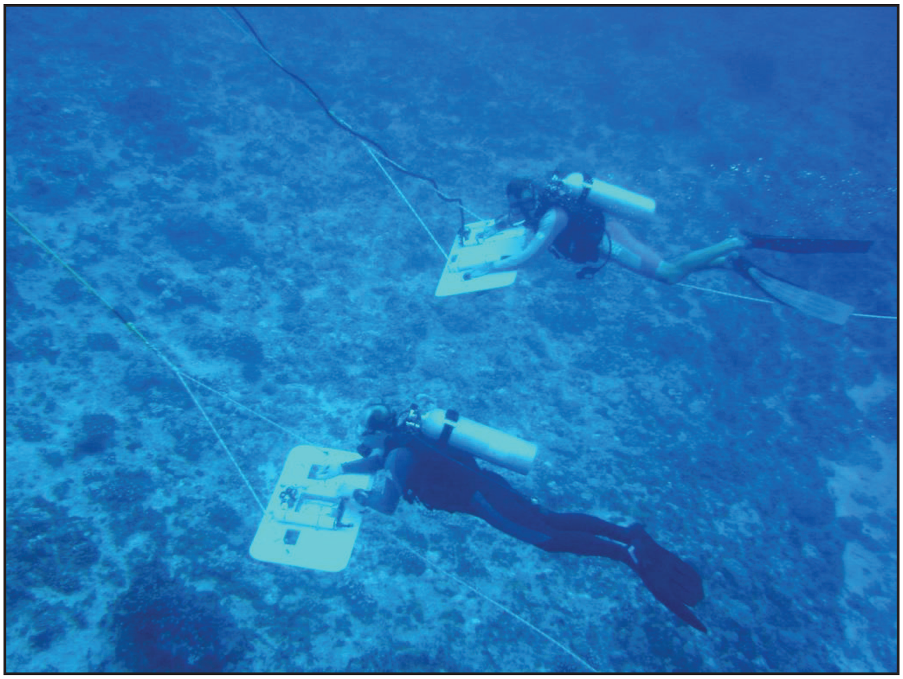
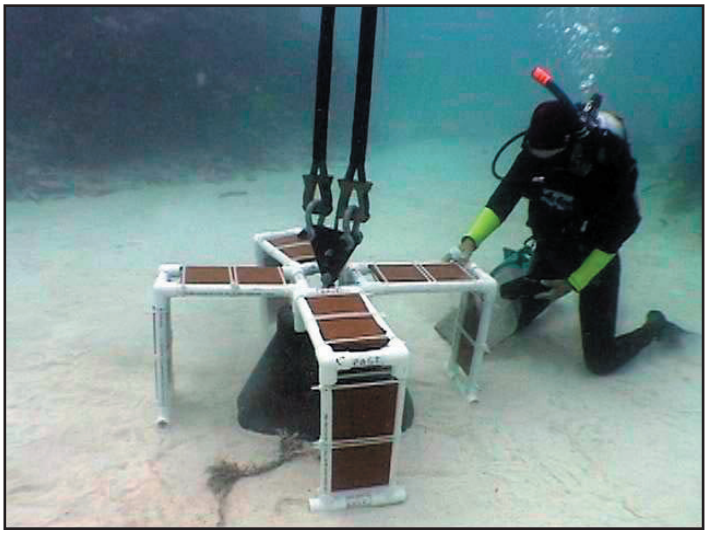


Figure 10.22. Photo of towboard divers surveying a reef in the NWHI. Photo: PIFSC-CRED.

Coral settlement and recruitment

In fall 2001, settlement plates were attached to the base of CREWS moorings at each of French Frigate Shoals, Maro Reef, Lisianski, Pearl and Hermes, Midway, and Kure (Figure 10.23A) to assess larval recruitment and enable coupling of biological data with physical data collected by the buoys. The plates have been collected and fresh plates installed at roughly one-year intervals since that time in order to examine them for settlement by calcareous organisms. After recruitment plates were collected, all calcareous organisms present on the collected plates were counted and measured (Figure 10.23B).

Coral recruits were present at all locations, but Maro had the highest density (270 recruits/m^2/year versus the next highest at Kure of 43 recruits/m^2/year) and a larger mean coral diameter (2.67 mm versus the next largest at Lisianski of 2.05 mm) than other plates. The recruitment rate at Maro is the highest rate yet recorded in the Hawaiian Archipelago. Recruits were identified from the families Acroporidae, Pocilloporidae, and Poriti-



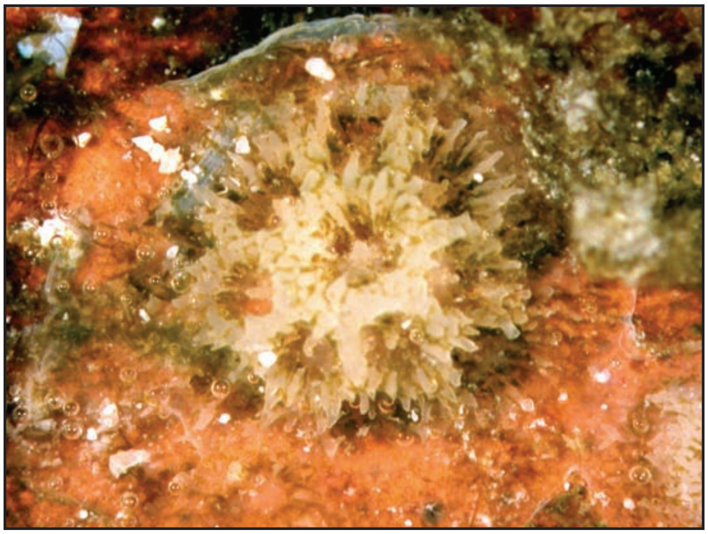


Figure 10.23. Left photo shows a newly-installed array of recruitment plates surrounding the anchor of an oceanographic buoy at FFS. Right photo shows NH2 - Pocilloporid recruit to a settlement plate deployed at MAR from October 1, 2002 to July 21, 2003. Photos: PIFSC-CRED; M. Dunlap.

dae, with Pocilloporids constituting up to 90% of the recruits. Lowest coral settlement occurred at Midway (7 recruits/m^2/year), followed by Pearl and Hermes (18 recruits/m^2/year). Coral recruits were more abundant on the undersides (horizontal) and insides (vertical) of plates at five of the six locations. While low settlement at those sites could be a reflection of naturally low recruitment, numbers may have been affected by an August 2002 bleaching event at the three northern atolls. Annual deployment and collection of plates will address whether low recruitment at these locations is typical or associated with bleaching events, as well as many recruitment questions important to management.

ALGAE

Until recently, algal collections from the NWHI were solely qualitative, intermittent, and often biased towards large, macroscopic species (Reinbold, 1899; Lemmerman, 1905; Howe, 1934; Buggeln, 1965; Tsuda, 1965, 1966; Balazs, 1979). Abbott (1989) listed all known algae reported from historic collections, and added considerable detail to our knowledge of microscopic turf and epiphyte species; however, she acknowledged that a paucity of collections from the NWHI undoubtedly underrepresented the true algal diversity present in these ecosystems. Additionally, many collections were made from drift algae or off lobster traps, disassociating the algae from any data about the environments they inhabit. To ameliorate this problem, expeditions to the NWHI over the past five years have focused on *in situ* sampling of algal diversity, and five recent works have greatly increased our phycological knowledge. Abbott (1999) and Abbott and Huisman (2004) thoroughly examined numerous red, brown, and green algal collections from the NWHI, and Vroom et al. (in press, a,b) completed a detailed study of marine algae from 57 sites at the French Frigate Shoals and increased the number of known algae from this atoll system by over 380%. Okano et al. (in prep.) examined 28 sites from the lagoon at Kure Atoll and documented 92 algal species, and Vroom and Page (in press) completed a multivariate analysis of algal percent cover along the entire NWHI chain. Because of these studies, 355 species of algae are now known from the NWHI chain (Table 10.10).

From an algal perspective, the NWHI contain many unique habitats and even several endemic species new to science which have recently been described (Figure 10.24; Abbott and McDermid, 2001, 2002; Vroom and Abbott, 2004a, b). Additionally, the NWHI contain a large number of Indo-Pacific algal species not found in the MHI. Among these, *Halimeda velasquezii*, represents one of the most common algal species in the NWHI. Expeditions during 2000-2002 found reproductive individuals of *H. velasquezii* for the first time (Vroom and Smith, 2003), allowing scientists to begin addressing ecologically-based algal questions for common species in the NWHI.

Table 10.10. Numbers of algal species currently known from the NWHI. Source: Abbott 1989, 1999; Vroom et al., in press, a,b.

Red algae	204
Brown algae	59
Green algae	92

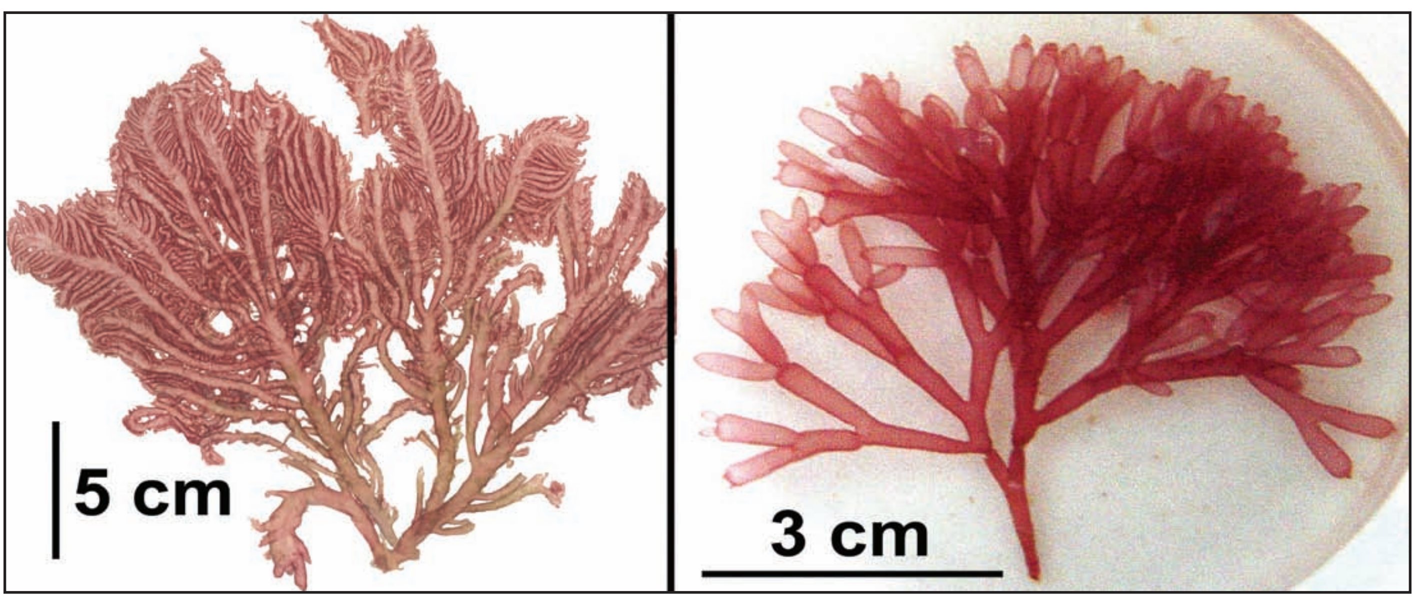


Figure 10.24. *Acrosymphtyon brainardii* (left) and *Scinaia huismanii* (right) are two newly described species of red macroalgae from FFS that are endemic to the NWHI. Photos: P. Vroom.

Quantitative baseline assessments of algal cover began on all NWHI in 2002 using a protocol devised specifically for remote tropical reef ecosystems (Preskitt et al., 2004). Detailed photoquadrat analysis combined with voucher specimens and field notes allowed for percent cover determination of algae and invertebrates at the species level. Analyses from French Frigate Shoals and Pearl and Hermes (Vroom et al., in press, a,b; Vroom et al., in prep.) have found that algal dominated reefs are normal for many of the healthy ecosystems of the NWHI. Expansive forereef and backreef regions are characterized by approximately 15% macroalgal cover while coral cover is less than 8%. Only select lagoonal and patch reef regions exhibited coral cover greater than macroalgal cover. This differs drastically from the generally held belief that healthy tropical reef ecosystems should be dominated by scleractinian coral species. Turf algal meadows were the most common component of essentially all benthic habitats and covered every non-living substrate except sand.

Multivariate analyses of 28 sites from the French Frigate Shoals using the Preskitt method allowed seven distinct biogeographical zones to be interpreted based on substrate-type and algal/invertebrate species composition (Figure 10.25; Vroom et al., in press, a,b). The largest biogeographical group was located on the closed, eastern side of the atoll system and characterized by high densities of the green macroalga *Microdictyon setchellianum*. The area surrounding La Pérouse Pinnacle on the open, western side of the atoll contained the highest crustose coralline algal cover at the atoll. Most lagoonal regions contained sand patches or broad regions of algal turf where macroalgae such as *Halimeda velasquezii, Turbinaria ornata,* and *Asparagopsis taxiformis* were very common. Oceanographic monitoring studies conducted concurrently with algal sampling suggested that water motion may be a major factor in defining algal distribution at the French Frigate Shoals. Multivariate percent cover studies similar to the one completed for the French Frigate Shoals are currently underway for Pearl and Hermes and Lisianski. Baseline assessment data for all other NWHI are in-hand, and available for future analyses.

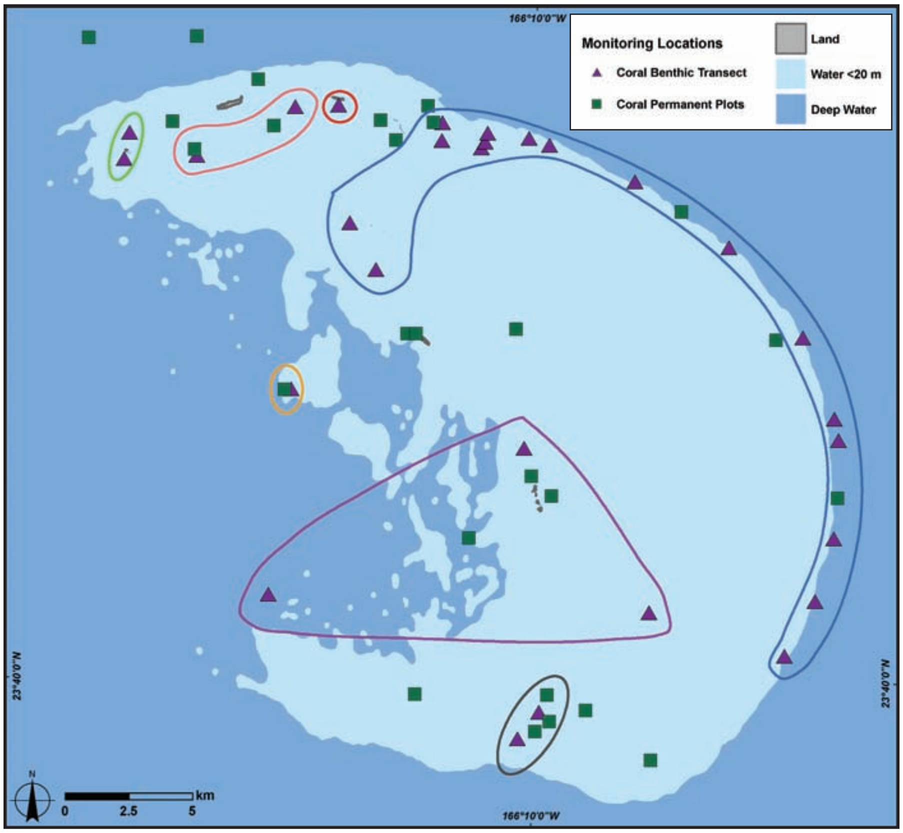


Figure 10.25. Map of FFS with seven biogeographical groups outlined in different colored lines. Biogeographical groups were determined, in part, through multivariate analysis of benthic species cover. Source: Vroom et al., in press, a,b.

Algal monitoring in the NWHI is still in its infancy. Rapid archipelago-wide studies found no significant differences in the prevalence or relative abundance of algal genera between research expeditions conducted in 2002 and 2003 (Vroom and Page, in press). Annual revisits to established sites throughout the NWHI will enable long-term data sets to be established that may reveal change over years or decades if environmental or anthropogenic changes occur. Analysis of similarity (ANOSIM) tests using Primer (Clarke and Warwick, 2001) revealed algal prevalence and relative abundance on reefs surrounding each island to differ more than comparisons among islands as a whole (Vroom and Page, in press). This is not surprising considering the number of different habitat types within a single island system (forereef, backreef, patch reef, etc.).

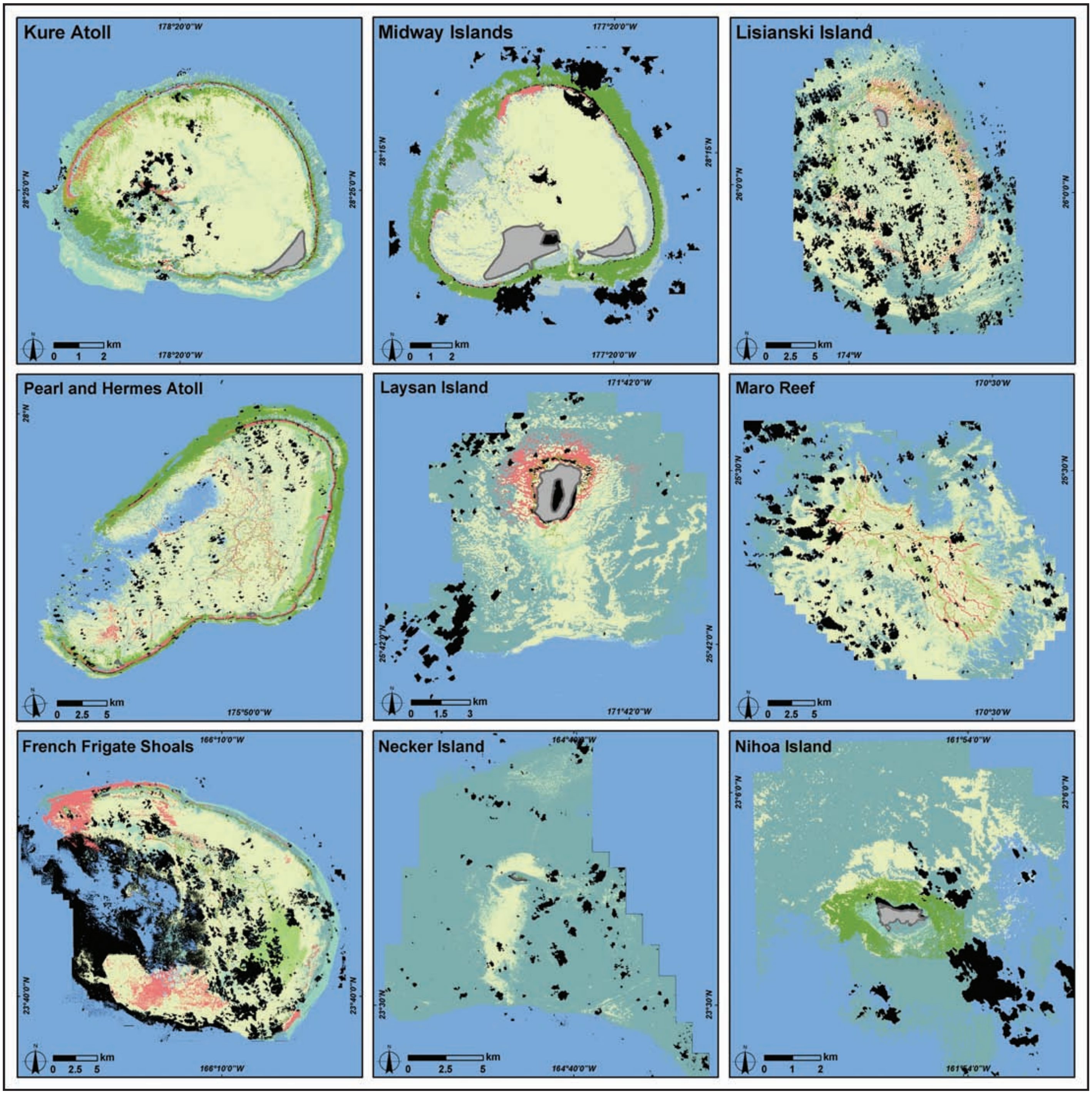
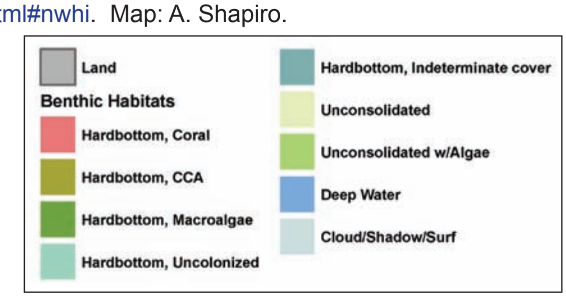


Figure 10.26. Nearshore benthic habitat maps were developed in 2003 by NOAA based on supervised classification of IKONOS satellite imagery. For more info, see: http://ccmaserver.nos.noaa.gov/rsd/products.html#nwhi. Map: A. Shapiro.

BENTHIC HABITAT MAPPING



In 2003 NOAA's CCMA released an atlas of digital maps depicting the shallow-water benthic habitats of the Northwestern Hawaiian Islands and several related products (Figure 10.26). The maps and derived bathymetry products were generated from IKONOS satellite imagery and classified using a hierarchical classification system that accounts for both geomorphologic structure and biotic cover. Despite difficulties associated with conducting ground validation in this remote area, accuracy estimates suggest that the maps, which were derived primarily through spectral analysis, are approximately 72% accurate for the major habitat classes (NOAA, 2003). A multibeam mapping project and other benthic habitat characterization techniques are being employed by PIFSC-CRED to generate similar and complimentary products.

ASSOCIATED BIOLOGICAL COMMUNITIES

FISH

Methods

NOAA Fisheries conducted quantitative monitoring of shallow-reef fishes in the NWHI during the 1990s to track the temporal dynamics of the shallow-reef fish forage base of monk seals (Monk Seal Forage Base Study, or MSFBS) at French Frigate Shoals in 1992 and Midway in 1993 (DeMartini et al., 1996). Stations were resurveyed at sites established by James Parrish and Hawaii Cooperative Fisheries Research Unit co-workers during the 1980s. Starting in 1995, annual sampling was conducted in late summer-early fall to control for seasonal effects by surveying shortly after most fish settlement. DeMartini et al. (2002) provides a comprehensive summary of the spatial and temporal patterns of shallow reef fishes at these two atolls during this period.

In late 2000, the Northwestern Hawaiian Resource Assessment and Monitoring Program (NOWRAMP) was established to assess the entire (ecosystem-level) resource base at all 10 emergent reefs and shallow (<20 m) shoals within the NWHI. Friedlander and DeMartini (2002) describe sampling and analysis designs in detail for the assessment-phase studies.

Both series of fish monitoring studies utilized *in situ* diver observations to tally fishes, by 1-10 cm (total length, TL) size classes, on belt transects of defined widths and lengths. On NOWRAMP surveys, length frequency data for larger, rarer fishes were augmented by timed (five-minute) tallies made within circular (10 m fixed radius) "stationary point count" plots. NOWRAMP surveys also included a "roving diver" component that provided species-presence data. The total search area at stations averaged 3,000 m^2 (DeMartini and Friedlander, 2004). As a separate but complementary effort on NOWRAMP surveys, pairs of divers were towed for an average of 50 minutes by motorized skiff (mean 2.66 km tow length) to estimate densities of large apex predators (Figure 10.27) at a necessarily much larger spatial scale (DeMartini et al., in press).

For the MSFBS, a total of nine stations (four outside, five inside the lagoon) were visited at French Frigate Shoals and at Midway on each survey. For the NOWRAMP surveys, three to about 20 stations were visited per reef on each cruise; and three major habitats (fore reef, back reef, lagoon patch reef) were used as major sampling strata. Stations were randomly located within strata selected based on relative exposure (i.e., windward, leeward) in order to increase spatial coverage and separate habitat- and reef-specific attributes. Total sampling effort (number of stations) during the assessment phase at each of the 10 reefs was proportional to total reef area and ranged from 10 at tiny Gardner Pinnacles to 74 at the largest atolls (French Frigate Shoals, Pearl and Hermes).

Figure 10.27. Large apex predators, such as sharks (left panel) and jacks (right panel), are abundant in the NWHI and dominate the ecosystem in terms of biomass. Large predators are conspicuously absent from most of the other jurisdictions in this report. Photos: J. Watt.

Results and Discussion

Initial insights into new baseline patterns of NWHI reef fish distribution and abundance are provided by DeMartini et al. (1996). Differences between French Frigate Shoals and Midway in the relative abundance of herbivores and carnivores and in the distribution of fish numbers and biomass among barrier reef and lagoon patch reef habitats were first noted. The major conclusion reached in this study was that reasonable statistical power (80% probability of rejecting a false null hypothesis) for detecting a large but less-than-catastrophic (50%) change in shallow-reef fish density would be attainable using a decade-long series of annual surveys only if species were pooled into higher taxonomic or trophic categories for analyses.

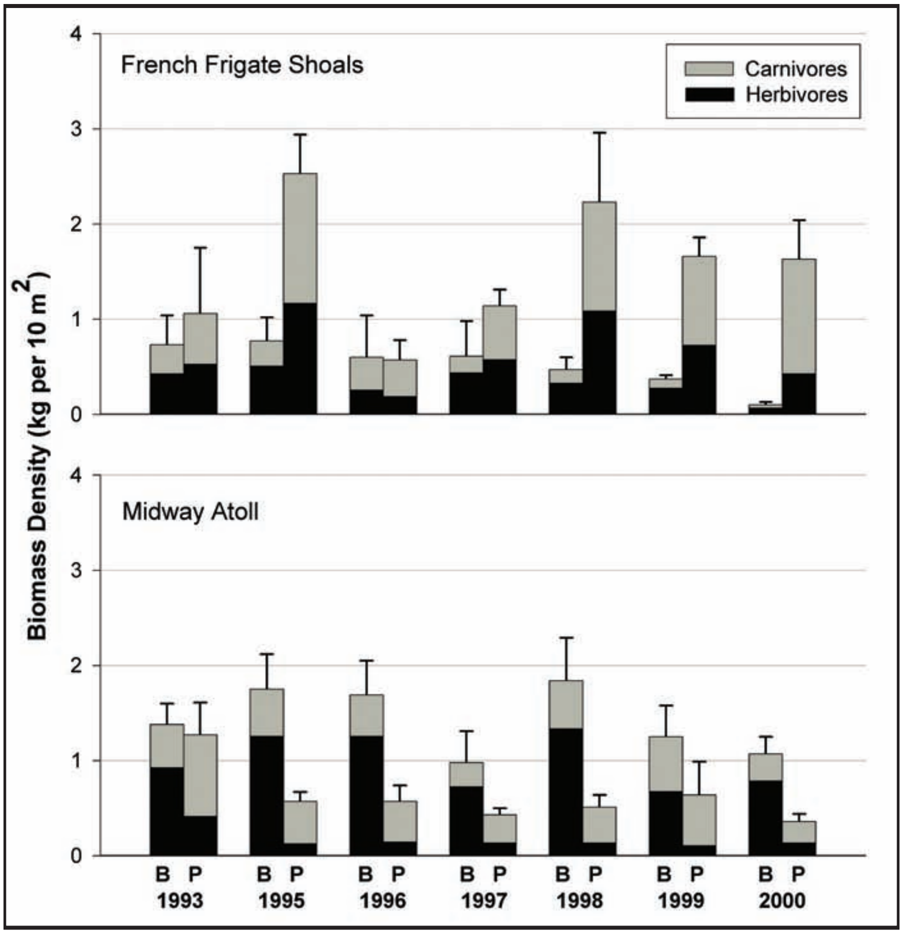


Figure 10.28. Biomass densities of herbivores (solid histograms) and carnivores (diagonals) at FFS and MID in 1992 (FFS only), 1993 (MID only), and 1995-2000 (both sites), in barrier (B) and patch (P) reef habitats. Standard errors are noted for total (herbivore plus carnivore) fishes. Source: DeMartini et al., 2002.

General results and conclusions related to the monitoring conducted by the MSFBS have been discussed by DeMartini et al. (2002). Briefly restated, these are: 1) There were no discernible temporal changes in the biomass densities of either herbivorous or carnivorous reef fishes at either French Frigate Shoals or Midway during the 1990s (Figure 10.28); 2) There was a consistently higher recruitment of young-of-year (YOY) life-stages of fishes at Midway Atoll versus French Frigate Shoals during the 1990s despite generally greater densities of older-stage fishes at French Frigate Shoals (Figure 10.29); and 3) Both giant trevally (*Caranx ignobilis*) and bluefin trevally (*C. melampygus*) were more frequently encountered and more abundant at French Frigate Shoals versus Midway, and the magnitude of this general difference increased (as giant trevally sightings decreased) subsequent to 1996 (Figure 10.30), at which time a recreational catch-and-release fishery was begun at Midway after the Midway Naval Air Station was closed and the atoll became a USFWS NWR (DeMartini et al., 2002).

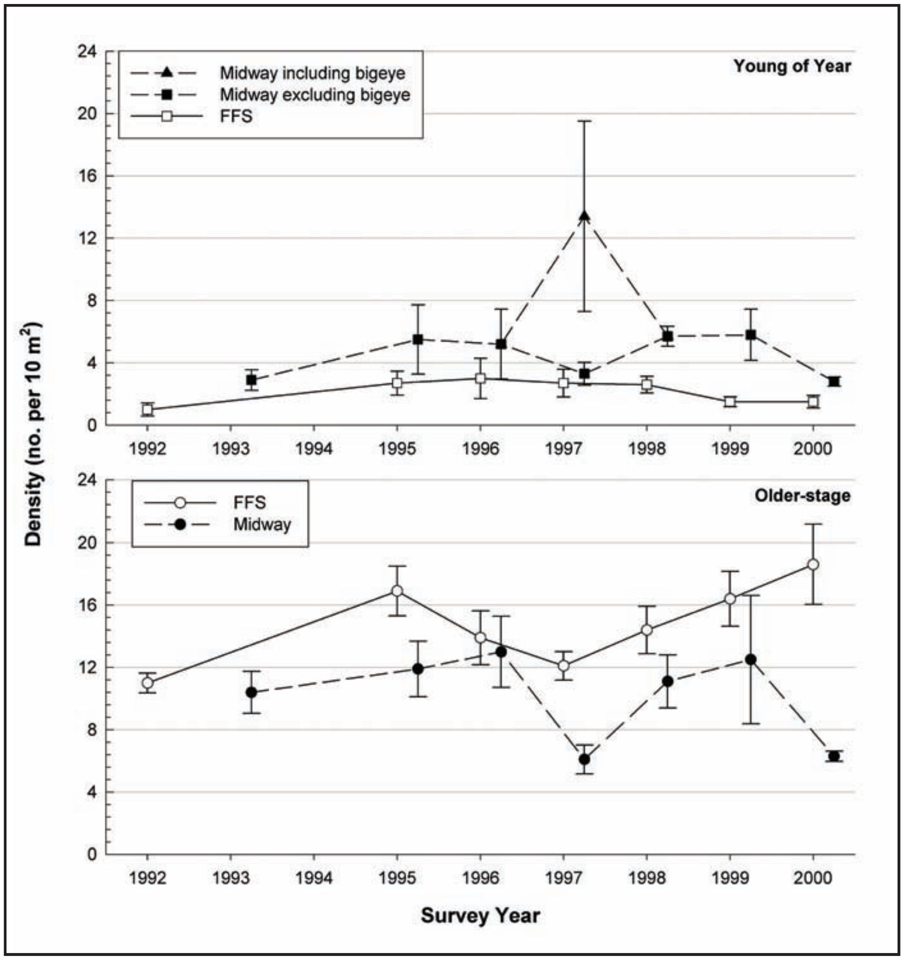


Figure 10.29. Time series of the estimated mean numerical density of YOY and older-stage fishes of all taxa at FFS and MID during each survey year. Each vertical bar represents 1 standard error (SE) of the estimated survey year grand mean for both major habitats. Source: DeMartini et al., 2002.

A comparison between the fish assemblages in the NWHI and MHI was conducted following sampling in 2000 across both regions (Friedlander and DeMartini, 2002). Grand mean fish standing stock in the NWHI was more than 260% greater than in the MHI across similar habitats (Figure 10.31). The most striking difference was the abundance and size of large apex predators (primarily sharks and jacks) in the NWHI compared to the MHI. More than 54% of the total fish biomass on forereef habitats in the NWHI consisted of apex predators, whereas this trophic level accounted for less than 3% of the fish biomass in the MHI. In contrast, fish biomass in the MHI was dominated by herbivores (55%) and small-bodied lower-level carnivores (42%). Most of the dominant species by weight in the NWHI were either rare or absent in the MHI and the target species that were present, regardless of trophic level, were nearly always larger in the NWHI.

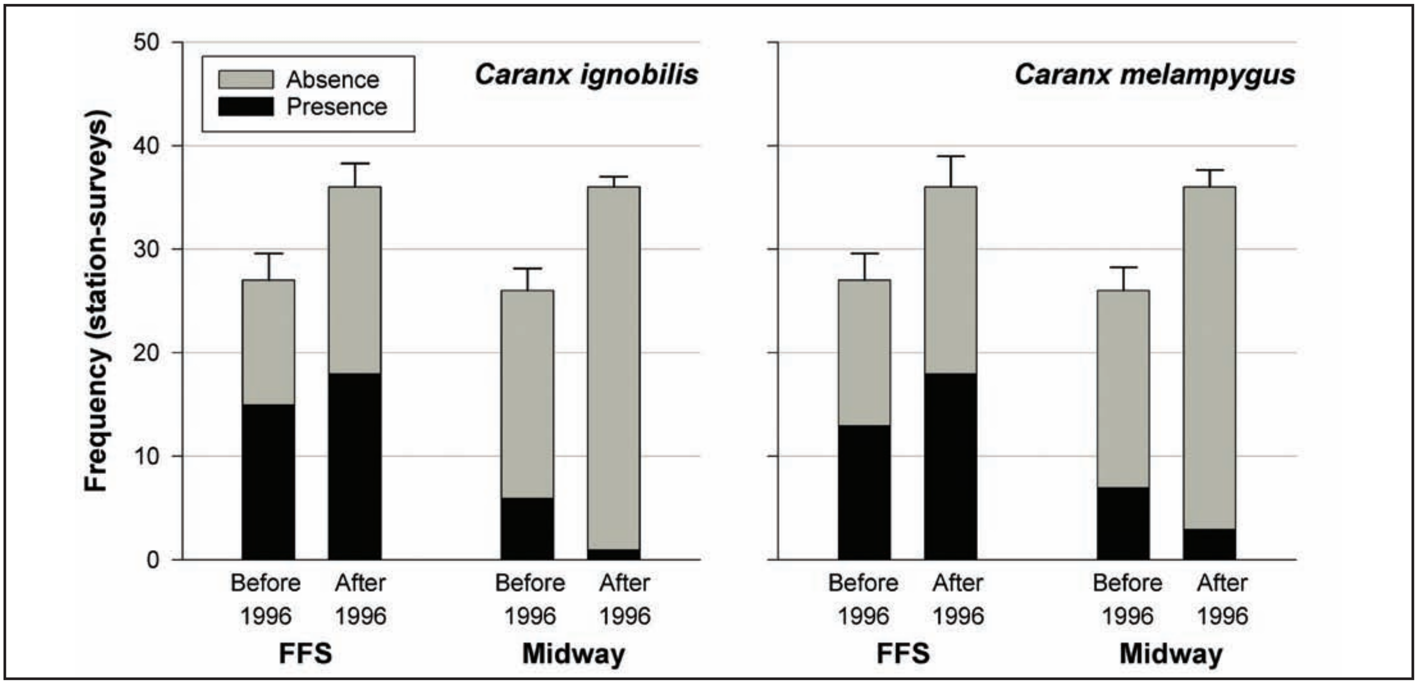


Figure 10.30. Relative presence-absence of giant trevally (*Caranx ignobilis*) and bluefin trevally (*C. melampygus*) at FFS and MID stations during 1992 (FFS) or 1993 (MID) through 1995-2000 pooled. The stacked presence-absence bars indicate species subtotals up to and including 1996 ("Before") versus after 1996 ("After") at each site. Vertical lines atop histogram bars are 1 SE. Source: excerpted from DeMartini et al., 2002.

Several assessment-focused studies complement the contemporary monitoring program described below. DeMartini (2004) recognized the importance of back reef, lagoon patch reef, and other sheltered (wave-protected) habitats as nursery areas for juvenile reef fishes in the NWHI. This study, based on re-analyses of some of the data collected for the MSFBS, contributes substantially to development of both "essential fish habitat" and "habitats of particular concern" which recognize the greater per-unit-area value of atolls due to their larger proportion of sheltered habitats.

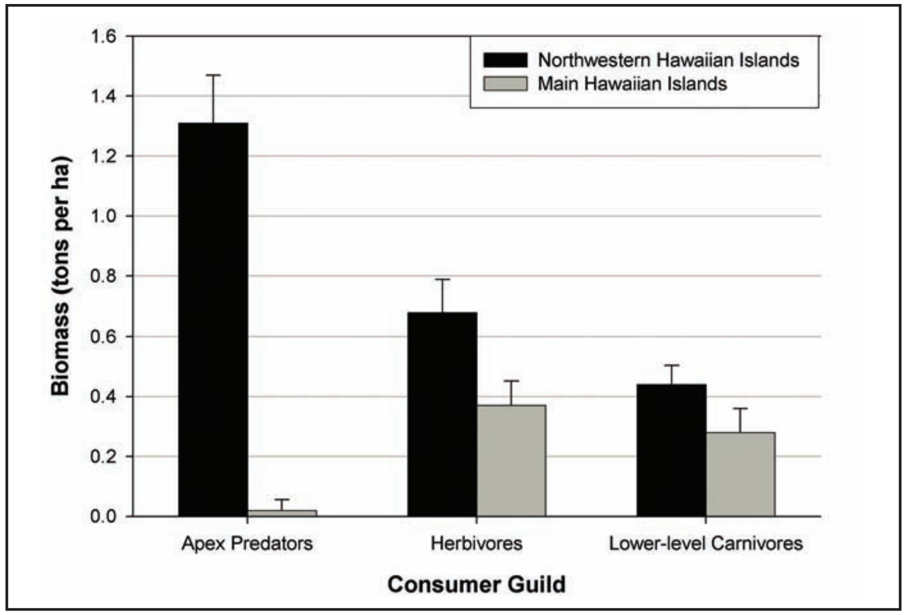


Figure 10.31.
and the NWHI.

Important to biodiversity concerns is the markedly high endemism of shallow reef fishes in the NWHI. Percentage endemism based on the typical species-presence criterion is about one-fifth higher (30% vs 25%) in the NWHI versus MHI (DeMartini and Friedlander, 2004). The MHI value is indistinguishable from present estimate of 23% for Hawaiian fishes based on comprehensive specimen sources including market sampling, poison stations, and museum collections (Randall, 1998). Endemism is even more strongly expressed in terms of standing stock per unit area–both biomass (mean 37%) and especially numerical (mean 52%) densities–in the NWHI, and increases with latitude throughout the Hawaiian Archipelago even though species-presence-based measures of endemism lack latitudinal pattern within the NWHI (Figure 10.32; DeMartini and Friedlander, 2004). These recent observations of a latitudinal effect on standing stock-based endemism were foreshadowed by an analogous pattern observed previously at French Frigate Shoals and Midway (DeMartini, 2004).

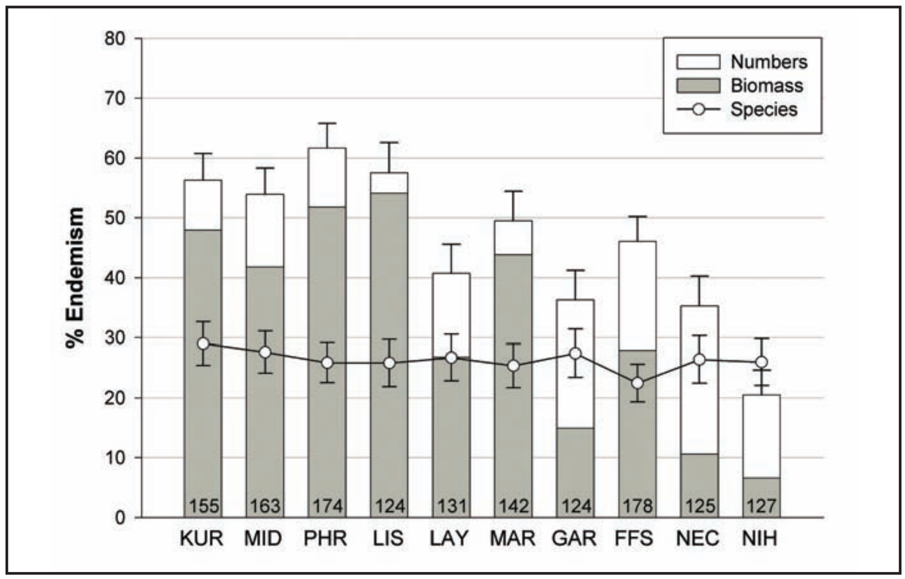


Figure 10.32. Various measures of percentage endemism (based on species presence-absence, and on numerical and biomass densities) at each of ten emergent NWHI reefs, illustrating patterns of endemism with latitude-longitude. Presence-absence data are indicated by line graph and density data by histograms. Species richness (number of species) is noted by numbers at base of histograms. Source: DeMartini and Friedlander, 2004.

Size structure data collected during the initial NOWRAMP assessment provided insights into the effects of apex predators on their shallow-water reef fish prey. Protogynous (female-to-male sex-changing) labroid fishes (wrasses and parrotfishes, especially the latter), the adult sexes of which conspicuously differ in body coloration, are the preferred prey of *C. ignobilis*, the dominant apex predator on shallow NWHI reefs (Sudekum et al., 1991; Friedlander and DeMartini, 2002). At the three northernmost atolls of the NWHI, body sizes at coloration (sex) change of labroids are larger, and overall size distributions are skewed larger in labroids and other prey fish species at Midway (Figure 10.33), where jacks are fewer, compared to two nearby atolls (Kure and Pearl and Hermes) where jacks are more abundant (DeMartini et al., in press). These latter observations have significant implications for reef fish management in the Hawaiian Archipelago. First, *in situ* observations,

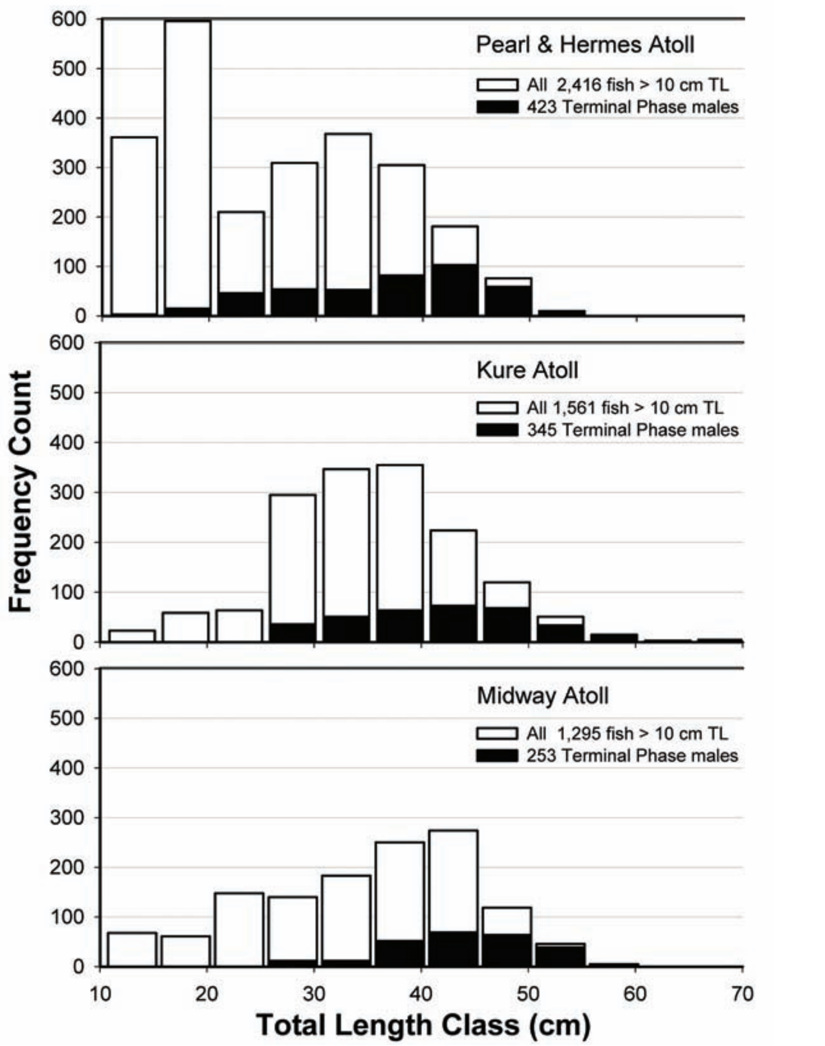


Figure 10.33. Body size (TL) frequency distributions of eight species of sexually dimorphic, sex-changing labroids (four parrotfishes, four wrasses) at (A) P&H, (B) KUR, and (C) MID in the far northwestern NWHI, during Sept.-Oct. periods of 2000 and 2002. Terminal-phase (sex-changed) males are indicated by fills within histogram bars. Source: DeMartini et al., in press.

Table 10.11. Non-coral invertebrate species identified to date in the NWHI.

PORIFERA	**23**	**ARTHROPODA**	
CNIDARIA		Pycnogona	3
Hydrozoans	10	Cirripedia	9
Scyphozoans	2	Peracarids	76
Anthozoans	13	Decapods	125
PLATYHELMINTHES	**5**	**ECHINODERMATA**	
NEMERTEA	**1**	Asteroids	11
BRYOZOA	**39**	Ophiuroids	26
BRACHIOPODA	**1**	Echinoids	21
SIPUNCULIDA	**1**	Holothuroids	17
ANNELIDA	**52**	**UROCHORDATA**	**25**
MOLLUSCA			
Gastropods	310		
Bivalves	66		
Cephalopods	2		
TOTAL=838			

instead of gonadal examination, can be used to estimate size at sex change, an important parameter for stock assessment. Second, prey size frequency distributions can be used as an effective proxy for predation intensity (predator abundance) when assessing functional change on NWHI coral reefs as part of an ecosystem-based approach to management (DeMartini et al., in press).

NON-CORAL INVERTEBRATES

Prior to efforts in 2000, there had been only two large-scale expeditions to the NWHI for the purpose of marine faunal surveys. The first was the Albatross Expedition in 1902 in which a variety of species were collected and deposited at the Smithsonian Institution's National Museum of Natural History. A second effort was the Tanager Expedition in 1923, which was organized by the U.S. Department of Agriculture and the Bishop Museum.

Recent efforts since 2000 have collected a large amount of non-coral marine invertebrate material (Table 10.11), much of which remains to be definitively identified. To date, a number of new species have been recorded for the Hawaiian Archipelago and some species might prove to be endemic to the NWHI. Mollusks, crustaceans, and echinoderms dominate the non-coral invertebrate fauna in the NWHI, which is typical for most coral reef communities. These cryptic fauna are more abundant in the NWHI than the MHI, although remote locations of the MHI that are not heavily impacted by anthropogenic stressors are comparably abundant (DeFelice et al., 2002). Species data for non-coral invertebrates is incomplete and collaboration with taxonomic experts throughout the world is in progress.

HAWAIIAN MONK SEAL

The Hawaiian monk seal (*Monachus schauinslandi*) is the only endangered pinniped occurring entirely within U.S. waters. Its current population is estimated at 1,300 seals, a decrease of about 60% since the 1950s. Counts declined about 5% per year from 1985 to 1993, remained relatively stable through 2000, and declined again in 2001. When compared historically, the monk seal beach count abundance index reached record lows for 2001, 2002, and 2003 (Figure 10.34).

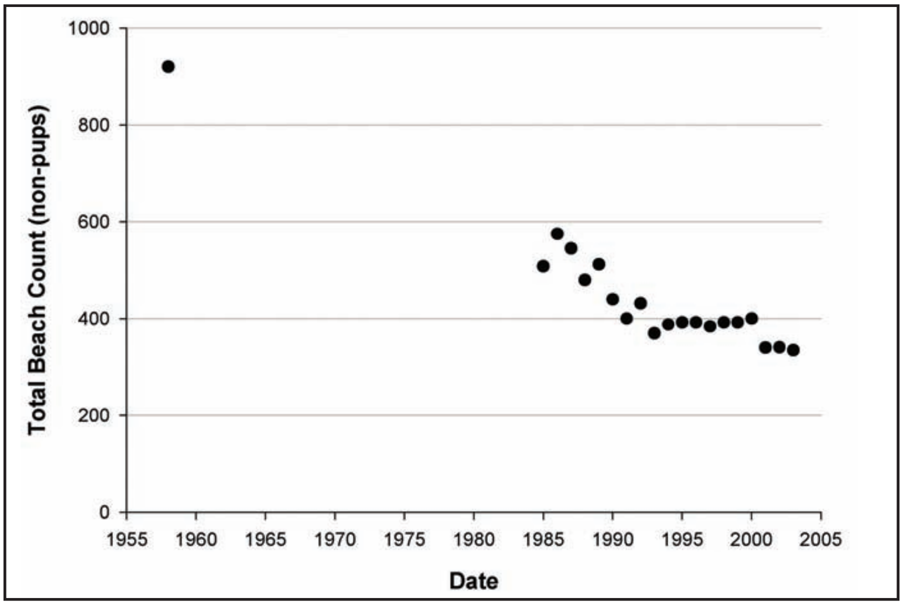


Figure 10.34. Historical trend in beach counts (non-pups) of Hawaiian monk seals at the six main reproductive subpopulations. Source: Antonelis et al., in review.

Population trends have been variable at the six main reproductive subpopulations in the NWHI. In recent years overall pup production and juvenile survival have decreased at most sites. 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 haulout and pup in the MHI. They commonly occur on isolated beaches for resting, molting, parturition, and nursing offspring, and forage on demersal and benthic prey. Past and present sources of anthropogenic and natural impacts to monk seals include hunting during the1880s, disturbance (e.g., active and post WWII military activities), entanglement in marine debris, direct fishery interaction 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.

HAWAIIAN GREEN SEA TURTLE

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 sea turtle or honu (Figure 10.35) comprises a spatially disjunct metapopulation with numerous distinct foraging grounds within the 2,200 km span of the Hawaiian Archipelago.

Figure 10.35. Greater than 90% of the Hawaiian green sea turtles' principal nesting areas are located on the sand islands of FFS. Photo: J. Watt.

The principal rookery for the Hawaiian green sea turtle is located on sand islands at French Frigate Shoals which accounts for >90% of all nesting within the Hawaiian Archipelago. 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. 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.

The 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 10.36). 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 protecting their nesting and foraging habitats in the Hawaiian Archipelago.

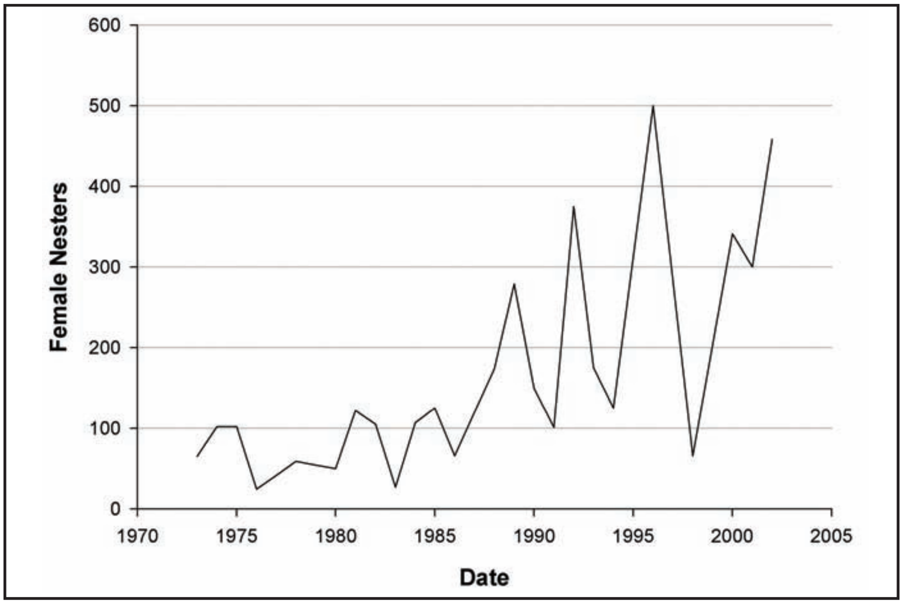


Figure 10.36. Nester abundance shown as the number of female green sea turtles nesting each year at East Island from 1973 to 2002. Source: Balazs and Chaloupka, 2004.

PEARL OYSTERS

The population of black-lipped pearl oysters, *Pinctada margaritifera*, at Pearl and Hermes Atoll were discovered in 1927 and heavily harvested. Conservative estimates indicate that approximately 150,000 oysters were either exported or killed during the harvest. An expedition in 1930 to assess the population post-harvest found 480 pearl oysters, and estimated 100,000 oysters remaining on the reef. More recent surveys in 1969, 1996, and 2000 found only a few oysters and it was assumed that the population had not recovered since the harvest.

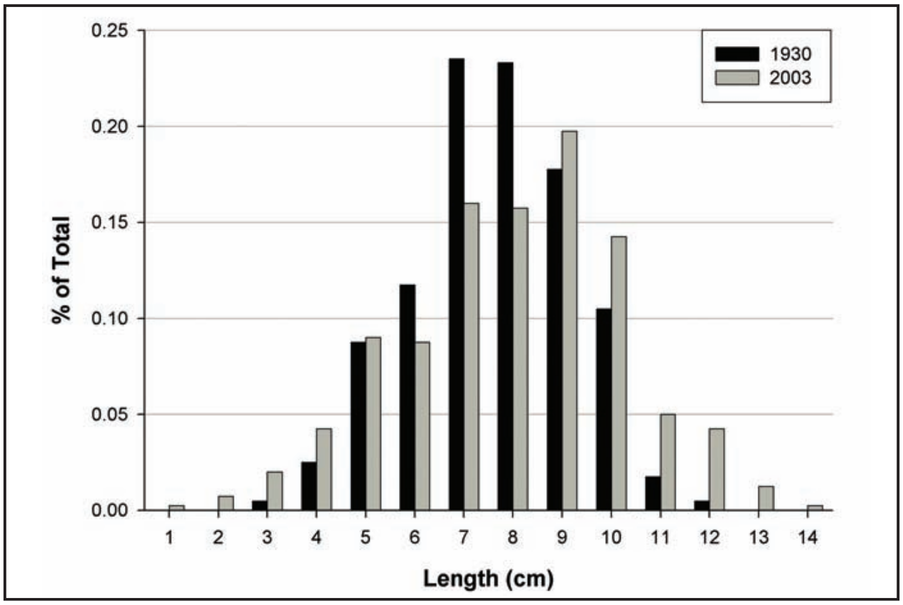


Figure 10.37. Pearl oyster size frequency distribution at P&H in 1930 and 2003. Source: Keenan et al., in review.

In 2003, the NOAA Fisheries-led multi-agency marine debris removal team spent several months conducting surveys at Pearl and Hermes that included documenting sightings of pearl oysters (Keenan et al., in review). Over 1,000 individuals were documented and mapped in this sampling effort. The average size of pearl oysters in the 2003 surveys was larger than the 1930 surveys (Figure 10.37). The number of individuals and the size structure from recent surveys may reflect a recovery of the population 70 years after harvest ceased and/or a more thorough sampling effort relative to previous surveys.

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 (5.5 million breeding annually) representing 21 species. More than 95% of the world's Laysan and Black-footed albatross nest here. For several other species such as Bonin petrel, Christmas shearwater, Tristram's storm-petrel, and Grey-backed tern, the NWHI supports colonies of global significance. The last complete inventory of NWHI breeding populations was done between 1979 and 1984. Population trends since then have been derived from more intensive monitoring at three islands. Population trends in the NWHI are stable or increasing for most species but there is concern for a few, especially the albatross.

Annual reproductive success (proportion of chicks fledged per egg laid) of Laysan albatross, *Diomedea immutabilis*, and Blackfooted albatross, *D. nigripes*, at French Frigate Shoals in the NWHI indicates strong coherence between the two species that is especially evident during two years of very low reproductive success (1984 and 1999) (Figure 10.38; Seki, 2004). Both years of low reproductive success occurred about one year after major ENSO events. Other seabird species such as Red-footed boobies, *Sula sula*; Red-tailed tropicbirds, *Phaethon rubricauda*; and Black noddies, *Anous tenuirostris*, also exhibited very low reproductive success in 1998-99, but not in 1984.

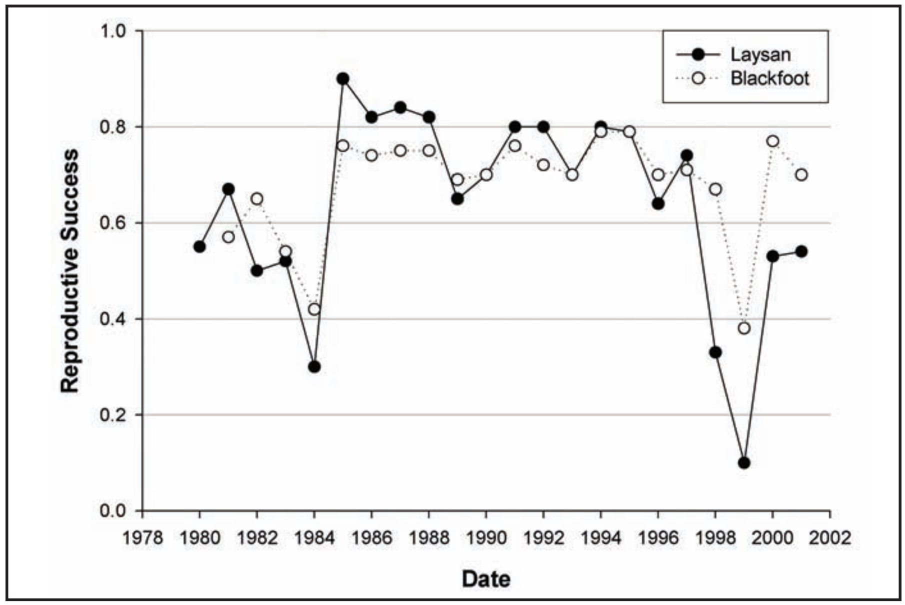


Figure 10.38. Temporal trends in the reproductive success of Black-footed and Laysan albatrosses monitored at FFS from 1980 to 2001. Source: Seki, 2004.

The conservation status of Hawaiian seabirds was assessed as part of the North American Waterbird Conservation Plan. Eleven of the 21 species were classified as highly imperiled or high conservation concerns at the broad scale of the plan (eastern North Pacific, western North Atlantic, and Caribbean). At the regional scale (Pacific Islands) six species were included in these highest concern categories: Laysan, Black-footed and Short-tailed albatross; Christmas shearwater; Tristram's storm-petrel; and Blue noddy. Greatest threats to seabirds in the NWHI are introduced mammals and other invasive species, fishery interactions, contaminants, oil pollution, and climate change. Over the past 20 years, active management in the NWRs and Hawaii State Seabird Sanctuary has included eradication of rodents (*Rattus rattus* at Midway and *R. exulans* at Kure); eradication or control of invasive plants; coordination among NOAA Fisheries, Fishery Management Councils, industry, and conservation organizations to reduce fishing impacts; and cleanup of contaminants and hazards at former military sites. The NWHI are unique in being one of the largest marine protected areas in the world, established in 1909 for the express purpose of protecting seabirds. Early protection and active management have resulted in large, diverse, and relatively intact seabird populations.

The estimated 14 million seabirds residing in the NWHI are primarily pelagic feeders that obtain the fish and squid they consume by associating with schools of large predatory fish such as tuna and billfish (Fefer et al., 1984). While both the predatory fish and the birds are capable of foraging throughout their pelagic ranges, which encompass the entire tropical ocean, the birds are most successful at feeding their young when they can find schools of predatory fish within easy commuting range of the breeding colonies. Recently fledged birds, inexperienced in this complex and demanding style of foraging, rely on abundant and local food resources to survive while they learn to locate and capture prey. Ashmole and Ashmole (1967) and Boehlert (1993) suggest that the circulation cells and wake eddies found downstream of oceanic islands may concentrate plankton and therefore enhance productivity near islands, thus allowing higher tuna populations locally.

Johannes (1981) describes the daily migrations of skipjack tuna and yellowfin tuna to and from the waters near islands and banks. Conservation of these tunas in the vicinity of seabird colonies will enhance the birds' ability to provide adequate food for their offspring. Wake eddies also concentrate the larvae of many reef fishes and other reef organisms and serve to keep them close to reefs, enhancing survivorship of larvae and recruitment of juveniles and adults back to the reefs. For at least four of the 21 seabird species breeding in the NWHI (brown noddies, black noddies, white terns, and brown boobies), significant proportions (33%-56%) of their diet originate from the surrounding coral reef ecosystem (Ashmole and Ashmole, 1967; Harrison et al., 1983; Diamond, 1978).

Overall Condition and Summary of Analytical Results

The remoteness and limited reef fishing activities that have occurred in the NWHI have resulted in minimal anthropogenic impacts. Large apex predators such as jacks, reef sharks, and amberjacks are one of the most striking and unique components of the NWHI ecosystem. These top carnivores are seldom encountered nowadays in the inhabited Hawaiian Islands.

The flora and fauna of the NWHI include a large percentage of species that are endemic to the Hawaiian Islands. The faunas of isolated oceanic archipelagos like the Hawaiian Islands represent species conservation hotspots that have become increasingly important due to the continual losses of biodiversity on coral reefs worldwide. The NWHI represent important habitat for a number of threatened and endangered species. The Hawaiian monk seal is one of the most critically endangered marine mammals in the U.S. (1,400 individuals) and depends almost entirely on the islands of the NWHI for breeding and the surrounding reefs for sustenance. Over 90% of all sub-adult and adult Hawaiian green sea turtles found throughout Hawaii come from the NWHI.

Despite their high latitude location, nearly as many species of coral have been reported from the NWHI (57) compared with the MHI (59). Kure is the world's most northern atoll and is referred to as the Darwin Point, where coral growth and subsidence/ erosion balance one another. Unlike the MHI where alien and invasive algae have overgrown many coral reefs, the reefs in the NWHI are free of alien algae and the high natural herbivory results in a pristine algal assemblage.

Spatial and temporal variability of key oceanographic processes influence the structure, function, and biogeography of the NWHI coral reef ecosystem. Although currents in the region are dominated by eddy-energy, there is a weak mean flow from the MHI towards the NWHI. Preliminary drifter observations suggest local retention at the northern atolls, supporting observations of increased endemism upchain. Wintertime temperature minima (17-20°C) and summetime maxima (27-29°C) are greater at the northern end of the chain compared with the MHI. Observations of an intermittent eastward-flowing Subtropical Countercurrent in the region between French Frigate Shoals and Gardner Pinnacles support the hypothesis of a genetic gateway to the archipelago from the central Pacific.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Administrative jurisdiction over the islands and marine waters is shared by NOAA, USFWS, and the State of Hawaii. Eight of the 10 NWHI (all except Kure and Midway Atolls) have been protected by what is now the Hawaiian Islands National Wildlife Refuge (HINWR) established by President Theodore Roosevelt in 1909. The Refuge includes all land and reef areas to 20 fathoms off Necker Island and to 10 fathoms off the remaining seven islands.

The State of Hawaii manages the Kure Atoll Wildlife Refuge and all waters around each of the islands and atolls from 0-3 miles except Midway. The State has recently proposed regulations that would create the NWHI Marine Refuge. The new NWHI Marine Refuge would: 1) require an entry permit for any activities within State waters; 2) prohibit fishing of any kind at Kure Atoll, Pearl and Hermes Atoll, Lisianski Island, Laysan Island, Maro Reef, Gardner Pinnacles, French Frigate Shoals, and Necker Island; 3) prohibit fishing of any kind from 0-10 fathoms in State waters surrounding Nihoa Island; 4) allow for Native Hawaiian cultural gathering; 5) prohibit engaging in any activity, including the anchoring of a vessel that can or does result in damaging or destroying coral, and; 6) prohibit engaging in any activity not authorized by this regulation. These proposed rules are undergoing final review and will be enacted into law sometime in early 2005. The State also issues commercial fishing permits to all fishermen fishing in the NWHI and landing their catch in Hawaii. The State maintains the data base on effort and landings that are used by the management agencies for fisheries management decisions.

NOAA Fisheries has also designated 10 areas from the shore to 20 fathoms in the NWHI as critical habitat for the Federally endangered Hawaiian monk seal, although this designation does not include any restrictions of activities. Commercial fishing in the NWHI within 100 m depth targets mostly bottomfish and previously lobsters, each of which is managed separately by the NOAA Fisheries through fishery management plans developed by the Western Pacific Regional Fishery Management Council. Both of these fisheries are limited entry with fewer than 20 vessels allowed to operate in each fishery. Presently, there are fewer than 10 vessels active in the bottomfish fishery. The lobster fishery has been closed by NOAA Fisheries since 2000 due to uncertainties in the lobster population model parameters used to accurately estimate the exploitable lobster population.

Except for Midway, the NOAA Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve (CRER), established in 2000 by President Clinton (Executive Order 13178 and amended with Executive Order 13196 in January 2001), extends protection and Federal jurisdiction beyond the offshore boundaries of State waters to a maximum distance of 50 nm (see Figure 10.1). Midway is outside both State of Hawaii and CRER jurisdiction and since 1996 has been under USFWS administration as the Midway Atoll NWR, affording protection to all reefs and islands at the atoll. This large reserve area, 2,200 km in length and 3-50 nautical miles (6-93 km) from shorelines, is managed by the Secretary of Commerce and may be designated as a National Marine Sanctuary. Executive Order 13178 also established caps on commercial fishing and 15 Reserve Preservation Areas in which extractive use is prohibited with limited exceptions. The Reserve boundaries lie seaward of the jurisdictional areas of the Hawaiian Islands NWR, Midway Atoll NWR, and State of Hawaii boundaries, mandating that all three agencies cooperate fully for effective protection of all NWHI and coral reefs.

Except for Kure and Midway, recreational and commercial fishing activities are prohibited within the 10-fathom isobath of the eight islands (and inside 20 fathoms around Necker) within the Hawaiian Islands NWR managed by the USFWS. Kure Atoll currently falls under State jurisdiction, and fishing is permitted on its shallow reefs. Under the State's proposed new marine refuge regulations, fishing will no longer be allowed within State waters at Kure. Midway Atoll NWR sponsored a catch-and-release sportfishery between 1996 and 2002, but all ecotourism activities including sport fishing have been greatly reduced due to funding shortfalls to operate the refuge associated transportation, housing facilities and utilities.

OVERALL STATE/FEDERAL CONCLUSIONS AND RECOMMENDATIONS

With coral reefs around the world in decline, it is extremely rare to be able to examine a coral reef ecosystem that is relatively free of human influence and consisting of a wide range of healthy coral reef habitats. The remoteness and limited activities that have occurred in the NWHI have resulted in minimal anthropogenic impacts. The region represents one of the few large-scale, intact, predator-dominated reef ecosystems remaining in the world and offers an opportunity to examine what could occur if larger more effective no-take marine reserves are established elsewhere. The high proportion of endemic species and unique mix of tropical and sub-tropical assemblages has identified the NWHI as a global biodiversity hotspot. The NWHI are critically important to a number of wide-ranging species such as seabirds, turtles, monk seals, and sharks (Figure 10.39). Strong ecological linkages are provided by these and a few other organisms for the transfer of energy and nutrients among ecosystems.

The nearly pristine condition of the NWHI allows us to understand how unaltered ecosystems are structured, how they function, and how they can most effectively be preserved. The NWHI provide an unparalleled opportunity to assess how a "natural" coral reef ecosystem functions in the absence of major human intervention. These reefs consist of discreet ecological subunits that can be used as replicates to examine large-scale ecological processes, while the scale of the existing fisheries allows for adaptive management strategies that can address questions related to stock decline and recovery. The NWHI represents a baseline in which to understanding natural fluctuations and measure the success of existing management regimes elsewhere. Lessons learned from the NWHI can be used to help develop more effective management strategies in the MHI and other ecosystems. The NWHI should not only be conserved for their intrinsic value, but also for their value to hedge against fisheries collapses and as a model for ecosystem-based management.


Figure 10.39. Seabirds, such as these Brown noddy terns and Brown booby at P&H (left photo), rely on the NWHI for nesting, feeding and breeding. The critically endangered Hawaiian monk seal (right photo) is an intergral component of the NWHI ecosystem. Photos: J. Watt.

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