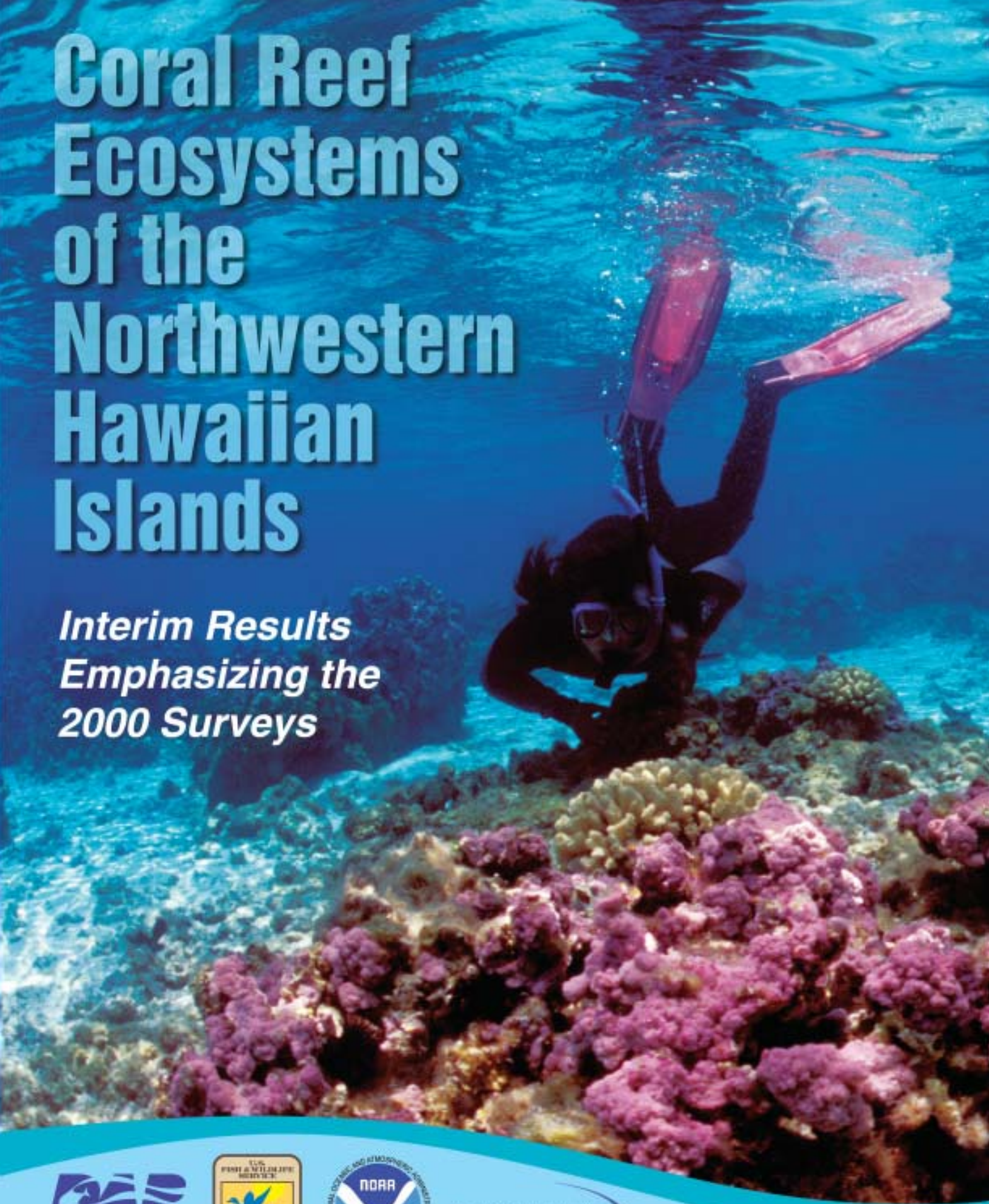
Coral Reef Ecosystems of the Northwestern Hawaiian Islands



Interim Results Emphasizing the 2000 Surveys

Division of Aquatic Resources
Department of Land and Natural Resources
State of Hawaii

Hawaii Coral Reef Initiative
Research Program

"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. Because of their relative isolation, the shallow reefs of the Northwestern Hawaiian Islands represent a large no-take zone, providing us with a unique opportunity to assess how 'natural' coral reef ecosystems function in the absence of major human intervention,"

Alan Friedlander, *fisheries ecologist with the Oceanic Institute and NOWRAMP expedition team member.*

Jim Maragos/USFWS

The opinions expressed in this report are entirely those of the contributors and do not necessarily reflect representative agency viewpoints.

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- Hawai'i Department of Land and Natural Resources
- National Marine Fisheries Service, Honolulu Laboratory
- Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve
- U.S. Fish and Wildlife Service, Honolulu Office

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Background photo: Jim Maragos/USFWS

Table of Contents

Executive Summary 4
Introduction 5
NWHI Survey Sites 6
Terrestrial Studies 7
Marine Field Surveys 8
Oceanography 10
Fish Studies 11
Coral Studies 14
Invertebrate Studies 16
Protected Marine Species 17
Algal Studies 18
Remote Sensing and Groundtruthing 20
Wide Range of Marine Habitats 22
Island Coral Reef Profiles
- Midway Atoll 23
- Kure Atoll 25
- Pearl and Hermes Atoll 26
- Lisianski Island and Neva Shoal 28
- Laysan Island 29
- Maro Reef 30
- French Frigate Shoals 32
- Gardner Pinnacles 33
- Necker Island 35
- Nihoa Island 36
- Raita Bank 37

Why Are The NWHI So Important? 38
What Are The Principal Threats 42
Spotlight on Marine Debris 43
Results of Contaminants Study 44
Remnants of a Ship Grounding 44
Where Do We Go From Here? 45
The Big Picture: Comparative Chart of the NWHI 46

Cal Hirai

The Northwestern Hawaiian Islands

The NWHI are the most remote large-scale coral reef ecosystem on the planet.

Laysan is the only low coral island in the NWHI that is not a part of an atoll.

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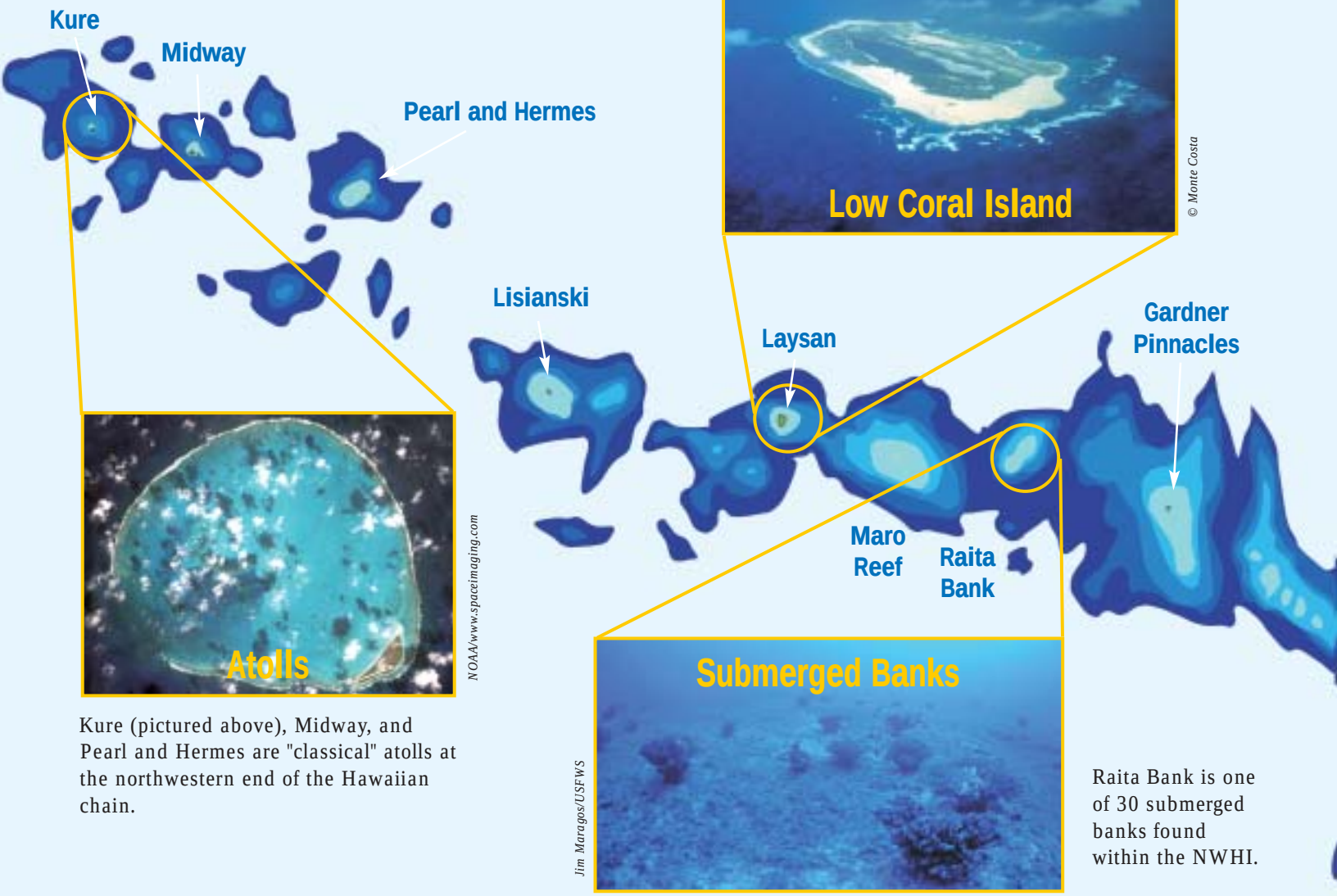


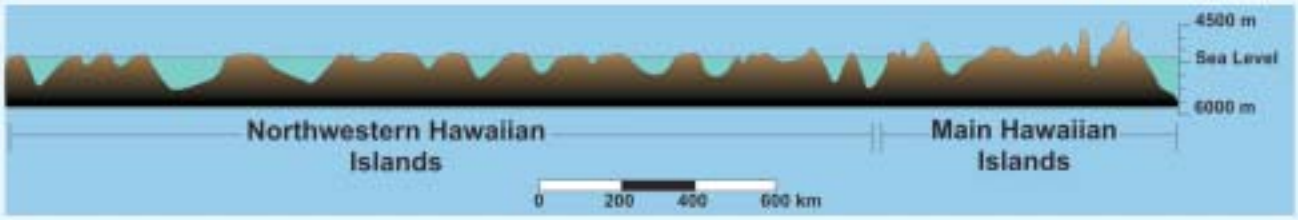
NOAA/www.spaceimaging.com

Kure (pictured above), Midway, and Pearl and Hermes are "classical" atolls at the northwestern end of the Hawaiian chain.

Jim Maragos/USFWS

Raita Bank is one of 30 submerged banks found within the NWHI.

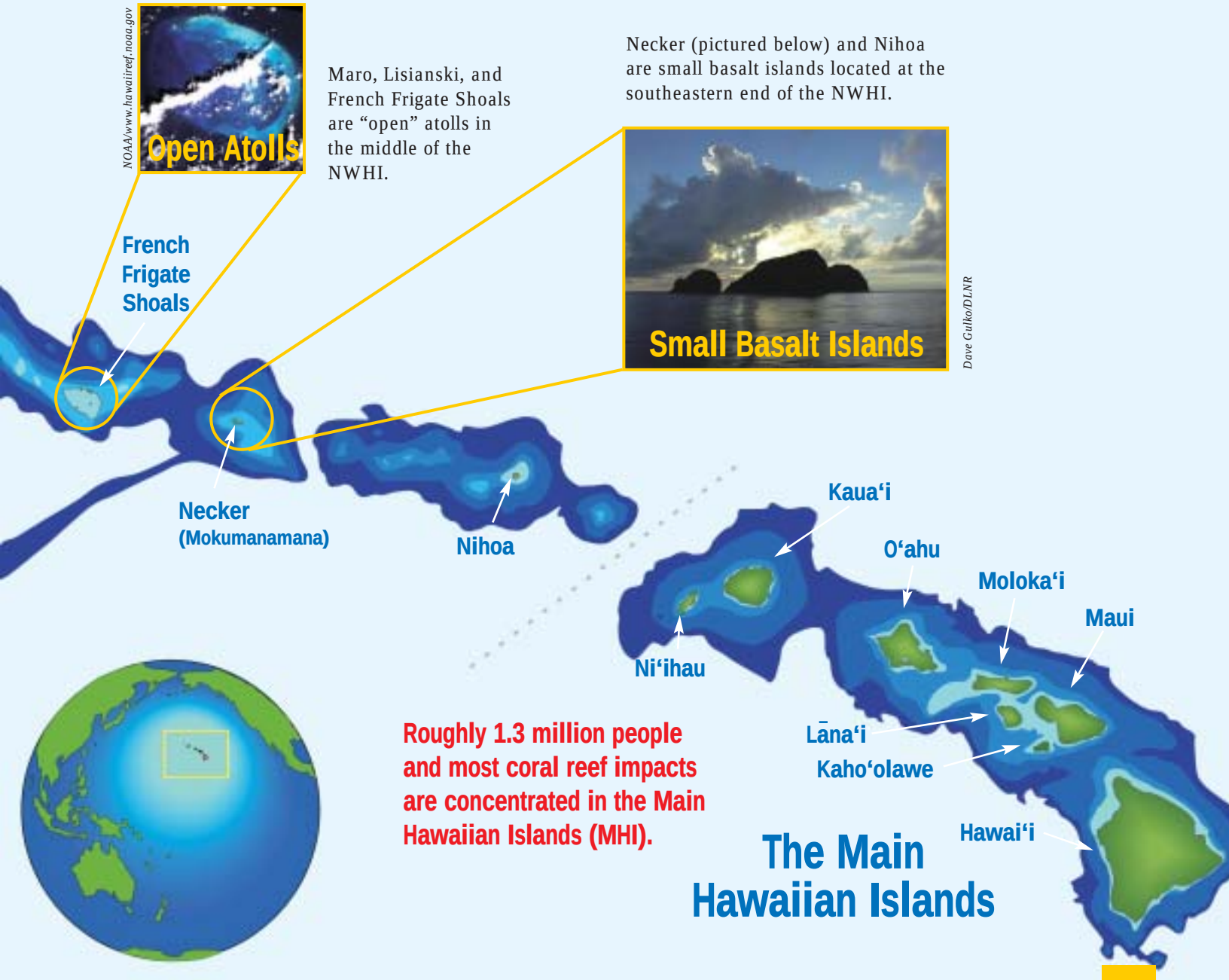
The 2000 Northwestern Hawaiian Islands Reef Assessment and Monitoring Program (NOWRAMP) expedition was a multi-agency and institutional partnership that brought together the best field resources (people, equipment and funding) of both the resource trustees (State and Federal) and the academic community. Field teams conducted rapid ecological assessments and bottom habitat mapping over vast areas within the largest expanse of coral reef wilderness left in the world.



Unlike many tropical island regions, Hawai‘i contains a wide variety of islands, submerged banks, and associated habitats for coral reefs.

Marine Protected Areas in the Northwestern Hawaiian Islands (NWHI)

In 1909 President Teddy Roosevelt established what is now the Hawaiian Islands National Wildlife Refuge and the first protected area for coral reefs in the NWHI, covering most of the shallow NWHI reefs near 8 of the 10 islands except Midway (Kure was later transfered to the State of Hawai‘i). In 1988 the Midway Atoll National Wildlife Refuge was established, extending protection to all its reefs. Both refuges are managed by the U.S. Fish and Wildlife Service. President Clinton created the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve by Executive Order 13178 in December 2000. The reserve is the second largest marine protected area in the world after the Australian Great Barrier Reef and protects additional NWHI reefs beyond the boundaries of the two Refuges and state waters. Roughly 1200 nautical miles long and up to 100 nautical miles wide, the reserve is managed by the National Oceanic and Atmospheric Administration, which may later designate the area as a National Marine Sanctuary. The reserve includes many no-take reefs down to depths ranging from 25 to 100 fathoms. Most or all extractive activities are prohibited in the no-take areas. Other reserve regulations include restrictions on anchoring, discharges, and non-extractive uses.



Executive Summary

During the past century, the remoteness and protective status of Northwestern Hawaiian Islands (NWHI) has spared her reefs the degradation suffered by most other coral reefs in the world. However, the world has since become "smaller" and more crowded, with the NWHI emerging as the only intact large coral reef ecosystem left on the planet. Although some NWHI land areas were degraded by alien species, mining, agriculture, and military use, today the islands support millions of migratory seabirds; endangered land and water birds and vegetation; and the nesting and feeding grounds of threatened sea turtles and endangered Hawaiian monk seals. Adjacent reef and shore areas remain relatively pristine and unexplored, but are now threatened by marine debris, potentially expanded fisheries, and eco-tourism. Furthermore, there have been no comprehensive collaborative investigations of the status of NWHI coral reefs during the last two decades.

Cal Hirai

The Northwestern Hawaiian Islands Reef Assessment and Monitoring Program (NOWRAMP) was launched in early 2000 taking advantage of the groundswell of political and public support for coral reef protection and the advances in modern technology now available to assess, map, monitor and manage large remote marine ecosystems. The major goal of NOWRAMP was to map and rapidly assess the shallow reefs of the NWHI for their biodiversity, status, and management needs. Grant funds from the Hawai'i Coral Reef Initiative Research Program served as a catalyst for eight management agencies and research institutions to team up and work collaboratively during 3 ship-based expeditions beginning September 2000 and collectively encompassing 80 ship days, 50 scientists and over 1,000 dives. Many of the mapping aspects have been deferred to 2002.

Cal Hirai

The NOWRAMP expeditions are the most comprehensive coral reef assessment of the NWHI to date including:

- Rapid ecological assessments (REAs) of reef life at 204 sites at all 10 islands and one bank,
- Over 100 towed diver video surveys covering more than 300 kilometers of reefs,
- Over 100 dives to collect hyperspectral and remote sensing data for future habitat maps,
- Sediment sampling from 36 sites to assess contaminants and 106 sites for micro-scale biodiversity,
- Collecting hundreds of reef algae and invertebrates to identify new species and records,
- Surveys of plants, birds, and insects on 8 of the 10 islands,
- High resolution IKONOS multi-spectral imagery acquired for each of the NWHI,
- Acoustic habitat characterization surveys over 4,600 kilometers of bank habitats,
- Bacteria sampling in unique hypersaline lakes at Laysan and ponds at Pearl and Hermes,
- Assessing impacts from marine debris, ship groundings and derelict fishing gear, and
- Oceanographic observations at 40 sites to measure salinity, temperature and depth.
- Coral Reef Early Warning System (CREWS) buoys and arrays of settlement/recruitment plates deployed at 6 NWHI.
- Coral cores collected at 6 NWHI for growth, carbonate production, dating, and climate change studies.

NOWRAMP results to date reveal the NWHI are much more pristine and diverse than anticipated:

1 Jacks, sharks and other top predators dominate fish populations, a situation not now encountered in any other large scale coral reef ecosystem,
2 Stony coral colonies are abundant, diverse, and often large (and likely very old in many areas), with total species variety exceeding that of the main Hawaiian Islands,
3 One-fourth of the reef animals and plant species reported are unique to Hawai'i, with many new species of sponges, algae, and coral discovered during the three expedition cruises,
4 Marine debris continues to degrade reef habitat at many NOWRAMP sites, injuring and killing corals and other wildlife, further corroborating years of marine debris assessments by the NMFS,
5 Marine alien species appear to not be a severe problem and are common only at Midway,
6 Reefs habitats are diverse, with some unique types not present in the main islands,
7 Large pods of spinner dolphins are regular residents in several atoll lagoons, corroborating decades of similar observations by others.
8 High levels of toxic contaminants were reported in nearshore waters of Midway and Kure.

Cal Hirai

The NOWRAMP team believes that the healthy and abundant populations of large predatory fish in the NWHI warrant careful protection in lieu of their depletion in the main islands and elsewhere in the tropics. Moreover, NWHI coral populations may better withstand bleaching from global temperature increases compared to those at more tropical latitudes. The NWHI also serve as the last refuge for many rare, threatened, or endangered marine and terrestrial species. The entire ecosystem warrants the enhanced protection afforded by existing national wildlife refuges, the new coral reef ecosystem reserve, and additional conservation measures being considered by the State of Hawai'i and the U.S. Department of Commerce.

Cal Hirai

Background photo: Cal Hirai

Introduction

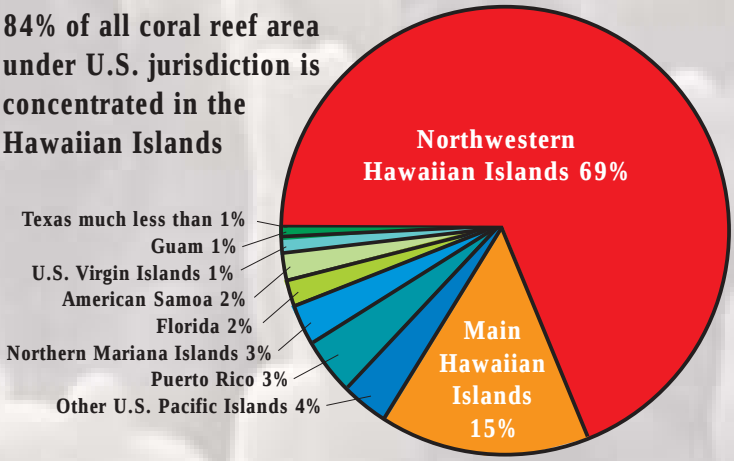
During September - October 2000, two research vessels, the *Rapture* and the NOAA ship *Townsend Cromwell*, provided logistical support for the Northwestern Hawaiian Islands Reef Assessment and Monitoring Program (NOWRAMP) expedition to assess the condition and health of the remote coral reef ecosystems of the Northwestern Hawaiian Islands. The 50 scientists and educators on board were able to spend 57 ship days collecting data from 11 islands, shoals and atolls, crossing over 2,400 miles of ocean. The collaborative expedition involved all key federal and state management agencies (U.S. Fish and Wildlife Service (USFWS), National Ocean Service (NOS), National Marine Fisheries Service (NMFS), Hawai'i Division of Aquatic Resources) and several research institutions (Bishop Museum, Universities of Hawai'i (UH) and California, Oceanic Institute), and was the first of its kind to comprehensively study and map the area's vast shallow coral reef ecosystems. The expedition allowed a wealth of new data to be collected, and eventually scientists and remote imagery specialists will be able to create accurate and detailed maps of the NWHI and their surrounding reef habitats using satellite images, other remote sensing information, and the towboard habitat surveys.

A second multi-agency expedition to the NWHI supported by the NMFS was completed in October 2001 aboard the *Townsend Cromwell* and *American Islander*. Some of these findings are combined with the 2000 REA survey results to provide a more complete and up-to-date overview.

Dave Gulko/DLNR

U.S. CORAL REEF AREAS

84% of all coral reef area under U.S. jurisdiction is concentrated in the Hawaiian Islands



(Source: Miller and Crosby, NOAA, 1998)

The results from the NOWRAMP expedition revealed a wide range of coral reef ecosystems that represent a unique marine wilderness of extreme importance, not only to the State of Hawai'i, but also to the nation and world as a whole. The majority of involved researchers and educators came away with a renewed respect for this expansive resource and a firm resolve that the reefs at these atolls, islands, and shoals deserve the maximum protection possible. This report not only conveys the key results of the expedition, but also explains their significance relative to management concerns, existing impacts, and comparisons with other reef areas.

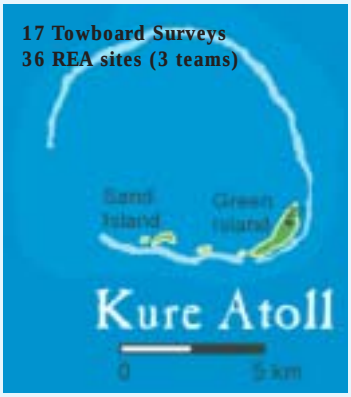
NOWRAMP was also the first major expedition to the Northwestern Hawaiian Islands to transmit daily media reports and incorporate public education goals into the expedition protocols. A public education team on the *Rapture* supported by a team in Honolulu provided daily environmental stories and research updates to the media and the public. Educational materials for public schools were produced prior to the expedition, and numerous schools followed the expedition on the web, through classroom activities and through live interactive interviews with the researchers and crew during numerous phases of the expedition. Students were drawn directly into the exploration and experienced how science, natural history and Hawaiian cultural history are important in their lives.

"In my 30 years of serving as chief scientist on a number of different expeditions, this trip was the best one ever," said Jim Maragos, NOWRAMP Principal Investigator. "Everyone on board, from all the different agencies, pulled together and worked really hard to make sure everyone's individual needs and goals were met. When I think about all the expertise and diverse talent on board, I'm honored to have been a part of the expedition and serve as the trip's leader."

Expedition Overview

NOWRAMP conducted multiple rapid ecological assessments (REAs) and tow-board surveys of reefs at the 10 NWHI and neighboring Raita Bank, resulting in the most detailed surveys of the NWHI coral reefs to date.

Kure Atoll

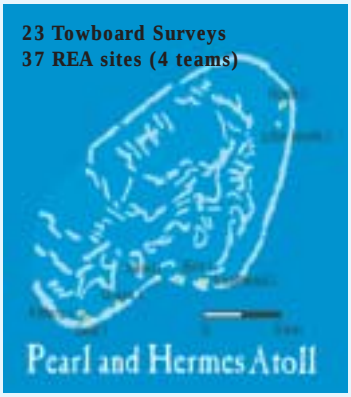


Classical atoll with one large pass, complete perimeter reef, lagoon with simple patch reefs, and several coral islets.

Midway Atoll

Classical atoll with two large passes, perimeter reef, lagoon with simple patch reefs, and several coral islets.

Pearl and Hermes



Classical atoll with multiple small passes, numerous low coral islets, reticulated reefs, near complete perimeter reef, and complex patch reefs.

Lisianski Island and Neva Shoal

Open atoll with large submerged reticulated reef, limited perimeter reef, and one large coral islet.

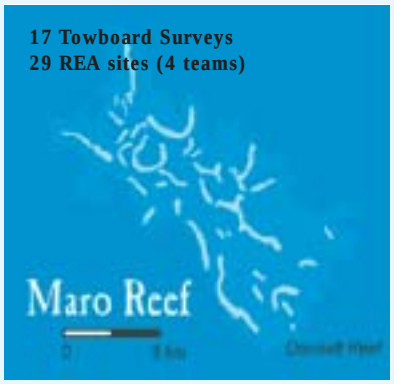
13Towboard Surveys
12 REA sites (2 teams)

Laysan

Low coral island with hypersaline lake, mostly submerged reefs, and some shallow lagoon reefs.

6 Towboard Surveys
10 REA sites (3 teams)

Maro Reef



Open atoll, lagoon filled with complex patch reefs, oceanic pinnacle reefs, large submerged reefs, but lacking perimeter reef and emergent land.

French Frigate Shoals

Open atoll lacking perimeter reef to the west, lagoon filled with reticulated and linear reefs, patch reefs, numerous low coral islets, and a central basalt sea stack (La Perouse Pinnacle).

Gardner Pinnacles

1 Towboard Survey
4 REA sites (2 teams)

Basalt sea stack.

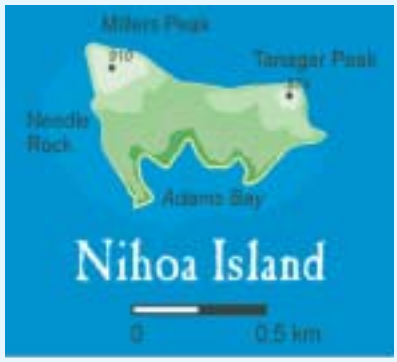
Necker Island

5 Towboard Surveys

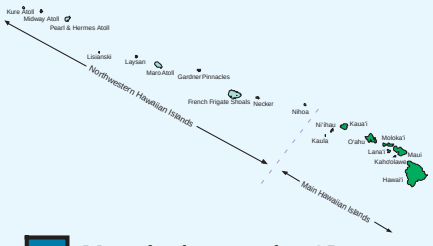
9 REA sites (2 teams)

Small basalt island.

Nihoa



3 Towboard Survey
8 REA sites (2 teams)



- Water depth greater than 25 m.
- Water depth less than 25 m.
- Reef crest.
- Intertidal.
- Land elevation less than 3 m.
- Land elevation 10 - 100 m.
- Land elevation less than 200 m.
- Land elevation less than 300 m.

Background photo: Jim Maragos/USFWS

Terrestrial Studies

The NWHI provide all habitat for several species of endangered plants and birds and many species of endemic insects.

Dave Johnson/USFWS

The Laysan Duck, an endangered species

The land team conducted surveys on all of the emergent areas of the NWHI. Some of the islands are visited only rarely due to their remoteness and hazardous access during poor weather and sea conditions. The land team was surprised by the number of alien insects and plants reported on most of the islands. Alien insects were found on all islands, disturbing the native insect and plant communities. Alien plants were found on all islands except Gardner Pinnacles. The biggest insect problems appeared to be big-headed ants on Kure and Midway, one species of grasshopper on Nihoa, and scale insects on Kure. The primary plant culprits appear to be *Verbesina* (golden crownbeard) and *Cenchrus* (sandbur).

'Aulani Wilhelm/DLNR

***Pritchardia remota,* Nihoa Fan Palm, an endangered species**

Dave Johnson/USFWS

Countless NWHI land species have gone extinct during recent centuries.

Entomologist Gordon Nishida conducted alien insect sampling at most of the islands. At Kure Atoll he recorded an astounding 26,500 alien ants per square meter. Such a result suggests that big-headed ants (*Pheidole megacephala*) have overrun the land ecosystem at Kure. Non-native ants are one of the few animals that can quickly and completely break an ecosystem. “They're ecosystem-busters,” remarked Beth Flint, USFWS. “Ants are incredibly effective and efficient predators and have few limits on their diet. They'll eat anything that doesn't have a defense. On Kure, these alien ants have no natural predators to control their population... As long as they can find food, their colonies will probably continue to grow.” Native insects would have no defenses against these ants, and therefore would be easy prey.

Dave Johnson/USFWS

The Hawaiian Monk Seal

The NWHI is home to the Hawaiian Monk Seal, the only surviving marine mammal wholly dependent on a coral reef ecosystem

The NWHI serve as important nesting habitat for millions of seabirds belonging to over 20 species, including the Brown Booby (right).

The NWHI are the largest tropical seabird rookery under U.S. jurisdiction (and perhaps the world). Millions of resident seabirds nest and thousands of migratory shorebirds winter in the NWHI.

Background photo: Dave Johnson/USFWS

Marine Field Surveys: Innovative, Comprehensive Data Collection

The NOWRAMP Expedition made use of towboard surveys with digital video to collect basic habitat information and estimate coral, algal and other bottom cover over broad areas. Multiple rapid ecological assessment (REA) teams, each comprised of three fish specialists, an algal specialist, a coral specialist and an invertebrate expert, conducted comparative surveys and gathered samples. Innovative use of digital video combined with fixed distance lasers allowed for accurate sizing of fish (bottom left) and corals.

The NWHI likely support the highest proportion of undescribed reef species (corals, sponges, algae, other invertebrates) compared to any other large reef ecosystem on the planet

Jim Maragos/USFWS

Extensive collections were made across a wide range of marine taxonomic groups and habitats, providing a cornucopia of new species and new records.

Brent Carmen/DLNR

Bill Walsh/DLNR

Use of lasers (right) allows for precise and safe measurement of fauna (left).

These data can be used to more accurately estimate fish length and weight (biomass)

Cal Hirai

Background photo: Cal Hirai

The NOWRAMP Remote Area REA Protocol

To maximize the comparability and coverage of field surveys, all REA teams used the same survey procedures, and were deployed over as wide an area as possible.

According to Rusty Brainard, chief scientist aboard the NOAA ship *Townsend Cromwell*, "this cruise was extremely successful, providing an excellent baseline data set to allow improved decision making and planning for management of the Northwestern Hawaiian Islands coral reef ecosystem. This success was due to the commitment and dedication of the crew ... and the entire multi-agency scientific complement."

TOWBOARD TEAM

Towboards allowed trained divers to census and classify habitats over extensive reef areas quickly (about 3 kilometers per dive). These results were then used to select the best areas for intensive benthic and fish assessments by the REA teams. These surveys are also being used to groundtruth the remote sensing imagery.

Each towboard team consisted of two divers with separate boards towed behind the same boat. A digital video camcorder was affixed to each board with one pointing down (90º) and the other pointing at a forward angle (20º) to capture a broader spectrum of habitat and substrate information. Divers maintained the cameras 1 meter above the bottom. Each towboard was equipped with paired lasers to project a scale onto the video. Water temperature, depth, and GPS data were recorded continuously during each towboard survey.

Camera pointing forward at 20º to capture information about the habitat complexity.

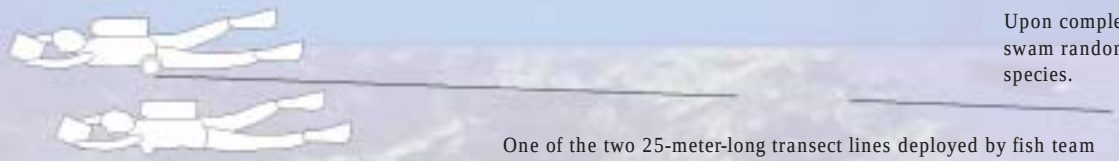
Camera pointing down at 90º to capture information about the composition of the substrate.

FISH TEAM

Each fish team consisted of three divers with two swimming three 25 m long transects per dive. During the deployment leg of the transect, both divers recorded size class-specific counts of all fishes greater than 20 cm within 2 m on each side of the line, while small and cryptic fish (i.e. less than 20 cm) were enumerated by size class during the "swim back" leg.

The third diver of the fish team completed four stationary point counts, each within a cylinder having a radius of 10 m, to estimate size and abundance of larger (greater than 25 cm in length) and more mobile fish. This diver also used video to capture "natural" fish assemblages and size information using the attached lasers.

Upon completion of transect surveys, teams swam randomly over the reef to record rare species.



One of the two 25-meter-long transect lines deployed by fish team and later used for surveys by the benthic team.

BENTHIC TEAM

The benthic team surveyed the first two of the fish team's transects to estimate corals, other invertebrates, and algae, but first waited at least 10 minutes to avoid disturbing the fish surveys.

Algal and invertebrate experts swam behind the coral diver documenting species and collecting specimens.

SEDIMENTS TEAM

A separate team focused on collection of sediment samples by grab and hand collection for later census of microscopic animals and laboratory analysis of chemical contaminants.

REMOTE SENSING TEAM

A remote sensing specialist collected hyperspectral signatures of various bottom features and organisms. The specialist also gathered groundtruthing data for later habitat mapping.

LAND TEAM

While the REA and towboarding teams were deployed underwater, a terrestrial team would land at adjacent islands, and assess the status of plants, insects, birds, monk seals and turtles.

The coral expert on each benthic (bottom habitat) team would initially videotape the substrate along each of the first two transects at a height of about 1 m above the center of each line. Later, the algal, invertebrate, and coral experts would swim the lines to record species and collect specimens, additional video, and photographs. All three would then conduct random swims near the end of each dive to record other rare species.

Cal Hirai

NOWRAMP algal biologist collecting new species of algae.

Background photo: Cal Hirai

Background photo: Dave Gulko/DLNR

Oceanography

The structure and function of all coral reef ecosystems are controlled by the prevailing oceanographic conditions to which the corals, fish, algae and invertebrates of the ecosystem are exposed. These biological components depend on the time-varying ocean currents, waves, temperature, salinity, water clarity, nutrients and many other oceanographic conditions. As these conditions change, so do the health, distribution, and species diversity of each reef community.

The NWHI, which are located in the center of the subtropical North Pacific Ocean, provide an excellent example of the role ocean conditions play in forming and maintaining reef ecosystems. 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 from 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. Although the ocean currents of the surface waters of the Hawaiian Archipelago are highly variable in both speed and direction of flow, they are primarily driven by the prevailing northeast tradewinds. Hence, the surface waters tend to flow predominantly from east to west. 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.

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 only survive in sheltered 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. The less hardy species cannot survive the pounding by these large winter waves.

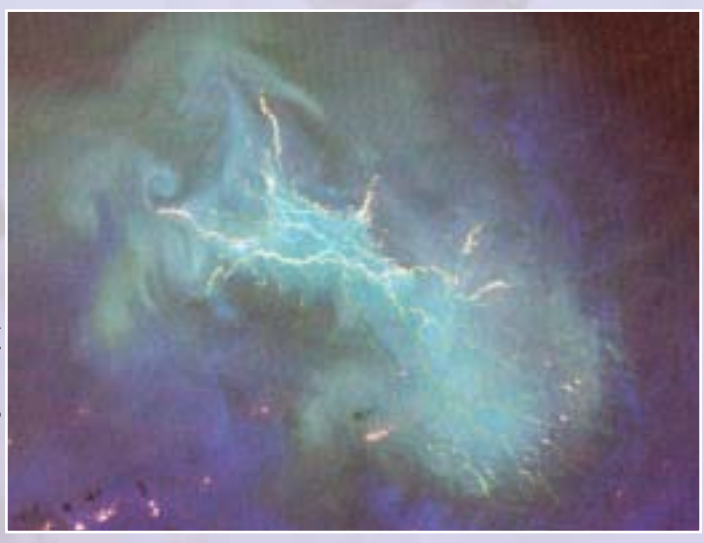
Since coral health and growth rates are a function of water temperature, ocean temperatures also have a profound influence on the reef ecosystems of the NWHI. As the northernmost large coral reef ecosystem in the world, the coral reefs of the NWHI are exposed to large seasonal temperature fluctuations, particularly the more northerly atolls at the northwestern end the chain. Sea surface temperatures at these northerly atolls range from as low as 18ºC (64.4ºF) in late winter to a high of about 28ºC (82ºF) in late summer. While the summer temperatures are similar along the entire NWHI, the winter temperatures tend to be about 3-4ºC 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 be at or near the lower limit for coral growth.

With the southward migration of the subtropical front comes generally more nutrient-rich water. So, while the coral growth may slow during the winter months at the northerly atolls, summer temperatures probably do not restrict growth, and overall biomass may be increased due to enhanced primary productivity of the ecosystems.

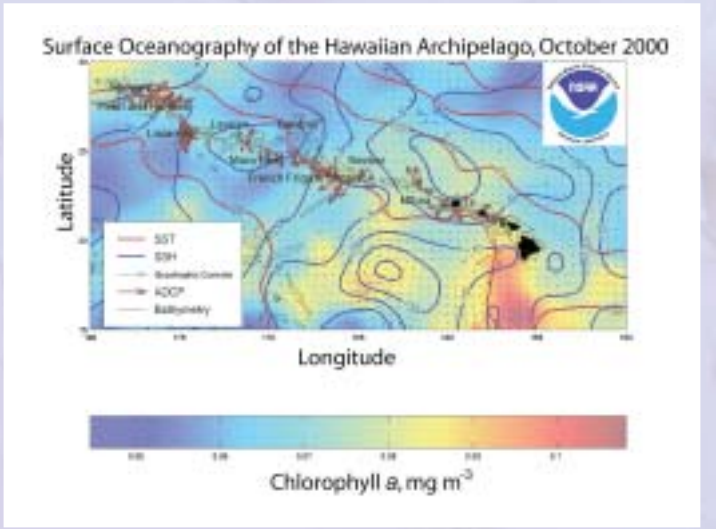
In order to assess the role of oceanographic conditions on the reef ecosystems of the NWHI, oceanographers from the NMFS have established a long-term oceanographic monitoring program consisting of shipboard observations of temperature, salinity and chlorophyll versus depth and ocean current profiles; satellite observations of sea surface temperature, sea surface height, significant wave height, surface winds, and chlorophyll; an array of six Coral Reef Early Warning System (CREWS) physical and biological monitoring buoys; and twelve satellite-tracked ocean current drifter buoys.

- Rusty Brainard (NMFS)

The 2000 Landsat image of Maro clearly delineates a large spiraling current feature (mesoscale eddy) that barely brushes past the far western reef extension at Maro near sites supporting high reef biodiversity.



Landsat Image Courtesy of NASA



Background photo: Jim Maragos/USFWS

Fish Studies

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. The NWHI provide a unique opportunity to assess how a "natural" coral reef ecosystem functions in the absence of major human intervention. Fishing activity on coral reefs tends to focus first on the larger more desirable species and progressively shift towards smaller less desirable ones as time goes on and resources decline. Typically these larger species are apex predators (top carnivores) that profoundly affect how the whole coral reef fish assemblage is structured. The NWHI allows us to look at how coral reef fish assemblages are organized in as natural a state as possible.

- Alan Friedlander (Oceanic Institute), Ed DeMartini (NMFS), Bill Walsh (DLNR)

Cal Hirai

Large Numbers of Sharks and Jacks

The most striking observation made for fishes on the cruises was the frequent encounter of large apex predators such as jacks (*ulua*), reef sharks (*mano*), and amberjacks (*kahala*). These top carnivores are seldom encountered by divers nowadays in the inhabited Hawaiian islands. These and other large fishes were curious and usually attracted to divers at all of the NWHI reefs visited-unlike the MHI, where they typically flee from divers. Giant trevally (*ulua aukea*), the largest and boldest of the jacks found in Hawaiian waters, sometimes bit at NOWRAMP divers' hands and gear. Fortunately the sharks were less bold if not less curious. One interesting, as yet unexplained, observation was the prevalence of gray reef sharks southeast of Maro Reef, in contrast to the preponderance of Galapagos sharks northwest of Maro Reef.

Big Fish

A number of species, like the Spectacled Parrotfish (*uhu uliuli*), Hawaiian Hogfish (*ʻaʻawa*), and Bigeye Emperor (*mu*), are quite abundant and obtain large size in the NWHI. These species are heavily exploited for subsistence and recreational use in the main Hawaiian Islands (MHI), and their reduced number and size is likely the result of overfishing. These species tend to be wary in the presence of divers in the MHI but were easily approached in the NWHI.

Jim Maragos/USFWS

Dave Gulko/DLNR

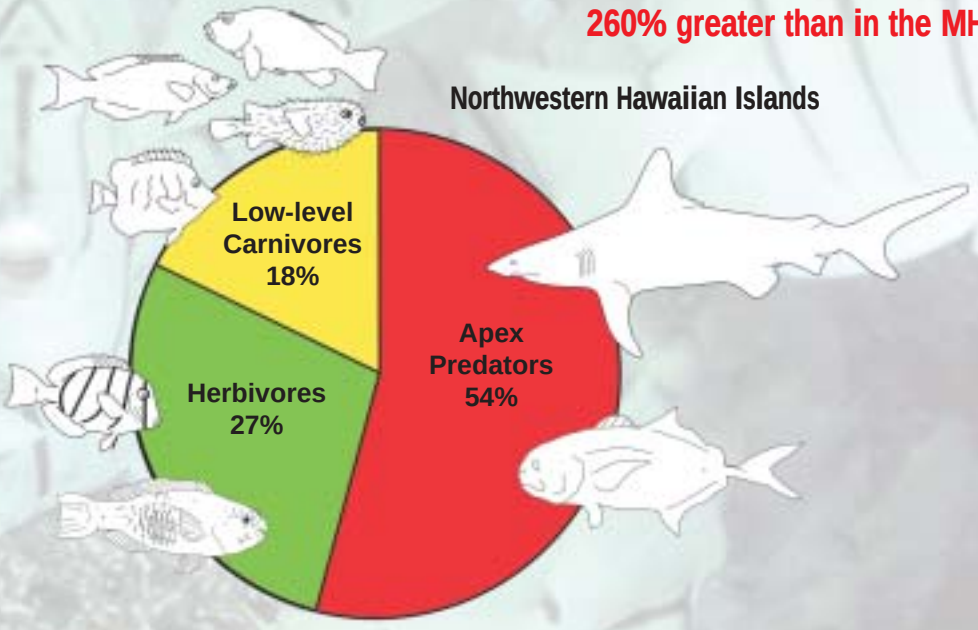
Grouper

Hapuʻupuʻu (left), the only endemic Hawaiian grouper, frequently approached and followed divers, similar to the behavior of other species of groupers on coral reefs elsewhere. Perhaps divers sufficiently resemble the habits of large fishes and fish-like animals that disturb the bottom; the disturbance attracts groupers searching for food. Although the groupers usually occur at depths greater than about 300 feet in the rest of the Hawaiian archipelago, *hapuʻupuʻu* were encountered at shallow diving depths at Midway and Kure atolls. Because of its high trophic level status, economic importance, and restricted shallow-water distribution at these sites, the *hapuʻupuʻu* is perhaps our best example of a Hawaiian endemic fish species deserving special protection.

Background photo: Jim Maragos/USFWS

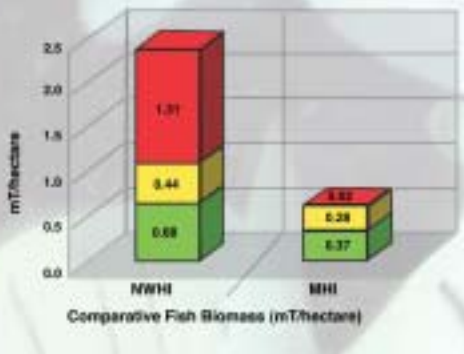
Comparison of Trophic Structure Between the Northwestern Hawaiian Islands and the Main Hawaiian Islands Based on Biomass

Average fish biomass in the NWHI is more than 260% greater than in the MHI!



NWHI Overall Fish biomass is 2.4 mT/hectare

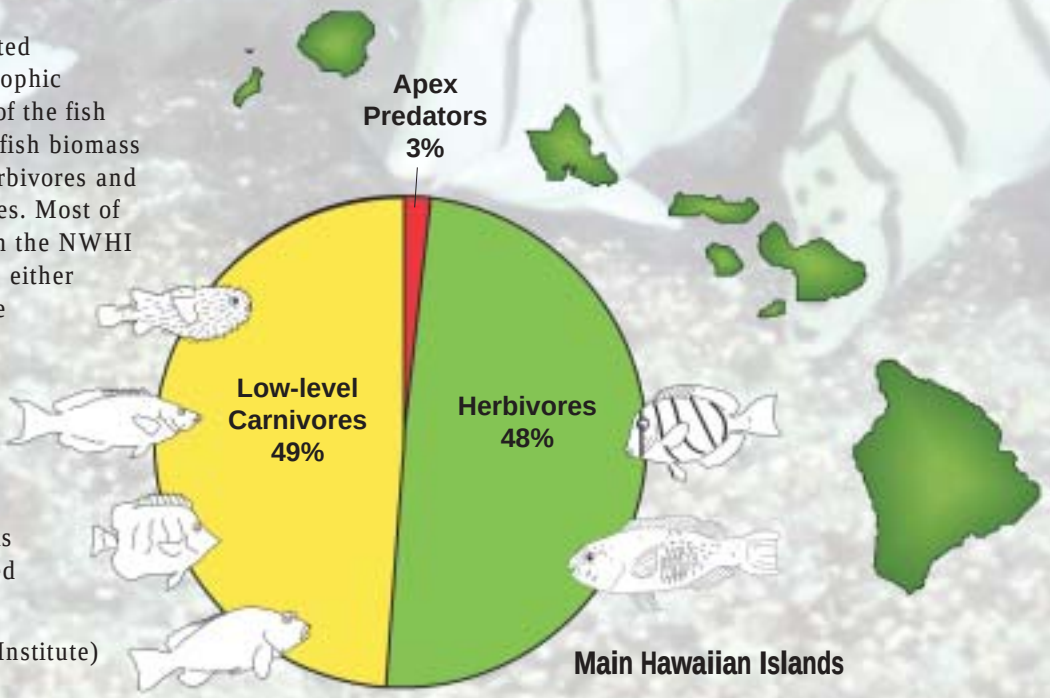
Only slightly less obvious than the frequent encounters with large predators was the generally high abundance and large average body size of all of the fishes, and the large proportion of carnivorous (animal-eating) versus herbivorous (plant-eating) fish species in the NWHI (left). The latter especially contrasts with the results of recent analogous observations made in the MHI (below).



The very high biomass of apex predator reef fish in the NWHI is perhaps unique in the world and a reflection of long periods without fishing pressure.

Average fish biomass in the NWHI is nearly three times greater than in the MHI. More than 54% of the total fish biomass 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 and small-bodied lower-level carnivores. Most of the dominant species by weight in the NWHI (jacks, sharks and groupers) 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. These differences represent both near-elimination of apex predators and heavy exploitation of lower trophic levels in the MHI (overfishing) compared to the largely unfished NWHI.

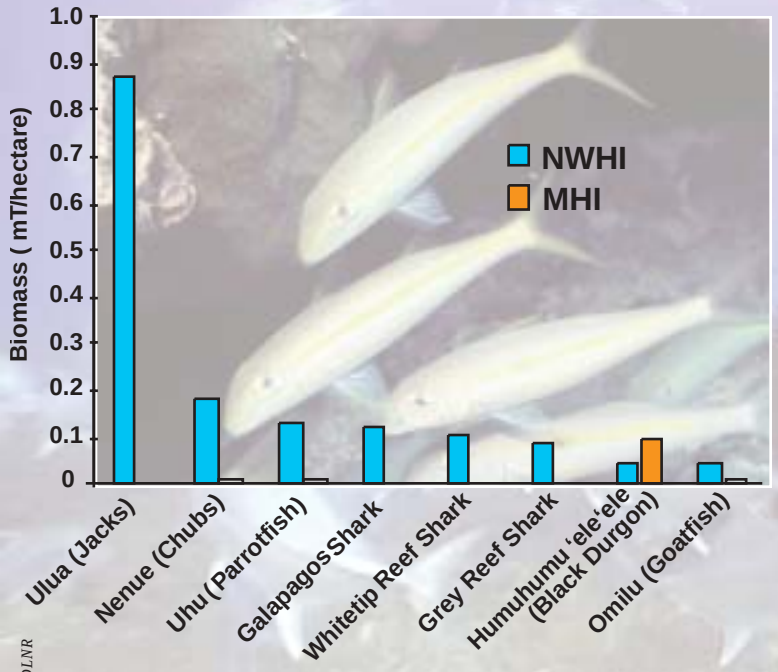
- Alan Friedlander (Oceanic Institute)



MHI Overall Fish Standing Stock 0.67 mT/hectare

Background photo: Jim Maragos/USFWS

Mean weight of apex predators in the NWHI was 570% greater than in the MHI while herbivores were 97% heavier in the NWHI.



Jim Maragos/USFWS

Background photo: Dave Gulko/DLNR

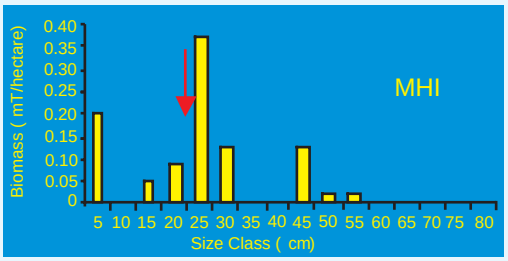
For all comparisons, fish biomass was higher in the NWHI compared to the MHI and was significantly greater in all cases except for the numerical abundance of herbivores (left).

Data for the *uhu uliuli*, a herbivorous parrotfish unique (endemic) to Hawai'i, illustrates that the basic NWHI-MHI dichotomy is not restricted just to carnivorous fishes (see box, below). As for the sharks and jacks, even the smaller NWHI carnivores like *'a'awa* and herbivores such as the *uhu uliuli* showed no fear of divers and were easily attracted to bottom disturbance caused by divers' fins.

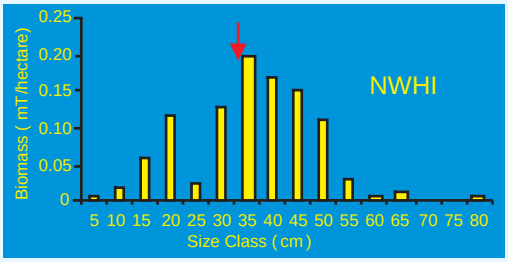
In addition to food fish, a large variety of ornamental species are abundant and harvested in the MHI. These species tend to be very resident and often establish and defend well-defined territories on the reef. Cleaner wrasses, likewise exploited for the aquarium fish trade, form conspicuous cleaning stations that serve the valuable function of removing parasites off other reef fishes.

As for all other components of the NWHI flora and fauna, the fish fauna of the NWHI includes a large percentage of species that are unique (endemic) to the Hawaiian Islands. Even though many of our Hawaiian marine fishes are unique to Hawai'i, the significance of (and our fascination with) the NWHI fish fauna, lies in its healthy, largely undisturbed status and its vulnerability and curiosity due to lack of human contact, not its taxonomic uniqueness. The NWHI, largely because of their remoteness, represent one of the last remaining large, intact and relatively pristine reef ecosystems in the world and for this reason alone deserve our careful stewardship.

Case Study: Where Have All The Parrotfish Gone?



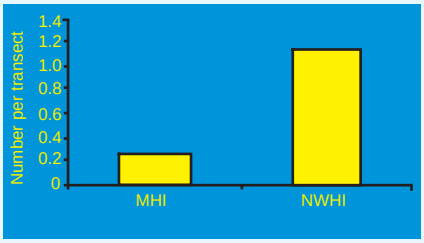
A comparison between size classes observed for parrotfish in the MHI (above) and the NWHI (below).



The Spectacled Parrotfish, *Uhu uliuli*, is an endemic species that is prized as a food fish in the MHI. Spearfishers target this species which is particularly vulnerable at night when it sleeps. As a result, this species has suffered from severe overfishing in the MHI. *Uhu uliuli* were commonly encountered in the NWHI and the abundance of terminal phase males was in sharp contrast to their near absence in the MHI. The species abundance was more than 700% greater and its overall standing stock was more than 1160% greater in the NWHI compared to the MHI. The average size (red arrows on graphs to the left) was more than 10 cm larger than those observed in the MHI. These findings strongly support the need for better management of reef fishes in the MHI.

- Alan Friedlander (Oceanic Instititute)

Dave Gulko/DLNR



Coral Studies

The NOWRAMP expedition found higher biodiversity of coral species in the NWHI than in the MHI, amazing scientists who assumed that species richness would be lower in the NWHI's cooler, subtropical waters.

Jim Maragos/USFWS

Acropora cerealis, **the latest of 6 table coral species of the genus *Acropora* confined to the NWHI and a new record for Hawai'i.**

Jim Maragos/USFWS

Montipora turgescens, **abundant only at the northwestern end of the Hawaiian chain.**

Jim Maragos/USFWS

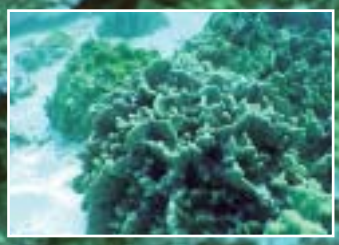
Unidentified *Montipora* sp., found at Maro Reef.

Jim Maragos/USFWS

Fungia granulosa **and *F. scutaria,* the first a new record, and both species abundant in the NWHI.**

Jim Maragos/USFWS

Undescribed species of the branching coral *Pocillopora* at Pearl and Hermes Atoll.



Dave Gulko/DLNR

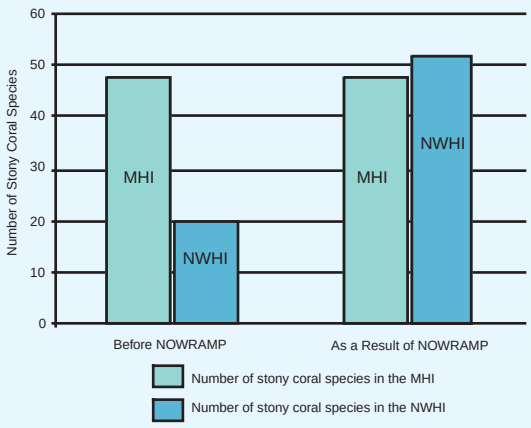
Unidentified *Porites* sp., rare in the MHI but larger and more abundant in the NWHI.

Dave Gulko/DLNR

Jim Maragos/USFWS

Large colony of the encrusting coral *Psammocora nierstraszi* at Maro Reef.

Unexpectedly High Biodiversity of Corals:



About 62 species of stony corals have now been reported from the Hawaiian Islands based on the 2000 - 2001 surveys in the NWHI. These include 11 new records from Hawai'i as a whole and over 30 new records for the NWHI. At least 3 and possibly as many as 6 species of stony corals and perhaps 1 or two 2 soft coral species may be new to science. At least 12 of the total NWHI coral species have not been reported in the MHI. Despite the short duration of surveys in the NWHI, only 9 species from the MHI remain unreported in the NWHI, and most of these are rare forms or confined to deep water habitats which could not be surveyed due to diving restrictions. Nevertheless, more species (52) have already been reported from the NWHI during the last 2 years than in all the previous surveys accomplished in the MHI (only 48 species).

The 2000-1 REA in the NWHI more than doubled the number of known Hawaiian coral species, exceeding that of the more thoroughly studied MHI.

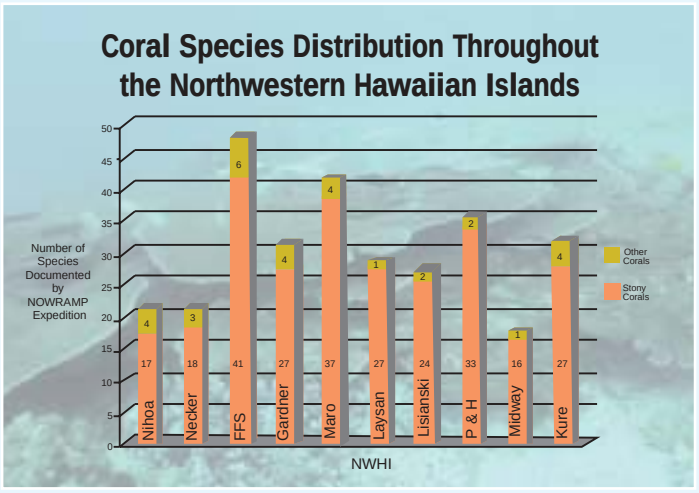
Jim Maragos/USFWS

Many large, living coral heads of several species occur in protected waters of the NWHI atolls and Laysan Island: these include the disk coral *Pavona duerdeni* (at Kure and Maro), table coral *Acropora cytherea* (FFS and Maro), finger coral *Porites compressa* (in the deep lagoons of Kure, FFS, Midway, and Pearl and Hermes), blue encrusting coral *Montipora turgescens* (in back reefs at Midway, Lisianski and Kure), massive lobe corals *Porites lobata* and *P. evermanni* (sheltered shallow reefs or back reefs at all atolls), and encrusting plate corals (*Montipora capitata*, *Porites* spp.) on deeper, semi-exposed reef slopes. The existence of these old, and possibly ancient animals are indicative of an extended period of environmental stability and favorable conditions for coral growth and survival in the NWHI.

Analysis of coral species distribution (right) suggests that diversity is higher at most of the atolls: Kure, Pearl and Hermes, Maro, Lisianski, and FFS. Laysan also supports a high number of species, perhaps due to protected shallow reefs off the southwest side of the island. Atoll lagoons afford greater protection from wave action and provide additional types of reef habitats (lagoon reef slope, perimeter reef crest, reef pass, back reef, patch reefs, reticulated reefs, etc.) that are absent elsewhere in the Hawaiian Islands. Moreover, larger atolls (Maro, FFS, P and H) provide more quantity of habitat, perhaps one reason for the greater number of coral species there. Midway, though an atoll, is small and shows lower coral diversity than other NWHI atolls. This is likely the result of only 4 REA surveys accomplished at Midway although other factors may also be contributing to the lower species totals (e.g. the atoll's history of chronic human disturbance, northerly location, or reduced coral larval recruitment). In contrast, twice as many corals were reported at neighboring Kure Atoll, but 9 times as many REA sites were surveyed there too.

Dave Gulko/DLNR

- Jim Maragos (USFWS), Dave Gulko (DLNR)



Dave Gulko/DLNR

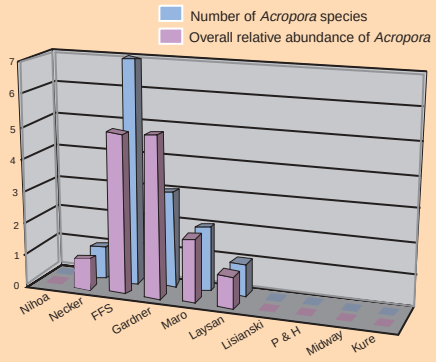
Acropora Table Corals

Two new species records for table coral were reported at French Frigate Shoals on the 2000 NOWRAMP expedition. One is *Acropora cerealis*, a small robust table coral. The second was collected but has not yet been examined. Table corals are restricted to French Frigate Shoals and four adjacent islands and atolls. French Frigate Shoals supports the highest number of *Acropora* species and the greatest number of coral species in the NWHI.

"Why this [*Acropora*] type of coral isn't commonly found in Hawai'i may be due to the remote locations of the islands," said Jim Maragos. "Coral colonies need a larvae source in order to establish and survive, and most of the Hawaiian Islands may just be too cold and too far away from any such source. *Acropora* favors warmer temperatures and doesn't survive well in places that experience large waves and storms as the MHI do. At FFS the *Acropora* may have become established from larvae that traveled in currents and eddies from Johnston Atoll, 450 miles to the southwest." The additional presence of table corals at Necker, Gardner, Maro and Laysan may be related to their close proximity to these same currents and eddies. Johnston Atoll probably serves as a "stepping stone" for dispersal of table coral larvae from the equatorial Pacific (where they are more common) to Hawai'i (where they are very rare). The larvae may have traveled in sufficient enough quantities to maintain a stable population here. About a dozen large colonies of *Acropora cytherea* were found a decade ago off the Na Pali Coast of Kaua'i, but could not be relocated during more recent surveys in 1997. These corals may have perished during hurricane Iniki, which struck Kaua'i in 1992. According to fish biologist Bill Walsh, "What comes with finding this coral is a wide variety of associated fish such as the chevron butterflyfish which feeds on the *Acropora*. This fish is not usually found apart from *Acropora* and is not found at all in the MHI."

Jim Maragos/USFWS

Jim Maragos/USFWS



Invertebrate Studies

Marine invertebrates are animals without backbones and include such diverse species as sponges, corals, worms, snails, lobsters, crabs, shrimp, clams, oysters, sea urchins, and seastars, to name only a few of the hundreds of known taxonomic groups. With the exception of corals, the invertebrates of the NWHI are still poorly known, and the NOWRAMP expedition allowed the first intensive scientific survey of non-coral invertebrates since a group of Bishop Museum scientists aboard the Coast Guard cutter *Tanager* explored these remote reefs in 1923. Only a small portion of the thousands of specimens collected on the NOWRAMP expedition have been identified because the process is slow and involves many steps. However, some patterns in the distribution and species composition of these animals are emerging.

High islands like Nihoa and Necker had distinct invertebrate assemblages, or groups of species, when compared to more northerly atolls like French Frigate Shoals and Pearl and Hermes. Atoll and high islands have contrasting environmental characteristics that support different species; in particular, the atoll lagoons provide unique habitat for species to survive and evolve. In the extensive French Frigate Shoals lagoon, a reef composed almost entirely of bivalve clams was found, a feature that is not known in the MHI. Also in these lagoons, NOWRAMP scientists collected specimens of sponges, snails and crustaceans that are new records to Hawai'i.

Cal Hirai

Dave Gulko/DLNR

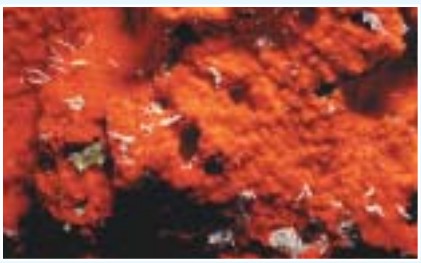
Unidentified *Sinularia* sp., confined to the shallow wave-washed slopes of small basalt islands in the NWHI.

The specimens collected from French Frigate Shoals were the first to be identified by NOWRAMP biologists, and thus the most is known about the invertebrates of this atoll. The invertebrate assemblage of FFS is diverse and contains as many as 600 species; more than 250 species (not including marine snails) are new records added by the NOWRAMP expedition. Over 230 additional species of marine snails have been added, tripling the number of previous known snail species at FFS. Of these, at least three are known to be new records to Hawai'i, and several others may be new to science. Nineteen sponge species were also collected at French Frigate Shoals, of which only two are currently known to science. The others are undescribed and possibly are found nowhere else in the world other than at French Frigate Shoals. Similar trends are certain to be apparent in other invertebrate groups (for example, shrimps and crabs), but results for these groups are still preliminary as the work progresses. Biologists expect similar results from the other islands visited by NOWRAMP, many of which were even more poorly known than French Frigate Shoals.

- Ralph DeFelice, Lu Eldredge, Scott Godwin, (Bishop Museum) and Dwayne Minton (UH)

Sponges: Seven New Species on a Single Dive!

Sponges are the most primitive multi-cellular animals. Their biology and taxonomy are poorly understood in the Hawaiian Islands and throughout the world. The sponges of the NWHI are virtually unknown and have never been collected or identified. Biologists on the NOWRAMP expedition collected more than 250 sponge specimens representing somewhere around 75 species, of which approximately 80% of these are new records to the Hawaiian Islands or undescribed species. Many of these species were found in unique lagoon habitats at Pearl and Hermes Reef and French Frigate Shoals, and are probably new endemic species, meaning that these islands are the only places in the world where they occur. NOWRAMP scientist Ralph DeFelice collected a variety of sponges at Pearl and Hermes, of which seven are thought to be new species, just from a single deep lagoon site!



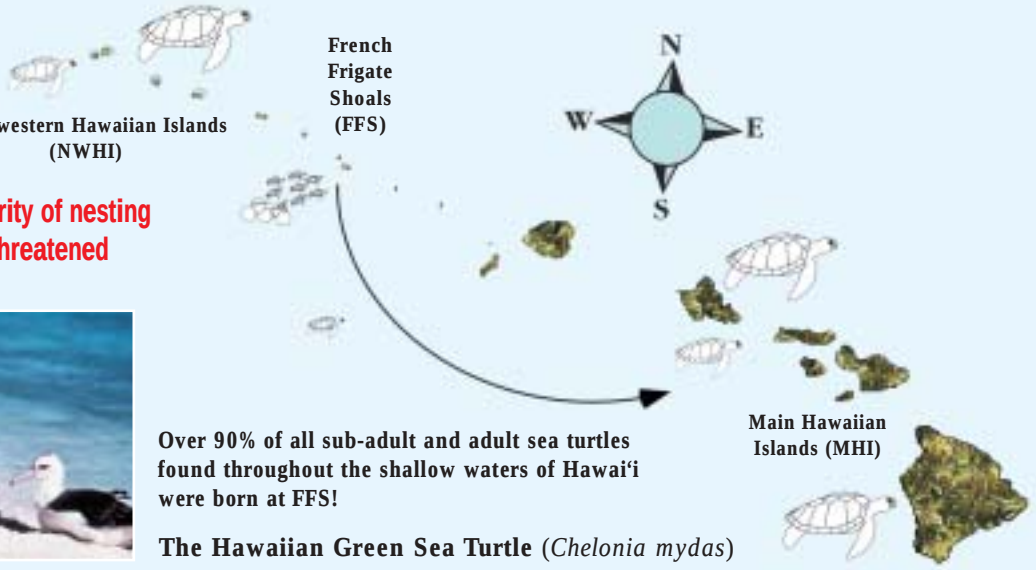
Jim Maragos/USFWS

- Ralph DeFelice, Lu Eldredge, Scott Godwin, (Bishop Museum) and Dwayne Minton (UH)

Jim Maragos/USFWS

Background photo: Jim Maragos/USFWS

Protected Marine Species



The NWHI provide the majority of nesting and mating habitat for the threatened Hawaiian Green Sea Turtle.

© Monte Costa

Over 90% of all sub-adult and adult sea turtles found throughout the shallow waters of Hawai'i were born at FFS!

The Hawaiian Green Sea Turtle (*Chelonia mydas*)

Under the leadership of George Balazs (NMFS), NMFS and the USFWS have worked together for the past 2 decades to monitor and assist the recovery of Hawaiian green sea turtles at French Frigate Shoals and throughout the Hawaiian Archipelago. Due to these collaborative efforts and enforcement of refuge and endangered species regulations, Hawaiian green sea turtle populations are rapidly increasing.

By virtue of their early legal protection (1909) and their extreme isolation by distance, the islands and reefs of the NWHI serve as an important haven for numerous rare organisms, many of which have disappeared from the MHI to the south. Fifteen of these species of plants and animals are listed and protected under the U.S. Endangered Species Act. Many others have yet to be listed but are vulnerable to extinction due to their small population sizes and limited distributions.

Nihoa Island serves as the only home for 3 endangered plants, 72 insects, and 2 small endangered land birds in the only remaining intact example of a Hawaiian coastal scrub community left in the world. The 200 remaining Nihoa Millerbirds, 1000 Nihoa Finches, and the lovely Nihoa fan palm rely on the absolute isolation and protection from invasive species and disturbance that the National Wildlife Refuge provides.

Further north, Laysan Island shelters the Laysan Finch and the only wild population of the Laysan Duck. This little island duck has the smallest range of any duck in the world.

Practically the entire population of the most rare pinniped in the US, the Hawaiian monk seal, depends on the islands of the NWHI for breeding and the surrounding reefs for sustenance. With a mere population of only about 1400 animals, Hawaiian monk seals remain one of the most critically endangered marine mammals living in U.S. waters. Ranging farther afield the Hawaiian Green Turtle grazes throughout the state but 90% of the entire population returns to French Frigate Shoals to breed on the beaches there.

The restoration, recovery, and enduring protection of these vulnerable species are some of the primary management objectives of the management agencies charged with the care of this area.

- Beth Flint (USFWS) and Rusty Brainard (NMFS)

John Brooks/NOAA

Atoll lagoon areas are important habitat for schools of dolphins.

The Hawaiian Monk Seal
(*Monachus schaunslandi*)

Background photo: Dave Johnson/USFWS

Algal Studies

A Large Number of New Species!

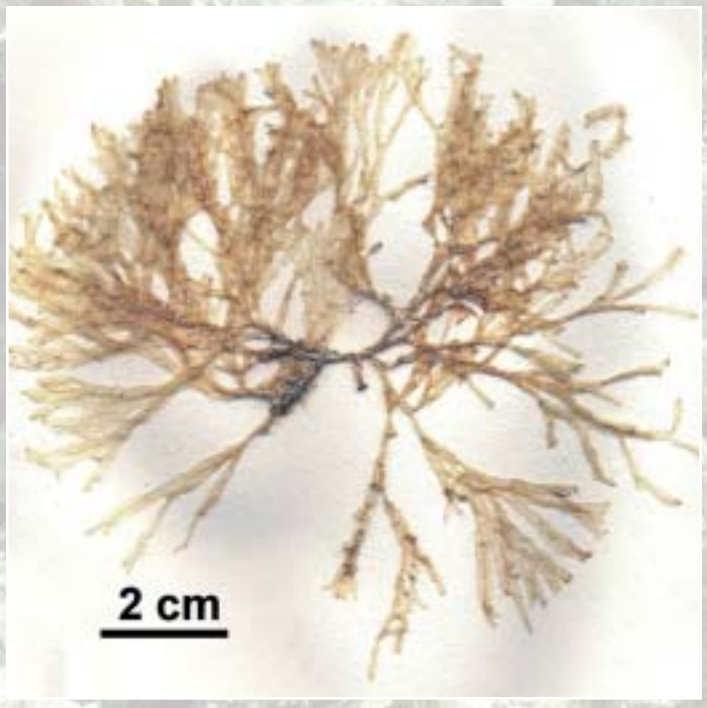
Unlike fish and coral biologists who can often identify their organisms in the field or by video transect, algal biologists require hours of laboratory time to properly identify and describe species. Many tropical reef algae are tiny, inhabiting algal "turf" communities that are rarely more than a couple of centimeters tall. In some locales, over 100 species of turf algae can occupy an area of only 10 square centimeters. Additionally, most large tropical algae require detailed microscopic study of reproductive structures and anatomy to confirm identities. Not surprisingly, work is slow, but the benefits are astounding! The results of the NOWRAMP expeditions have increased the number of known algal species from FFS by almost 1000%!!! Several species new to science (and possibly one genus) are being described, and species known only from other parts of the world are being found.

- Peter Vroom (UH Botany)

Jim Maragos/USFWS

French Frigate Shoals

Species of marine algae from the NWHI have been known since 1900, mainly because of a 1-month visit by a German scientist to Laysan Island, and subsequent short visits by the Coast Guard Cutter *Tanager* to several islands in the 1920's, including Laysan and Midway. Additional collections from various islands were tallied by Abbott in 1989, yielding 205 species for the entire NWHI. Of this number, more than half came from Midway Atoll. These numbers have increased by about 1.5 times in the last 11 years, and will jump again when NOWRAMP collections are fully identified.



Peter Vroom/UH Botany

New species of *Scinaia* (Rhodophyta) from French Frigate Shoals

Results of NOWRAMP Algal Analysis of French Frigate Shoals (FFS)

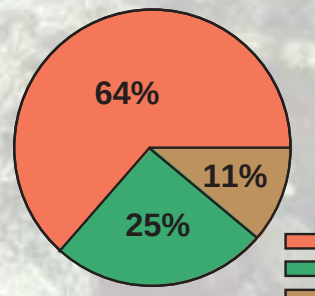
	Species new to science	Species new to Hawai'i	Species new to FFS	Species previously reported from FFS
Red Algae	4	0	70	6
Green Algae	0	2	28	2
Brown Algae	0	0	10	4
Total	4	2	108	12

Cal Hirai

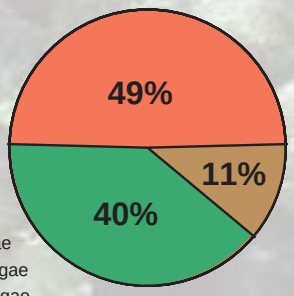
Marine algae from the French Frigate Shoals (FFS) are represented by three previous incidental collections, amounting to 15 species. Considering the hundreds of nooks and crannies among the broken coastlines of the shoals, this island group is in obvious need of attention. We are almost finished with algal identifications from the FFS, and can expect a final total of over 150 species. At this point, 120 previously described genera are recorded, and we expect 6-8 new species to be described. Although this is a respectable total (8 times more than what was known when we started!), what is more interesting is that the proportion of red algae to green and brown algae indicates that the flora of French Frigate Shoals reflects cooler water than the flora of Enewetak (northern Marshall Islands, 2,000 nautical miles to the southwest of FFS). Enewetak was reported to have 89 species of green, 24 of brown, and 109 species of red algae, a significantly different proportion than the total of 32 green, 13 brown, and 79 species of red algae from French Frigate Shoals identified thus far. Nonetheless, there are always more red algal species than green and brown algal species in the tropics, as has been documented by most islands in the Pacific. Currently, we have identified 112 new records for French Frigate Shoals (mostly red algae), and four new species, all red algae. When the NOWRAMP collections are completely identified, we will be able to substantially increase the number of new records and rewrite geographic species distributions, which will indicate more clearly the relationships of tropical and subtropical marine floras.

- Isabella Abbott (UH Botany)

Algal Division representation at French Frigate Shoals, NWHI



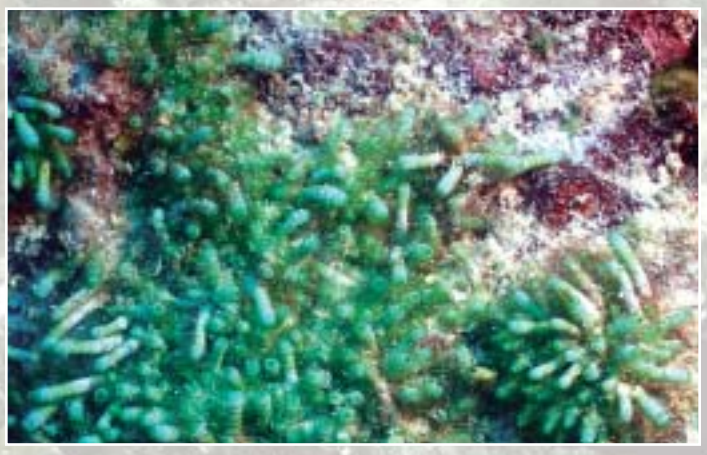
Algal Division representation at Enewetak Atoll, Marshall Islands



of which 8% of the combined species are endemic to Hawai'i

Jim Maragos/USFWS

Fields of turban algae *Turbinaria ornata* on the reef crest at Midway Atoll.



Jim Maragos/USFWS

Clumps of the green alga *Neomeris* at Maro Reef.

The Importance of Calcareous Algae: *Halimeda*

Extensive beds of the calcified green alga *Halimeda* are critical sand producers in many lagoonal areas on French Frigate Shoals. These algae encase themselves in calcium carbonate, the same substance used to build coral skeletons and giant clam shells. Core samples from atolls in the Pacific have found that many reef systems are built on layers of algal (not coral!) sand. Large sand patches composed almost exclusively of algal chips are a common sight throughout the NWHI, and stress the importance of algae in healthy tropical reef systems.

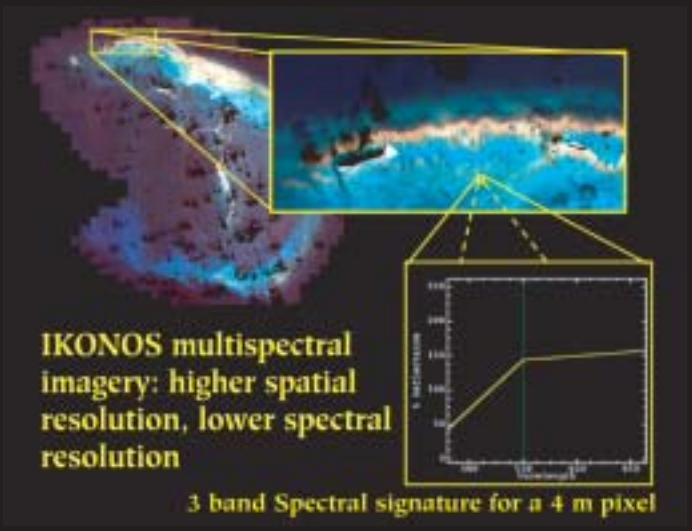
- Peter Vroom (UH Botany)

Linda Preskitt/UH Botany

Background photo: Linda Preskitt/UH Botany

The NWHI will be the first large-scale coral reef ecosystem to be mapped using IKONOS satellite imagery.

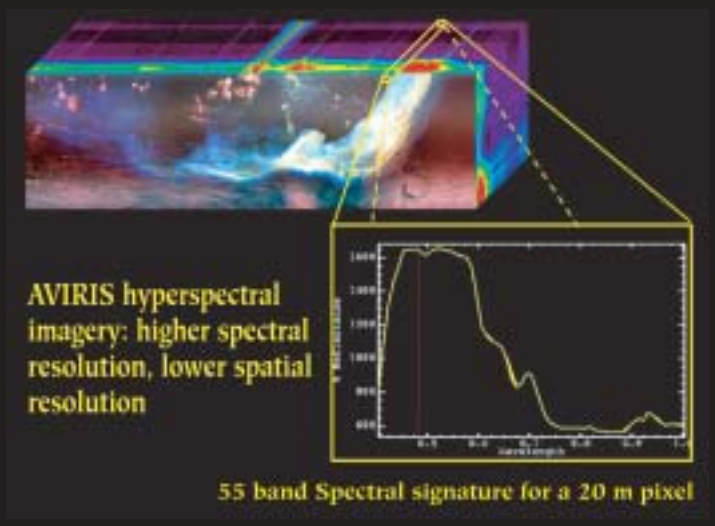
Conservation strategies for the NWHI require a comprehensive knowledge of marine habitats and the associated biological communities. The immense size, remoteness and isolation of NWHI coral reefs make remote sensing technology an essential tool to monitor and manage these ecosystems. Mapping the marine habitats is critical to understanding the distribution and relative abundance of benthic organisms and habitat types, and to detect changes in the ecosystem over time. Maps also contribute to management planning by identifying environmentally sensitive areas, and hotspots of biological diversity.



Daria Siciliano/UCSC, Rick Stumpf and Kris Holderied /NOS, from Space Imaging imagery

Coral reef remote sensing is a relatively new discipline. The NOWRAMP project took advantage of several types of remotely sensed data. We used two types of imagery to produce maps of the benthic communities, and in-situ measurements and groundtruthing information to understand the spectral characteristic of this unique ecosystem. The two types of imagery are: hyperspectral images, gathered by the airborne sensor AVIRIS (Airborne Visible Infra Red Spectrometer), operated by NASA's JPL; and multispectral images, gathered by the IKONOS satellite. Hyperspectral and multispectral remote sensing both rely on the electromagnetic energy reflected from surfaces. The difference lies in the number of spectral bands that capture the reflected electromagnetic energy. Hyperspectral imagery consists of readings of reflected energy in many (typically >50), narrow, contiguous spectral bands (i.e., wavelength intervals), so that for each pixel in the image a continuous spectrum of the underlying substrate is produced (above). This is a spectral signature, or a fingerprint that corresponds to the set of biological and physical constituents of the substrate being measured. Multispectral imagery, on the other hand, consists of readings of reflected energy in few (usually 3-7), broad, non-contiguous spectral bands (left). Because of an inherent trade-off between spatial and spectral resolution in the manufacture of the sensors, the coarser spectral resolution nonetheless allows for a higher spatial resolution, so that the pixels in the multispectral image are considerably smaller: 4 m for IKONOS versus 20 m in AVIRIS images.

By identifying a spectral signatures unique to a species of coral, or alga, or a physical substrate it is possible to use this fingerprint as input to a

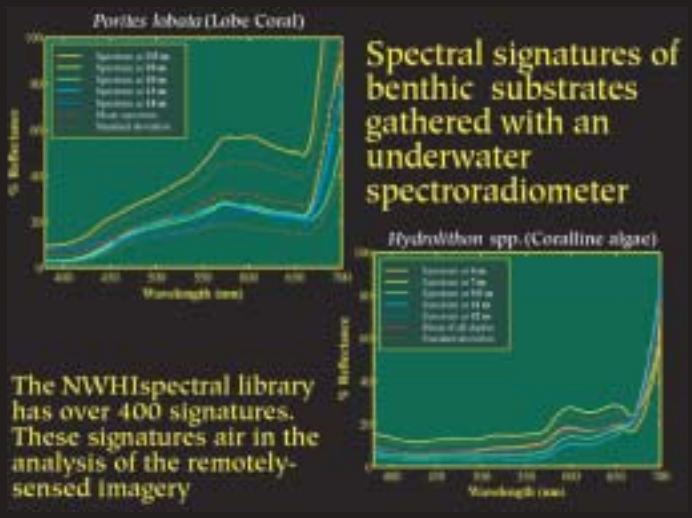


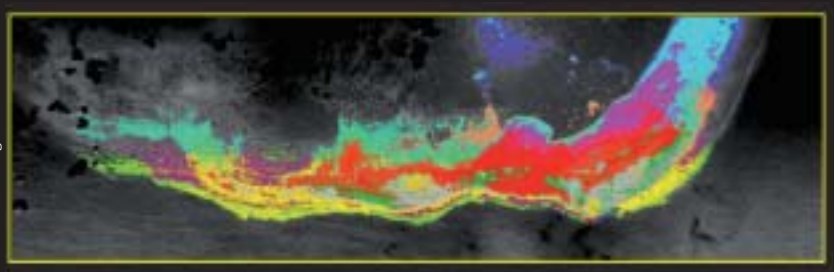
Daria Siciliano/UCSC, from JPL/NASA image

hyperspectral or multispectral image and have that substrate mapped throughout the image. Examples of spectral signatures from the NWHI are shown below. These are averages of many tens of readings acquired for a particular species of coral and coralline alga at the different depths shown. The average spectra across all depths with their standard deviation are also shown. The spectral library that has been gathered so far for the benthic communities in the NWHI comprises over 400 spectra. Many were obtained from organisms endemic to this ecosystem, so that their spectral fingerprint is likely to be unique, and has been documented for the first time during the NOWRAMP expedition.

The spectral library was gathered using a spectroradiometer encased in a waterproof housing, used in conjunction with a Spectralon panel for reference irradiance measurements. The instrument measures reflected energy in 512 spectral channels with bandwidths of 3 nm, covering the UV to the Near IR. The NOWRAMP expedition represents the first time that an untethered underwater spectroradiometer was used in a coral reef ecosystem, since the special underwater housing was custom-built for this purpose.

Once unique spectral signatures are identified, the spectral library is resampled to the spectral response of the imager, for example, 10 nm bands for AVIRIS and 70-80 nm bands for IKONOS. The spectra are again analyzed to search for unique patterns in the spectral geometry of the signatures. In order to be used as input to the hyperspectral and





Daria Siciliano/UCSC, from JPL/NASA image

South rim of French Frigate Atoll-AVIRIS hyperspectral image from supervised classification, field data used as imput to the analysis

- Live coral
- Dead coral and epiphytic algae
- Sand and rubble
- Rubble and epiphytic algae
- Coralline algal ridgea
- Fleshy algae
- Live coral
- Rubble
- Shallow sand

Jim Maragos/USFWS

NOWRAMP scientist Daria Siciliano collecting a hyperspectral signature.

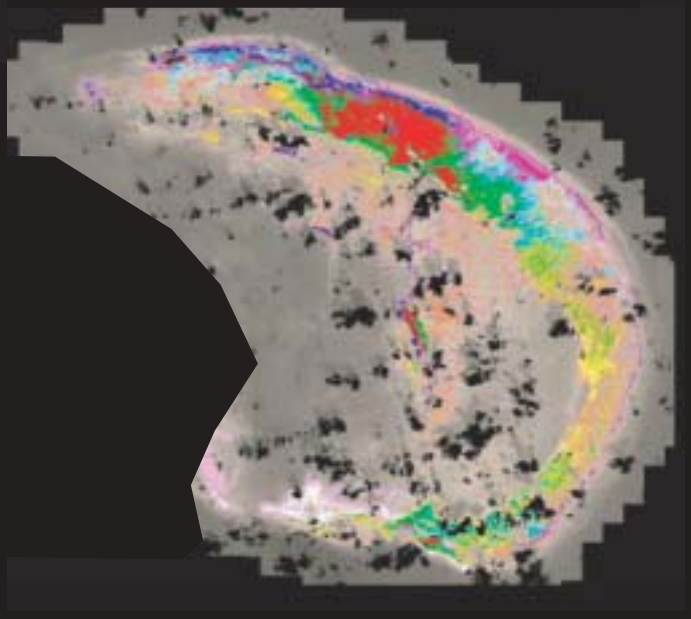
multispectral images, the spectral library needs to be run through an algorithm that models how the spectral signatures from the benthic communities might have been modified by the overlying water column. The effect of the water column on the light that travels to and from the ocean floor is in fact very complex, and continues to be the subject of intense research by optical and physical oceanographers.

The imagery was also processed and analyzed using several algorithms to produce benthic maps like those shown (above and right). An atmospheric correction algorithm was applied, and features in the image that were not of interest (for example, clouds and emergent sand islands) were masked. The images were then classified using supervised and unsupervised techniques, relying the former on field data gathered during the NOWRAMP expedition, the latter using the inherent spectral characteristics of the images.

These maps are then ground-truthed using information from the field, and their accuracy assessed. The resulting thematic maps are used for management and conservation purposes, often to identify networks of environmentally sensitive areas, biodiversity hotspots, and to detect changes in the ecosystem through the years.

- Daria Siciliano (UCSC)

IKONOS mosaic of French Frigate Shoals Atoll



Daria Siciliano/UCSC, Rick Stumpf and Kris Holderied /NOS, from Space Imaging imagery

In an unsupervised classification, an algorithm identifies clusters of pixels with similar spectral characteristics. These classes are then identified with field data from the Towboard team and the benthic teams.

Hyperspectral Fingerprints: The *Lyngbya* Files

The blue-green algae, *Lyngbya* sp., has now been found in dense quantities at the site of three shipwrecks in recent years. The first sighting was at Helen Reef off Palau where the shadow, or 'footprint', of the algae is large enough to be seen from aerial photos. The second sighting was at a shipwreck at Rose Atoll, located at the eastern end of the American Samoan island chain. The Rose Atoll shipwreck occurred in 1993 when a 250-ton ship broke up over the reef and spilled large quantities of fuel along the reef. The fuel killed nearly all the red coralline algae around the wreck site, allowing for a nearly immediate infestation by *Lyngbya* and other blue-green algae. *Lyngbya* is an opportunistic, invasive algae that establishes itself where disturbances like shipwrecks and diebacks occur along reefs. Although the algae is naturally occurring and not an alien species, its aggressive nature prevents the re-establishment of coralline algae and other algae species once it settles into an area. “Because of the way *Lyngbya* alters reef habitat, its presence reduces the quality and integrity of an ecosystem,” said Jim Maragos, USFWS coral biologist. Maragos has documented the relationship between this algae and iron on the reef from remnant pieces of shipwrecks from several areas in the Pacific. Studies show that the growth of *Lyngbya* is stimulated by such iron, which acts as a fertilizer; as such, the impacts to coral reef ecosystems from shipwrecks may be long-felt. Hyperspectral signatures for *Lyngbya* were collected at Pearl and Hermes and Kure Atoll near remnants of vessel wreckage. They can help track *Lyngbya* infestation from remote sensing imagery at shipwrecks in the NWHI, and assist in clean-up efforts.

Jim Maragos/USFWS

Fields of the blue-green alga *Lyngbya*, a possible indicator of iron enrichment from a nearby shipwreck (pictured) at Pearl and Hermes Atoll.

The Wide Range of Habitats

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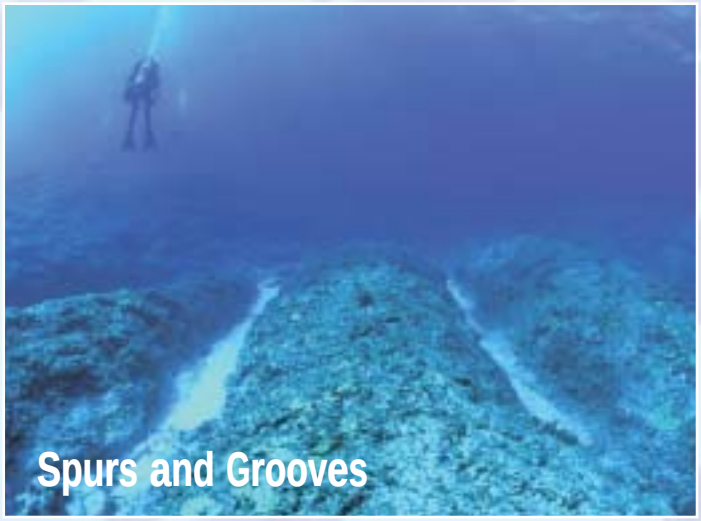

Jim Maragos/USFWS

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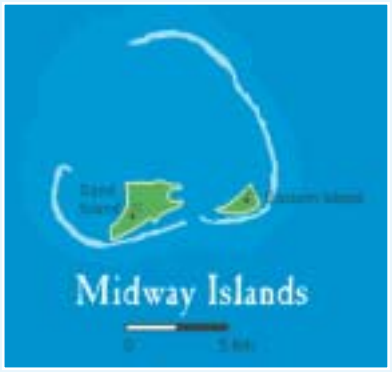
Jim Maragos/USFWS

CLASSIFICATION OF NWHI CORAL REEF HABITATS

SYSTEM	ZONE	GEOMORPHOLOGY	BOTTOM COVER
small basalt island	land/emergent	shallow flats	blocks
basalt sea stack	intertidal	bench	boulders
low coral island	reef crest	patch reef	cobbles
classical atoll	fore reef	linear reef	pebbles/gravels/rubble
open atoll	shelf/terrace	reticulated reef	sand
submerged bank/reef	deep escarpment	pinnacle/mound	mud/clay
	back reef	reef slope	basalt pavement
	lagoon slope	vertical wall	carbonate pavement
	lagoon floor	cave	crustose coraline algae
		hole	fleshy algae
		overhang	turf/mixed algae
		canyon	seagrass meadow
		trench	stony coral
		spurs-and-grooves	soft coral
		pass/channel	boring sea urchins
		secondary islet	boring clams
		artificial	sponges

Background photo: Jim Maragos/USFWS

Midway Atoll

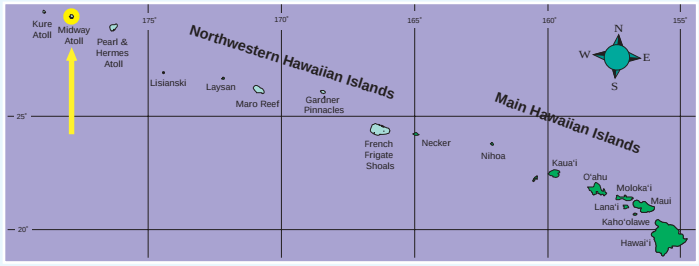


Midway Atoll is the second most northern atoll in the world, lying 60 nautical miles east southeast of Kure Atoll. Its land area (1.42 km^2) and reef area (223 km^2 to depths of 100 m) are larger than that of Kure. However, Midway was substantially degraded during the half century of the U.S. Navy's occupation of the atoll; reef areas were dredged and filled to enlarge land areas for airfields and excavate reef areas for the deep draft harbor, navigation channels, and military fortifications and facilities. The World War II Battle of Midway resulted in intensive bombing of the islands and reefs. More recently, alien species, airplane-bird collisions, unexploded ordnance, fuel spills, sewage discharge, recreational fishing, and chemical contaminants further degraded reef and land habitats. At times, up to 6,000 servicemen and dependents inhabited the atoll. More recently, the U.S. Fish and Wildlife Service (USFWS) and Navy have cooperated in habitat restoration and resource conservation. Since 1996, the USFWS has jurisdiction over Midway Atoll National Wildlife Refuge.

Rob Shallenberger/USFWS

NOWRAMP surveys in 2000 at Midway were limited to four REA reef sites due to time constraints, and the lack of complete and extensive REAs make it difficult to fully characterize the reef habitats and species at the atoll. To date only 16 species of stony coral have been reported although there are probably more. The blue encrusting coral *Montipora turgescens* is common in the shallow lagoon and dominates back reef habitats. Although not emphasized during NOWRAMP surveys, reef algal populations at Midway have been previously collected and described by Drs. Karla McDermid and Isabella Abbott. Invertebrate abundance was greater in areas farther away from Sand Island. The back and fore reef areas had a moderate level of abundance in mobile species and low levels of encrusting

USFWS



species. An unusually large amount of colorful Christmas tree worms *(Spirobranchus sp.)* were especially numerous on the reefs.

Common habitats on ocean-facing reef slopes include wave-scoured spur-and-grooves full of holes and overhangs, and rubble and sand filled flats and channels. Live coral cover is low, although pink encrusting coralline algae are abundant. Dredged areas, seagrass meadows, and patch reefs are common inside the lagoon. Rock-boring urchins *(Echinometra, Echinostrephus)*, calcareous green algae *(Halimeda)*, and the brown turban algae *(Turbinaria)* are also abundant.

Midway was one of only a few of the NWHI where the Hawaiian grouper *(hapu'upu'u)* was reported, but jacks *(ulua)* were less common relative to other NWHI atolls. Large schools of goatfish and bluestripe snapper *(ta'ape)* were observed. The latter is an alien species intentionally introduced to the main islands several decades ago and has now spread as far as Midway in the Hawaiian Archipelago. Boarfish and knifejaws were seen under many of the overhangs, and these fish are rarely seen elsewhere in the Hawaiian Archipelago except at Kure and Pearl and Hermes. Large goatfish *(kumu)* were often found sitting motionless in small depressions. Large numbers of cleaner wrasses and juvenile cleaners were seen in lagoon areas. In general, lagoon areas seemed to support an abundance of juvenile fish and resident pods of dolphins.

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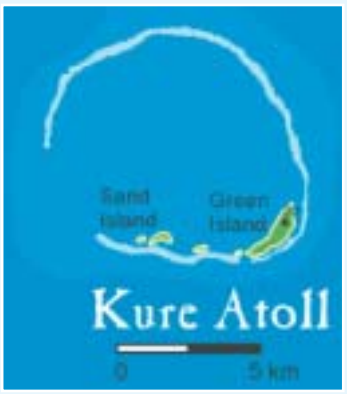
The shallow reefs at Midway have a history of fishing pressure during the Navy years and more recently due to catch and release sport fishing. Perhaps as a result, the reef fish populations at Midway are depressed relative to those observed at other locations in the NWHI. The overall number of *ulua* observed over a 10 year period was lower at Midway compared to French Frigate Shoals. The inception of the catch and release fishery for *ulua* at Midway since 1996 may have further reduced the numbers of this species there.

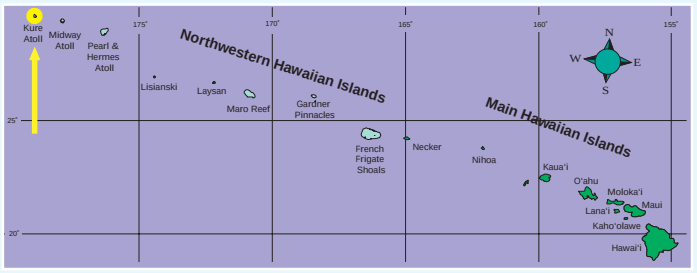
The only concentration of marine alien species found anywhere in the NWHI have been reported from Midway and are probably are related to its history of vessel traffic and harbor operations. Controlling the spread of marine alien species to other NWHI is a major concern, especially from ships visiting the NWHI. Results from contaminant analysis of lagoonal sediments collected at Midway Atoll has detected "high" levels of PCBs, DDT, polycyclic aromatic hydrocarbons (PAHs), arsenic, and above-median concentrations of cadmium, lead and tin (see page 44).

Jim Maragos/USFWS

Kure Atoll

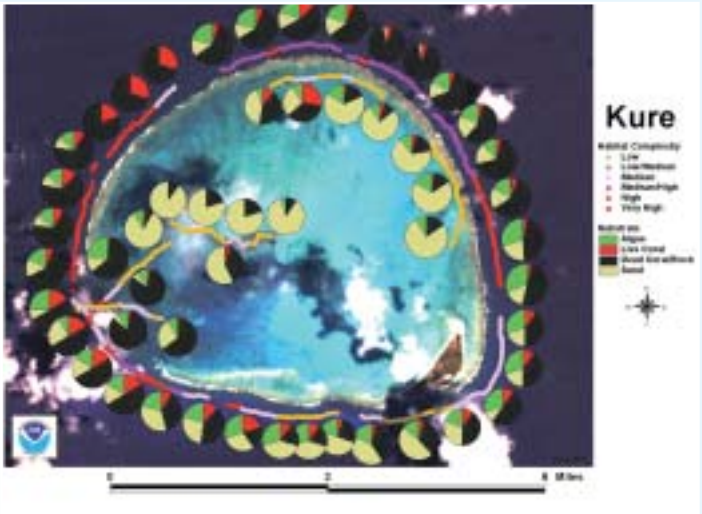


At Latitude 28.5ºN, and Longitude 178ºW, Kure has the distinction of being the northernmost atoll in the world, and lies at the northwestern end of the Hawaiian chain, about 1,240 nautical miles northwest of Honolulu. The atoll is small with land area totaling 0.86 km^2 and reef areas to 100m totaling 167 km^2. Pre-NOWRAMP scientific surveys were not as extensive and reported only 13 coral species and sparse coral cover, suggesting the atoll is barely surviving near sea level. However, NOWRAMP coral scientists have doubled observed number of species and report high coral cover in some of the back reef and lagoon areas. Although coral cover is very low on ocean-facing reefs, coralline algae are abundant and the reefs appear healthy. Large schools of dolphins, jacks, sharks, knifejaws, goatfish and chub inhabit the lagoon and inshore reefs, and the native grouper *hapu'upu'u* is conspicuous. The turquoise and transparent waters of the mostly shallow lagoon add to the beauty of the atoll, and sea turtles, monk seals and seabirds are especially abundant near Green Island at the southeast corner of the atoll. The U.S. Coast Guard operated a long-range navigation (LORAN) station at Kure for several decades.



The habitats of Kure provide an unexpected diversity of corals and macroinvertebrates. Kure as the northernmost atoll, was not expected to have the abundance and diversity of invertebrate species reported at more southern habitats in the NWHI. The variety of corals, echinoderms, crustacea, and mollusks recorded at Kure was therefore surprising. Large massive colonies of *Porites compressa*, *Porites evermanni*, *Pavona duerdeni*, *Montipora capitata*, and *Montipora turgescens* were found at many sites within the lagoon. Diversity of coral species was unexpectedly high (27 stony coral species) and small recruits were observed in a number of areas. Towboard and REA surveys revealed that the highest concentrations of crown-of-thorns seastars in the NWHI were observed along the outer barrier reefs of Kure's eastern shore. Many were observed feeding on *Pocillopora* corals. A high level of encrusting species was associated with the dead coral heads in some lagoon areas. In the lagoon much of the *P. compressa* had the green algae *Microdictyon* growing between the branches. A large number of unattached green macroalgae, *Codium* sp. was found both inside and outside the lagoon, and specimens were in good condition.

Rob Shallenberger/USFWS



Rusty Brainard, Stephani Holzwarth and Michael Parke/NMFS from NASA image

A Place Where Giant Groupers Abound on Shallow Reefs

Dave Gulko/DLNR

Due to over-fishing, it has become extremely uncommon to see giant groupers on reefs anywhere. The endemic Hawaiian grouper, *Epinephelus quernus (hapu'upu'u)*, is rarely found in the MHI, and then, only in deep waters where it is actively fished for food. At Kure and Midway Atolls, these apex predators were found in relatively shallow waters on the outer reef slopes. In fact, these huge reef fish were so common at Kure, they would often follow the researchers around like enormous, curious puppy dogs; staying right behind the diver until they reached the edge of their territories, at which point the neighboring grouper would take up the behavior. As such, Kure may represent one of the last places on the planet where such large fish are extremely common on shallow reefs; suggesting that Kure may truly represent an ecological portrait of what coral reefs were like prior to the impacts of the modern world and further highlighting the need for its maximum protection.

Jim Maragos/USFWS

Knifejaws (above), dragon eels and the masked angelfish *(Geniacanthus personatus)* were seen both at Kure and Midway. Outside reef slopes were characterized by large numbers of jacks, Galapagos sharks, numerous Hawaiian grouper and masked angelfish (below right) holding territories. On one dive we encountered over 30 Galapagos sharks in a single reef pass. In some areas, numerous small schools of planktivorous fish were observed; some outside areas had large numbers of Hawaiian lionfish and turkeyfish. Nocturnal planktivores such as cardinalfish (above right) and *'aweoweo*, which rarely are seen in any numbers during the day in the MHI, were extremely numerous and out in the open at Kure, raising interesting questions regarding traditional natural history views of these animals. Overall, Kure created more questions than it answered in regards to popular views regarding coral reef fish ecology.

Habitats encountered included outside reef slopes, wave-scoured spur and groove habitats, occasional overhangs and holes, passes, carbonate platforms, and patch reef habitats with lots of rubble, surrounded by rubble and sand flats. Common bottom dwellers included branching *Pocillopora* corals, rock-boring sea urchins and macroalgae. In some lagoon areas, large numbers of cleaner wrasses and their juveniles were observed. In general, the lagoon supported lots of juvenile fish. Numerous large lobsters *(Panulirus marginatus)* were also observed (below, center).

NOWRAMP observations of the wreckage of the 1998 grounded fishing vessel, *Paradise Queen II* off the southeast side of the atoll were limited to shallow waters directly adjacent to shore. A towboard survey along the deeper waters of the wreck site did not reveal any evidence of the wreck. The largest piece of the broken hull continues to sit atop the coral reef crest approximately 75 yards offshore. The vessel's wheelhouse sits on the sand about a quarter of a mile to the southwest. Lobster traps (about 500) stacked near the vegetation line still remain, a result of trustee overseen salvage efforts that removed them from the reef area immediately after the incident. The plastic lobster traps were disassembled, stacked, with lead weights removed and stockpiled in containers to await removal from Green Island.

Cal Hirai

Dave Gulko/DLNR

Once the vessel broke apart, insulation material and miscellaneous cargo items like life jackets were scattered across the beach. Divers also noted that the remanants of the main trap/haul line from the vessel shredded into wisps of shattered fiber which were lodged in numerous places.

The dislodged wheelhouse of the *Paradise Queen II* (now on the beach) is now surrounded by jumbles of fishing and cargo nets (see page 44). Within fifty feet of shore were several floating masses of nets, rope and other debris. These were later removed by the NOWRAMP land team.

"In the brief time we had here on island during this trip, we were only able to remove a fraction of the nets we saw caught in the nearshore reefs," said Nalu Yen (DLNR). "We are taking note of the locations of the other nets and will try to remove them during our next visit to the island."

Yen pointed out that floating and tangled nets weren't the only marine debris problems on the island; piles of debris were found everywhere along the beach and posed continuing hazards for the seabirds, monk seals, and turtles which utilize the island to rest and breed. Often these animals entangle themselves in the debris, impale themselves on it, or even try to eat it and feed it to their young, mistaking small plastic objects for food.

The good news is that in 2001, the NMFS/NOS marine debris program removed 51,735 pounds of derelict fishing gear from the coral reefs at Kure. Results from contaminant analysis of lagoon sediments collected has shown that one site had "high" concentrations of copper and nickel (see page 44).

Jim Maragos/USFWS

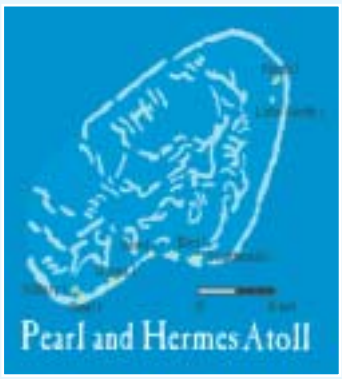
Ancient Massive Corals ??

The massive coral colonies found in Kure's and other nearby NWHI atoll lagoons are surviving amongst some of the northernmost limits for stony corals. Colder waters means these species are thought to grow at slower growth rates (especially during winter months) compared to the same species found farther south in Hawai'i or elsewhere in the Pacific. The slower growth rate, combined with their massive size (some single colonies were measured to be almost 20 feet tall!), would suggest that these colonies may be extremely ancient living organisms. Earlier investigators believed that the corals at Kure grew very slowly, but these large colonies were not measured. If this can be documented, these possible marine equivalents of Joshua Trees represent not only an extremely important biological and ecological resource, but also a priceless living historical resource. On-going cooperative efforts between UCSC (lead investigator Daria Siciliano) DLNR and USFWS, will use coring and dating techniques to more accurately determine the growth rate and age of these massive colonies in order to assist in their proper management and to provide more information regarding the slow recovery rates of these important national treasures.

Jim Maragos/USFWS

Dave Gulko/DLNR

Pearl and Hermes Atoll



Pearl and Hermes Atoll lies about 90 nautical miles east southeast of Midway Atoll. Although its land area ranks fifth (0.36 km^2), there are numerous small islets along the southern half of the atoll, and its reef area ranks second (1,166 km^2 to depths of 100 m) among the 6 atolls in the NWHI. The atoll is important for seabird nesting, endangered Hawaiian monk seal pups, and mating populations of spinner dolphins that regularly visit the atoll's lagoon. Threatened green turtles were numerous and large, aggressive populations of the giant trevally (ulua aukea) were encountered by NOWRAMP teams at the atoll.

The NOWRAMP teams encountered an amazing variety of coral reef habitats and species at Pearl and Hermes Atoll, including 33 species of stony corals. Mushroom corals were diverse *(Cycloseris tenuis, C. vaughani, Fungia granulosa, and F. scutaria)* and common at many of the survey sites, sometimes in large numbers.

Jim Maragos/USFWS

Due to high wave activity during the 2000 NOWRAMP expedition, outside reefs were extensively surveyed only with towboards while only the eastern, western and southern portions of the atoll were surveyed with REA teams. Carbonate pavement and eroded spur and groove habitat dominated ocean-facing reefs, mostly with relatively low live coral cover but high populations of boring urchins *(Echinometra, Echinostrephus)*. Holes, overhangs, mounds of coral rubble, and shallow sand depressions were also common. The northwestern facing reefs exposed to the full force of the high winter surf were observed to have amazingly deep vertical canyons. These canyons and overhangs frequently dropped to depths greater than 100 feet. While dominated by fleshy algae cover, the southern reef slope was observed to have an surprisingly high abundance and diversity of reef fish associated with frequent holes and shallow overhangs. The east and south reef slopes also had the second highest abundance of crown-of-thorns seastars in the NWHI and the associated predation on numerous Pocillopora corals.

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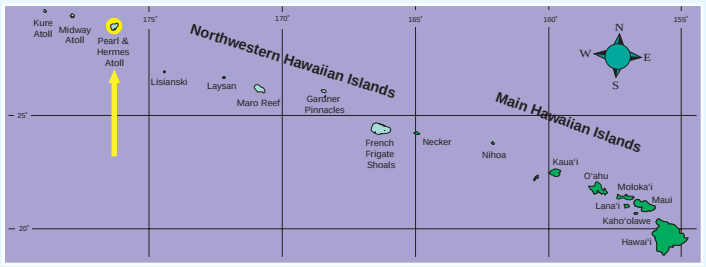
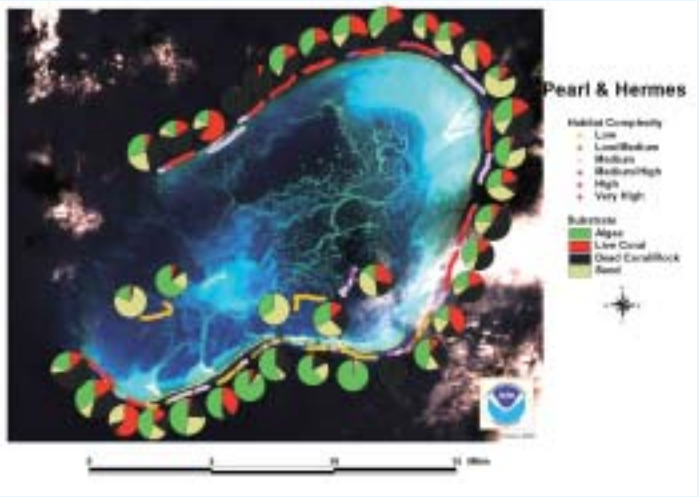


Reef habitats abundant and variable at Pearl and Hermes given its large size, allowing greater abundance and diversity of the large invertebrates that were found in its lagoon. Unique and shallow doughnut-shaped reefs surrounding deep lagoon holes create isolated enclaves of organisms within the larger lagoon environment. Numerous lobsters and moon snail egg-cases were observed, and ten new sponge species for Hawai'i were collected from these habitats. Elsewhere in the lagoon ark shells were numerous on elevated reefs, and seagrass meadows, rubble flats and sand flats were common. Flourishing finger coral gardens *(Porites compressa)* were concentrated on patch reefs in the north central lagoon. Reticulated reefs (right) filled much of the southern, central and eastern lagoon, with a base mostly of dead *P. compressa* or rubble cemented together by calcareous algae. Southern back reef habitats and northwestern ocean and open lagoon pinnacles were covered with several branching species of *Pocillopora* corals. Large patches of the green net alga, *Microdictyon setchellianum*, and the red alga, *Stypopodium hawaiiensis* dominated bottom habitats in the lagoon. These species provide cover and food for juvenile fish and small invertebrates such as crustaceans, while providing substrate for turf algae and invertebrates such as sponges and hydroids.

© Monte Costa

On June 5, 2000 the long-line fishing vessel *Swordman I* ran aground on the eastern side of Pearl and Hermes Atoll. At the time of the grounding, a number of seabird species were fledging and monk seal pups were present. The annual coral spawning for some of the species present at this atoll was thought to take place during the week following the grounding. In response to the imminent danger to the environment posed by the grounded vessel, the U.S. Coast Guard, in cooperation with government management agencies, sponsored the removal of the vessel off the reef at a cost of about $1.5 million in July 2000.



Rusty Brainard, Stephani Holzwarth and Michael Parke /NMFS from NASA imagery

Lobsters, lobsters everywhere???

Jim Maragos/USFWS

NOWRAMP team found what may be the remnants of a lobster trap in the shallow southeastern lagoon of Pearl and Hermes.

Lobsters are thought to be common inhabitants of the shallow-water reefs in the NWHI. In contrast, the NOWRAMP benthic REA teams reported few lobsters anywhere except in the lagoon at Kure Atoll. At other atolls and islands one or two lobsters were observed on shallow reefs, hiding in crevices and under ledges at many of the expedition's survey sites. While these observations were interesting, NOWRAMP sampling constraints limit their interpretation. Because many species of lobsters in the NWHI are more common in deep reef areas, which were not sampled as part of the NOWRAMP program, their status cannot be adequately assessed using REA data.

Dave Gulko/DLNR

Reef Fish Galore!

Jim Maragos/USFWS

A large variety of uncommon reef fishes were reported on the ocean reefs of the atoll, including saber squirrelfish within a number of the larger holes along with large eels, numerous Galapagos sharks, sandbar sharks and big jacks (*ulua*). Numerous Anthias were seen in shallow water out in the open. Also spotted were the Japanese angelfish (*Centropyge interrupta*), masked angelfish (*Genicanthus personatus*), bandit angelfish (*Desmoholacanthus arcuatus*), Thompson's anthias, and milletseed butterflyfishes. Large numbers of plankton feeding fish were observed. Both barred and spotted knifejaws (*Oplegnathus fasciatus* and *O. punctatus*) were typically found. On one survey, the dive team was surrounded by large numbers of *ulua* reaching a maximum of over 300 individuals. One moderate sized tiger shark was observed during a towboard survey on the north outside reef. Lagoon areas supported large groups of goatfish, hundreds of juvenile *aweoweo* in the open on the outside of some patch reefs, while large schools of juvenile parrotfish (*uhu*) were seen swimming around the inside edges of reef holes in some of the larger patch reefs.

Dave Gulko/DLNR

What Happened to the Pearl Oysters?

At one time, the black-lipped pearl oysters were so common at Pearl and Hermes Atoll that they formed the basis of an entire industry: their shells were used to make buttons. Unfortunately, through short sightedness and greed, these large, magnificent creatures were over-harvested and nearly eliminated from Hawai'i within just a few years. Concerned about the fishery and whether the population could sustain such heavy harvesting, the Hawaiian Territorial Government, under the advice of the U.S. Bureau of Commercial Fisheries, passed an Act in May 1929 making it unlawful to take pearl oysters in Hawaiian waters. The Territorial Government also appropriated money to commission an expedition in 1930 to search for the oyster beds. Only 480 oysters were found. Unfortunately, it was too late; in 1969, only one oyster was found at Pearl and Hermes. This species has never recovered and continues to be very rare in the main Hawaiian Islands. The NOWRAMP expedition found only a handful of black-lipped pearl oysters, predominately at Pearl and Hermes Reef, but they were rare and smaller than those recorded from the early 1900s, illustrating not only the long-term damage that humans can do to a coral reef species if they are not protected and managed, but how difficult it is for a coral reef to recover from over-harvesting, even with 70 years of full protection.

- Ralph DeFelice, Lu Eldredge, Scott Godwin, (Bishop Museum) and Dwayne Minton (UH)

Cal Hirai

Jim Maragos/USFWS

Note: Pearl oysters are fully protected under Hawaii State law (HAR 13-83-1) and should never be handled except for authorized purposes.

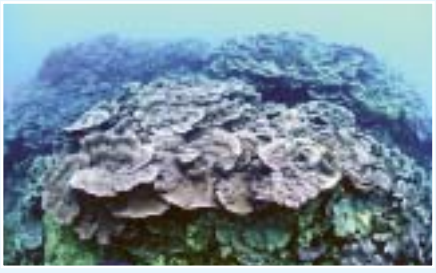
Lisianski Island & Neva Shoal

Lisianski Island, together with adjoining Neva Shoal, consists of an open atoll ecosystem located 150 nautical miles southeast of Pearl and Hermes Atoll. The island is large (1.46 km^2), and coral reef habitats are extensive (979 km^2), ranking third in size among the 6 atolls of the NWHI. During NOWRAMP 2000, only the *Townsend Cromwell* with its single REA team surveyed Lisianski. Nevertheless, the towboard team succeeded in surveying much of the extensive reef system and characterizing the distribution of bottom habitats, although the number of REA sites was inadequate to characterize the biodiversity of the reef life to the same degree as at others of the larger NWHI. The October

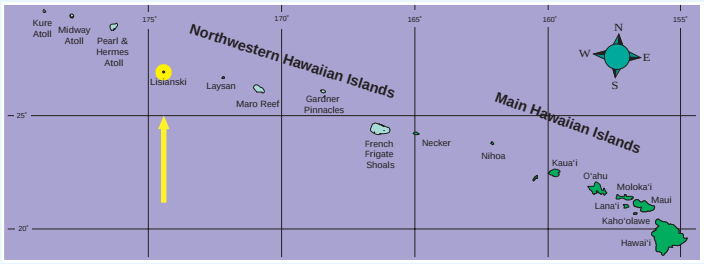
Jim Maragos/USFWS

2001 expedition allowed 4 additional REA sites to be surveyed following the earlier NOWRAMP procedures, and more detailed observations on coral diversity to be collected. During this same expedition, a moderate-sized wreck was found in the interior of Neva Shoal with the bow protruding about 2 m into the air from a water depth of over 10 m. The details of this wreck have not yet been determined.

Lisianski is a low coral island mostly encircled with a beautiful white sand beach and covered with native beach vegetation. Large numbers of Hawaiian monk seals frequently visit the island, and green turtles are also commonly seen on the beaches. Large populations of seabirds seasonally nest and migratory shorebirds visit the island. Most of the shallow reefs lie within the broad oval-shaped Neva Shoal to the south of the island and consist of a radial pattern of elongated ridges and troughs generally oriented in a north- and south axis. Despite lacking a perimeter reef, the system of linear and reticulated reefs afford some protection from the prevailing northeast trade wind swells and large winter swell from the north and northwestern Pacific. Turbidity was high on the reefs during the 2001 surveys; periods of wind and wave turbulence, and the lack of an intact perimeter reef, may allow fine sediments to be easily and constantly re-suspended. Despite this, live coral cover is generally very high on the southern eastern and northeastern outer reefs.



Jim Maragos/USFWS



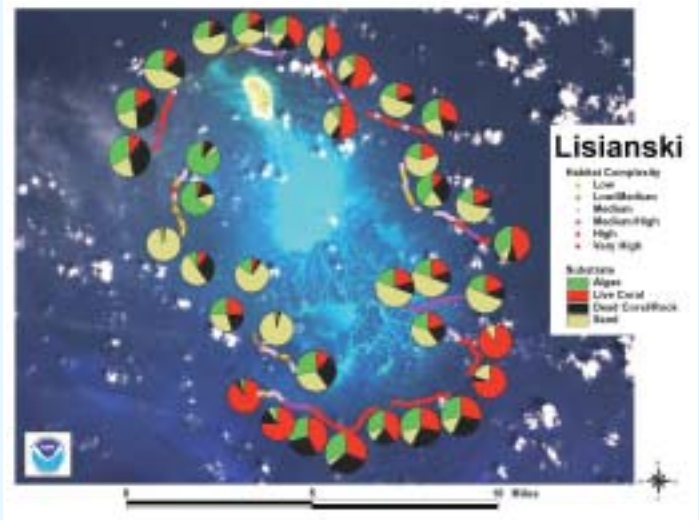
Towboard divers described the eastern reefs of Neva Shoal as "coral gardens" and among the most scenic areas observed in their 300 kilometers of habitat coverage.

© Monte Costa

A total of 24 species of stony corals have now been reported from Lisianski-Neva Shoal. These numbers are generally lower than those reported from the other atolls, probably the result of inadequate survey coverage. Nevertheless, coral cover was high especially along the deeper offshore sides of elevated reefs and on solid substrate patches in the depressions between the shallow linear and reticulated reefs. Massive coral heads of *Porites lobata* and *P. evermanni* were dominant at most of the 12 REA sites, and finger coral heads of *P. compressa* were also abundant. Elsewhere, sand and rubble patches were common and coral cover lower in progressively deeper and more exposed waters. The tops of the shallowest reefs nearly awash at low tide were covered with encrusting pink coralline algae. Reef habitats closer to the island were shallower and dominated by sand depressions and elevated mounds of the encrusting corals *Montipora turgescens* and *M. capitata*, reminiscent of the patterns observed at shallow protected reefs at Midway and Kure. Various forms of fleshy algae became progressively more abundant closer to shore, and overgrew corals and other hard surfaces at depths less than 2 to 3 m. It may be that the substantial guano deposits on the nearby island are dissolving and releasing nutrients in inshore waters, and stimulating the prolific growths of algae (see page 33 box).

Jim Maragos/USFWS

Monk seals accompanied divers at several of the inshore sites, and jacks and sharks were especially numerous.



Rusty Brainard, Stephani Holzwarth and Michael Parke /NMFS from NASA imagery

Laysan Island

Laysan is an isolated coral island with a large interior hypersaline lake, approximately 120 nautical miles east of Lisianski. Laysan's land area (4.11 km^2) is the largest, and its reef area (57 km^2 to depths of 100 m) the smallest of those in the NWHI. Most coral reefs at Laysan are in deeper waters with the only shallow reef an unusual embayment and channel off the southwest side of the island. Deeper reef habitats were mostly robust spur-and-grooves around most of the island and a heavily eroded northern section with numerous caves, overhangs and large holes on a sloping reef with small sand channels. The base of these reefs and the spur-and-grooves ended in broad sand flats with numerous small overhangs and holes. Common invertebrates included rock-boring sea urchins and encrusting pink coralline algae dominating all shallow wave-washed habitats. Laysan appears to be the northern limit for several species of Hawaiian surgeonfish. Large schools of convict tangs foraged in the embayment reef and channel.

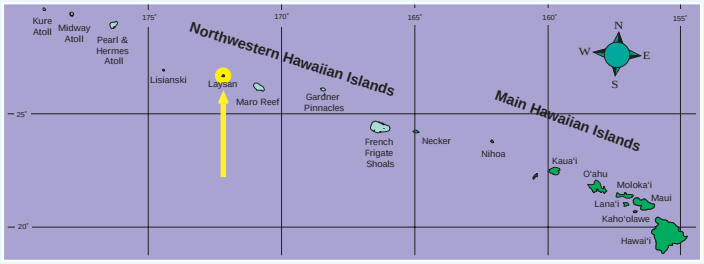
Twenty-seven species of stony coral are reported at Laysan, a high number for such a small reef. The embayment affords protection to corals with some very large massive and encrusting (*Porites, Pavona*) corals present on the sandy floor of the small sub-lagoon.

Jim Maragos/USFWS

Several species of *Pocillopora* branching corals are common, and a rare species of *Acropora* was also reported. Towboard surveys were conducted around the entire island in depths between 5 and 20 m. Likewise, REA surveys were conducted on the outside reefs on each side of the island. The outside reefs were only surveyed on the western and southern portions of Laysan supporting relatively low live coral cover at the depths surveyed. Although algal biomass within the sub-lagoon area is small, there is still a diverse community of macro- and turf algal species.

Terrestrially, Laysan is described by many as the “crown jewel” of the NWHI, Laysan was once the target of exploitation and degradation. The island's relatively easy access and volume of seabirds attracted guano traders and feather poachers at the turn of the 20th century. In just 20 years, the poachers killed over 350,000 seabirds including albatross, frigatebirds and terns. The camps of guano traders mined hundreds of thousands of tons of guano and their activities dramatically altered the island's ecosystems. During this period, rabbits and pigs were introduced onto the island. Given the abundance of vegetation on the island and the ready-made burrows already dug by

'Aulani Wilhelm/DLNR



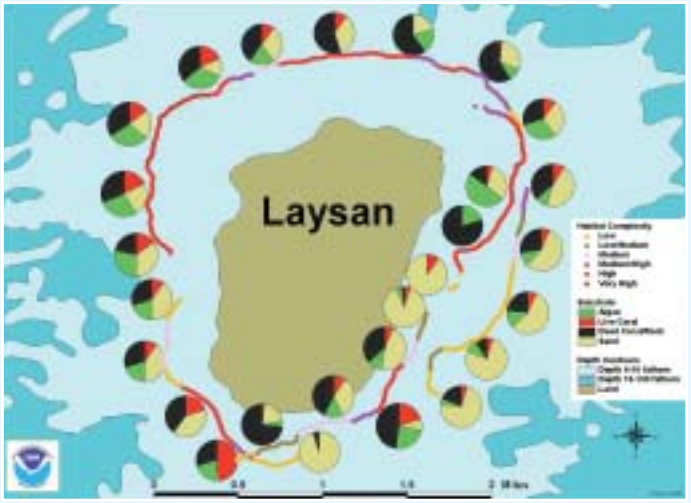
seabirds, the rabbit population exploded. In 30 years, the impact of guano mining, feather poaching, and rabbits caused the Laysan albatross population to plummeted from an estimated one million in 1891 to about 30,000 in 1923. Several land birds endemic to Laysan went extinct including the Laysan honeycreeper and millerbird. Luckily, the island's two remaining endemic land birds, the Laysan finch and the Laysan duck survived. Over the past decade, the USFWS has removed alien plants and restored native vegetation to the island. By 1998, there were approximately 8,000 finches found on the island. In 2000, nearly 400 ducks were recorded, another indication that the island is on the road to recovery.

USFWS

The Laysan Duck, an endangered species, now relies entirely on Laysan's lake for survival. Fossil bones from Mokapu (O‘ahu) indicate that the Laysan Duck once had a much wider distribution in throughout the Hawaiian Archipelago.

© Monte Costa

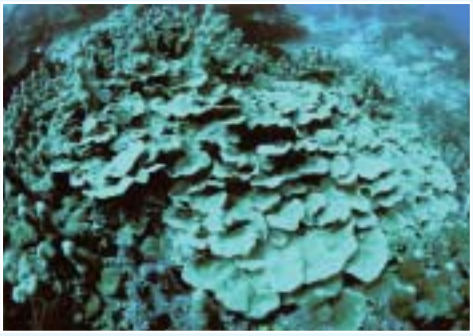
Two University of Hawai‘i (UH) microbiologists joined the NOWRAMP expedition to collect water, sediment and substrate samples from the large hypersaline lake in the middle of Laysan Island. The lake has a high salt content, two and a half times that of seawater. The samples will be chemically analyzed to determine how the Laysan lake differs from other lakes. The microbiologists will also cultivate bacteria from the lake in the hopes of finding new bacteria species that may yield useful enzymes and antibiotics for pharmaceutical, chemical, or industrial use.



Rusty Brainard, Stephani Holzwarth and Michael Parke/NMFS

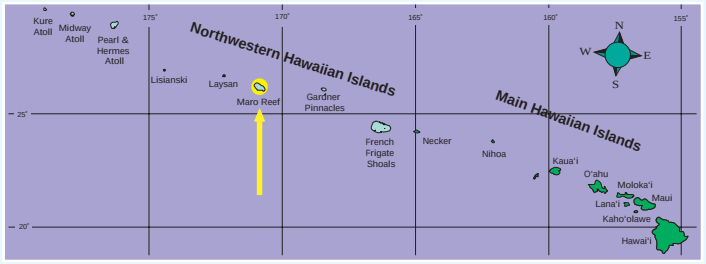
Maro Reef

Maro Reef, the largest coral reef in the NWHI (1,508 km^2 to depths of 100 m), is located about 60 nautical miles east of Laysan Island. Maro stands out as an open atoll that lacks any emergent land, except for a few large coral blocks awash on the shallow reef crest at low tide. The interior perimeter reef is incomplete with many large gaps that expose some portions of the lagoon area to wave action and re-suspension of fine sediments, subjecting most shallow reefs to turbid water during trade wind conditions or the approach of large swells from the north during the winter. Especially dramatic is the lack of an exterior perimeter reef with linear reefs radiating out from the lagoon in all directions like the spokes of a wheel.



Jim Maragos/USFWS

Maro Reef remains largely enigmatic because of its huge size, unusual structure, difficult access, and lack of adequate survey sites prior to NOWRAMP surveys. According to invertebrate biologist Dwayne Minton, "Maro is a very strange place. When I dove with the *Townsend Cromwell* on the eastern side of the Reef we saw pinnacles without much coral, only slimy algal 'fuzz'. The water was silty and the pinnacles were covered with lots of bivalves like ark shells, rock and spiny oysters, which bored themselves into the pinnacles. We saw sharks every dive and the water was usually murky. We were always looking over our shoulders." Unlike the other atolls, biologists found few sea urchins at Maro. Such a lack of urchins may explain the amount of algal "fuzz", and in turn, may explain the lack of coral cover in some areas. In contrast, the *Rapture* REA teams reported extremely high coral cover off the west side of Maro.



"My first dive at Maro Reef was the best dive I've ever had in the Hawaiian Islands," said coral researcher Jim Maragos. "I was very surprised by the abundance and diversity of coral, and even more surprised because we had heard it was such an inhospitable place. Instead, we found wonderful coral." Including additional 2001 REAs, researchers have now reported 37 stony coral species from Maro and coral cover ranging from zero to 95% depending on location. "There was more reef diversity in one place at Maro than we've saw on our 12 dives at Pearl and Hermes Atoll combined," said Maragos. In addition, coral cover at some of the Maro sites surveyed exceeded most other places on this expedition.

Maro Reef may still be an atoll surviving on the edge. "Because the reefs are fairly narrow and are not consolidated, the reefs could be on the verge of drowning," said Maragos. "It is a contradiction. On one hand, we found lots of healthy reefs. But because they aren't connected together and the reefs aren't very thick, they remain vulnerable to storm surges and waves." For reef fish biologist Bill Walsh, "at the sites I dove, there was an incredible diversity in fish and coral abundance."

Maro Reef is an extremely complex and large reef area, with many hazards to navigation, making exploration of the place challenging. Little information is available about the atoll and it is a dangerous place to work at. The nautical charts lack detail and accuracy and most ships avoid the area.

Some of the NWHI reef ecosystems, particularly Maro Reef and Lisianski/Neva Shoals, have unique geo-morphologies that have not reported elsewhere.

Jim Maragos/USFWS

The Importance of Crustose Coralline Algae

The hard pink encrusting algae (termed crustose coralline algae) functions like cement by preventing coral reefs from falling apart during storms and high surf. In areas where there is a minimal amount of stony coral, the crustose coralline algae becomes the primary reef builder especially in shallow water where there is continual washing by wave action and currents. These pink or purple reefs were especially conspicuous at Pearl and Hermes Atoll and Maro Reef. Crustose coralline algae also provides food for herbivores such as parrot fish and mollusks.

The photo on the right is a typical reef scene from Maro Reef, the photo on the far right shows the coverage of crustose coralline algae (colored pink) that makes up such a scene.

- Ryan Okano (UH Botany)

Linda Preskitt/UH Botany

Both pinnacle and reticulated reef dives in the northwestern end of the reef complex contained high numbers of coral species. *Montipora capitata* dominated the reef slopes forming large plates at the base and along the steepest portions of the reef slope. Near the top of the reef slope mounds of finger coral *Porites compressa*, large columns of the disk coral *Pavona duerdeni* and sheet-like growths of *P. lobata* and other *Montipora* spp. were extremely common. The large table coral *Acropora cytherea* and smaller table corals were also common. Non-reef-building tube corals such as *Tubastraea* and *Balanophyllia* were found under large overhangs and in caves at these sites. Among the many coral species now documented from Maro Reef is a new species of *Montipora* discovered during the 2001 visit. Many other sites at Maro Reef are dominated by crustose coraline algae that are maintaining the physical integrity of the reef in areas where coral cover is low, and the green sand producing alga *Halimeda* was also common.

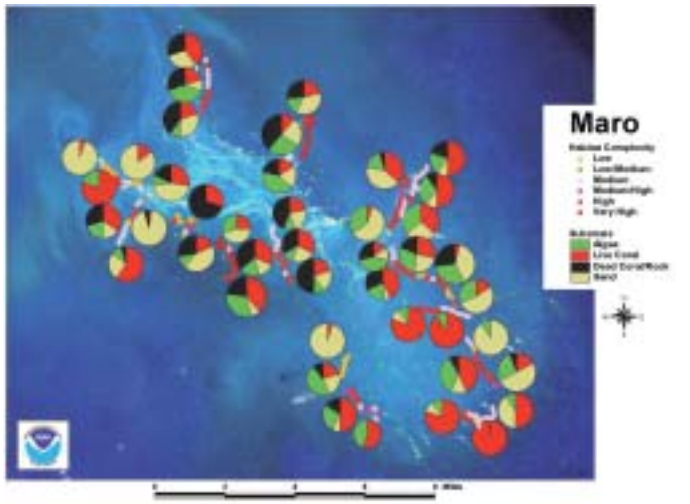
Brent Carmen/DLNR

Large rays were observed swimming around a number of the pinnacle reefs at Maro.

Jim Maragos/USFWS

Other reef habitats encountered at Maro include steep reef slopes with numerous overhangs, holes and small caves, ocean pinnacles and patch reefs completely covered with live coral, shallow lagoon reef pinnacles surrounded by extensive sand flats, and reef holes filled with very fine sediments.

A number of large *ulua* and *omilu* followed the divers around. Both white-tip and grey reef sharks were seen. Large manta rays (upper left) and eagle rays were noted. Numerous obligate coral-feeding butterflyfish species, large numbers of surgeonfish and a wide variety of predators were observed.



Rusty Brainard, Stephani Holzwarth and Michael Parke /NMFS from NASA imagery

Jim Maragos/USFWS

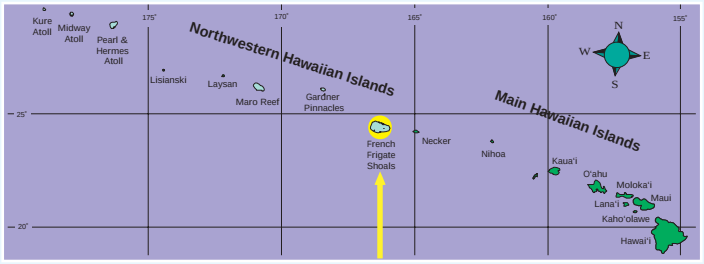
Crown-of-Thorns Seastars

While the Crown-of-Thorns Seastar (*Acanthaster planci*) causes reef stress all over the Pacific where it feeds on an assortment of corals, such outbreaks have been extremely rare in Hawai'i where the seastar occurs in relatively low numbers. Interestingly, towboard data from NOWRAMP suggests that *Acanthaster* is common along the south and east outer reef slopes at Kure and Pearl and Hermes Atolls at the northwestern end of the NWHI, perhaps due to extremely high percentages of branching coral (*Pocillopora*) and structure of the reef slopes. Unfortunately, similar surveys were not conducted at Midway, which is between these two atolls. Coincident with these *Acanthaster* sightings was a significant increase in the abundance of white (dead or dying) *Pocillopora* corals. Many of the *Acanthaster* were observed actively feeding on *Pocillopora* corals. The numbers of seastars seen in some areas of the NWHI, though much higher than the MHI, may not represent an outbreak but instead may reflect the response of a predator to a continual abundance of relatively fast-growing preferred prey food (*Pocillopora*).

- Rusty Brainard (NMFS) and Dave Gulko (DLNR)

Dave Gulko/DLNR

French Frigate Shoals



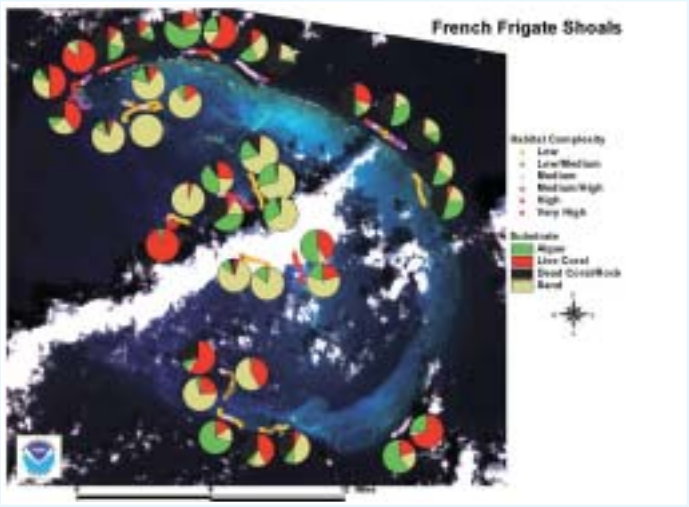
French Frigate Shoals (FFS) is a large open atoll located 500 nautical miles northwest of Honolulu and about halfway between Kauai and Midway Atoll. French Frigate Shoals ranks 6th in terms of land area (0.23 km^2) and 4th in terms of coral reef habitat (733 km^2 to depths of 100 m) among the 10 NWHI. The atoll probably supports the widest range of reef habitats due to the presence of both atoll and basalt features (including La Perouse Pinnacle). The perimeter reef of the atoll resembles a backwards "C", protecting the eastern half of the atoll. The western rim of the atoll is completely open except for the pinnacle in the north central lagoon. Major habitats ranged from ocean-facing reef slopes to numerous patch reefs, pinnacles, and linear reefs throughout the eastern half of the lagoon.

Jim Maragos/USFWS

The numerous small islets at FFS also attract the largest proportion of endangered Hawaiian monk seals in the NWHI and are the nesting grounds for over 90% of all green sea turtles found in Hawai'i. The islets also provide nesting grounds for hundreds of thousands of seabirds. Tern is the largest island at FFS, and was enlarged via dredging and filling by the U.S. Navy just prior to World War II. Later the U.S. Coast Guard operated a LORAN station that was abandoned in 1979. The USFWS has improved facilities at Tern to operate it as a year-round field station and research facility. The Navy and Coast Guard eras left behind considerable metallic waste and toxic chemicals at Tern and East Islands, and efforts are underway to remove these contaminants from the atoll and replace the failing seawall around Tern Island.

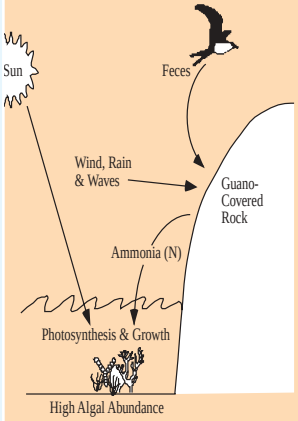
Forty-one species of stony coral were reported from French Frigate Shoals, the most from any of the NWHI. Rare table corals were seen at almost all sites, primarily the largest species, *Acropora cytherea*, and five other *Acropora* species: *Acropora cerealis*, *A. gemmifera*, *A. nasuta*, *A. valida* and *A. paniculata*. Table corals were small at most shallow "outside" areas exposed to heavy wave action, while several lagoon and semi-protected areas supported large populations of the large table coral (*Acropora cytherea*).

Reticulated reefs are concentrated on the shallow eastern half of the lagoon with reef habitats further protected by a continuous perimeter reef. Live finger coral and lobe coral (*Porites*) occur along the sides of the reticulated reefs and form numerous small patch reefs and mounds over sand and rubble flats, often with caves and overhangs. The western half of the lagoon is open, and coral cover is higher in the transition zone between the two halves of the lagoon, and on patch reefs and deep reefs at the northern and southern extremes of the lagoon. Table, finger, lobe, rose (*Pocillopora*), and other corals (*Cyphastrea*, *Leptastrea*) are locally abundant. Much of the back reef area directly to the east of these linear reefs shows lower coral cover but with isolated patches of large lobe and finger coral heads. Habitat created by coral species within the lagoon is home to many macro and turf algae species, which provide food for many reef herbivores. The bottom of lagoon reef slopes often contained large mats of *Halimeda* with turf algal cover.



Rusty Brainard, Stephani Holzwarth and Michael Parke /NMFS from NASA imagery

La Perouse Pinnacle: How Seabirds Shape A Productive Algal Habitat



Le Perouse Pinnacle is a steep-sided basalt sea stack in the middle of French Frigate Shoals and is the last remnant of the original volcano still above sea level that formed the foundation for the atoll. The pinnacle is home to a large number of seabirds and appears whitish from the large amounts of guano that has accumulated. Between the high and low water line is a clear zone of intertidal green algae, including species of *Caulerpa*, *Cladophoropsis*, and the red alga, *Asparagopsis*, among others. The base of La Perouse provides an algal habitat unlike any other in this region: this zone is probably very high in nitrogen (necessary for growth and photosynthesis) from the guano and experiences high wave action from ocean swells, creating conditions that favor the growth for the reported species.

- Linda Preskitt (UH Botany)

Linda Preskitt/UH Botany

Robert Shallenberger/USFWS

FFS provides the majority of nesting habitat for the threatened Hawaiian green sea turtle

Large invertebrates at FFS, including echinoderms, crustaceans, mollusks, and various encrusting species were both abundant and diverse due to the large variety of habitats present. Some unique lagoon reef structures housed large numbers of ark shell (*Arca ventricosa*) and thorny oyster (*Spondylus* sp.). One site had extremely large mats of chaetopterid worms underneath overhangs, suggesting periods of suspended sediments.

Ocean facing reefs around the eastern half of the atoll showed the effects of persistent trade wind generated wave action. Shallow fore reef habitats were mostly sand deposits, carbonate pavement, and rubble flats. Reef crest habitat is characterized by carbonate pavement with reef holes. Pink and purple encrusting coralline algae covered much of the shallow pavement habitats and reef crests, the last punctuated with numerous reef holes. Massive spur-and-groove habitat dominates windward slopes at depths of 10-15 m with many of the channels filled with sand.

Outer reef waters supported gray reef sharks, numerous Cheveron butterflyfish (*Chaetodon trifascialis*) pairs associated with the table coral, *Acropora*, and large schools of jacks. Fish assemblages were variable in the lagoon, with areas high in tabletop corals attracting juvenile chevron butterfly fish, lots of juvenile fish including schools of parrotfish, and schools of adult surgeonfish. A number of large peacock groupers (*Roi*) were found around overhangs. The grouper was originally introduced in the MHI a half century ago, and FFS is now the furthest northwest in the Hawaiian chain that these alien fish have been observed.

Jim Maragos/USFWS

Three NOAA scientists served as a NOWRAMP field team responsible for collecting sediment samples from NWHI lagoon waters to analyze for possible chemical contaminants. In addition, the team identified the numerous tiny animals inhabiting sand, species that are not usually looked at by reef scientists but which are a vital part of the ecosystem. The data they collected will serve as a baseline for comparison with other studies on reefs and other habitats in U.S. areas. According to NOAA's Donna Turgeon, the lead Sediment Team scientist, "We have more than 15 years of data on toxic contaminants from around the continental United States, the Caribbean, and even international coastal areas, but this will be the first data we collect from the NWHI. We are looking forward to perhaps finding some answers as to where marine mammals with high tissue levels of polychlorinated biphenyls (PCBs) may have been exposed to such organic contaminants in the region," explained Turgeon. PCBs are organic compounds that are known carcinogens. They have been found in significant levels in marine mammals, like monk seals, from the region. Turgeon focused her search for PCBs and other toxic chemicals in areas that had a previous military history including French Frigate Shoals, Midway and Kure, but also at "control" areas (Maro, Pearl and Hermes) where such toxicity was expected to be absent (see page 44).

The Mystery of the Wayward FADs of French Frigate Shoals

NOWRAMP researchers spotted several large yellow buoys near NWHI reefs; two of these large buoys were spotted at FFS in 2000, one just inside the reef along the south side of French Frigate Shoals near Disappearing Island. A third buoy was also spotted and recovered from FFS in 2001 by the *Townsend Cromwell*.

It turns out these large buoys are Fish Aggregation Devices (FADs) that had broken their moorings in the MHI and had ended up hundreds of miles to the northwest at FFS. Staff at the Department of Land and Natural Resources (DLNR) were later contacted in Honolulu and they determined that one of the FADs had been lost off of Makapu'u on O'ahu. This FAD was seen dragging a long mooring chain over the coral reef (right). The FAD 'EK' recovered in 2001 had been lost off the north shore of Kauai.

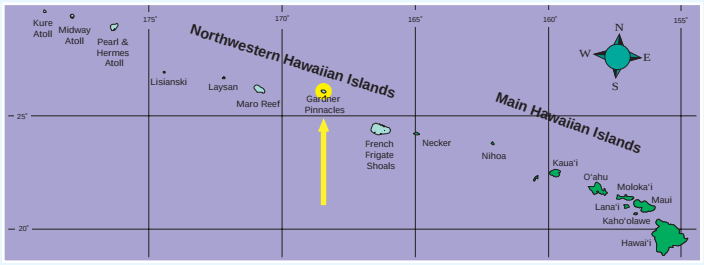
FAD's have been installed at various locations around the MHI by DLNR and serve to attract oceanic fish in the water to aid fishers in their search for suitable catch. According to DLNR, it is not known when the FAD found at FFS had broke off its mooring in the MHI, but it was sometime between 1995 and 1999. Either winds or currents or both moved the FAD to French Frigate Shoals. "This is not the first FAD to show up in the NWHI," said a DLNR spokesperson. "Recently a different one found its way to Midway and at least 3 others broke off and were found in the NWHI in the early '80's." Interestingly, this raises questions regarding other materials (such as marine debris, abandoned gill nets, etc.) from the MHI that might drift to the NWHI. Given the high amounts of alien algae in the MHI and the ease with which it can entangle into nets or attach onto buoys and their mooring lines, the FADs at FFS should serve as a wake-up for resource management agencies in regards to this issue.

Jim Maragos/USFWS

Jim Maragos/USFWS

Reef damage caused by broken FAD mooring chain dragging across reef flat at FFS.

Gardner Pinnacles



Gardner Pinnacles are steep basalt sea stacks, located approximately 150 nautical miles east southeast of Maro Reef. Shallow marine habitats (less than 20 m depth) are restricted to the immediate vicinity of the pinnacles, but beyond are extensive shelves that extend many miles away from the shallow pinnacles and total 1,904 km^2 to depths of 100 m, the most of any island or bank in the NWHI. In contrast, the "land" area totals only 2 hectares (0.02 km^2), the least of any of the NWHI. The pinnacles are often difficult to approach due to exposure from large waves from any direction, but the *Rapture* REA marine and land teams were successful in accomplishing limited surveys. Four dives around the tiny volcanic pinnacles revealed a quick and somewhat complete look at the shallow waters immediately adjacent to land. At the bottom submerged base of the pinnacles, divers found flat, wave-cut shelves that seemed to surround the entire pinnacle and extend outward beyond the limits of underwater visibility. In very large swell conditions, the towboard team managed to conduct one towboard survey around the entire pinnacle.

© Monte Costa

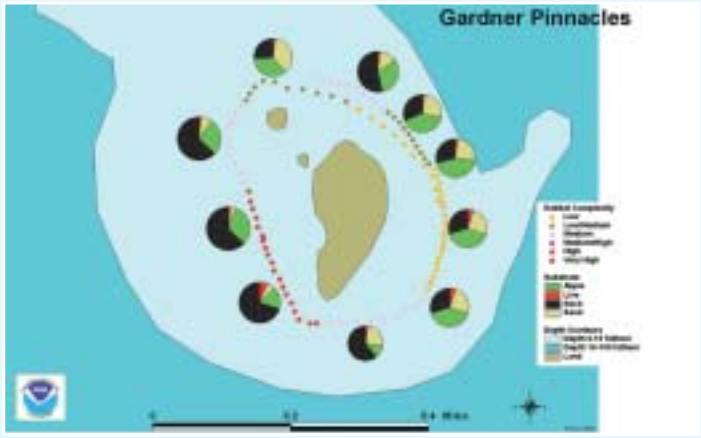
Dave Johnson/USFWS

Jim Maragos/USFWS

Coral biologists recorded 27 species of coral at Gardner, considerably more species than were seen at the comparable basalt islands of Necker and Nihoa. The leeward (western) side affords more shelter from trade wind generated waves and there *Acropora* table corals were the dominant species. Additionally, holes, trenches, caves, and slabs of basalt created many nooks and crannies where sponges and tube corals (*Tubastraea, Balanophyllia*) were abundant. Elsewhere, especially on shallower basalt slopes and flat basalt pavements, stony corals were poorly developed, and, despite the higher diversity, coral cover ranged from less than 1% to a maximum of 15% live cover. In contrast, expansive sheets of the soft coral *Sinularia* carpeted much of the steep basalt slopes at depths of 5-15 m. Expedition researchers suspect that the low coverage and slow growth are due to the scouring action of waves.

Gardner, while being the smallest location surveyed, held amongst the higher number of fish species observed in the NWHI. This is the first location to the south where we encountered the red lip parrotfish (*Scarus rubroviolaceous*), the doublebar goatfish (*Parapeneus bifasciatus*), and the reef triggerfish, (*Rhinecanthus retangulus*), all species that are commonly observed in the MHI. Perhaps the deeper extensive shelves surrounding the pinnacles provides an extensive reservoir of fish species attracted to the shallower habitats.

The land team was able to scale the steep cliffs of the pinnacles and explore the typically inaccessible volcanic rocks, which are the least visited of all the islands in the NWHI. A rare find on land was the blue-gray noddy, a rare tern that is infrequently seen in the NWHI. During the 2000 trip wildlife biologists found nine species of seabirds including terns, noddies, boobies and frigate birds. These numbers compare to a total of nineteen species of seabirds that were previously recorded at Gardner, twelve of which breed on the precipitous cliffs. The biologists also saw two species of migratory shorebirds, the ruddy turnstone and the golden plover. Scaling the steep, guano-covered island was well worth it for entomologist Gordon Nishida who found what he believes are two new species of spiders. He also found a third spider that hadn't been previously recorded from Gardner. According to Nishida, only 8 insects and 2 mites had ever been recorded to exist on the island before the 2000 expedition.



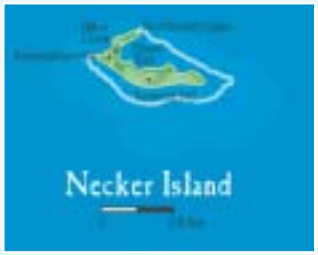
Rusty Brainard, Stephani Holzwarth and Michael Parke/NMFS

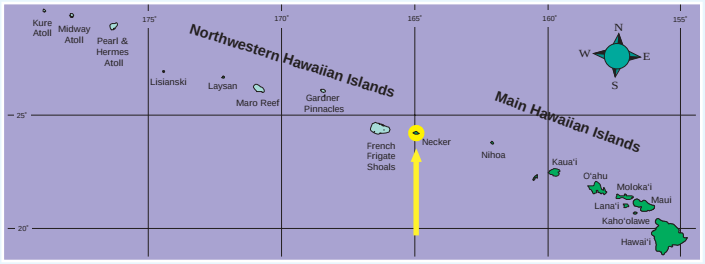
Dave Johnson/USFWS

Last Refuge for the Giant *Opihi*?

In old Hawai'i, limpets were gathered by the indigenous population as a major food item. In modern times, these *opihi* have become overfished in Hawai'i as the island populations have increased and non-Hawaiians have developed a taste for this abalone-like animal. The *opihi* also fetches very high market prices, further stimulating commercial harvest of the species. Currently it is rare to find *opihi* in any large concentrations anywhere in the MHI. The endemic giant *opihi* (*Cellana talcosa*), the largest of the Hawaiian limpets, has all but disappeared from the MHI; requiring a basalt substrate, it is also rare in the NWHI. NOWRAMP and NMFS teams found relatively large concentrations of these rarely found invertebrates on the small intertidal areas at Gardner Pinnacles and Necker Island. Given its near disappearance elsewhere throughout the chain, additional steps need to be taken to protect these remaining populations of *Cellana*.

Necker Island
(Mokumanamana)





Necker (Mokumanamana) Island is a small basalt island about 90 nautical miles east of French Frigate Shoals. Its land area is 16 hectares (0.16 km^2), the second smallest of the NWHI, but its surrounding marine habitat to depths of 100 m totals 1,538 km^2, the second largest in the NWHI. Shallow water marine habitats to a depth of 20 m are limited to the immediate vicinity of Necker, and all NOWRAMP dive surveys were confined to these areas. Beyond are extensive deeper shelves extending many miles from the island, especially to the southeast. These broad offshore areas are commercial fishing grounds for bottom fish and lobsters. Many Hawaiian monk seals are known to haul out on the small rocky beach in Shark's Cove. Many seals were also present in the water near Necker during surveys, often following divers. All shallow marine habitats are basalt surfaces heavily eroded, scoured, and seem unfavorable for coral growth.

'Aulani Wilhelm/DLNR

Necker was visited in ancient times and still contains unique Polynesian cultural sites and artifacts.

Jim Maragos/USFWS

Shark Bay is a unique, broad wave planed basalt flat on the north side of Necker, and the bottom community is dominated by a variety of large, abundant algae, a phycologist's dream. Large invertebrates for this high island were surprisingly abundant; probably due mainly to some shelter from wave action provided by Shark Bay. This bay had great abundance and diversity of sea cucumbers and sea urchins, and lobsters were common.

Jim Maragos/USFWS

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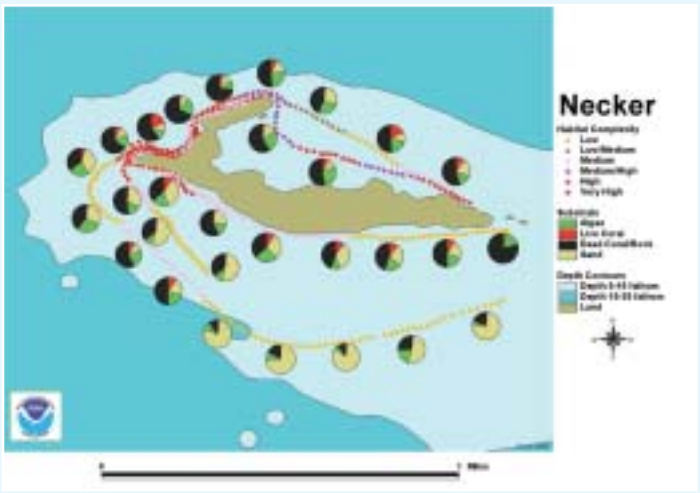
The more exposed areas of Necker were dominated by sea urchins and encrusting invertebrates (bryozoans, tunicates). Sixteen species of stony coral were found overall at Necker Island, with the rose coral *P. meandrina* and lobe coral *P. lobata* the most commonly encountered coral species. Small colonies of the finger coral *P. compressa*, the branching coral *P. ligulata*, and the corrugated encrusting coral *P. varians* were some of the coral species encountered on Necker that were not seen at neighboring Nihoa. An unusual form of the soft coral *Sinularia* was also noted from this island, attached to elevated basalt surfaces. All corals were rare on flat bottom habitats where wave scour is severe. Caves, overhangs and trenches provide small-scale habitat for some corals. Major habitats encountered included basalt benches with sand channels, some with a thin veneer of carbonate pavement, and often covered with rose corals.

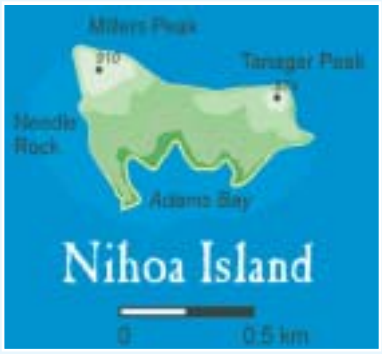
'Aulani Wilhelm/DLNR

Fish assemblages at Necker were similar to those seen at Nihoa and the MHI, though biomass of fish was higher than farther south in the chain. Gray reef sharks, manta rays and monk seals were observed in the shallow waters directly surrounding the island.



Rusty Brainard, Stephani Holzwarth and Michael Parke/NMFS

Nihoa Island

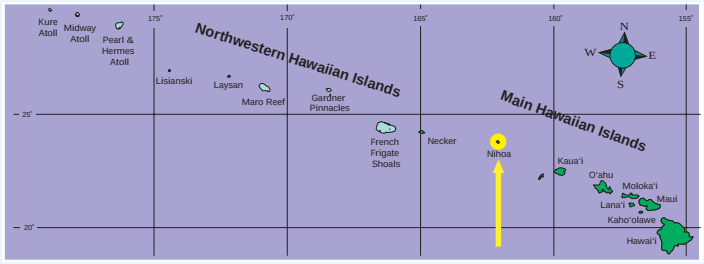


Nihoa is a small basalt island at the southeastern end of the NWHI, 160 nautical miles east southeast of Necker and 240 nautical miles northwest of O'ahu. Surrounding marine habitats to depths of 100 m total only 246 km^2, ranking it seventh among the NWHI. Nihoa was inhabited by Hawaiians for several centuries before being abandoned in prehistoric times, and although land habitats are steep they support numerous archaeological sites. Several endangered plants, the endangered Nihoa finch (below) and the endangered Nihoa millerbird are all confined to the island. Shallow marine habitats are all basalt and similar to those of Necker in being heavily eroded and scoured by wave action.

© Monte Costa

The principal shallow water bottom habitats around Nihoa consist of hard basalt as vertical walls, horizontal wave-cut basalt benches, elevated mounds, and large blocks and boulders. Thin deposits of carbonate sand accumulate in holes and depressions where they are not easily washed away by wave surge. A thin veneer of encrusting pink coralline algae covered many rocky elevated surfaces in shallow water. For an exposed habitat there is a lot more macroalgae at Nihoa than expected. The red alga, *Asparagopsis taxiformis* (*limu kohu* in Hawaiian) is an edible algae that is common at Nihoa but becoming harder to find in the MHI. The sand-producing green alga, *Halimeda velasquezii* and upright thalli of the brown alga *Lobophora variegata* were also common around Nihoa. In contrast, large invertebrates were uncommon around the island. Ledges, boulders, holes, overhangs, and channels provided some sheltered habitat for encrusting species such as sponges, bryozoans and tunicates. Rock boring sea urchins (*Echinostrephus aciculatus and Echinometra mathaei*) and the sea star (*Linckia multifora*) were the most abundant large invertebrates at all sites surveyed. The crown-of-thorns sea star was rarely observed at Nihoa, and probably feeding on the rose coral, *Pocillopora meandrina*.

Jim Maragos/USFWS

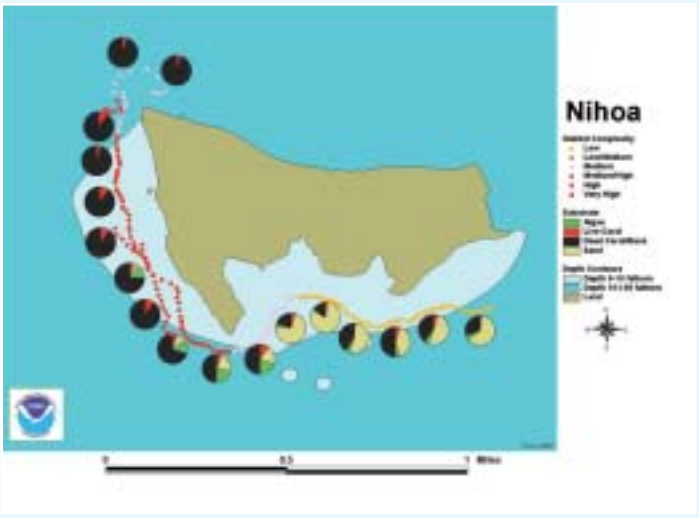


USFWS

Only seventeen species of stony coral were found at Nihoa and coral cover was low, with the most common species being small encrusting forms of *Porites lobata* and branching rose coral colonies. Corals were more common on hard surfaces elevated above the bottom where the scouring effects of wave action are less severe. Colonies of the soft coral *Sinularia* were seen firmly attached to elevated basalt surfaces.

The amount of shallow reef habitat immediately surrounding Nihoa and Necker is small, especially as compared to the other NWHI atolls and islets. According to coral biologist Jim Maragos (USFWS), "Because the reefs are small, fewer fish and other species have colonized them and have been able to survive. This doesn't mean that the reefs are unhealthy, just that they cannot support a large variety and number of species."

"Corals at Nihoa and Necker have a tough time surviving," explained Maragos. "They suffer from constant scouring from swells and currents that rush against nearly all sides of these tiny islands, breaking coral and making it very difficult for new corals to grow," said Maragos. "Because of these circumstances, there is little suitable habitat upon which strong coral colonies can flourish. Around these islands, there are only submerged reefs, no emergent ones. Most are found at depths of 40 feet or below. On the north side of Nihoa, few corals were found until 70 feet. At nearly all sites surveyed, most of the coral found were low growing, encrusting species that have adapted to high energy environments."



Rusty Brainard, Stephani Holzwarth and Michael Parke/NMFS

Jim Maragos/USFWS

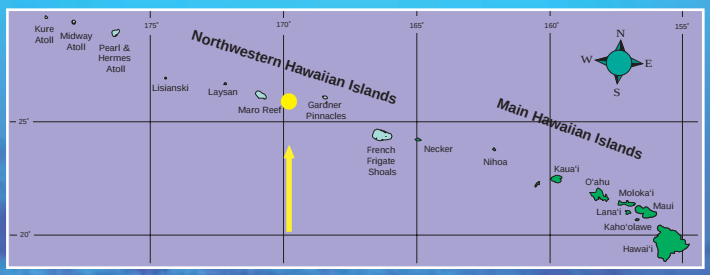
Nihoa from a distance actually resembles one of the main Hawaiian Islands, until one gets close enough to see the abundance of marine life and pristine natural habitats. As such, it serves as an example of what the larger Hawaiian Islands might have been prior to the impacts of man.

Entomologist Gordon Nishida (above) has documented 72 unique (endemic) species of insects on Nihoa.

'Aulani Wilhelm/DLNR

Jim Maragos/USFWS

Raita Bank



Jim Maragos/USFWS

Jim Maragos/USFWS

Jim Maragos/USFWS

In October 2001, towboard and REA teams dived on Raita Bank, the only deeper submerged reef thus surveyed as a part of NOWRAMP. Aside from the reefs surrounding the 10 NWHI, there are an additional 30 submerged banks with reefs in the vicinity, many very large, such as Raita. The crest of Raita is at depths of 20 m, but divers were swept along by strong currents, with most dives ending up in the 30-35 m range. Bottom habitat was very barren and planed by wave action, and live coral accounted for less than one percent cover and only 8 species based on three REA dives. A few small reef holes attracted shallow sand deposits and higher localized biodiversity. The dominant corals were several branching coral species of *Pocillopora*. Dead standing corals actually were more abundant and provided elevated habitat for a host of invertebrates and haven for smaller fish. Sharks and jacks hovered above the bottom and the floor of the bank crest was carpeted with the green mesh-like alga, *Microdictyon*. In general reef species abundance and diversity were low. However, since only Raita was dived during the 2001 expeditions, it is hard to generalize on the condition and status of the submerged banks of the NWHI without more intensive investigations on additional banks.

During the 2001 *Townsend Cromwell* cruise, NMFS investigated many of these deeper submerged banks by using an acoustic seabed classification system and a Tethered Optical Assessment Device (TOAD) towed camera system. Researchers investigated almost 4700 kilometers of habitat over the submerged banks at Necker, French Frigate Shoals, Brooks Banks, St. Rogatien Banks, Gardner Pinnacles, Raita Bank, Maro Reef, Pioneer Bank, Bank #8 and Midway. Preliminary results from these surveys indicate that the banks are generally somewhat barren and dominated by extensive sand and algal beds.

Why Are The Northwestern Hawaiian Islands So Important?

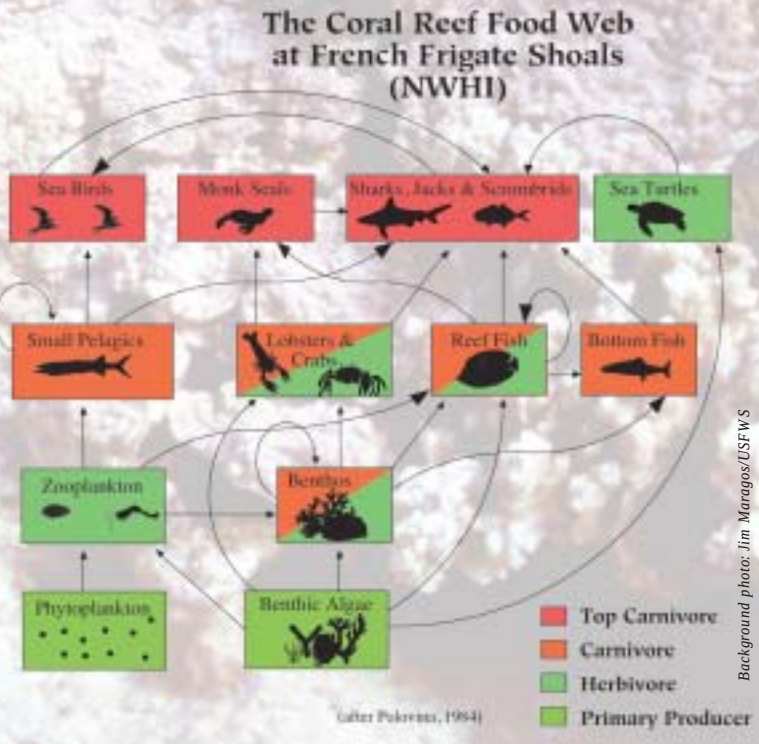
With coral reef ecosystems around the world in serious decline, it is rare to find a large-scale coral reef ecosystem that is relatively free of human impact and consisting of a wide range of coral reef habitats. The limited reef fishing activities that have occurred in the NWHI have resulted in minimal anthropogenic impacts. These reefs are among the few large-scale, intact, predator-dominated reef ecosystems remaining in the world, and offer a chance to examine what could occur if larger, more effective, no-take marine protected areas were implemented in the MHI and elsewhere in the nation and the world. These areas should not only be set aside for their intrinsic value, but also for their value to enhance fishing and hedge against fisheries collapses by potentially providing sources of recruits. Fisheries on coral reefs tend to focus first on the larger more desirable species and progressively shift toward smaller less desirable ones as time goes on and resources decline. Typically these larger species are apex predators that can have a profound effect on how a coral reef fish assemblage is structured. The NWHI is one of the few places left in the world that is sufficiently pristine to study how unaltered ecosystems are structured, how such ecosystems function, and how they can be most effectively preserved. The differences in fish assemblage structure observed by this expedition are evidence of the high level of exploitation in the MHI and the pressing need for effective ecosystem-level management of reef systems in the MHI as well as the NWHI.

The NWHI are also the home of many plants and animals on the brink of extinction that deserve to survive and be protected. Many species have already been lost there in recent centuries at the hands of humans, especially plants and ground nesting seabirds. Despite the valiant efforts of modern conservation agencies and legions of volunteers, alien species continue to threaten vulnerable endemic species of plants and birds, and may later threaten marine species unless precautions are taken. The endangered Hawaiian monk seal, despite concerted conservation efforts over the past several decades, continues to dwindle in numbers and may not survive to the end of this century.

Other unique birds, plants, corals, algae, sponges and other species are found only in the NWHI, and Hawaiian populations of threatened green turtles must nest without disturbance in the NWHI to survive. These turtles are important to the marine tourism industry in the MHI and have increased in numbers over the last 20 years. In contrast, most other marine turtle species in the world are likely heading to extinction. Over 20 species of seabirds totaling many millions nest in the NWHI, one of the largest rookeries in the world, and an initial motivation for its formal protection by President Teddy Roosevelt a century ago. Several of the species attain their largest breeding population levels in the NWHI.

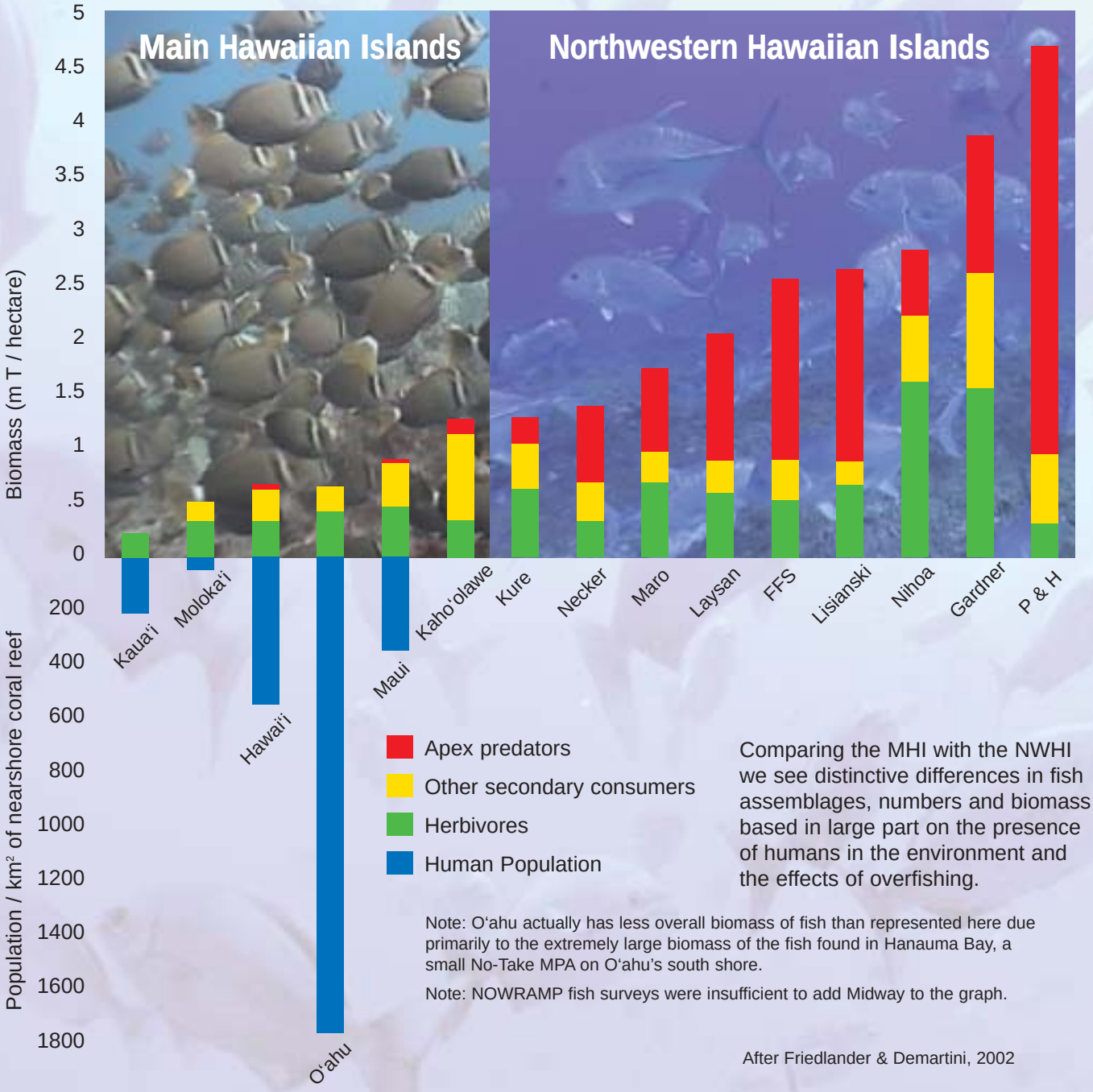
The main reasons why the NWHI reefs have remained largely pristine to this time is that they were out of harm's way in the remote central Pacific and largely protected as part of one of the nation's large scale protected area, perhaps the first protecting reefs in the world. But the world and its burgeoning human populations are crowding in on these islands and reefs, with entrepreneurs eager to harvest her remaining large fish and gain access to these last pristine places. More sinister are the effects of global climate change that may eventually degrade most of the world's reefs, and never-ending accumulations of marine debris on the islands and reefs dumped into distant oceans by fishers of another culture and ethic. Protection of the NWHI will require the concerted efforts of many people, agencies, and institutions to prevent further injury and to restore the unique species, populations, and their habitats for the benefit of future generations of humans and wildlife.

"Sustainable fishing" may not be possible in the shallow coral reef waters that make-up the NWHI if we want to preserve these unique ecosystems in their present state. It is clear that this special mega-ecosystem needs to be managed at the ecosystem level including all islands, reefs and the adjacent ocean, with all individuals, communities, management agencies and resource trustees doing their fair share to cooperate and give a helping hand, and to protect the unique natural and Hawaiian cultural heritage residing in these sacred places.



Background photo: Jim Maragos/USFWS

A Place Where Large Amounts of Fish Roam Freely



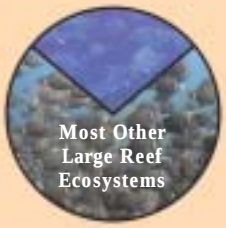
Comparing the MHI with the NWHI we see distinctive differences in fish assemblages, numbers and biomass based in large part on the presence of humans in the environment and the effects of overfishing.

Note: O'ahu actually has less overall biomass of fish than represented here due primarily to the extremely large biomass of the fish found in Hanauma Bay, a small No-Take MPA on O'ahu's south shore.

Note: NOWRAMP fish surveys were insufficient to add Midway to the graph.

After Friedlander & Demartini, 2002

Carnivores 30%



Herbivores 70%

Carnivores 72%

Herbivores 28%

The end result is that the NWHI represents perhaps the last major coral reef ecosystem where large predators dominate.

Dave Gulko/DLNR

Background photo: Jim Maragos/USFWS

A Place Where Rare Species Have Refuge

Jim Maragos/USFWS

Jim Maragos/USFWS

A Place Where Fragile Coral Reefs Still Thrive

Jim Maragos/USFWS

Jim Maragos/USFWS

Jim Maragos/USFWS

A Place Where Endemic Species Abound

Endemism

About one fourth of the shallow water species inhabiting reefs in the Hawaiian Islands are endemic or unique to the islands. For example, 15-18 species of coral out of a total of 62 species are endemic and 24.3% of the shore fish species in Hawai'i are endemic. Similar proportions have been reported for marine mollusks and marine algae. Why is endemism so high in Hawai'i? Why should we care?

There are two basic reasons for the high marine endemism in Hawai'i: the species are very old and the islands are very isolated from other large coral reefs in the Pacific. In isolated situations, ancestral species successfully reaching Hawai'i can undergo genetic drift and evolve into new species, unique to the islands. The oldest of the contemporary Hawaiian Islands are Midway and Kure Atolls in the NWHI, and are about 20-25 million years old. But there are many older former Hawaiian Islands that have drowned, called the Emperor Seamounts. These stretch past Kure all the way to the Kamchatka Trench off Siberia and are at least 60 million years old, not counting even older seamounts that are already subducted under the trench. All of these seamounts were once islands that formed at the same hotspot off the Big Island (Hawai'i), and were carried by the Pacific Plate towards the northwest, just as the existing islands are moving. The ancestral reef species that inhabited these earliest islands must have hopped to the younger islands during this journey, allowing the ancestral species to survive and evolve into new species over a period of 60 million years or more.

Hawai'i is also geographically isolated from its nearest large neighbors, some 1,000 to 2,000 miles to the southwest (Lines, Phoenix, Marshalls, Gilberts, Samoa). It is difficult for the larvae of reef species to survive these long distances and reach Hawai'i. It is even more difficult because the prevailing currents generally run from east to west, requiring colonizers to move "upstream." Moreover the subtropical environment in Hawai'i would be less favorable to many warm tropical recruits, and the severe wave and storm conditions around the islands would further deter successful establishment. As a result only a few species reached the islands and were then able to evolve into new species in isolation of the ancestral gene pools. This has resulted in a lower total number of species but with a higher proportion of unique or endemic species.

Endemic species are important because they are found only in Hawai'i and deserve our aloha and stewardship. They can also provide benefits to mankind and other species. The NWHI are important in this case because they have served as the pathways and reservoir for species that have colonized the MHI from the northwest. Thus, it is not surprising to learn that NWHI species endemism and diversity is as high or higher than reported in the MHI for some reef species such as corals. And it is also vital to protect these species from the threats of alien species and habitat loss that has already claimed so many extinct species in Hawai'i. Endemism is truly the most important reason why Hawai'i is unique and why the NWHI warrant our utmost respect and protection.

Jim Maragos/USFWS

In general, over 25% of Hawaiian reef animals are endemic, found nowhere else in the world. This means there is no outside reservoir to replace these organisms.

Jim Maragos/USFWS

Background photo: Jim Maragos/USFWS

What Are The Principal Threats?

Threat	Vector (Immediate Causes)	Impact Concerns	Current Management Response	Solutions?
Commercial Fishing	• Existing Fisheries: Lobster Fishery Bottomfish Fishery • Potential Precious Coral Fishery	• Gear Damage To Coral Reef And Other Bottom Habitat • Bycatch Of Reef Species • Overharvesting	• NWHI Lobster and Precious Coral Fisheries Currently Closed • Limited Operating Areas For Other Fisheries • Gear Restrictions	• No-Take, No-Entry Areas • Vessel Monitoring Systems (VMS) • Enhanced Insurance For Prompt Removal Of Grounded Vessels
Shipping Accidents/ Groundings	• Existing Fisheries: Lobster Fishery Bottomfish Fishery Longline Fishery Cruise Ships • Potential Precious Coral Fishery • Research Vessels	• Oil Spills/ Grounding Scars • Gear Damage • Cyanobacteria On Metal Wreckage (Chemical Stimulation)	• Better Coordination Amongst Resource Trustees • Limited Operating Areas For Other Fisheries	• Enhanced Insurance • VMS USCG
Marine Debris	• North Pacific Fisheries • NWHI fisheries? • MHI? Jim Maragos/USFWS	• Entangles Monk Seals, Sea Turtles and Sea Birds • Bulldozes Corals • Alien Species • Ingestion	• Multi-agency Removal Expeditions © Monte Costa	• At-sea Removal • Tagging
Tourism/ Recreational Fishers	• Live Aboard Dive Charters • Recreational Fishing Boats • Cruise Ships	• Disruption Of Pristine Habitat • Vessel Groundings • Alien Species • Alteration Of Natural Behaviors and Fish Assemblages	• FWS Permitting • Long Distance and Inaccurate Charts • Lack Of Available Vessels That Can Make The Voyage Safely	• Control Access • Limit Activities USFWS
Habitat Destruction Alien Species	• Marine Debris • MHI Vessels • Scuba Divers • Researchers • Hull Cleaning At Dockside	• Overgrowth and Loss Of Native Species • Trophic Guild Displacement • Alteration Of Fish Assemblages	• Educate NWHI Visitors Prior To Visit Jen Smith/CH Bolony	• Better Coordination Amongst Resource Trustees • Operation Protocols For All Visiting Vessels and Researchers

A Closer Look At Marine Debris

Once a sea bird ingests plastic it is often difficult to remove. Eventually the animal dies of starvation.

Jim Maragos/USFWS

John Broods/NOAA

© Monte Costa

Dave Gulko/DLNR

Driftnets and gillnets often entangle mobile fish and shellfish such as this lobster; eventually they die of starvation or are taken by predators.

The volume of marine debris washing ashore in the NWHI is staggering! For each of the last four years, a multi-agency partnership has actively removed over 20 tons/year! This is thought to represent about 5% of the debris material on NWHI shorelines and reefs. In 2001, the NMFS-led multi-agency marine debris removal program removed 69.1 tons of marine debris from Kure and Pearl and Hermes Atolls

Often, by the time marine debris washes ashore, it's already caused extensive damage to the reefs

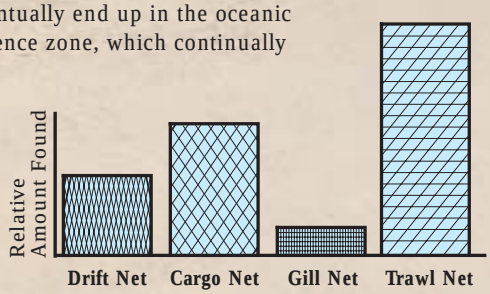
Ray Boland/NMFS

Marine debris is a serious threat to the survival of endangered and threatened species such as the Hawaiian monk seal and green turtle.

Dave Gulko/DLNR

Marine debris also causes serious damage to corals when it snags them or works its way across the reef before finally coming ashore.

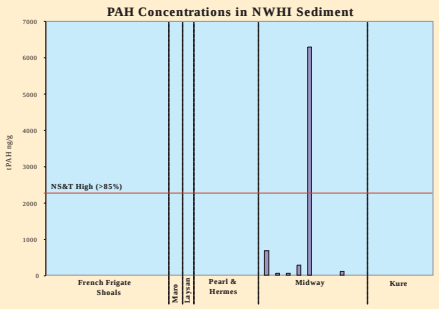
The NWHI are uniquely situated to trap large amounts of marine debris that slowly drifts within the slow-moving North Pacific gyre. Oceanographic studies have shown that marine debris from almost anywhere in the North Pacific Ocean will likely eventually end up in the oceanic convergence zone of the subtropical North Pacific. This convergence zone, which continually accumulates marine debris, migrates north and south with the seasons. During the winter months, this convergence zone shifts south and deposits large amounts of marine debris onto the reefs and islands of the NWHI. During El Niño winters, this convergence zone shifts even further south and deposits marine debris onto the reefs and beaches of some of the MHI.

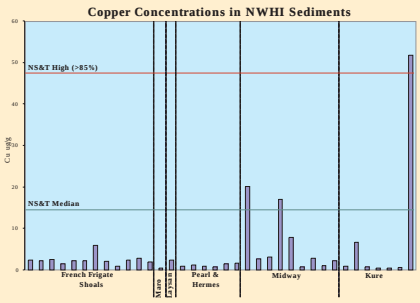


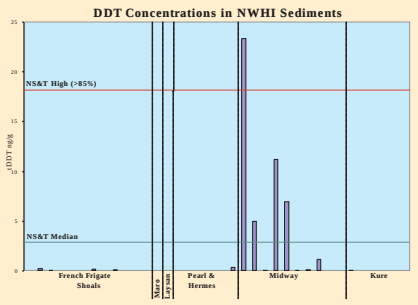
- Rusty Brainard and Mary Donohue (NMFS)

NOWRAMP 2000

Contaminants



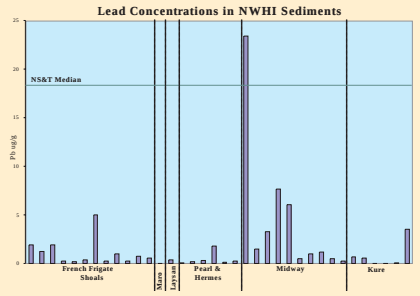


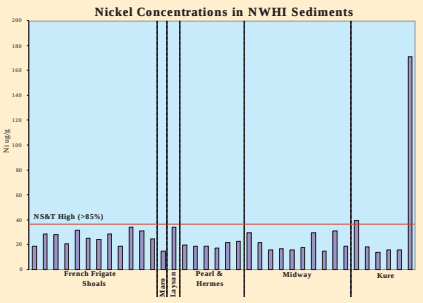


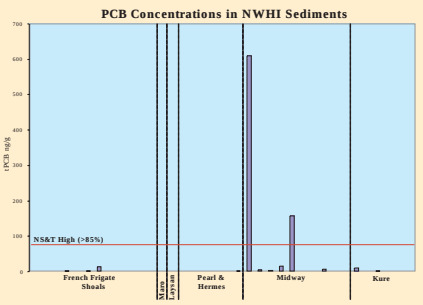
In response to concerns by U.S. Fish and Wildlife scientists over high levels of toxic contaminants (e.g., PCBs and lead) in NWHI wildlife (e.g., moray eels, Hawaiian monk seals, and albatrosses), a preliminary survey of island near-shore sediments was conducted during the NOWRAMP expedition. Results are in from the analyses of 36 sediment samples for over 70 toxic contaminants. A few of the chemical concentrations measured in sediments from these NWHI samples are unexpectedly "high" ["high" used here is above the 85th percentile of concentrations measured in the coastal United States by the NOAA National Status and Trends (NS&T) Program]. Most remarkable though, is that these levels were found in sediments containing more than 99% sand and gravel, not fine-grained as those measured by the NS&T Program. The concentrations of groups of organic compounds ∑PCB, ∑DDT, ∑Dieldrin, ∑Chlordane, and ∑PAH were undetectable, very low, or at least below the NS&T median at all sites except three. One Midway site had ∑DDT concentration above the NS&T median. Two other Midway sites had "high" levels of ∑PCB, ∑DDT, and ∑PAH, and one of these had a "high" concentration of arsenic and above-median concentrations of cadmium, lead and tin. A fourth site on Kure Atoll was the only site with "high" concentrations of copper and nickel. In light of these results, a broad-scale assessment of contamination in NWHI sediments and the tissues of indicator species should be initiated.

- Donna Turgeon, Michelle Harmon, Kevin McMahon (National Ocean Service/NOAA)

Note: The sigma symbol (∑) means 'the sum of' (i.e. these toxic organic chemicals have been aggregated into groups).







Remnants of a Ship Grounding

Mike Cripps/DOH

On October 16, 1998, an 80' lobster fishing vessel, the *Paradise Queen II* ran aground on the coral reef facing Green Island at Kure Atoll (left). An estimated 4,000 gallons of diesel fuel was released into the environment along with other hydraulic and lubricating oils. 7,000 out of the original 11,000 gallons of diesel fuel were removed during salvage operations overseen by the U.S. Coast Guard.

Over time, storms broke the vessel into chunks, which may have acted as small bulldozers as they were pushed over the living reef by wave action (right and above right).

NOWRAMP surveys at Kure detected the presence of cyanobacteria in areas adjacent to the grouding site of the vessel (see page 24). REA teams found remnants of plastic line throughout the immediate area.

© Monte Costa

Hundreds of plastic lobster traps (below right) were removed from the reef area during salvage operations. Traps were moved to shore, disassembled and stacked to reduce the likelihood of further environmental harm. Even so, NOWRAMP teams still found that other plastics from the ship still remain on shore.

© Monte Costa

The Paradise Queen II grounding serves as an example of the types of adverse and enduring impacts that even a small ship grounding can have on a pristine ecosystem.

© Monte Costa

Where Do We Go From Here?

NOWRAMP 2000-1 was only an initial field phase of assessing the coral reefs of the NWHI. The mapping phase is to be accomplished in 2002 with the support and cooperation of the National Ocean Service. Although the scope of the initial REA was the most comprehensive ever accomplished for this largest of U.S coral reef ecosystems, much more assessment, mapping, long-term monitoring, and directed research are needed to insure the ecosystem is protected adequately and managed properly. The following are brief summaries of the goals and scope of follow-on studies, but with the caveat that even these will be subject to revision as we learn more from ongoing and planned studies:

1. Map the coral reef habitats of the NWHI using a combination of satellite and aircraft based remote imagery and "ground-truth" surveys to provide essential baseline data for further research and management (especially multi-spectral IKONOS and hyper-spectral imagery).

2. Complete additional diver-based REA surveys of some of the NWHI where coverage during the 2000-1 expeditions was insufficient to properly characterize the status of the ecosystems (especially Midway, Lisianski, and selected shallow banks).

3. Extend REA surveys to depths below 20m employing SCUBA, remotely-operated vehicles, towed arrays, and submersibles to assess the status of deeper reefs and fishery stocks, and also extend surveys into shallower waters.

4. Correct existing navigation charts of the NWHI via ship-based multi-beam and side-scan, sub-surface profiling, bathymetric, towed array, and airplane-based LIDAR surveys, and installation of land-based geodesic control points.

5. Establish a long-term monitoring program for the reefs and associated oceanography of the NWHI, via repeated surveys and analyses at permanent in-situ sites, at randomly selected sites, and supplemented with remotely sensed data.

6. Establish long-term research for comparative assessment of fish populations at completely protected (no-take), semi-protected, and unprotected reef sites for the purpose of managing and adjusting fishery regimes to conserve fishery stocks.

7. Assess the impact of marine debris on coral reefs and subsequent rates and patterns of recovery of native reef animals and plants in the NWHI as a means of strategizing future limited resources targeted for marine debris cleanup efforts.

8. Conduct more complete evaluations of ecosystem processes in the NWHI to assist developing management frameworks to maintain its fragile pristine nature in the face of potential increased human interest.

9. More fully assess the impact of current and recently closed fishery regimes on coral reef ecosystems, including habitat, trophic, and ecosystem level effects to improve fisheries management into the future.

10. Conduct intensive surveys for alien species on NWHI coral reefs to better strategize control and eradication efforts.

11. Conduct a more comprehensive survey of chemical contaminants in sediments and wildlife tissues from near-shore reef and lagoon sites off the NWHI islands and atolls to assess environmental impacts and better strategize future containment and removal programs.

12. Accomplish retrospective research on the growth and health of corals and other suitable indicators of coral reef ecosystems as a means of better predicting past and future patterns of change and needed restoration and management efforts.

13. Accelerate description and publication of information on species new to science and new species occurrences in the NWHI to protect rare native species and to head-start control programs on new undesirable alien species.

Research is already underway for many of the above categories, and we plan to report on the results of these efforts in future reports. The principal benefit of these efforts will be to improve protection of this unique large-scale ecosystem and to better educate the public, the managers, and ourselves on the conservation values and needs for this pristine ecosystem and natural laboratory for coral reef conservation.

John Brooks/NOAA

John Brooks/NOAA

Background photo: John Brooks/NOAA

The Big Picture: Northwestern Hawaiian

In general, top 5 sites for each category	Ecological Concerns					
	Relatively High Coral Cover (per unit area)	High Coral Spp. Diversity	Unique Coral Spp./ Assemblages	High Fish Biomass	Unique Fish Spp./ Assemblages	High Fish Spp. Diversity
Kure	✓	✓	✓ 2	✓	✓ 6	✓
Midway			✓ 3		✓ 7	
Pearl & Hermes	✓	✓	✓	✓ 4	✓ 8	✓ 12
Lisianski/Neva	✓					
Laysan						
Maro	✓	✓	✓	✓	✓ 9	✓
Gardner		✓		✓ 5		✓
FFS	✓	✓ 1	✓ 3	✓	✓ 10	✓ 11
Necker						
Nihoa						

1 Highest coral diversity in the NWHI.

2 Ancient, massive living coral colonies. *Montipora turgescens.*

3 *Montipora turgescens, M. dilatata* (Midway). Large table *Acropora (FFS).*

4 Highest biomass of fish in the NWHI.

5 Second highest NWHI fish biomass.

6 Hawaiian Grouper, Knifejaw, Dragon Moray.

7 Hawaiian Grouper, Masked Angelfish, Knifejaw.

8 Knifejaws and Masked Angelfish.

9 *Chaetodon trifascialis.*

10 *Chaetodon trifascialis.*

11 Second highest number of fish species in NWHI.

12 Highest number of fish species in NWHI.

© Monte Costa

Islands Coral Reefs Comparative Chart

				High Human Use [19]			
Unique Invertebrate Assemblages	High Invertebrate Diversity	Diversity of [17] Habitat Types	Protected Species (Turtles, Monk Seals) [18]	Sport Fishing	Lobster Fishery [21]	Bottomfish Fishery	Tourism
13				20			
				X			X
14				20	X	X	
						X	
					X	X	
15					X		
16							
				X	X	X	22
				X			22

13 Relatively large number of lobster in lagoon.

14 Pearl oysters.

15 *Cellana talcosa.*

16 Ark shell habitats, unique sponge species.

17 Atolls have the widest range of coral reef habitats in the NWHI.

18 Areas that have the highest numbers.

19 The '**X**' marks those areas that have the HIGHEST human use in each category.

20 Concerns exist about the recreational fishery at Midway expanding to Kure and Pearl and Hermes atolls.

21 Lobster fishery is currently closed.

22 Anecdoctal evidence suggests that boats from Kaua'i and O'ahu have taken people to Necker and Nihoa.

Jim Maragos/USFWS

Background photo: Jim Maragos/USFWS

NWHI 2000 & 2001 Expedition Participants and Support Staff

NOWRAMP is an active partnership involving 20 management agencies, resource trustees, research institutions, NGOs, and volunteers.

Bishop Museum

The BM provided staff, scientific and educational expertise, media equipment, web page support and data analysis for NOWRAMP.

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The DLNR provided staff, scientific expertise, educational and media support, equipment, permitting, data analysis, planning support and funding for NOWRAMP.

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National Ocean Service (NOAA)

The NOS provided staff, scientific expertise, equipment, satellite imagery, data analysis and funding for NOWRAMP.

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UH provided staff, scientific expertise, diving safety support, equipment, data analysis, planning support and funding (HCRI-RP) for NOWRAMP.

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U.S. Fish and Wildlife Service (DOI)

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Dave Johnson, *Refuge Manager. Island Survey Team (R).*
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Barabara Maxfield, *Public Information Officer- Shore-based Support.*
Dick Wass Ph.D., *Refuge Manager- Fish (TC)*

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Cal Hirai, *Professional Videographer. PIE Team (R).*
Rex VonArnswaldt, *Professional Videographer. PIE Team I (R).*

Background photo: Jim Maragos/USFWS

Webpages on the NWHI

NOWRAMP Website and NWHI Info:
http://www.hawaii.edu/ssri/hcri/NOWRAMP
http://explorers.bishopmuseum.org/NWHI
http://www.hawaiireef.noaa.gov

U.S. Fish and Wildlife Service

www.pacificislands.fws.gov
midway.fws.gov

NOAA

http://coralreefs.gov/
http://www.coralreef.noaa.gov
http://www.biogeo.nos.noaa.gov
http://www.hawaiireef.noaa.gov

State of Hawaii – Department of Land and Natural Resources

http://www.state.hi.us/dlnr/

University of Hawaii Botany Department

http://www.botany.hawaii.edu/ReefAlgae
http://www.botany.hawaii.edu/Invasives

Hawaii Coral Reef Initiative Research Program

http://www.hawaii.edu/ssri/hcri

National Marine Fisheries Service

http://atsea.nmfs.hawaii.edu
http://www.nmfs.hawaii.edu

Bishop Museum
http://explorers.bishopmuseum.org/NWHI
http://bishopmuseum.org/research/nwhi/index
http://hbs.bishopmuseum.org/hbsl.html

Other Resources

Certified Marine Expeditions
http://www.rapture-expeditions.com/

University of California at Santa Cruz
http://www.biology.ucsc.edu/people/potts/

Background photo: Jim Maragos/USFWS

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Acronyms & Abbreviations

BM- Bishop Museum
Co-PI- Co-principal Investigator
DLNR- Department of Land and Natural Resources
DOI- U.S. Department of the Interior
FAD- Fish Aggregation Device
FFS- French Frigate Shoals Atoll, NWHI
HCRI-RP- Hawai'i Coral Reef Initiative Research Program (UH)
JPL- Jet Propulsion Lab
MHI- Main Hawaiian Islands
mT- metric tons
NMFS- National Marine Fisheries Service (NOAA)
NOAA- National Oceanic and Atmospheric Administration
NOS- National Ocean Service (NOAA)
NOWRAMP- Northwestern Hawaiian Islands Reef Assessment and Monitoring Program
NWHI- Northwestern Hawaiian Islands
P & H- Pearl and Hermes Atoll, NWHI
PI- Principal Investigator
PIE- Public Information and Education
R- Certified Marine Expeditions Ship *Rapture* (NOWRAMP Research Vessel)
REA- Rapid Ecologoical Assesment
TC- NOAA Ship *Townsend Cromwell*
UH- University of Hawai'i
USFWS- U.S. Fish and Wildlife Service (DOI)

Special Acknowledgement

This document is dedicated to Kevin Flanagan, UH Assistant Diving Safety Officer and NOWRAMP Expedition Dive Officer aboard the *Rapture*. Kevin is currently recovering from a severe bout of cancer and is remembered by the entire NOWRAMP family as a person of integrity and caring who contributed greatly to both the safety and success of those involved in these expeditions.

Dave Gulko/DLNR

The Northwestern Hawaiian Islands are the last large-scale coral reef wilderness remaining on the planet and support the highest degree of unique reef species (about 25%) for any large coral reef ecosystem.

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