Papahānaumokuākea
Marine National Monument

NATURAL RESOURCES SCIENCE PLAN

2011-2015

PAPAHĀNAUMOKUĀKEA MARINE NATIONAL MONUMENT

NATURAL RESOURCES SCIENCE PLAN

April 2011

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Acronyms

AS	Alien Species Action Plan
CFO	Coordinated Field Operations Action Plan
DLNR	State Department of Land and Natural Resources
EAR	Ecological Acoustic Recorders
ESA	Endangered Species Act of 1973
FFS	French Frigate Shoals
FWS	U.S. Fish and Wildlife Service
HAMER	Hawai'i Archipelago Marine Ecosystem Research
HIMB	Hawai'i Institute of Marine Biology
HMC	Habitat Management and Conservation Action Plan
HURL	Hawai'i Undersea Research Laboratory
km	kilometers
LORAN	U.S. Coast Guard Long-Range Aid to Navigation
Management Plan	Monument Management Plan
MB	Migratory Birds Action Plan
MCS	Marine Conservation Science Action Plan
MD	Marine Debris Action Plan
MHI	main Hawaiian Islands
mi	miles
MMB	Monument Management Board
MMPA	Marine Mammal Protection Act of 1972
MOA	Memorandum of Agreement
Monument	Papahānaumokuākea Marine National Monument
MPAs	Marine Protected Areas
MTA	Maritime Transportation and Aviation Action Plan
nm	nautical miles

NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOWRAMP	Northwestern Hawaiian Islands Reef Assessment and Monitoring Program
NWHI	Northwestern Hawaiian Islands
OHA	Office of Hawaiian Affairs
ONMS	Office of National Marine Sanctuaries
P	Permitting Action Plan
PCBs	polychlorinated biphenyls
PMNM	Papahānaumokuākea Marine National Monument
Science Plan	Papahānaumokuākea Natural Resources Science Plan
TES	Threatened and Endangered Species Action Plan
USCG	U.S. Coast Guard
VS	Midway Atoll Visitor Services Action Plan


Photo: James Watt

Maro Reef.

1.0 Introduction

The Papahānaumokuākea Marine National Monument (PMNM, Monument) was established on June 15, 2006 by Presidential Proclamation 8031, creating one of the world's largest marine protected areas around the Northwestern Hawaiian Islands (NWHI). This Proclamation was the most recent in a series of executive orders issued over the last 100 years by six U.S. Presidents and one State of Hawaiʻi Governor to protect the outstanding ecological and cultural resources of the NWHI. The importance of protecting these unique values was further recognized through the inscription of the Monument as an UNESCO World Heritage site, for both nature and culture, on July 30, 2010.

The Monument's management is underpinned by its vision "to forever protect and perpetuate ecosystem health and diversity and Native Hawaiian cultural significance of Papahānaumokuākea." Formal responsibility for achieving this vision is shared by the State of Hawaiʻi, Department of Land and Natural Resources, (DLNR), the U.S. Department of the Interior, Fish and Wildlife Service (FWS), and the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), collectively named the Co-trustees. To coordinate management for Papahānaumokuākea at the field level, the Co-trustees signed a Memorandum of Agreement (MOA) on December 8, 2006, which established the Monument Management Board (MMB). This seven-member board includes two members from each of the Co-trustee agencies as well as the Office of Hawaiian Affairs. Additionally, the current management arrangements continue a long-standing tradition of active civic engagement in the protection and management of the NWHI by stakeholders from non-governmental organizations, academia, other government agencies, and the public. A coordinated framework for working together to achieve the Monument's vision is articulated by the Monument Management Plan (Management Plan) through six Action Plans for:

- Understanding and Interpreting the NWHI;
- Conserving Wildlife and Habitats;
- Reducing Threats to Monument Resources;
- Managing Human Uses;
- Coordinating Conservation and Management Activities; and
- Achieving Effective Monument Operations.

The Papahānaumokuākea Natural Resources Science Plan (Science Plan) is the first of a number of "step-down" plans called for in the Management Plan. The Science Plan aims to facilitate the Management Plan's goal for understanding and interpreting the NWHI, and to provide the information required to support management actions, such as managing threats, permitting activities, and evaluating the effectiveness of management efforts.

The Science Plan complements two related step-down plans which are under development: A Cultural Research Plan and a Maritime Heritage Plan. The forthcoming Papahānaumokuākea Cultural Research Plan will address priorities and methodologies for Native Hawaiian cultural research within and about the NWHI. Monument management operates under the policy that natural, cultural, and historic resources have equal value, and Native Hawaiians traditionally manage all natural resources as cultural resources. Both the Natural Science and the Cultural research plans seek to address management needs and concerns within Papahānaumokuākea, and while they are drafted and reviewed separately, the Management Plan expresses a goal of ultimate integration. The forthcoming Papahānaumokuākea Maritime Heritage Plan aims to facilitate an interdisciplinary understanding of historical resource use within the Monument. Through a focus on maritime archeology, historical ecology, and Native Hawaiian heritage, the Heritage Plan links to the Natural Resources Science Plan by facilitating research that informs our understanding of how past resource use has influenced the ecosystems being managed today.

Among the threats to Monument resources, the direct and indirect effects of climate change, including sea level rise, changing weather patterns, and ocean acidification, are significant, cross-cutting concerns. Current science suggests that climate change is likely to have profound effects on the NWHI's ecosystems and protected species; thus, understanding climate change impacts and adaptation options is reflected throughout the Science Plan. Additionally, the Monument offers a unique opportunity to understand climate variability and its impacts in the absence of confounding factors, such as human uses and pressures. The Science Plan aims to use this advantage to inform broader management efforts to support ecosystem resilience.

Overall, this Science Plan establishes a research and monitoring framework, and a prioritized list of research activities, to inform management of the Monument's natural resources. The Science Plan is organized into three sections:

- Section 1 provides an overview of the Monument, describes the purpose and scope of the Science Plan, and defines the Science Plan's primary stakeholders;
- Section 2 describes the process used to develop the Science Plan, including the information and data sources that informed its development;
- Section 3 presents the Research and Monitoring Framework developed for the Science Plan. It then describes the Monument's prioritized research needs under five themes, including their relationship to the Management Plan.

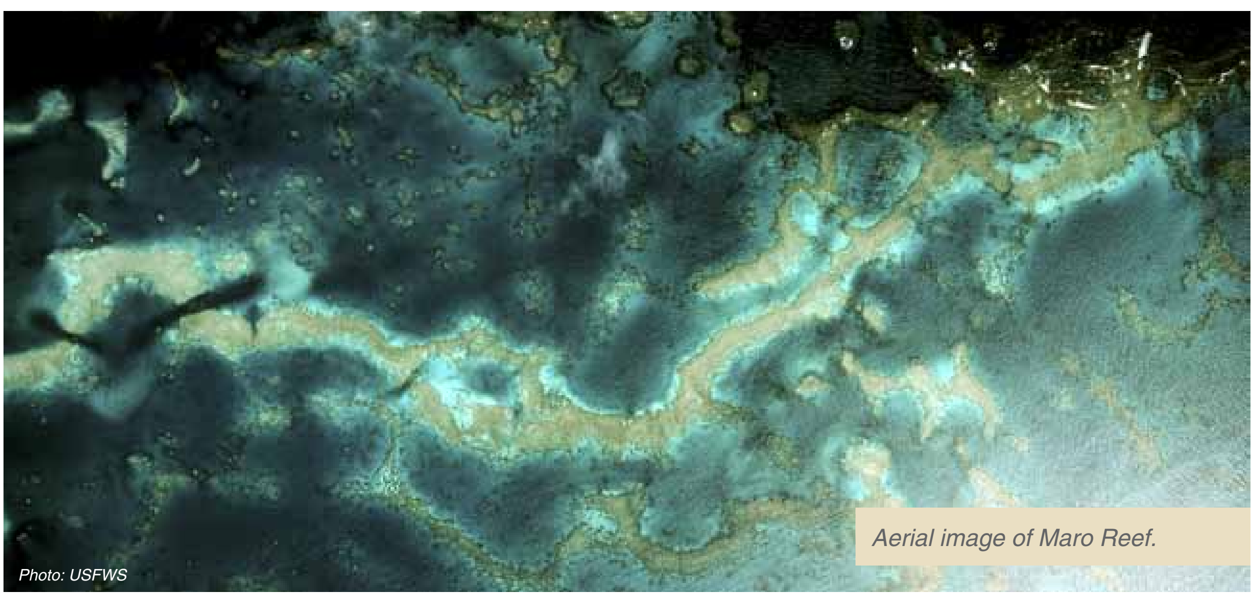


Photo: USFWS

Aerial image of Maro Reef.

1.1 Overview of the Monument

The Monument is situated in the northwestern portion of the Hawaiian Archipelago, located northwest of the Island of Kaua'i and the other main Hawaiian Islands (MHI) (Figure 1). A vast, remote and largely unexplored and uninhabited marine region, the Monument encompasses an area of approximately 139,793 square miles (mi^2) (362,061 square kilometers [km^2]) of Pacific Ocean. Spanning a distance of approximately 1,200 miles (1,043 nautical miles [nm] or 1,931 km), the 100-mile (87 nm or 161 km) wide Monument is dotted with small islands, submerged banks and reefs, and atolls that extend from subtropical latitudes to near the northern limit of coral reef development.

Formal scientific research has been ongoing in the NWHI for over 300 years and has undergone four historical phases (Grigg 2004). The discovery/naturalist phase was marked by massive sample collection followed by a second phase of synthesis. A third discovery and data collection phase was characterized by the use of new instrumentation and technology. Finally, the fourth and current phase is marked by another period of synthesis.

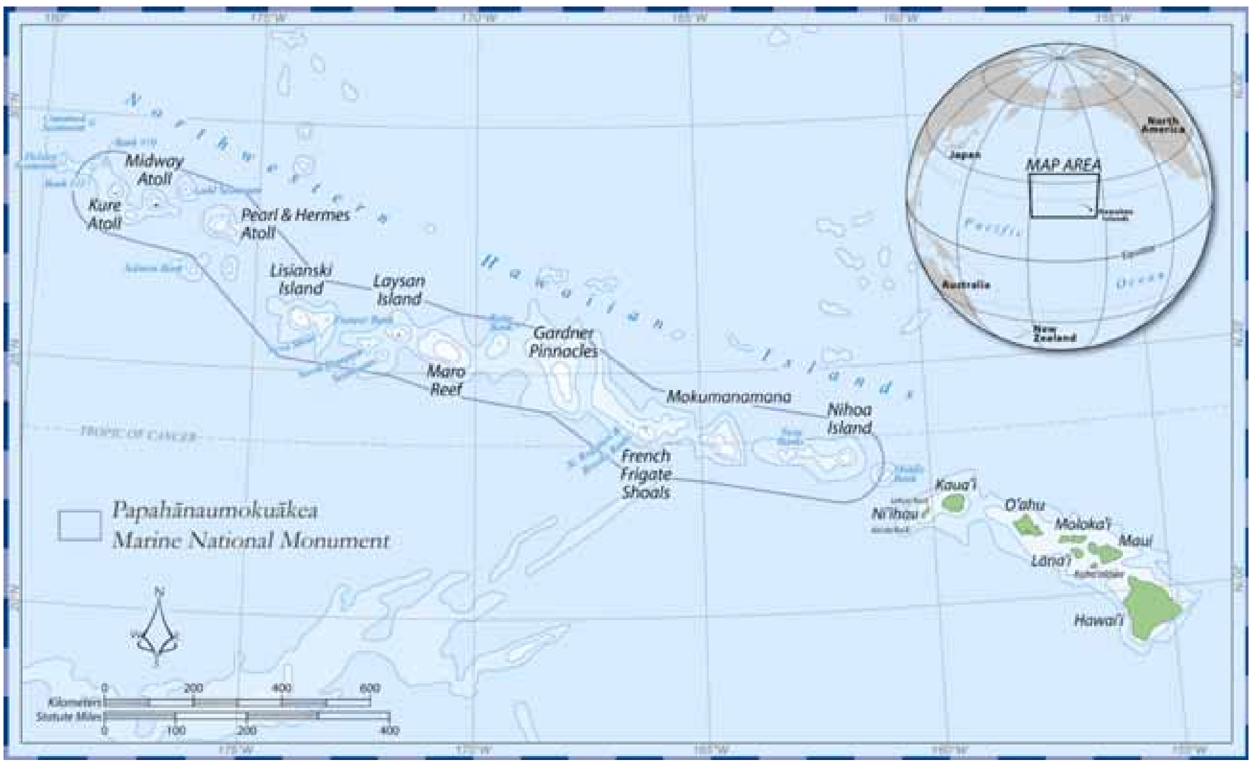


Figure 1. Map of the Papahānaumokuākea Marine National Monument

Management of the Monument is the responsibility of three Co Trustees: the State of Hawai'i, FWS, and NOAA. NOAA and FWS promulgated final regulations that provided the federal authority for the Monument under Title 50 Code of Federal Regulations Part 404 on August 19, 2006. These regulations codify the scope and purpose, boundary, definitions, prohibitions, and regulated activities for managing the Monument, and also codified the framework under which the State of Hawai'i would join with NOAA and FWS as a Monument Co-Trustee.

Access to the Monument is restricted and regulated through the issuance of permits. Proposed research and monitoring activities must be able to demonstrate that they meet specific criteria codified in 50 Code of Federal Regulations 404.11 to obtain a permit, as well as meet applicable criteria provided by relevant state statutes and regulations.

In addition, when the Co-Trustees signed a MOA on December 8, 2006, they established roles and responsibilities as well as coordination bodies and mechanisms for managing the Monument, including the MMB. The need for coordinated research and monitoring efforts to better understand and address major threats to Monument resources is highlighted in the MOA. The MOA also calls for joint resource assessment, monitoring, and research, including, but not limited to: population studies, species inventories and assessments, and studies of impacts from derelict fishing gear.

1.2 Purpose and Scope of the Plan

The Science Plan aims to provide the information required to effectively implement the Monument Management Plan. The NWHI consist of a complex assemblage of natural resources in relatively undisturbed condition compared with the MHI and many other marine-based ecosystems in the world (Friedlander et al. 2005). Protecting the health and integrity of these resources is a key priority for resource managers. Effective management decisions related to both resource use and protection must be based on reliable information on the biological characteristics of the organisms and habitats, their ecological relationships and an understanding of the natural temporal variations that characterize their ecosystems. In addition, the Monument represents a unique opportunity to improve management decision-making, to advance management-driven ecosystem science through research on ecosystem components and processes, and to develop models and other tools to predict ecosystem responses to natural and anthropogenic perturbations, such as climate variability and change, in the absence of confounding factors of human uses and pressures. The Science Plan characterizes research needs and activities to achieve these goals over the next 15 years, and outlines priorities for the next 5 years (2011 to 2015).

The Science Plan is not considered a static document. The proposed list of research topics in the Science Plan is not intended to be comprehensive or to preclude possible research activities not explicitly listed, but rather to illustrate the importance of relating proposed research activities to current information needs and management activities identified in the Monument Management Plan. Conserving and managing natural resources, especially in a globally changing climate, requires flexibility to adapt to unanticipated or evolving events. As conditions, resource status and knowledge bases change, Monument managers will use professional judgment and discretion to likewise adapt scientific needs. As new science needs arise, future research will be assessed with the same scrutiny and prioritization as proposed in this plan to ensure consistency in management efforts of this unique and special place. Managers will assemble on an annual basis to evaluate the current needs and prioritize any unexpected needs for the following year.

1.3 Stakeholders

The Science Plan serves as a guide for a broad range of stakeholders, including scientists, resource managers, the MMB, Monument's Co-Trustees, and the public. The Science Plan provides managers and scientists the means to direct scientific research toward finding answers to important resource management questions. Researchers from academic and research institutions can use the Science Plan to focus their research proposals on topics that are relevant to the management needs of the Monument.

The Science Plan will serve as a guide for the MMB to review and evaluate permit applications for research in the Monument. As new research proposals arise, this plan will be used by permit coordinators and others as a tool to evaluate research needs, merit, and applicability to management efforts. Managers will take into consideration the documented need for research in the applicant's request and use the Science Plan's focus areas and priority rating as tools to make determinations on research requests. Additionally, the Science Plan will serve as a driver for potential requests for additional research proposals as funding and access space arise.

2.0 Summary of Planning Process

The Science Plan prioritizes the research needed to inform management decision-making in the Monument, and it builds on extensive discussions, planning, and prioritization efforts conducted over the last 5 years. The Plan is based on the best available information and data, drawn from the published literature, reports, the Monument permit database, expert consultations, and the Monument Management Plan. The Science Plan was developed by a science planning team (Science Plan Team) composed of Monument managers, scientists, and other designated Co-trustee representatives, through the following steps:

- A 15-year research and monitoring framework was developed for the Science Plan, including themes and focus areas, building on the Hawai'i Archipelago Marine Ecosystem Research (HAMER) Plan and a comprehensive review of existing information;
- A public review of the Science Plan's proposed research and monitoring framework was conducted;
- Research profiles for ongoing and potential new research and monitoring activities were developed, based on review of permitted research and monitoring activities and input from scientists and managers;
- Research and monitoring gaps and needs were identified through comparison of existing research and the information needs identified in the Management Plan;
- Research and monitoring activities were prioritized by management needs; and,
- A public review of the draft Natural Resources Science Plan was conducted.

2.1 Development of a Research and Monitoring Framework for the Monument

The research and monitoring framework for the Science Plan is structured on the HAMER Plan (NOAA 2008), a long-term (10-year), cooperative, multi-agency plan focusing on living marine resources across the entire Hawaiian archipelago. The HAMER Plan was drafted, reviewed, and approved by the Co-trustees and other key agencies, and it was reviewed by an external, expert panel. Although this Science Plan was modeled after the HAMER Plan, it differs in a number of critical aspects (Table 1).

Table 1. Comparison of HAMER Plan and Science Plan

Plan Components	HAMER Plan	Science Plan
Geographic scope	Hawaiian archipelago-wide	Northwestern Hawaiian Islands only
Driving force	Understanding ecological function	Support of management issues
Activity completeness	Little to no overlap with existing research	Includes current research initiatives
Time Frame	10 years	15 years

In addition to the HAMER plan, key information sources used in the development of the science plan include:

- Papahānaumokuākea Monument Management Plan (2008)
- Quarterly Progress Reports of the Hawaiʻi Institute of Marine Biology – ONMS Pacific Region Partnership (2006 – current)
- Research permit database for the NWHI (2002 - 2008)
- State of Coral Reefs Ecosystems in the NWHI (2005)
- Information Needs for Conservation Science and Management of the NWHI (2004)
- NWHI 3rd Scientific Symposium (2004)

2.2 Public Review and Comment

Public scoping related specifically to the Science Plan was conducted in November of 2007. This process, along with the extensive public comment and scoping process associated with the development of the final Management Plan (TEC 2008) aided in finalization of Science Plan themes. These public review and public comment processes are done in part to satisfy related requirements contained in the National Environmental Policy Act and the State of Hawaiʻi's statutory environmental impact review process. In addition to these requirements, the scoping process's objectives also included:

- Helping constituencies gain a clear understanding of the purpose of the Science Plan.
- Developing preliminary focus themes for this Science Plan.
- Identifying opportunities for research that would contribute to better management of the Monument.
- Developing two-way communication with the public and science community to facilitate information sharing.
- Complying with the federal Council on Environmental Quality's, and the State of Hawaiʻi's Office of Environmental Quality Control's, rules and regulations to ensure stakeholder involvement throughout the planning process.

The Science Plan scoping period began with the publication of a Notice of Intent to prepare the Science Plan on November 6, 2007. The Co-Trustee agencies encouraged the public to submit comments through the conclusion of the scoping period on November 30, 2007. In addition, a public scoping meeting was scheduled in Honolulu on November 15, 2007. Prior to this meeting, advertisements were placed in local newspapers announcing the Co-Trustees' intent to prepare the Science Plan, providing the time, date, and location of the public scoping meeting, as well as the duration of the scoping comment period.

Forty-three members of the public attended the meeting and were encouraged to visit the poster stations, discuss the theme with experts, and provide written comments specific to each particular theme. Comment cards, color-coded by theme, were available at each station for the public to provide their comments. These comments were consolidated and summarized in the Science Plan scoping report (TEC 2008). The Science Plan theme "Human Impacts" generated the greatest number of comments (14), with many of these concerns being related to the impacts of research and the desire to place limits on the amount of scientific collections. Many statements advocated that extraction be limited or not allowed. Other comments focused on control and monitoring of research activities and assessment of long-term cumulative impacts. Marine debris and alien species introduction were issues identified for further research and management action. A few comments suggested the types of research that should be conducted within the Monument.

The TEC report (2008) concluded:

> *There were few substantive comments on the research themes and this may have been related to an unfamiliar scoping meeting format. Outside of the research themes, the relevant comments were largely supportive of research if it was prioritized, managed, monitored (short and long-term), met research goals, and was in support of better Monument management.*

A second request for public comment was sought for review of the Draft Natural Resources Science Plan in July 2009. This review period sought public input on the content and structure of the draft plan. Similar to the scoping process, the Draft Science Plan comment period began with a notice in the Federal Register on July 9, 2009. The Co-Trustee agencies encouraged the public to submit comments through the end of the comment period on August 10, 2009. Comments were sought via a variety of web and print media as well as two public meetings. The first public meeting was held on July 21, 2009 in Honolulu at PMNM's offices, and the second meeting two days later at Mokupāpapa Discovery Center in Hilo.

At each meeting, PMNM staff presented a short overview of the draft Science Plan and its content. Following the presentation, members of the public were encouraged to submit formal comment via testimony, oral tapings or written comments. A total of 21 people attended the public meetings, and three people gave testimony.

A total of 57 comments were received by 12 individuals/organizations on the draft Natural Resources Science Plan. The majority of these comments were in reference to the prioritization process used in the plan. Additional comments reflected proposed revisions and additional activities to be addressed in various sections of the plan. The final plan reflects appropriate changes requested via public comments as well as revisions requested by the MMB.

2.3 Profiling Ongoing and Potential New Research and Monitoring Projects

Profiles of ongoing and potential new research and monitoring projects were developed to characterize the range of projects conducted in the Monument. Projects described in the profiles were categorized by Science Plan theme and focus area and by Management Plan priority management need, strategy, and activity. This categorization was then used to develop a generalized list of research and monitoring activities from which to identify gaps and information needs (Section 2.4) and assign priority ratings (Section 2.5).

A template was developed to prepare the profile and summarize information on ongoing and potential new research and monitoring activities. The template contained five sections:

- Research/monitoring project title and description;
- Relationship of research/monitoring activity to Science Plan themes and focus areas;
- Location, methods, and timing of research/monitoring project;
- Potential impacts of research/monitoring project on natural/cultural resources; and
- Education and outreach associated with the research/monitoring project.

The first two sections of the template provided important information on what activities were occurring or proposed to allow for a comparison of the specific research needs of Monument managers. All sections of the template provided information useful in the preparation of the environmental assessment of the Science Plan, including location of research and monitoring activities, methodologies, and sample collection.

Templates were distributed to scientists and managers with experience or knowledge of the NWHI science and management issues to complete. A total of 116 templates were disseminated to individuals from FWS, the DLNR, U.S. Geological Survey, various NOAA agencies (National Marine Fisheries Service (NMFS) Pacific Islands Fisheries Science Center, NOAA Office of National Marine Sanctuaries, NMFS Pacific Islands Regional Office, Center for Coastal Fisheries and Habitat Research, NMFS Southwest Fisheries Science Center, and Center for Coastal Monitoring and Assessment), the University of Hawai‘i (Hawai‘i Institute of Marine Biology, Hawai‘i Undersea Research Laboratory, and departments of Botany, Zoology, and Oceanography), Bishop Museum, and other academic institutions (University of California Santa Cruz, Stanford University, Duke University, University of Miami, University of Maine, Saint Mary’s University, Texas A&M, and Wake Forest University).

Research and monitoring profiles were completed for 55 ongoing and potential new projects using the template. Information from the profiles was used to develop a generalized list of research and monitoring activities. This list was used to identify gaps and information needs for management decision-making and as the basis for prioritization of research and monitoring activities in the Science Plan.

2.4 Identification of Research and Monitoring Gaps and Needs

Profiles were used to develop a generalized list of ongoing and potential research and monitoring activities occurring in the Monument. This list of research and monitoring activities was categorized by Science Plan theme and focus area and then by Management Plan priority management need, strategy, and activity.

Monument staff reviewed the categorized research and monitoring activities to identify specific gaps and information needs to improve management decision-making in the Monument. The Management Plan served as a basis for identifying research and monitoring gaps and needs. In some cases, specific research and monitoring activities identified in the Management Plan were not included in the list, and therefore were added and categorized.

A total of 157 research and monitoring activities were compiled, sorted by research theme, and linked to strategies and activities from the Management Plan. This list of research and monitoring activities was reviewed and prioritized by a panel of MMB agency representatives (Science Plan Panel). This panel was composed of individuals selected to represent their agencies in the review and prioritization process. Through evaluations by the MMB and Science Plan Panel, the list of 157 research and monitoring activities was reduced to 97 activities. These activities reflect science needs the managers would like to ascertain information about to increase their understanding and enable them to better manage the Monument. The list of activities is by no means a compilation of all possible research; it is intended to specify actual information needs of the managers.

2.5 Prioritization of Research and Monitoring Activities

Prioritization of research and monitoring activities in the development of the Science Plan serves several important functions, including:

- Guiding the development of research and monitoring proposals by the scientific community that address priority management needs;
- Facilitating review and evaluation of specific research proposals for the NWHI for permitting by the MMB; and
- Providing the public with information on priority information and data needed to manage the natural resources of the Monument.

The primary focus of the Science Plan and resulting prioritization of research activities is to elucidate the value of research activities and their ability to better inform and enhance management efforts. The broad nature of proposed research activities is aimed to fill current knowledge gaps at a basic level, in which to provide managers with baseline information to make informed decisions in the face of future threats, including a changing climate. This plan is designed to act as a first step toward guiding research activities in PMNM and by no means is intended to broadly approve specific research agendas. Subsequent to this plan, proposed research activities will be subject to more detailed examinations of project merit and potential impacts via the Permitting Process (Figure 2). For information on the permitting process please visit Papahānaumokuākea's website at: http://papahanaumokuakea.gov/resource/permits.html

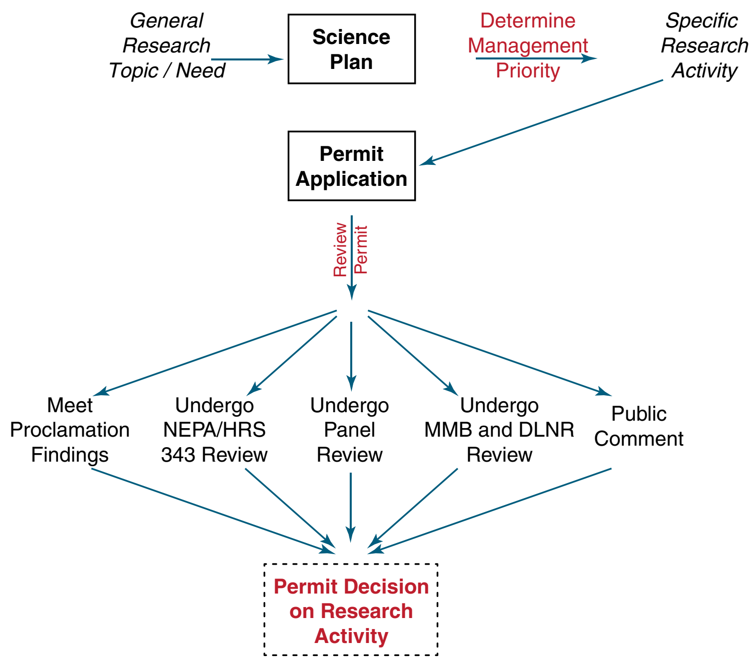


Figure 2. Proposed research flowchart

The list of 97 research and monitoring activities was reviewed and prioritized by the Science Plan Panel in February 2010. The Science Plan Panel was tasked to evaluate each activity based on its importance to the future protection and conservation of resources of the Monument. Research activities were initially evaluated to determine the criticality of conducting the research activity to the future protection and conservation of natural resources. Points were added to the initial rating if the activity supported legal mandates of one (or more) of the Co-trustees or strategies in the Management Plan. As climate change is one of the most significant threats to resources in the NWHI, an additional point was awarded if the activity directly enhanced knowledge regarding climate change. An overview of this prioritization process is provided in Figure 3. Science Plan Panel members were encouraged to conduct their own information needs assessment, which involved articulating priority needs in the form of a scientific question and identifying which Management Plan activities would be supported by the proposed research. This exercise led to a few additional proposed research activities, which were rated by the Panel.

Each Science Plan Panel member was asked to rate each of the research activities individually according to the provided prioritization scheme. The ratings of each member were aggregated and averaged to determine a consolidated numerical value. This value was then given a rating of "high," "medium," or "low" as previously determined by the prioritization scheme (refer to Average Rating column in Section 3 tables). If any agency deemed a research activity to be critical, this rating superseded any numerical value and retained its "critical" rating in the final document. Although the Monument operates as a single entity, panel members felt it important to still respect individual agency requirements or mandates. As such, if an activity was critical to any individual agency, the panel as a whole agreed that this activity should be given highest priority in the Science Plan.

In addition to rating each research activity, panel members were asked to assign timeframes in which the activity should be initiated. This temporal consideration helped to further prioritize research activities because knowledge from a particular activity could be deemed a high priority, while recognizing that the information may not be needed immediately. The "Timeframe" column in Section 3's tables reflects the time periods in which the activity should be initiated.

The Science Plan identifies activities that are needed to fulfill the mandates of the Monument's managing agencies. Due to the diverse mandates of the collective managing agencies, there are many stated research and monitoring needs that have been deemed critical in the Science Plan, and many of these activities are already on-going. For additional information on specific ongoing and past research and monitoring projects, please see the Monument's annual Permit Report documents (www.papahanaumokuakea.gov).

Research and monitoring priorities are listed in Section 3 by Science Plan theme and focus area. The tables include descriptions of the research activity, the averaged activity rating, the time frame when the activity should be implemented, and the Management Plan elements that the activity will support.

New research and monitoring needs are expected to emerge subsequent to adoption of the Science Plan. These activities will be reviewed and prioritized on a case-by-case basis. In addition, the Science Plan will be reviewed annually, and new research and monitoring will be identified, prioritized, and added, as needed, to effectively implement the Management Plan.

'Opihi monitoring transect.

Photo: NOAA

How important is the Research activity to the future protection and conservation of resources in the Monument

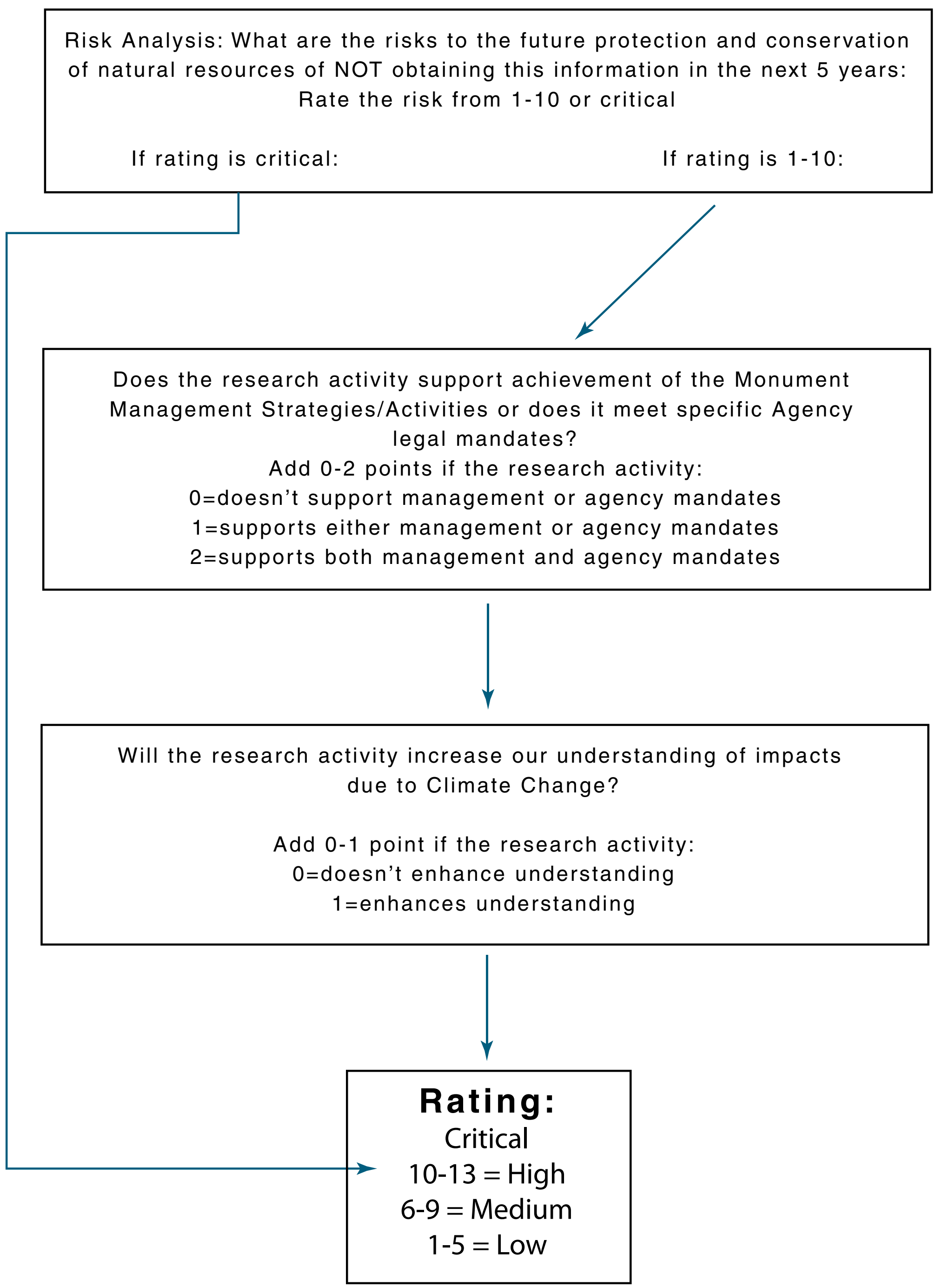


Figure 3. Prioritization process used for the Science Plan

3.0 Research Themes and Focus Areas

The 15-year framework for the Science Plan is presented as five research themes and associated focus areas. These themes are presented in a logical sequence beginning with the habitats and biodiversity of the NWHI and ecological processes and connectivity of these ecosystems. This discussion is followed by a sub-section covering the human impacts on those ecosystems. The next theme covers indicators and monitoring of ecosystem change, followed by modeling and forecasting ecosystem change. Within each of the five research themes, several focus areas split out the topics to more functional areas of effort. Overall, the Science Plan and the five themes can be considered as part of an ongoing process to "map," "monitor," and "model" the NWHI (Figure 4). All of these factors assist in the central objective to conserve and manage Papahānaumokuākea.

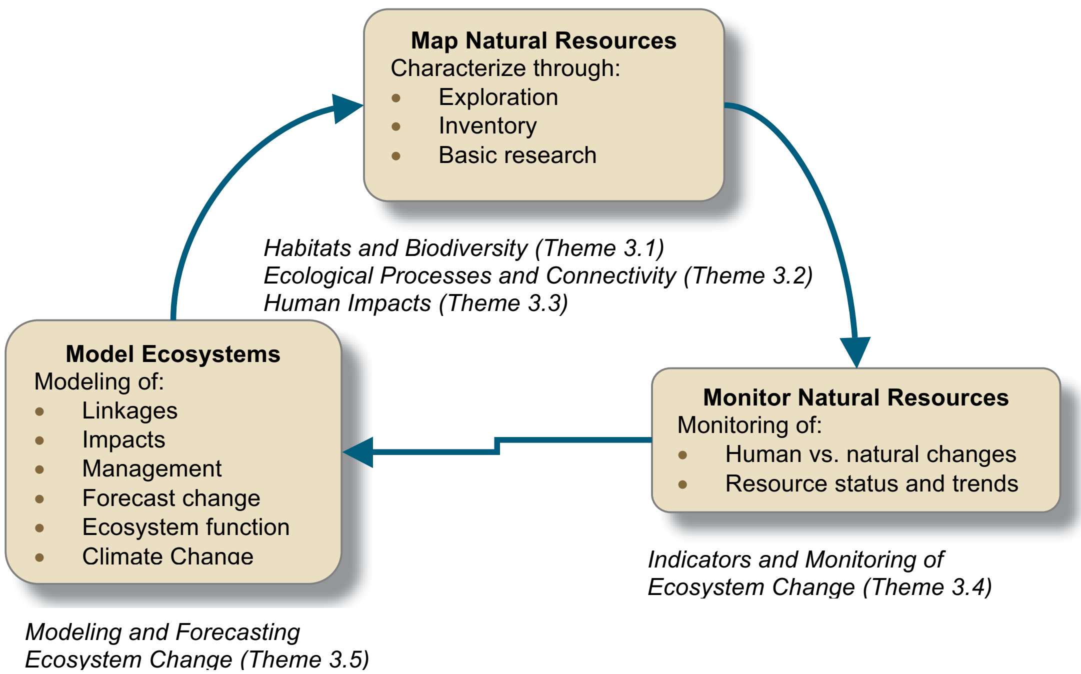


Figure 4. Research and monitoring process and related themes for the Science Plan

Each of the five themes – Habitats and Biodiversity, Ecological Processes and Connectivity, Human Impacts, Indicators and Monitoring of Ecosystem Change, and Modeling and Forecasting Ecosystem Change – are outlined in Section 3. A brief paragraph explaining the theme's importance is provided at the beginning of each sub-section and is followed by several focus areas. Each focus area contains four components:

1. Importance of focus area;
2. Index of management needs as defined by the MMP;
3. Current topical knowledge in the NWHI; and
4. Research needs and opportunities.

Together, these components provide an overview of management needs as well as previous, ongoing, and proposed research in the NWHI.

3.1 Habitats and Biodiversity

Unidentified coral species at French Frigate Shoals.

Proper conservation and management of the Monument requires an understanding of the biodiversity within the NWHI, as well as the physical habitats where this life resides. The intimate interconnections between habitats and biodiversity mean that science in the Monument needs to consider the linkages between these two ecosystem components. Biodiversity studies should include a consideration of key taxa that are fundamental to the functioning of ecosystems in the NWHI or that are part of the mandated responsibilities of Co-Trustees. Special focus will be given to research on native and protected species. This work requires a dynamic consideration of the health of studied species and populations, and the diseases and contaminants that affect them. It is also essential to characterize the diversity of habitats in the NWHI, to study processes of habitat change, and to consider the mechanisms by which biodiversity affects these habitats and these habitats affect biodiversity. This theme is especially challenging given the broad size of the NWHI archipelago relative to the current status of exploration and research. This theme is comprised of four focus areas: habitats, native biodiversity, specially protected species, and health and disease.

Climate change is expected to heavily impact the Monument's habitats and biodiversity (Mimura et al. 2007). For example, coral reef habitats have been damaged by bleaching events, which are linked to increases in sea temperatures (Carilli et al. 2010). Beach areas are reduced by rising sea level, which impacts all organisms that rely on beach habitat, including protected species such as the Hawaiian monk seal and green turtle (Baker et al. 2006, Fuentes et al. 2010a,b). Global temperature increases are thought to influence the occurrence and intensity of El Niño-Southern Oscillation (ENSO) events, which alter patterns of movement and reproduction in fish (Wang and Fiedler 2006) and seabirds (Friedlander et al. 2005). Secondary effects of climate change on biodiversity and habitats include increased turbidity, nutrient loading, and damage from extreme storms. Ocean acidification slows the growth rates of corals (Hoegh-Guldberg et al. 2007, Jokiel et al. 2008, De'ath et al. 2009). The coincident effects of rising sea level and slower growth diminish the value of the coral as structural habitat for the reef community (Hoegh-Guldberg et al. 2007). Evidence for the role of climate change in exacerbating coral disease is mounting (Baskett et al. 2010).

3.1.1 Habitats

This focus area is concerned with exploration, description and mapping of the terrestrial, shallow-water and deep-water habitats of the NWHI, in order to form the basis for a geo-referenced catalog of the habitats. A description and understanding of the habitats and their spatial distribution will establish a habitat baseline for the NWHI. This baseline is essential as an anchor for monitoring change within the ecosystem, understanding natural fluctuations, and providing a gauge to measure management efforts to protect, maintain, and restore native habitats and the biodiversity that depends on these habitats. Despite the level of scientific study conducted to date, most of the NWHI remains relatively unexplored, not only for deep water habitats, but also for many shallow water habitats.

Functional relationships among the habitats, organisms, and abiotic processes of the NWHI ecosystems are not well understood. Supporting and facilitating research into such topics is one of the essential management tasks in the NWHI. In addition, the activities in this focus area support numerous national and international research activities. For example, coral reef habitats will be mapped in partnership with NOAA, the FWS, the U.S. Geological Survey, the Smithsonian Institution, the American Museum of Natural History, Bishop Museum, various local, regional and international institutions, and the State of Hawai‘i to support the U.S. Coral Reef Task Force's mandate to develop shallow-water coral reef ecosystem maps for all U.S. waters.

Strategies in the Monument Management Plan of Relevance to Habitat Research and Monitoring

Conserving Wildlife and Habitats:
Habitat Management and Conservation Action Plan

- HMC-1: Within 15 years, develop and implement a strategy for restoring the health and biological diversity of the shallow reefs and shoals where anthropogenic disturbances are known to have changed the ecosystem, using best available information about pre-disturbance conditions.
- HMC-2: Within 10 years, investigate and inventory sources of known contamination from historical human uses of the NWHI and, where appropriate, coordinate with responsible parties to develop plans and complete cleanup actions.
- HMC-3: Protect and restore beach strand and crest habitats over the life of the plan.
- HMC-4: Within 10 years, restore and maintain coastal mixed grasses and shrubs on all the coralline islands and atolls of the Monument using best available historical information about the original indigenous ecosystem.
- HMC-5: Within 10 years, restore and maintain coastal mixed grasses and shrublands on basalt islands in the Monument.
- HMC-6: Maintain and better understand the Monument's wetland and mudflat habitats to benefit migratory shorebirds and waterfowl for the life of the plan.
- HMC-7: Maintain, enhance, and, where appropriate, develop freshwater seeps, intermittent streams, and freshwater ponds as necessary for the benefit of native species for the life of the plan.
- HMC-8: Maintain no more than 150 acres of ironwood woodlands on Sand Island, Midway Atoll, to provide seabird nesting and roosting habitat for the life of the plan.
- HMC-9: Protect and maintain 120 acres of vertical rocky cliff-face habitat at Nihoa and Mokumanamana for nesting seabirds for the life of the plan.
- HMC-10: Fulfill wilderness stewardship responsibilities in the Monument within 5 years.

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Current knowledge

The Northwestern Hawaiian Islands Reef Assessment and Monitoring Program (NOWRAMP/ NWHI RAMP) was initiated by NOAA and FWS in 2000 to characterize and monitor the coral reefs of the NWHI using a consistent set of sampling protocols to establish a baseline for future data gathering and monitoring change over time. NWHI RAMP surveys conducted on an annual basis since 2000 have provided managers with a baseline of floral and faunal abundance and distribution, oceanographic data collection, and sediment contaminant studies.

NOAA has also led a significant mapping effort using satellite imagery, multi-beam sonar, and other remote sensing methods to provide detailed maps of the shallow and deep-water features of the Northwestern Hawaiian Islands. The *Draft Atlas of the Shallow-Water Benthic Habitats of the NWHI* (NOAA 2003) was developed through a partnership with NOAA, the State of Hawai‘i, the University of Hawai‘i, FWS, and Analytical Laboratories of Hawai‘i. NOAA published the *Bathymetric Atlas of the NWHI* (Miller et al. 2004) in 2004. These documents begin to describe the marine habitats and bathymetry of the NWHI and establish important baseline information for resource managers. Efforts are under way to collect more data for groundtruthing to further refine and complete these characterizations.

The mosaic of benthic habitats in the Monument consists mostly of coral-dominated areas, stretches of hard-bottom, algal-dominated meadows, and vast expanses of unconsolidated sediments such as sand and mud inhabited by few benthic infauna where water is less than 20 meters deep. Deeper benthic habitats have not been well-studied (Maragos et al. 2009). On most islands in the Monument, coral cover on the fore reef is highest along the northwest, north, or northeast sectors; the pattern is different at Lisianski/Neva Shoal, where the coral cover is highest in the southwest (Maragos et al. 2009).

Less extensive, but no less important, were exploratory research efforts during the 2006 NWHI RAMP surveys and Census of Marine Life surveys that revealed many new and undescribed species, not only at FFS where most of the search effort was concentrated, but also at virtually all of the other islands within the Monument. A new discovery of the table coral *Acropora* was made in the southwest spur-and-groove habitat at Pearl and Hermes Atoll and off the shallow southeast fore reef at Neva Shoal (Maragos et al. 2009). These studies revealed that dozens of corals and other invertebrates and likely comparable numbers of algal species remain unknown, undescribed, likely endemic, and possibly very rare and vulnerable. Given the paucity of exploratory research to date relative to the large area

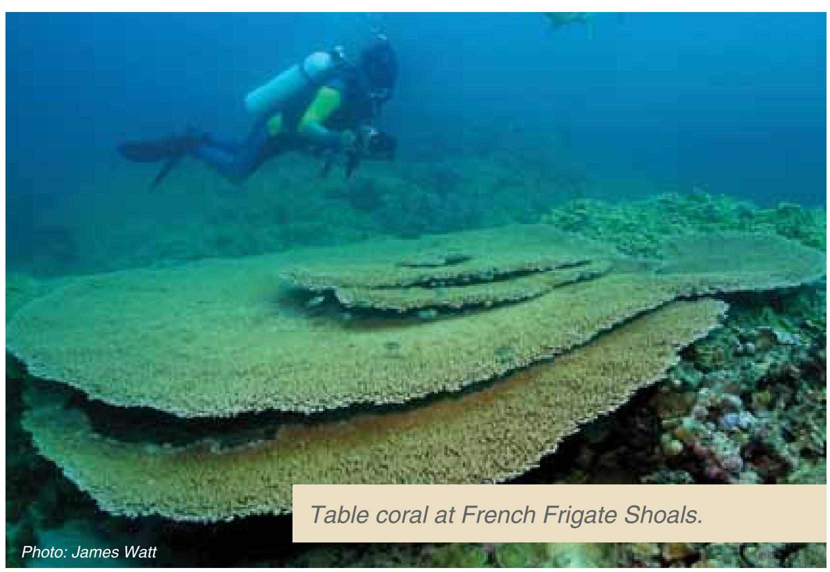
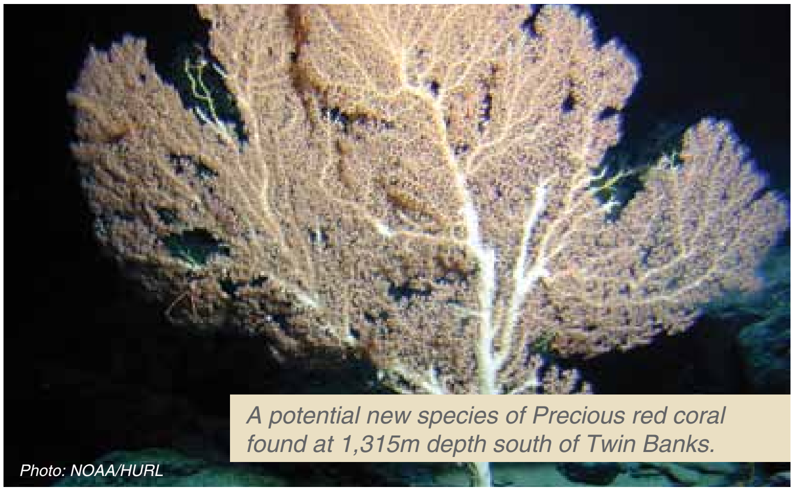


Table coral at French Frigate Shoals.

Photo: James Watt



A potential new species of Precious red coral found at 1,315m depth south of Twin Banks.

of the NWHI, little information is available on the extent of these unknown species and their habitats. From a management perspective, any species that is unknown, in essence, does not exist, and programs designed to protect them cannot be executed.

NOAA, in partnership with the University of Hawai‘i's Hawai‘i Undersea Research Laboratory (HURL), has begun cursory investigations into the deep sea to document and describe the habitats and associated flora and fauna. Similar to the Census of Marine Life project, these investigations have revealed dozens of new records of fish, and new species and records of corals and other invertebrates.

Scientists from HIMB have participated in multiple research cruises in the Monument since 2005. Research activities addressed a variety of topics including (1) biogeographic characterization of habitats; (2) acoustic monitoring of sharks to evaluate habitat use, particularly with respect to interactions with monk seals; (3) exploration of mesophotic reefs (30 – 150 meters depth); and other habitat-based studies (HIMB 2009).

A "Condition Report" produced for the Monument (ONMS 2009) provides an evaluation of habitat status and trends. Both deep-sea and shallow-reef habitats are in generally good condition; however, shallow areas have been impacted by threats that originate beyond the boundaries of the Monument, including derelict fishing gear, marine debris, and coral bleaching. Derelict fishing gear is particularly damaging to table coral, which has a limited distribution and is in decline. Declines in table coral are exacerbated by outbreaks of coral diseases, *Acropora* white syndrome and *Acropora* growth anomalies (Work et al. 2008). Although existing levels of habitat loss or alteration may preclude full development of living resource assemblages, these impacts are "unlikely to cause substantial or persistent degradation in living resources or water quality" (ONMS 2009, page 23). However, global perturbations such as increasing rising sea temperatures and sea level pose significant threats to marine habitats, especially in shallow waters (ONMS 2009). Another threat to habitat that limits predictions about future habitat quality is increased ocean acidification, which has the potential to degrade the coral reefs that provide structural habit for entire communities.

Sea surface temperature fronts have an important but poorly understood role in the Monument's ecosystems. A frontal system forms where water masses converge, causing a complex pattern of downwelling and upwelling flow. The unique environment created by the fronts tends to support high biological diversity, ranging from phytoplankton to zooplankton to marine birds and mammals. Apex predators rely on frontal areas to provide forage as they migrate through the North Pacific. NOAA has proposed using remotely sensed data to track sea surface temperature fronts across remote areas over time in an effort to understand their role in supporting the Monument's ecosystems (Desch et al. 2009).

In 2009, NOAA produced imagery of the geologic and benthic habitat information available as of January 2009, for each emergent island in the NWHI. Images were based on IKONOS satellite imagery and multibeam data analyses. At present, imagery is suitable for mapping about 50 percent of the shallow-water area (from 0-30 m) (Weiss et al. 2009). Research, monitoring, and management would all benefit from additional mapping of shallow-water benthic habitat.

Terrestrial habitats at the NWHI have been described in terms of their importance to native and protected species. For example, the Laysan Island Restoration Plan details the biological history of the island's habitats and lays out a plan for ecological restoration of habitat structure and function. This plan includes restoration of plants, terrestrial arthropods, and avian components of the biological community that occurred at Laysan Island before human contact and the loss of many of the island's species. Similar planning and restoration activities are under way at Pearl and Hermes, Midway, and Kure Atolls. Other important terrestrial habitats include the rocky cliff-face habitat at Nihoa and Mokumanamana Islands for bird nesting, the beach strand and crest habitat, the coastal mixed grasses and shrubs on all of the coralline islands, the mixed grasses and shrubs on the basaltic islands, and the mudflat and wetland habitats in the Monument that are important for migratory shorebirds and waterfowl as well as endemic endangered land and water birds. While some of these habitats have been well mapped, data gaps exist in several key areas for these important terrestrial habitats.

Research needs and opportunities

Table 2. Prioritized list of research activities needed to further understanding of habitats in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Habitats and Biodiversity				
Habitats				
Describe intertidal zone community structure and habitat types to establish baselines.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1
Determine habitats utilized by protected species to further enhance their conservation and protection by maintaining or improving important habitats.	Critical	6 to 10 years	Conserving Wildlife and Habitats	TES-1.3 TES-3.2 TES-3.3 TES-6.1 HMC-3.1 HMC-4.7 HMC-5.2
Evaluate translocation potential for non-marine avifauna and terrestrial plants and invertebrates.	Critical	10 plus years	Conserving Wildlife and Habitats	HMC-7.1
Use a combination of remote sensing, acoustic, optical, and diver data collection techniques to characterize and map shallow water (<30 meters) benthic habitats to establish baselines.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Habitats and Biodiversity				
Habitats				
Use a combination of acoustic, optical, and diver data collection techniques to characterize and map deep water (>30 meters) benthic habitats to establish baselines.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.3 MCS-1.4
Use a combination of acoustic, optical, and diver data collection techniques to describe fish and invertebrate communities in deep waters (>30 meters) to establish baselines.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.3 MCS-1.4
Describe the community structure of deeper reefs (60-150 meters) to establish baselines.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.3 MCS-1.4
Determine distribution of species within habitats to gain insight into how the marine ecosystem functions and what habitats are necessary for key species to prosper.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4
Characterize, map, and monitor for changes in the terrestrial habitats for plant, vertebrate, invertebrate and microbial species.	Medium	1 to 5 years	Conserving Wildlife and Habitats	HMC-3.1 HMC-3.2
Characterize and monitor for changes in the terrestrial plant, vertebrate, invertebrate and microbial species by habitats.	Medium	6 to 10 years	Conserving Wildlife and Habitats	TES-6.1 TES-7.5 MB-1.2 HMC-4.2 HMC-4.5
Characterize, map and monitor pelagic ecosystems to determine hotspot potentials.	Medium	6 to 10 years	Understanding and Interpreting the NWHI	MCS-1.3 MCS-1.4


Hawaiian green turtle.
Photo: James Watt


Sooty terns.
Photo: Kittipong Janthasang

3.1.2 Native biodiversity

This focus area is concerned with systematic exploration of the NWHI flora and fauna to characterize the richness, diversity, and life history of native species. Maintaining the native species and populations of the NWHI is essential to ensure ecosystem stability and integrity, and for the sustainable management of the ecosystem for future generations. However, many marine species have yet to be described in the NWHI, especially corals, other invertebrates, algae, and deep-water communities. Primary goals are to inventory, map, and assess native species as the basis for improving management. Part of this focus area will be to identify sites of high diversity ("hot spots") and highlight rare species that may be vulnerable and require protection. Understanding the ecological role of key native species in the NWHI and safeguarding this biodiversity will help maintain ecosystem stability. To gain a full ecosystem understanding of biodiversity, exploration would also need to extend to deep-water habitats.

Information in this focus area will help to document native biodiversity, and to understand the role that native species play in maintaining a stable ecosystem. Information on life history and habitat requirements will help assess population vulnerability and provide the basis for restoration efforts. Some species that require protection may also need to be evaluated for threatened or endangered status and protection of critical habitat in accordance with the Endangered Species Act (ESA). Additionally, biodiversity "hot spots" will be characterized to help develop effective management strategies.


Japanese anglefish.

Photo: James Watt


Endemic Nihoa Finch.

Photo: Wayne Levin


Spinner dolphins.

Photo: James Watt

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF RELEVANCE TO NATIVE BIODIVERSITY RESEARCH AND MONITORING

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Conserving Wildlife and Habitats:
Threatened and Endangered Species Action Plan

- TES-5: Conduct activities to increase Laysan duck populations in the Monument over the life of the plan.
- TES-6: Maintain stable or increasing populations of the Laysan finch, Nihoa finch, and Nihoa millerbird in the Monument over the life of the plan.
- TES-7: Establish populations of each listed plant species on one to three additional Monument islands and ensure genetic material is also protected in approved repositories for the life of the plan.
- TES-8: Ensure protection of threatened and endangered species by facilitating Endangered Species Act consultations for Monument activities throughout the life of the plan.

Migratory Birds Action Plan

- MB-1: Protect and enhance habitats for terrestrial and marine migratory birds throughout the life of the plan.
- MB-4: As threats are removed, restore seabird species at sites where they have been extirpated.

Habitat Management and Conservation Action Plan

- HMC-4: Within 10 years, restore and maintain coastal mixed grasses and shrubs on all the coralline islands and atolls of the Monument using best available historical information about the original indigenous ecosystem.
- HMC-5: Within 10 years, restore and maintain coastal mixed grasses and shrublands on basalt islands in the Monument.
- HMC-6: Maintain and better understand the Monument's wetland and mudflat habitats to benefit migratory shorebirds and waterfowl for the life of the plan.
- HMC-7: Maintain, enhance, and, where appropriate, develop freshwater seeps, intermittent streams, and freshwater ponds as necessary for the benefit of native species for the life of the plan.
- HMC-9: Protect and maintain 120 acres of vertical rocky cliff-face habitat at Nihoa and Mokumanamana for nesting seabirds for the life of the plan.
- HMC-10: Fulfill wilderness stewardship responsibilities in the Monument within 5 years.

Current Knowledge

With the establishment of the Hawaiian Islands Reserve in 1909, native birds were the first wildlife species in the NWHI to be managed for conservation by the U.S. Government. Early protection was important to ensure that stable populations of native seabirds, shorebirds, passerines, and ducks were maintained at a time of intense exploitation. Selected seabird colonies in the NWHI have been monitored by the FWS and the State of Hawaiʻi for decades. These monitoring activities will continue to be a high priority for managers.

In 2009, the Monument was recommended for consideration as a World Heritage Mixed Site, partly in recognition of the high degree of endemism in both marine and terrestrial flora and fauna (Keller et al. 2009). The Monument boasts one of the world's last apex predator dominated ecosystems, where sharks and jacks control their prey as they did elsewhere before humans depleted their numbers (Friedlander et al. 2009a). The Monument also supports the largest tropical seabird rookery in the world.

A school of Pacific chub in the waters of Midway Atoll.

From 1992 to 2000, NOAA Fisheries conducted quantitative monitoring of reef fishes in the NWHI as part of its Monk Seal Forage Base Study. In 2000, the NOWRAMP was established to assess the entire resource base (including biodiversity) at all 10 emergent reefs and shallow (less than 20 meters) shoals within the NWHI. This ecosystem-level assessment is a multi-agency partnership through NOAA, the Hawai‘i Coral Reef Initiative, and FWS. Results from past and ongoing expeditions can be obtained from a variety of sources (Maragos and Gulko 2002; DeFelice et al. 2002; DeMartini and Friedlander 2004; DeMartini et al. 1996, 2002, 2005; Friedlander and DeMartini 2002; Maragos et al. 2004; Friedlander et al. 2005; Brainard et al. [CoML report]; Friedlander et al. 2008).

In addition to shallow water reef monitoring, NOAA is initiating a Mesophotic reef monitoring program. The Mesophotic reefs (30-100 meters in depth) are home to numerous fishes, corals and other invertebrates and constitute an integral portion of the marine ecosystem. Mesophotic reefs are not well-studied anywhere, but are thought to serve as sources of organisms to recolonize shallow reefs following disturbance. In August, 2009, the first technical diving survey of the Monument’s deep reefs recorded four species of black corals that were previously unknown in the area (HIMB 2009).

NOAA, in partnership with the University of Hawai‘i’s HURL, has begun cursory investigations to document and describe the biodiversity of the deep sea. Similar to the Census of Marine Life project, these investigations have revealed dozens of new species of fish, corals and other invertebrates. Most of the marine mammals in the Monument, including the Hawaiian monk seal, forage in very deep water, increasing the importance of monitoring and managing these essential resources (ONMS 2009).

Research needs and opportunities

Table 3. Prioritized list of research activities needed to further understanding of native biodiversity in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Habitats and Biodiversity				
Native species				
Identify new terrestrial species and records for the NWHI to enhance knowledge and further conservation efforts.	Critical	1 to 5 years	Conserving Wildlife and Habitats	HMC-5.1
Use a combination of optical and diver data collection techniques to collect ecosystem monitoring data, including new marine species and records for the NWHI.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-2.1
Use a combination of optical and diver data collection techniques to collect ecosystem monitoring data, including fish reproduction, growth and size distribution data to provide the scientific basis for improved management of fish stocks and fisheries.	Medium	6 to 10 years	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.5
Use a combination of data collection techniques to collect ecosystem monitoring data, including invertebrates such as corals and lobsters.	Medium	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.2
Monitor physical and biological parameters associated with freshwater seeps and ponds.	Medium	1 to 5 years	Conserving Wildlife and Habitats	HMC-7.1

3.1.3 Specially protected species

This focus area is concerned with the study of special status species in the NWHI to promote their population growth and recovery. Although this subject also covers non-endangered animals protected by the Marine Mammal Protection Act (MMPA) and Migratory Bird Treaty Act — for example, spinner dolphins and Laysan albatross — the majority of the science is driven by the federal mandate of the ESA to fulfill individual endangered species recovery plans and protect their critical habitat. These include recovery plans for monk seals, sea turtles, short-tailed albatross, Laysan duck, passerine birds, baleen whales, sperm whales, and a number of plant species. The role of some species is more conspicuous than others, and because of the uncertainty in how the ecosystem as a whole works, protecting vulnerable species and their habitat is a key strategy to maintaining overall ecosystem function.

Basic research on population structure and dynamics and understanding the threats to the status of the species are expected to help managers in making decisions that promote the population growth and recovery of protected species.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF RELEVANCE TO SPECIALLY PROTECTED SPECIES RESEARCH AND MONITORING

Conserving Wildlife and Habitats:
Threatened and Endangered Species Action Plan

- TES-1: Support activities that advance recovery of the Hawaiian monk seal for the life of the plan.
- TES-2: Determine the status of cetacean populations and verify and manage potential threats over the life of the plan.
- TES-3: Ensure that nesting populations of green turtles at source beaches are stable or increasing for the life of the plan.
- TES-4: Work with the international recovery team for short-tailed albatrosses to facilitate an increase in the total breeding population of this species to at least 25 breeding pairs occurring on sites other than Torishima and Senkaku islands for the life of the plan.
- TES-5: Conduct activities to increase Laysan duck populations in the Monument over the life of the plan.
- TES-6: Maintain stable or increasing populations of the Laysan finch, Nihoa finch, and Nihoa millerbird in the Monument over the life of the plan.
- TES-7: Establish populations of each listed plant species on one to three additional Monument islands and ensure genetic material is also protected in approved repositories for the life of the plan.
- TES-8: Ensure protection of threatened and endangered species by facilitating Endangered Species Act consultations for Monument activities throughout the life of the plan.

Reducing Threats to Monument Resources:
Marine Debris Action Plan

- MD-1: Remove and prevent marine debris throughout the life of the plan.
- MD-2: Investigate the sources, types, and accumulation rates of marine debris within 5 years.

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Current knowledge

The NWHI is home to at least 40 endangered or threatened species from five different groups. The status and research in each group is summarized below.

Hawaiian Monk Seal: The Hawaiian monk seal population is in decline, with only about 1,200 monk seals remaining. (ONMS 2009) Modeling predicts that the species' population will fall below 1,000 animals by the year 2012. In spite of more than two decades of efforts to manage, study, and recover the species, actions to date have not been sufficient to produce a recovering population (Antonelis et al. 2006; Parrish and Abernathy 2006). The monk seal metapopulation can be divided into six major and two smaller subpopulations in the NWHI and one in the MHI (Littnan et al. 2009). Variability in population dynamics among the subpopulations is attributed to both natural environmental conditions and human disturbance (NMFS, 2007). French Frigate Shoals currently supports the largest monk seal colony in the NWHI, but this subpopulation is expected to decline in the

A curious Hawaiian monk seal at Kure Atoll.

Photo: James Watt

next few years because of imbalances in the age structure (Littnan et al. 2009). Recent work by Schultz and her colleagues at HIMB demonstrated weak population structure in the monk seal, suggesting that individuals may be relocated from one area to another without compromising genetic structure (HIMB 2009). Meyer and Holland of HIMB are investigating predation by the Galapagos shark (*Carcharhinus galapagensis*) on Hawaiian monk seal pups at FFS. The study focuses on understanding seal pup predation dynamics, with attention to the potential for shark culling as a means to reduce pup mortality (HIMB 2009). Monk seals may be further threatened by increasing sea level, which may reduce available resting habitat as beaches become inundated (ONMS 2009).

Two humpback whales.

Photo: HIHWNMS/NOAA Fisheries MMHSRP Permit #932-1489

Cetaceans: In the NWHI, sightings and acoustic recordings of baleen whales as well as smaller dolphins have been documented. Five species of baleen whales are listed as "Endangered" under the ESA, and as "Depleted" under the MMPA. In addition to these five endangered or depleted species, at least 19 other species of whales and dolphins are legally protected under the MMPA and are found in the NWHI for all or part of the year. Hawaiian spinner and bottlenose dolphins are year-round residents of the Monument. Other species, such as the spotted dolphin and humpback whale, make use of the NWHI as part of their migratory life cycles (ONMS 2009). Johnston et al. (2007, cited in ONMS 2009) identified important wintering ground of the humpback whale in the NWHI.

Ongoing passive acoustic monitoring of ambient sounds using Ecological Acoustic Recorders (EARS) documented that Maro Reef and Lisianski Island are apparent 'hot spots' of humpback whale activity (Lammers et al. 2009, cited in HIMB 2009). Singing patterns from December through April indicate that north Pacific humpback whales overwinter at the Monument. Separate studies have suggested that humpback whales from the Bering Sea may be breeding in an unidentified area in the central north Pacific (Calambokidis et al, 2008). The HIMB team is evaluating the acoustic records from the Monument to determine the likelihood that the MHI and the NWHI populations are continuous (HIMB 2009).

Overall, management actions and efforts to reduce the impacts to cetaceans in the NWHI have been limited, based on the sparse species information available (Andrews et al. 2006).

Marine Turtles: Marine turtles documented in the NWHI include the green and loggerhead (listed as threatened), and the hawksbill and leatherback (listed as endangered). Sea turtle populations have declined across the Pacific because of nesting habitat loss,

Hawaiian green turtle under the pier at Midway.

Photo: James McFall

harvesting eggs and turtles for commercial and subsistence purposes, and fishery interactions. Research has been conducted on the green turtle nesting population in the NWHI since 1973 and represents one of the longest time series of nesting abundance data for any sea turtle population. The Hawaiian green sea turtle stock is showing signs of recovering after more than 25 years of protecting their nesting and foraging habitats in the Hawaiian Archipelago (Chaloupka et al. 2008). About 90 percent of the green sea turtles in the Hawaiian Islands nest in the NWHI, the majority on a few islets at FFS (Balazs and Chaloupka 2006) that are now threatened by rising sea levels linked to climate change.

Migratory Birds: The majority of all tropical seabirds in Hawai‘i nest in the Monument, and these breeders plus an equal number of species of non-breeding seabirds transit through or forage in the waters of the Monument. Seabird colonies in the NWHI constitute one of the largest assemblages (14 million birds and 22 species) in the world. More than 95 percent of the world's Laysan and black-footed albatross nest here. Statute and policy at several levels mandate the protection and management of migratory bird populations in the Monument. International treaties, domestic legislation, executive orders, state law, and FWS policy require the conservation of these species. Breeding populations across the NWHI were last surveyed in 1984. Recent surveys focused on three islands (Midway Atoll, Laysan Island and Nihoa) show most species are stable or increasing, with the exception of red-tailed tropicbirds, which appear to be in decline at Midway Atoll due to low adult survivorship at sea (Arata et al. 2009, Klavitter et al 2009, Laniawe 2008). High-quality breeding habitat, low predation risk, and low disturbance conditions support these populations, despite the less than perfect conditions they may encounter when foraging outside the Monument (Keller et al. 2009). However, some seabirds, like the albatrosses, may be adversely affected by climate change, longline fishing, food shortages, contaminants, ingestion of plastics, and other processes beyond the boundaries of the Monument. Potential threats to seabirds within the Monument include negative interactions with introduced species, overgrowth of nesting habitat by alien plant species, loss of nesting habitat to sea level rise, and ingestion of lead-based paint chips (Keller et al. 2009). In addition, foraging seabirds are harmed by marine debris and surface pollutants (ONMS 2009).

Sooty tern chick on Mokumanamana.

Endangered Birds: Five bird species occurring in the NWHI are protected under the ESA. Three of these are songbirds: the Laysan finch (Laysan Island and Pearl and Hermes Atoll) and the Nihoa finch and the Nihoa millerbird, (both endemic to Nihoa Island). The range of the Laysan duck is the most restricted of any duck species in the world and so is especially vulnerable to extinction because of its small population size (less than 1,000 ducks). In 2004 and 2005, 42 Laysan ducks were translocated to Midway Atoll National Wildlife Refuge. The translocation was successful in establishing Laysan ducks at Midway Atoll and, as of

April 2010, the population numbers approximately 473 ducks (USGS unpub. data). In 2008, endangered short-tailed albatross were observed on Kure Atoll (one), Midway Atoll (four), and Laysan Island (one).

Plants: Six plant species known historically from the NWHI are listed as endangered. The ohai, *Sesbania tomentosa*, is present on Nihoa and Necker Islands. *Mariscus pennatiformes* spp. *bryanni* is known only from Laysan Island. *Cenchrus agrimonioides* var. *laysanensis* was historically known from Laysan Island and Midway and Kure Atolls, but has not been seen there since about 1980. The *Amaranthus brownii* and *Schiedea verticillata* species are endemic to the NWHI and are currently restricted to Nihoa Island. The loulu fan palm is also endemic to the NWHI and historically occurred on Nihoa and Laysan. The Nihoa species, *Pritchardia remota*, is thought to be different from the now-extinct Laysan species, *Pritchardia* spp. (Athens et al. 2007). The Nihoa species has been replanted on Laysan Island to replace the now-extinct Laysan species.


Photo: Wayne Levin

Loulu palm on Nihoa.

Research needs and opportunities

Table 4. Prioritized list of research activities needed to further understanding of protected species in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Habitats and Biodiversity				
Specially protected species				
Monitor and characterize Galapagos shark predation on Hawaiian monk seal pups at French Frigate Shoals and evaluate different techniques (i.e. deterrents, removals, translocations) to decrease pup mortality.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES-1.2 TES-1.6
Develop strategies that can enhance the survival of female monk seals to increase recruitment into breeding class.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES-1.2
Model potential effects of climate change on terrestrial species that are either protected, dominant or keystone.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES-1.3 TES-3.2 TES-3.3

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Habitats and Biodiversity				
Specially protected species				
Determine diet and foraging behavior of monk seals using a variety of techniques and correlate that with ongoing prey abundance studies and environmental monitoring.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES-1.2
Determine important habitats (terrestrial and marine) for monk seals using a variety of observing and telemetry techniques.	Critical	1 to 5 years	Understanding and Interpreting the NWHI and Conserving Wildlife and Habitats	MCS-1.5 TES-1.2 TES-1.3
Examine monk seal diet to determine prey species and variation in diet and compare to other apex predators or fisheries.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES 1.2
Examine monk seal condition, survival, foraging behavior and diet and compare between populations of seals.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES 1.2
Examine biocontaminants in blood and other tissues to determine presence and load of these chemicals and assess their impacts to monk seals.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES 1.2
Design and implement translocation plans (moving seals from areas of lower to areas of higher survival) to increase survival in juvenile monk seals.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES-1.2 TES-5.2 TES-6.2 TES-7.1 TES-7.2 TES-7.3 TES-7.5
Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Characterize and monitor populations of green turtles nesting and foraging in the NWHI through surveys, tagging, and modeling of existing data.	High	1 to 5 years	Conserving Wildlife and Habitats	TES-3.1
Conduct studies of seabird trophic interactions and foraging and how they relate to demographic and population traits.	Medium	10 plus years	Conserving Wildlife and Habitats	MB-3.1 MB-3.2
Determine habitats utilized by cetaceans to further enhance their conservation and protection by maintaining or enhancing important habitats.	Medium	6 to 10 years	Conserving Wildlife and Habitats	TES-2.1
Conduct studies of population demography on cetaceans.	Medium	1 to 5 years	Conserving Wildlife and Habitats	TES-2.1

3.1.4 Health and disease

This focus area is concerned with understanding the effect of disease on NWHI biodiversity. It will be important to identify the diseases present in the area, with a priority focus on diseases that affect protected and endemic species. Understanding the effects on the health of species and populations of the NWHI ecosystem is an integral part of safeguarding biodiversity at the NWHI and maintaining a sustainable ecosystem. As the NWHI is considered one of the last relatively pristine large coral reef ecosystems remaining in the world, it provides the unique opportunity to document the normal levels of disease in a coral reef system exposed to limited human influence.

Research on health and disease at the NWHI is expected to help maintain biodiversity by establishing a baseline for the presence of disease and allowing managers to identify and minimize the impacts of a disease outbreak. Additionally, research in this area will provide managers with the tools to establish a disease monitoring program to detect and stop the spread of new diseases in the NWHI.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF RELEVANCE TO HEALTH AND DISEASE RESEARCH AND MONITORING

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Conserving Wildlife and Habitats:
Migratory Birds Action Plan

- MB-2: Minimize the impact of threats to migratory birds such as habitat destruction by invasive species, disease, contaminants (including oil), and fisheries interactions for the life of the plan.

Current knowledge

Past research on marine health and disease at the NWHI has included work on coral and reef fish disease and avian botulism (Work et al. 2002; Aeby 2006). Aeby (2006) reported tumors on *Acropora* as well as lesions associated with parasites, bacteria, and fungi on a number of different coral species. The most common disease was *Porites trematodiasis* caused by a digenetic trematode. Additionally, past research on reef fish disease identified the introduced blue striped snapper (ta‘ape), *Lutjanus kasmira*, as a vector for protozoal and epitheliocystis-like infections (Work et al. 2003).

In the marine environment, health and disease research has been conducted on corals, coral symbionts, and fish. Although levels of coral disease in the NWHI are much lower than elsewhere in the Indo-Pacific (Aeby 2006a), table coral has been infected by both *Acropora* white syndrome and *Acropora* growth anomalies (Work et al. 2008), diseases which may be spreading from Johnston Atoll (ONMS 2009). Studies have been conducted to examine the effects of white syndrome and growth anomalies on *Acropora* reproductive output (Aeby and Work 2007), as well as the role of biodiversity in influencing coral disease outbreaks and outcomes in *Acropora* white syndrome (Aeby, in HIMB 2009). Additional research has evaluated disease resistance among individual *Porites lobata* at the FFS and genetically diverse colonies of *Pocillopora damicornis* at FFS and PHA (Karl, in HIMB 2009). Further studies have comparatively assessed the diversity of bacteria associated with healthy and health-compromised corals at the NWHI (Salerno et al. 2007), and the diversity of the coral endosymbiont *Symbiodinium* and its role in coral disease susceptibility (Stat and Gates 2007). For example, Stat and Gates (2007) have identified an association between *Symbiodinium* clade A and a higher incidence of disease.

It has been suggested that the introduced ta'ape brought a parasitic nematode into the NWHI. To examine this, nineteen goatfish (*Mulloides flavolineatus*) from Johnston Atoll, which has not yet been invaded by ta'ape, were examined for disease. Although goatfish did harbor other types of gut parasites, no nematode infections were documented. These findings support the hypothesis that the nematode was introduced into Hawai'i by ta'ape (HIMB 2007).

Work et al. (2010) identified avian botulism type c as the primary cause of mortality of 159 Laysan ducks on Midway Atoll in 2008. Avian pox virus (*Poxvirus avium*) is a mosquito-borne disease that forms lesions on about 50 Laysan albatross chicks at Midway Atoll each year (J. Klavitter pers. comm.). Although pox does not negatively affect fledging success, it can cause bill and skull deformities in severe cases (Young and VanderWerf 2008). Studies have yet to be conducted on the long term effects of avian pox on albatross.

Research needs and opportunities

Table 5. Prioritized list of research activities needed to further understanding of native resource health and disease in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Habitats and Biodiversity				
Health and disease				
Determine the presence of high risk diseases and potential catastrophic emerging diseases and develop vaccinations as appropriate.	Critical	6 to 10 years	Conserving Wildlife and Habitats	TES 1.2
Determine the various impacts of marine diseases on host species and the surrounding community to evaluate effects at an ecosystem-wide scale to further understand impacts to biodiversity and ecosystem functioning.	Critical	6 to 10 years	Understanding and Interpreting the NWHI	MCS-1.2
Determine how marine diseases spread to find possible mitigation/eradication methods, allowing managers to maintain ecosystem health.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.4 MCS-2.1
Investigate occurrence, severity, and impacts of diseases in populations of green turtles nesting and foraging in the NWHI.	Medium	6 to 10 years	Conserving Wildlife and Habitats	TES 3.1
Study disease and disease control and monitor for occurrences and outbreaks in avifauna and terrestrial plants.	Medium	6 to 10 years	Understanding and Interpreting the NWHI	MCS-1.1

3.2 Ecological Processes and Connectivity

The islets, reefs, and atolls that make up the NWHI cannot be considered as isolated units; nor can the NWHI be considered in isolation from the MHI. These systems are intimately linked and affect one another. Major sources of connectivity include oceanic and atmospheric processes, passive transport of biota and nutrients via currents and upwelling, active transport of animals through movement and migration, and the dynamics of population groups. The study of energy flow through the system by understanding trophic relationships and food webs is also a primary component of this theme. These factors are major drivers of the health, productivity and resilience (the ability of ecosystems to absorb and recover from change) of these ecosystems. Understanding the major processes that affect and connect the components of the NWHI and how these managed ecosystems affect the surrounding areas is fundamental to effective management of the Monument.

The principles that define ecological processes and connectivity operate in all parts of the world, regardless of local climate or condition. For example, nutrient transfer occurs in all communities. However, the specific types of processes that dominate in a given location are influenced by local and global climatic conditions. Current research on the ways in which climate change affects ecological processes includes the effect of sea temperatures on ENSO, and the unexpected balancing effect of the Pacific Decadal Oscillation (Hilbish et al. 2010); the effects of climate change on trophic transfer (Eriksson-Wiklund et al. 2009); and changes in distribution and abundance of key species, with subsequent community effects (Cheung et al. 2009, 2010). The physical, chemical, and biological perturbations that are initiated by climate change are expected to have an increasingly negative effect on marine resources around the world, as well as on the human populations that are linked to those resources economically and culturally (Halpern et al. 2008). A similar analysis of anticipated impacts at the Monument concluded that processes related to climate change posed the greatest threat to coastal and nearshore resources (Selkoe et al. 2008).

3.2.1 Oceanographic and atmospheric processes

The health, functioning, biogeography and biodiversity of the NWHI are significantly influenced by the area's oceanographic and atmospheric conditions and processes (for example, vertical and horizontal water movements, waves, storms, temperature, salinity, turbidity, and nutrients). Physical oceanography and associated biological processes connect the various components of the NWHI with each other and link the NWHI with the MHI and other parts of the Pacific region. The importance of these oceanographic processes is not limited to the marine environment, for it greatly affects the terrestrial environment by influencing the ecology of organisms that routinely move between land and sea (seabirds). The most fundamental aspects of oceanography and connectivity to be understood include the temporal and spatial patterns of water exchange, both horizontal and vertical movements. This understanding can lead to information on the effects of these currents on regional primary productivity, sea temperature, ocean chemistry, and other parameters critical to ecosystem health and functions in an archipelagic setting such as the NWHI. Understanding oceanographic processes and atmospheric conditions can lead to developing a unified hydrographic model that will serve as a basis for modeling and forecasting important processes and impacts, such as the transport of nutrients, larvae, and marine debris to, from, and within the NWHI and identifying the sources and sinks of larval populations.

The effect of this research will be, among other things, to create a basis for understanding, modeling, and forecasting important inputs to the NWHI, such as the transport of nutrients, larvae, and marine debris to, from, and within the NWHI and identify the sources and sinks for larval populations. It will also help to understand changes in weather patterns and storm events and their impacts on island ecosystems. Understanding these processes is an essential basis for improved management of the ecosystem overall and protected species and critical areas in particular. Through this knowledge managers will be better able to understand and predict the effects of climate change and their relation to potential management actions to conserve species and habitats.

Strategies in the Monument Management Plan of Relevance to Oceanographic and Atmospheric Research and Monitoring

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Reducing Threats to Monument Resources:
Marine Debris Action Plan

- MD-2: Investigate the sources, types, and accumulation rates of marine debris within 5 years.

Current knowledge

Previous and ongoing research and monitoring programs have addressed basic weather parameters of precipitation, temperature, and winds, as well as a wide range of water quality and chemistry parameters, circulation patterns, and oceanographic characteristics through a variety of means. In particular, a number of studies have been undertaken to understand oceanographic processes and transport in the NWHI as the basis for developing oceanographic circulation models and transport models. Oceanic productivity modeling has demonstrated clear spatial patterns in ocean productivity but has been unable to trace the path of the energy flow into the community. Transport models have identified large-scale patterns in ocean circulation but need to establish the sources and sinks for larval populations.

Biological ecosystems in the Monument are shaped by oceanographic processes, including ocean currents, waves, nutrients, temperature, and other measures of water quality. Boreal winter storms and significant wave events affect the distributions of corals, algae, and their associated animal assemblages (Desch et al 2009). Much of what is known about the oceanographic conditions in the NWHI comes from NOAA's shipboard Acoustic Doppler Current Profilers and satellite remote sensing data (Desch et al. 2009). Wave power varies on both annual and decadal temporal scales, allowing the range of sensitive species to expand and contract over time. Long-term data on sea surface temperature, which varies with latitude, indicates that the Monument's ten management regions fall naturally into three latitudinal subgroups (Desch et al. 2009). Remotely-sensed ocean color data demonstrates that low chlorophyll (low productivity) ocean water has expanded worldwide, and now occurs at the

NWHI. Further expansions of oligotrophic waters threaten the photosynthetic underpinnings of marine food webs (Desch et al. 2009).

Research needs and opportunities

Table 6. Prioritized list of research activities needed to further understanding of oceanographic processes in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Ecological Processes and Connectivity				
Oceanographic processes				
Determine sources of marine primary productivity that drive food chains to better understand and protect mechanisms of ecosystem functioning.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4
Track tidal movements for long-term monitoring to assess large-scale changes to the environment.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1
Track weather information for long-term monitoring to assess large-scale changes to the environment.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1

3.2.2 Passive transport of nutrients and living resources

The movement of water masses into, out of, and within the NWHI plays a major role in ecosystem health, functioning, biogeography, and biodiversity. The diversity and abundance of living resources and the productivity and health of NWHI marine ecosystems depend on ocean currents and upwelling that transport larvae and nutrients. The passive transport of nutrients and living resources that results from horizontal currents and vertical water movements (upwelling) is fundamental to marine ecosystems. This passive transport is important at many scales — from that of an individual atoll up to the scale of physical oceanographic processes that link the NWHI with the MHI and other parts of the Pacific region. Horizontal and vertical water movements are key drivers of primary productivity, sea temperature, acidity and other fundamental parameters of ecosystem health and productivity. The temporal and spatial patterns of these water movements in relation to biological processes (such as spawning and recruitment events) are critical to the distribution, abundance, and health of species and populations.

Shoreline at Laysan.

Photo: James Watt

Addressing these kinds of research issues will enable managers to understand temporal and special patterns of productivity as well as larval dispersal and recruitment and create management areas based on sources, sinks, and transport pathways.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF RELEVANCE TO PASSIVE TRANSPORT OF NUTRIENTS AND LIVING RESOURCES RESEARCH AND MONITORING

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Conserving Wildlife and Habitats:
Habitat Management and Conservation Action Plan

- HMC-1: Within 15 years, develop and implement a strategy for restoring the health and biological diversity of the shallow reefs and shoals where anthropogenic disturbances are known to have changed the ecosystem, using best available information about pre-disturbance conditions.

Current knowledge

Water movements and oceanographic characteristics have been documented and monitored in a number of previous and ongoing studies and programs. Some of these programs have been undertaken to understand oceanographic processes and transport in the NWHI as the basis for developing oceanographic circulation models and transport models. Modeling has identified large-scale patterns in ocean circulation and clear spatial patterns in ocean productivity. Additional work is required to trace nutrient and energy flows, as well as establishing the sources and sinks for larval populations.

Patterns of connectivity within and among the Hawaiian Islands are being studied using a biophysical model to simulate coral dispersal between reefs under a variety of conditions: strong El Niño, strong La Niña, and neutral. The northwestern islands were shown to be constantly and strongly connected by dispersal. In some seasons, larvae may disperse from Johnston Atoll to the mid-Hawaii archipelago. High-resolution ocean current data and computer simulation suggested that pelagic larval transport occurs between adjacent islands, regardless of larval duration; longer larval periods increase the connectivity between non-adjacent islands. Based on larval transport modeling, the Monument seems to be largely self-sustaining, with differences among islands explained by their location with respect to larval sources. Species with short larval periods settle on Nihoa, Middle Bank, Ni‘ihau and Kaua‘i from both within the Monument and the MHI, but do not cross from the northernmost NWHI to areas farther south, or vice versa. However, species with longer

‘Opihi, Hawaiian limpets.

Photo: NOAA

larval periods (90 days) are transported across essentially the entire Hawaiian Archipelago (Friedlander et al 2009b).

Researchers at HIMB have recently completed a study of rice corals across the Hawaiian Archipelago that demonstrates limited larval exchange between the far Northwest and central portions of the Monument, and between the Monument and the MHI. However, substantial larval exchange between Johnston Atoll and Lisianski Island indicates the need for a single management unit that extends beyond the formal boundary of the Monument (HIMB 2009).

Research needs and opportunities

Table 7. Prioritized list of research activities needed to further understanding of passive transport in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Ecological Processes and Connectivity				
Passive transport of nutrients and living resources				
Use remote sensing as well as in-situ observations and instrumentation to monitor, alert, model, and report environmental and biological phenomena influencing and associated with marine ecosystems.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1

3.2.3 Active transport and movement of living resources

Marine or terrestrial organisms travel or migrate into, out of, and within the NWHI on a regular or periodic basis. This active transport has important effects on population abundance and dispersal. Some species movements and migration patterns may occur in relation to various biological and environmental variables (for example, prey abundance, temperature, lunar or tidal cycles, thermoclines, and bottom topography). Other movements may be more episodic, for example as a result of extreme weather events. There may be critical habitats or resources that are important in determining the movement of organisms, such as bird nesting habitat. The migration and episodic movement of key species within the NWHI are important to understanding the connectivity between islands and atolls. The movement of biota into and out of the NWHI drives the linkages of these species and populations with the MHI and other parts of the Pacific region. This information is critical to delineating the range, distribution and threats of the species and populations occurring in the NWHI as a basis for their management.

The expected outcome of research into these issues is improved management of these populations and the resources and habitats upon which they depend, for example, identifying critical habitat needed by key species in the NWHI that may be sensitive to human impact and environmental change.

Strategies in the Monument Management Plan of Relevance to Active Transport and Movement of Living Resources Research and Monitoring

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Conserving Wildlife and Habitats:
Threatened and Endangered Species Action Plan

- TES-1: Support activities that advance recovery of the Hawaiian monk seal for the life of the plan.
- TES-2: Determine the status of cetacean populations and verify and manage potential threats over the life of the plan.
- TES-3: Ensure that nesting populations of green turtles at source beaches are stable or increasing for the life of the plan.

Managing Human Uses:
Permitting Action Plan

- P-2: Track and monitor permitted activities and their impacts.

Current knowledge

Research undertaken to date on active transport of species into the NWHI involves mark and recapture studies as well as passive tracking studies with the use of satellite tags or a network of fixed acoustic monitoring stations. Specific studies on the movement of organisms into and within the NWHI include mark and recapture of albatross (Anderson et al. 2006, see USFWS action plan for complete references) as well as spinner dolphins (Karczmarski 2005), and satellite tracking of endangered species (monk seals) (Parrish and Abernathy 2006) and top predators (sharks and jacks) (Lowe et al. 2006). Acoustic telemetry of jobfish (a snapper) and giant trevally (a jack) demonstrated site fidelity (Meyer et al., 2007a, b). These large predatory fish moved within the atoll toward channels and reef passes to spawn, but did not wander from one atoll to another. Ongoing research includes the use of satellite tags and a network of 23 fixed acoustic monitoring stations at nine NWHI locations and 50 stations in the MHI to monitor top marine predators (sharks and jacks) implanted with acoustic tags (Meyer and Holland 2007). Data from these listening stations will be analyzed in relation to various environmental and biological factors (including those affected by anthropogenic activity) to identify the factors that may influence movement of target species. Satellite and geolocator tags are currently deployed on Laysan and black-footed albatross and red-tailed tropicbirds on Kure Atoll, Midway Atoll, and FFS to understand breeding and non-breeding season movement patterns (J. Klavitter pers. comm.). Like albatross, with their far-ranging distribution, most breeding seabirds face threats outside the NWHI and are in great need of study.

Other ongoing studies that document the movements and population trends of breeding seabird species in the NWHI include long-term, at-sea surveys conducted by NOAA and others (see publications by Balance, SWFSC). Many seabird species are not sufficiently monitored at the breeding colonies; therefore, increases and changes in population size are detected from data collected at-sea in their foraging ranges.

Long-term trends in biological and anthropogenic activities in the Monument have been monitored using non-intrusive passive acoustic methods since 2006. In September 2006, four Ecological Acoustic Recorders (EARs) were deployed at French Frigate Shoals, Pearl and Hermes, and Kure. Three additional EARs were installed at Maro Reef, Lisianski Island, and Midway, and a second unit was deployed at Pearl and Hermes, in September, 2008 (HIMB 2009).

Research needs and opportunities

Table 8. Prioritized list of research activities needed to further understanding of active transport/movement of resources in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Ecological Processes and Connectivity				
Active transport and movement of living resources				
Monitor exchange of monk seals between subpopulations and the MHI using photo-id, telemetry and other techniques.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES 1.2
Support research to investigate movements and habitat use of predatory Galapagos sharks at French Frigate Shoals	Critical	1 to 5 years	Understanding and Interpreting the NWHI and Conserving Wildlife and Habitats	MCS-1.5 TES-1.2 TES-1.6
Determine what scales apex predators operate at to better understand their impacts to marine communities and how to protect these highly mobile species.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.5
Assess marine turtle movements and migrations within the NWHI and between the MHI, Johnston Atoll, and NWHI through biotelemetry, tag returns, and sightings.	High	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.5
Determine home ranges of various fish species to better understand their role/function in the ecosystem, and to determine the scale at which protection is best implemented.	Medium	6 to 10 years	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.5

3.2.4 Population dynamics and genetic structure

Genetic studies of flora and fauna can compare the similarity or differences of the genetic material between populations of species at various locations across the NWHI. These studies create the potential to quantify the relative connectivity between populations at discrete sites as well as the continuum of the flow of genetic material across the entire archipelago. These kinds of genetic studies can produce data on the thousands of different species found in the archipelago, regardless of life history traits and reproductive strategies. These data inform our understanding of population dynamics and connectivity patterns within the NWHI, and between the NWHI, the MHI, and with other parts of the Pacific region. Studies of genetic structure are often the only method that can provide insights into population size and gene flow rates for many species. The value and certainty of genetic studies are well documented, and these studies can provide unbiased and extensive data to help understand issues such as life history traits and the impacts of genetic bottlenecks on species. These results contribute to the improved understanding of the ecosystem and sound management decisions, for example, on identifying species groups that need stricter protection and locating sanctuary areas.

The expected output from research to address genetic structure and population dynamics will be improved understanding of species level biodiversity in the NWHI as a basis for effective management and conservation, especially when linked with information on passive transport and active movement of organisms.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF RELEVANCE TO POPULATION DYNAMICS AND GENETIC STRUCTURE RESEARCH AND MONITORING

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Conserving Wildlife and Habitats:
Threatened and Endangered Species Action Plan

- TES-2: Determine the status of cetacean populations and verify and manage potential threats over the life of the plan.
- TES-3: Ensure that nesting populations of green turtles at source beaches are stable or increasing for the life of the plan.
- TES-7: Establish populations of each listed plant species on one to three additional Monument islands and ensure genetic material is also protected in approved repositories for the life of the plan.

Current knowledge

Genetic studies began in the waters of the NWHI when fishery managers needed to know whether larval dispersal in commercial bottomfish populations allowed for these stocks to be classified as an archipelago-wide or a discrete population. Since 2000, a number of genetic studies on a wide variety of species have been conducted that address many different questions. Studies of corals at FFS indicate connectivity between Johnston Atoll, 900 miles south of the NWHI. This information will aid managers in understanding the resilience of species to disease and bleaching events. Likewise, genetic studies on discrete spinner dolphin pods from the Big Island to Kure Atoll assisted in understanding how these populations behave and how they should be managed (Andrews et al. 2008).

Ongoing projects compare genetic connectivity across the archipelago and provide an understanding of individual movement and larval dispersal on an ecosystem scale, as well as genetic differentiation within individual island ecosystems. Preliminary studies on the biological connectivity of fish and invertebrates in the NWHI indicate that dispersal is highly species dependent. Genetic analyses of species distribution have shown strong differentiation in the absence of obvious geographic barriers, suggesting more restricted movement of larvae and the possibility that local adaptation may be an important aspect in the ecosystem. These findings have profound implications for marine resource management and may help explain the high degree of species endemism that is not seen in any other tropical marine ecosystem of comparable size.

The population structure and genetic history of black-footed albatross and Laysan albatrosses have been studied by Walsh and Edwards (2005) and Young and VanderWerf (2008). In addition to the information on the demography and life history of these species, these data are also useful in determining the provenance of birds killed during commercial fishery operations.

Selkoe and others at HIMB developed and tested statistical methodology and a framework for "interdisciplinary seascape genetics" to build predictive models of connectivity in the NWHI based on biogeographic, oceanographic and genetic data (HIMB 2009).

Research needs and opportunities

Table 9. Prioritized list of research activities needed to further understanding of population dynamics and genetic structure in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Ecological Processes and Connectivity				
Population dynamics and genetic structure				
Utilize genetic analyses to identify maternity of monk seal pups to increase the accuracy of reproductive rate estimates for population monitoring purposes.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES 1.2
Use molecular tools to assess the genetic structure of marine turtle populations nesting and foraging in the NWHI and to investigate changes in population dynamics over time.	Medium	6 to 10 years	Understanding and Interpreting the NWHI	MCS-1.5
Determine if there are multiple distinct populations of cetaceans to enhance conservation and protection of these highly mobile species.	Medium	6 to 10 years	Understanding and Interpreting the NWHI and Conserving Wildlife and Habitats	MCS-1.5 TES-1.3 TES-1.2
Conduct studies of population demography and genetic structure on selected dominant or keystone plants, vertebrates, or invertebrates.	Medium	6 to 10 years	Understanding and Interpreting the NWHI and Conserving Wildlife and Habitats	MCS-1.5 HMC-5.1

3.2.5 Resilience

Understanding ecosystem resilience - the ability of the NWHI ecosystem to absorb or recover from disturbance and stress - will enable the NWHI to be managed to best maintain functions and services in response to short- and long-term change, including climate change. Understanding ecosystem resilience is important in knowing how well natural systems will respond to perturbations and changes in environmental conditions. Research across a gradient of environmental stressors in the NWHI can test critical questions about why and how some taxa or ecosystems appear to rebound well from stress while others do not. Understanding the capability and mechanisms that facilitate resilience in the ecosystem, especially regarding (a) the pathways to resilience, and (b) the naturally occurring modifiers of resilience, enables managers to focus on priority components of the ecosystem. Studies across a range of priority components and across a gradient of environmental stress conditions and stress agents can lead to a robust capacity for projecting ecosystem reactions to likely changes through models.

Research on ecosystem resilience can be expected to improve management by integrating information on how the ecosystem will respond to short-term impacts and long-term change and thereby increase the ability for managers to anticipate, model and address changes in the system.

Strategies in the Monument Management Plan of Relevance to Resilience Research and Monitoring

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Conserving Wildlife and Habitats:
Threatened and Endangered Species Action Plan

- TES-1: Support activities that advance recovery of the Hawaiian monk seal for the life of the plan.

Current knowledge

Numerous studies include aspects that relate to the ability of species, populations, or habitat to respond to stress and that monitor species, populations, and habitats in relation to specific impacts. However, there has been little or no work in the NWHI that specifically focuses on resilience, especially at the ecosystem level.

Researchers at HIMB have initiated studies focused on factors that affect the resilience of coral colonies to bleaching and disease. One study (Stat and Gates) is examining how the various Symbiodinium types are distributed among coral hosts, and the extent to which the corals themselves influence the type of Symbiodinium they acquire. The relationship of coral to symbionts is a critical factor determining the resilience of coral communities to climate change HIMB 2009). Another study (Aeby) is examining the role of biodiversity in limiting the spread of coral disease.

Research needs and opportunities

Table 10. Prioritized list of research activities needed to further understanding of resilience in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Ecological Processes and Connectivity				
Resilience				
Use remote sensing as well as in-situ observations and instrumentation deployed at long-term observing sites to provide time-series datasets which are utilized for the monitoring, alerting, modeling, and reporting of environmental and biological phenomena influencing and associated with coral reef fish populations.	Medium	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.5 MCS-1.4
Use remote sensing as well as in-situ observations and instrumentation deployed at long-term observing sites to provide time-series datasets which are utilized for the monitoring, alerting, modeling, and reporting of environmental and biological phenomena influencing and associated with coral reef ecosystem resilience.	Medium	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.5 MCS-1.4

3.3 Human Impacts

Despite its remote location and largely uninhabited condition, the NWHI are subject to a wide range of past, present, and future anthropogenic impacts, both from within and from outside the area. Understanding the sources, types, and magnitude of these impacts, as well as developing suitable responses, is essential for managing the Monument ecosystems. Some of the human impacts that have been the focus of past research efforts in the NWHI include studies on the effects of marine debris and pollution, un-permitted activities, the residual effects of historical human activities in the NWHI (such as dredging, landfills, storage tanks, and other contamination), and human-facilitated species invasions. These impacts are central components of the Science Plan. However, a new major anthropogenic threat to the Monument that requires immediate attention is the study of impacts of climate change on these ecosystems. The research plan for detecting and responding to emerging threats must remain readily adaptable, as anticipating all important emerging human impacts in the Monument is impossible. Research, management, and recreational activities have the potential to impact species and habitats, and these impacts need to understood and avoided.

A growing body of evidence indicates that specific human activities have directly affected global climate, and are continuing to do so. In turn, climatic changes such as increased sea temperature and ocean acidification may make marine resources more vulnerable to other human activities

(Harley et al. 2006). Changes in sea level, sea temperature, ocean chemistry, ocean currents, precipitation, and other marine processes influence biological communities in complex ways. For example, environmental perturbations outside of the evolutionary norm may reduce the suitability of the habitat for key native species. This is seen when elevated sea temperatures lead to coral bleaching. The initial damage to coral, if extensive enough, can cause a cascade of effects that degrade the reef habitat for organisms that once used the reef for food, shelter, or spawning (Hoegh-Guldberg et al. 2007). Corals may be overgrown with algae, or invasive species may gain a competitive advantage when native species are compromised (Coles et al. 2009). Although coral are the most widely recognized marine invertebrates affected by climate change, other benthic invertebrates are impacted as well. Environmental changes associated with climate change are linked to larger ecological processes, including changes in larval dispersal and recruitment success, shifts in community structure and range extensions, and the establishment and spread of invasive species (Przeslawski et al. 2008). Increases in water temperature have been implicated in the encroachment of invasive ascidians (Stachowicz et al., 2002) and bryozoans (Saunders and Metaxas 2007). Additional pathways by which humans affect climate change are discussed in Section 3.3.3.

3.3.1 Human activities

Despite its remote location and largely uninhabited condition, the NWHI have been subject to a wide range of anthropogenic stressors, notably: marine pollution, dredging, invasive species, vessel groundings, and fishing. Understanding the sources, types, and magnitude of human interactions with the physical and biological environment of the NWHI is essential for management of the NWHI. This focus area is concerned with understanding the impact of anthropogenic activities on the NWHI ecosystem and identifying potential management actions to mitigate these impacts.

For example, dredging associated with coastal development has altered current flow, temperature regimes, shoreline configuration, and coastal erosion patterns with deleterious effects to coral reef ecosystems (Maragos, pers. comm.). Additionally, multiple studies by the Navy, the Coast Guard, FWS, and academic institutions, including University of Hawaiʻi, Rutgers University, University of Michigan, University of California-Davis, and University of California-Santa Cruz, have documented contaminants on islands and shallow waters in the Monument, including pesticides, batteries (lead and mercury), transformers with PCBs, capacitors, and barrels. These studies have shown that up to 30 percent of the material consumed by foraging seabirds can be soil (Hui and Beyer 1998, Beyer et al. 1994), and that contaminated soil can result in direct intake of toxic substances by foraging birds. As a specific example, ingestion of sand contaminated by carbofuran, a pesticide washed ashore with marine debris on Laysan, is attributed with causing the deaths of endangered Laysan finches, until FWS identified and removed the source (Campbell et al. 2004, David et al. 2001).

Existing management actions to mitigate human impacts include the collection of marine debris, eradication of invasive species at Kure, Laysan, FFS, and Midway, and the monitoring and removal of contaminants. FWS continues to monitor contaminant levels in and around buildings at Midway and to remediate lead contamination that causes "droop wing" and mortality of fledging albatross. The Navy and Coast Guard have also remediated some contamination in soil, sediment, water, reefs, and marine and terrestrial biota.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF RELEVANCE TO HUMAN IMPACTS RESEARCH AND MONITORING

Conserving Wildlife and Habitats:

Threatened and Endangered Species Action Plan

- TES-1: Support activities that advance recovery of the Hawaiian monk seal for the life of the plan.
- TES-2: Determine the status of cetacean populations and verify and manage potential threats over the life of the plan.
- TES-8: Ensure protection of threatened and endangered species by facilitating Endangered Species Act consultations for Monument activities throughout the life of the plan.

Migratory Birds Action Plan

- MB-2: Minimize the impact of threats to migratory birds such as habitat destruction by invasive species, disease, contaminants (including oil), and fisheries interactions for the life of the plan.
- MB-3: Monitor populations and habitats of migratory birds at a level sufficient to ascertain natural variation and then to detect changes in excess of that variation that might be attributed to human activities, including anthropogenic climate change.

Habitat Management and Conservation Action Plan

- HMC-1: Within 15 years, develop and implement a strategy for restoring the health and biological diversity of the shallow reefs and shoals where anthropogenic disturbances are known to have changed the ecosystem, using best available information about pre-disturbance conditions.
- HMC-2: Within 10 years, investigate and inventory sources of known contamination from historical human uses of the NWHI and, where appropriate, coordinate with responsible parties to develop plans and complete cleanup actions.
- HMC-9: Protect and maintain 120 acres of vertical rocky cliff-face habitat at Nihoa and Mokumanamana for nesting seabirds for the life of the plan.

Reducing Threats to Monument Resources:

Marine Debris Action Plan

- MD-1: Remove and prevent marine debris throughout the life of the plan.
- MD-2: Investigate the sources, types, and accumulation rates of marine debris within 5 years.
- MD-3: Develop outreach materials regarding marine debris within 2 years.

Alien Species Action Plan

- AS-1: Conduct planning to prioritize by threat level, invasiveness, and practicality of eradication or control all nonnative organisms in the Monument over the life of the plan.
- AS-2: Engage in active surveillance to monitor existing infestations and to detect new infestations of alien species over the life of the plan.
- AS-3: Establish and enforce quarantine procedures appropriate for each site and habitat (terrestrial and aquatic) in the Monument to prevent the invasion or reinfestation of nonindigenous species over the life of the plan.
- AS-9: Engage Monument users and the public in preventing the introduction and spread of alien species.
- AS-10: Participate in statewide and Pacific regional alien species efforts.

Maritime Transportation and Aviation Action Plan

- MTA-1: Increase awareness of navigational hazards and ecological sensitivity of the Monument.
- MTA-2: Conduct studies to identify potential aircraft and vessel hazards and adopt measures to prevent adverse impacts.

Managing Human Uses:

Permitting Action Plan

- P-2: Track and monitor permitted activities and their impacts.

Current knowledge

Historical coastal development and disturbance at the NWHI consisted of guano mining at Laysan, naval base construction at Midway and FFS, military activity on Pearl and Hermes, and construction and maintenance of U.S. Coast Guard Long-Range Aid to Navigation (LORAN).

Marine pollution can be defined as the introduction by humans, whether directly or indirectly, of substances or energy to the marine environment that results in deleterious effects. These effects may include hazards to the health of marine life and humans, hindrance of marine activities, and impaired water quality. Marine pollution may originate from land-based or sea-based human activities in the form of point-source discharges, groundwater discharges, or nonpoint-source runoff. Studies conducted by the FWS, USCG, Navy, and the University of Hawaiʻi have documented contamination in soil, sediment, and biota at FFS, Kure, and Midway. Direct impacts to black-footed albatrosses in the form of reduced hatching success have been linked to high organochlorine levels by Ludwig et al. (1997). Finkelstein et al. (2007) found a correlation between levels of organochlorines and elevated levels of mercury and impaired immune function in black-footed albatross.

Accumulation of marine debris is one of the greatest anthropogenic impacts on the NWHI ecosystem. Marine debris degrades the aesthetic value of the coastal environment, creates navigational hazards, and has significant bio-ecological impacts. Thousands of albatross chicks die each year with stomachs full of small plastic debris they were fed from parents foraging throughout the Monument and the Pacific. Mortality caused by entanglement in derelict fishing gear, primarily nets, has also been documented for several mobile marine species in the NWHI, with impact on the Hawaiian monk seal being of greatest concern because of the highly endangered status of this animal (Boland and Donohue 2003; Henderson 1990, 2001). A multi-agency effort to remove and recycle derelict fishing gear and other marine debris has been in place since 1996. From 1996 to 2005, a total of 542 tons of marine debris was removed from the NWHI. In addition to removal efforts, strategic research is now focused on understanding the dynamics of marine debris, specifically accumulation rates and locations. A recent study estimated accumulation rates to be 52 metric tons annually, due to the location of the NWHI and the debris transport driven by North Pacific gyres and frontal zones. Even if all new input of debris were stopped, existing debris in the ocean will continue to accumulate in the NWHI for years to come.

Marine debris often liters shorelines across the entire span of the Northwestern Hawaiian Islands.

Photo: Wayne Levin

Research needs and opportunities

Table 11. Prioritized list of research activities needed to further understanding of human activities and associated impacts in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Human Impacts				
Human activities and impacts				
Track and evaluate the impacts of human activities and actions on natural resources to maintain and ensure ecosystem health and function.	Critical	1 to 5 years	Managing Human Uses	P-2.2 VS-1.3
Locate, investigate and evaluate effects of contamination in terrestrial and nearshore areas.	Critical	1 to 5 years	Conserving Wildlife and Habitats	MB-2.2 HMC-2.1 HMC-2.2 HMC-2.3 HMC-2.5 HMC-2.6 HMC-2.7
Assess effects of ongoing human use on terrestrial habitat.	Medium	10 plus years	Managing Human Uses	VS-1.3
Determine potential impacts to natural resources resulting from human presence to regulate human activities and minimize impact to the ecosystem.	Medium	1 to 5 years	Achieving Effective Monument Operations	CFO-2.3
Investigate the integrity of known landfills and dumps to determine potential effects to surrounding habitats and biota.	Medium	1 to 5 years	Conserving Wildlife and Habitats	HMC-2.2
Use new technologies to improve the location and removal of debris at sea.	Medium	1 to 5 years	Reducing Threats to Monument Resources	MD-2.1 MD-2.2
Determine the effects of marine debris and evaluate its role in changes to ecosystem health and function.	Medium	6 to 10 years	Reducing Threats to Monument Resources	MD-2.1 MD-2.2
Determine the effects of manmade structures on nearshore and submerged habitats to evaluate its role in changes to ecosystem health and function.	Medium	6 to 10 years	Conserving Wildlife and Habitats	HMC-3.2
Research historic disposal sites and investigate them for contamination to determine potential effects on surrounding habitats and biota.	Medium	1 to 5 years	Conserving Wildlife and Habitats	HMC-2.3
Conduct studies to determine the effects of contaminants on seabird species.	Medium	1 to 5 years	Conserving Wildlife and Habitats	MB-2.2 MB-2.3 HMC-2.1 HMC-2.6 HMC-2.7

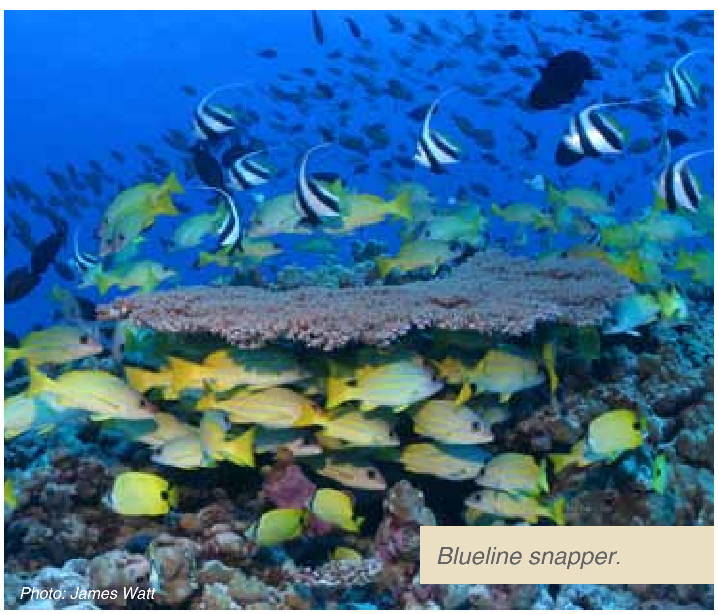
Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Human Impacts				
Human activities and impacts				
Characterize and monitor the effects of marine debris on cetaceans in the Monument.	Medium	10 plus years	Conserving Wildlife and Habitats and Reducing Threats to Monument Resources	TES-2.3 MD-2.1 MD-2.2
Investigate effects of anthropogenic iron sources on marine resources.	Medium	6 to 10 years	Conserving Wildlife and Habitats	HMC-2.4
Examine the correlation between reproductive success and contaminant loads in marine and terrestrial species to determine effects on population structure.	Medium	1 to 5 years	Conserving Wildlife and Habitats	TES-4.2 MB-2.2
Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Study contaminant levels in birds and their habitats.	Medium	6 to 10 years	Conserving Wildlife and Habitats	MB-2.2 HMC-2.1
Conduct risk assessment to determine safe levels of lead in soils.	Medium	1 to 5 years	Conserving Wildlife and Habitats	MB-2.2 HMC-2.1 HMC-2.2 HMC-2.3 HMC-2.5 HMC-2.6 HMC-2.7
Conduct studies on potential aircraft and vessel hazards and impacts to surrounding habitats and species.	Low	10 plus years	Reducing Threats to Monument Resources	MTA-2.1
Monitor and fingerprint oil found washed ashore to determine origins of the imported oil.	Low	1 to 5 years	Conserving Wildlife and Habitats	MB-2.2 HMC-2.1 HMC-2.2 HMC-2.3 HMC-2.5 HMC-2.6 HMC-2.7
Assess impacts of historic land use on impacted habitats and organisms.	Low	10 plus years	Conserving Wildlife and Habitats	HMC-2.1 HMC-2.2 HMC-2.3 HMC-2.7 HMC-3.2

3.3.2 Alien and invasive species

Although the remoteness and relative inaccessibility of the NWHI have helped to prevent the introduction of most alien species, the area is vulnerable to introductions through a variety of pathways. Increased vessel visitation, deployment of gears used and exposed to alien and invasive species elsewhere, and transport of cargo are of particular concern. While continued rigorous inspection of all vessels' hulls, equipment, and scientific gear, and a zero tolerance for aquatic invasive species or ballast water discharge, has minimized the exposure of the NWHI to alien and invasive species, introductions are still possible and hence are a substantial threat to Monument resources. Invasive species compete with native species and reduce their likelihood of survival. Understanding the status and trends of these species, and the pathways that introduce these species, will help minimize impact to the NWHI ecosystem. Aside from global climate change, invasive and alien species are the most severe threat to native and endemic species with limited distributions in the NWHI.

This focus area is concerned with understanding the impact of invasive species on marine and terrestrial biodiversity and ecosystems of the NWHI. Principal goals are to identify the biological and ecological requirements of alien species, understand the interaction between native and alien species, and understand the influence of environmental conditions on turning alien species into invasive threats. These latter conditions may include changes in ocean temperature that may enable introduced species to spread to areas previously unavailable because of their physiological limitations. It is also critical to identify the major anthropogenic vectors and their attendant risks for introduction of invasive species into NWHI. The ultimate goal of research in this area is to safeguard native biodiversity to maintain a sustainable ecosystem function by minimizing the exposure of the NWHI to invasive species.

Information from invasive species studies is expected to help identify new alien species that have arrived in the NWHI, assess their potential impact, and determine effective eradication strategies. Additionally, this research should help identify vector pathways and hubs associated with introduction of invasive species into the area and provide tools to guide management.



Blueline snapper.

Photo: James Watt

Verbesina on Kure Atoll.

Photo: Cynthia Vanderlip

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF RELEVANCE TO ALIEN AND INVASIVE SPECIES RESEARCH AND MONITORING

Reducing Threats to Monument Resources:
Alien Species Action Plan

- AS-1: Conduct planning to prioritize by threat level, invasiveness, and practicality of eradication or control all nonnative organisms in the Monument over the life of the plan.
- AS-2: Engage in active surveillance to monitor existing infestations and to detect new infestations of alien species over the life of the plan.
- AS-3: Establish and enforce quarantine procedures appropriate for each site and habitat (terrestrial and aquatic) in the Monument to prevent the invasion or reinfestation of nonindigenous species over the life of the plan.
- AS-4: Eradicate the house mouse population on Sand Island, Midway Atoll, within 15 years.
- AS-5: Prioritize infestations of alien terrestrial arthropods by species and locations and, within 5 years, develop and subsequently implement plans to control and if possible eradicate the highest-priority species.
- AS-6: Control and eventually eradicate the highest-priority invasive plants in the terrestrial parts of the Monument within 15 years.
- AS-7: Investigate methods to eventually eradicate aquatic invasive organisms already known to be present in the Monument, and conduct regular surveillance for new invasions.
- AS-8: Conduct and facilitate research designed to answer questions regarding invasive species detection; effects on ecosystem; and alien species prevention, control, and eradication over the life of the plan.
- AS-9: Engage Monument users and the public in preventing the introduction and spread of alien species.
- AS-10: Participate in statewide and Pacific regional alien species efforts.

Current knowledge

There is a considerable body of existing work on terrestrial invasive species in the NWHI (Conant and Rowland, in preparation; Nishida 1998, 2000; Wanless et al. 2007). Some of the species identified as invasive include the introduced grass *Cenchrus echinatus*; the invasive annual golden crown-beard (*Verbesina encelioides*;); the house mouse (*Mus musculus*) on Sand Island at Midway Atoll; 19 species of social hymenopterans such as ants and wasps at all islands in the Monument; the grey bird locust (*Schistocerca nitens*) at Nihoa Island, Mokumanamana, FFS, and Lisianski Island; and two introduced mosquito species, *Aedes albopictus* and *Culex quinquefasciatus*, at Midway Atoll. Ongoing work in the NWHI has led to the successful eradication of *Rattus rattus* at Midway Atoll, *Rattus exulans* at Kure Atoll, and the introduced grass *Cenchrus echinatus* at Laysan Island.

Invasive plant species have been implicated in the decline of nest success in several endangered seabirds in the NWHI. For example, the golden crown-beard has invaded the nesting habitat of the Laysan albatross and the black noddy; other invasive plants threaten the nesting habitats of the Bonin petrel, Christmas shearwater, Tristram's Storm-petrel, masked booby, red-tailed tropic bird (Keller et al. 2009).

Data on marine invasive species were collected from a marine invasive species survey by the Bishop Museum at Midway, from multidiscipline efforts conducted under the auspices of the NWHI NOWRAMP in 2000 and 2002, and USCG in 2000, 2002, and 2003. A total of 11 alien marine invertebrate, fish, and algal species have been recorded in the NWHI, with the highest concentrations at Midway Atoll (Godwin et al. 2006). Maritime vessels are recognized as the primary vector for transporting marine alien species through contaminated vessel equipment, hull fouling, ballast water, and ballast sediment. Additional vectors include deliberate and accidental release and transport by artificial substrates such as Fish Attractant Devices and marine debris.

Research needs and opportunities

Table 12. Prioritized list of research activities needed to further understanding of alien/invasive species in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Human Impacts				
Invasive species				
Survey terrestrial alien/invasive species to determine presence and distribution, and impacts of these species.	Critical	1 to 5 years	Conserving Wildlife and Habitats and Reducing Threats to Monument Resources	MB-1.1 AS-1.2 AS 2.1 AS-2.2 AS-5.1 AS-5.2 AS-5.3 AS-5.4 AS-6.1 AS-6.2 AS-6.3 AS-6.4 AS-8.2
Investigate competitive interactions between alien/invasive and native species to attempt to mitigate for current and future invasions, as well as help prioritize control efforts.	Critical	1 to 5 years	Reducing Threats to Monument Resources	AS-1.2 AS-7.1 AS-7.2 AS-8.1
Identify and map distribution of social Hymenopterans.	Critical	1 to 5 years	Reducing Threats to Monument Resources	AS-5.1
Investigate eradication techniques for all social Hymenopterans.	Critical	1 to 5 years	Reducing Threats to Monument Resources	AS-5.2
Determine the methods of transport, rate of spread, and habitat preferences of alien/invasive species to inform protocols to attempt to stop introductions, slow spread, or mitigate for current invasions.	Medium	1 to 5 years	Reducing Threats to Monument Resources	AS-2.1 AS-7.1 AS-7.2 AS-8.1
Develop methods to control and/or eradicate terrestrial invasive species.	Medium	1 to 5 years	Reducing Threats to Monument Resources	AS-5.4

3.3.3 Climate change

The Intergovernmental Panel on Climate Change has established global change as a significant threat to marine environments and small island ecosystems (Mimura et al. 2007). Within this context, PMNM managers have identified understanding the impacts of global changes and evaluating options for adaptation as a high priority for research. In particular, five global change impacts have been identified as having the greatest potential effect on the NWHI ecosystem: more extreme weather events, changes in sea temperature, rising sea levels, alternations in oceanic chemistry, and shifts in precipitation patterns. Some of the main impacts from these changes may include:

- Loss of coastal habitats, due to storms and sea level rise, that impact marine animal nesting and foraging areas with few alternatives for relocation due to the remoteness of the NWHI.
- Degradation of coral reef ecosystems due to increased incidence of coral bleaching, disease, and storm damage, compounded by reduced calcification rates and rising sea levels.
- Impacts on marine food webs due to habitat loss and ocean acidification
- Degradation of terrestrial ecosystems due to changing weather patterns and shifts in freshwater systems.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF RELEVANCE TO CLIMATE CHANGE RESEARCH AND MONITORING

Understanding and Interpreting the NWHI: Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Current knowledge

Although the specific effects of climate change are difficult to predict, existing data about conditions and trends at the Monument support the assumption that global change is currently impacting NWHI ecosystems, or will in the future (Friedlander et al. 2009). For example, sea level rise is expected to inundate shorelines and reduce critical habitat for endangered Hawaiian monk seals and threatened Hawaiian green sea turtles at Pearl and Hermes Reef (Baker et al. 2006). Millions of nesting seabirds and migratory Arctic shorebirds are also predicted to be effected.

Regional predictions for the North Central Pacific Gyre area are for increases of surface temperature of 0.5 to 1.0 °C, within the life of the Management Plan. The magnitude of sea level rise by 2090 from thermal expansion of water and melting of land-based ice sheets ranges from 0.18 meters to 0.59 meters. A rise of 0.48 meters is predicted to cause loss of 3 to 65 percent of the terrestrial habitat in the NWHI, ranging from severe effects on the low, sandy atolls and minimal effect on Mokumanamana and Nihoa (Baker et al. 2006). Projected precipitation maps indicate a decrease of 10 to 20 percent of average precipitation by 2090 in the NWHI. It is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases in tropical sea surface temperatures. Shoreline erosion and saltwater intrusion into subsurface freshwater aquifers have already been noted throughout the Pacific (Shea et al. 2001).

Anomalies in sea temperature are expected to increasingly cause coral bleaching in the NWHI. Mass coral bleaching in the NWHI occurred during late summer 2002 (Aeby et al. 2003; Kenyon and Brainard 2006; Hoeke et al. 2006). Before this event, the NWHI were believed to be less susceptible to bleaching because they lie at high latitude. Bleaching was most severe, however, at the three northernmost atolls (Pearl and Hermes, Midway, and Kure), which experienced both higher and lower sea water temperatures than the other reef areas of the NWHI. Bleaching occurred but was less severe at Lisianski and farther south in the NWHI.

Of the studies implemented in the NWHI in 2010, many are focused on questions that may provide insight into the impacts of climate change. Among these are studies of coral bleaching, skin cancer in fish, parasite life cycles, genetic diversity of reef fishes, biological indicators of coral disease, temperature effects on coral health, behavior of top marine predators, and molecular diversity of coral-endosymbionts (NOAA 2010). Historical research programs can provide baseline condition data that create a framework within which climate change hypotheses can be tested. For many questions, however, no historical data are available, and current work is aimed at documenting baseline conditions.

Aerial image of Pearl and Hermes.

Photo: Dan Polhemus

Research needs and opportunities

Table 13. Prioritized list of research activities needed to further understanding of climate change in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Human Impacts				
Climate change				
Determine how climate change affects the distribution and populations of species in the NWHI to identify sensitive areas and species.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4
Forecast areas or species groups that may be particularly sensitive, and determine plans for mitigation in advance.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.5
Model the effects of sea level rise on terrestrial resources.	Critical	1 to 5 years	Conserving Wildlife and Habitats	MB-3.1 HMC-3.1 HMC-3.2
Forecast areas or species assemblages that may be particularly sensitive to increasing sea surface temperatures, and determine plans for mitigation in advance.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4 MCS-1.5
Forecast areas or species assemblages that may be particularly sensitive to rising sea levels and/or changes in currents, and determine plans for mitigation in advance.	High	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4 MCS-1.5
Forecast areas or species assemblages that may be particularly sensitive to ocean acidification, and determine plans for mitigation in advance.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4 MCS-1.5
Model potential changes in frequency and intensity of extreme climate events	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES-1.2 TES-1.3 TES-3.2 TES-3.3 MB-3.1 HMC-3.1 HMC-3.2

3.4 Indicators and Monitoring of Ecosystem Change

Long-term monitoring is an essential tool for scientists to detect and understand changes in the ecosystem. Monitoring may also identify issues that may warrant active management actions. Effective monitoring requires appropriate parameters and measures that can effectively detect change and trends within three categories: ecosystem and ecological changes, biodiversity and habitat changes, and changes caused by human activities. Ongoing monitoring using these parameters provides the basis for identifying the system's intrinsic variability, and understanding temporal and spatial changes in its process and patterns as a basis for improved management.

Growing concern about the ways that climate change may affect resources at the Monument is reflected in the Science Plan. Research and monitoring projects that include specific variables related to climate change are essential to understanding the process by which climate change affects local resources. For example, studies of coral disease and coral bleaching include an analysis of sea temperatures. Likewise, studies of the range expansion of an invasive species may evaluate temperature as well as ocean circulation patterns to understand changes in distribution. Effective monitoring requires that interaction among variables be evaluated along spatial and temporal gradients so that cause and effect relationships can be tested. The Science Plan recognizes that conditions in the Monument reflect the interaction of ecological processes and human impacts on biodiversity and habitats. Climate change can affect all of these elements, singularly and jointly.

3.4.1 Ecological process metrics and monitoring

Understanding the ecological processes behind ecosystem change and how ecosystems have changed in the past is critical to modeling future conditions and identifying management needs. An appropriate suite of parameters and indicators is necessary to effectively detect changes in ecological processes and ecosystems. These metrics should be designed to characterize natural variability and, when possible, differentiate between natural and anthropogenic effects at useful resolutions. However, metrics must also be practical and simple so that non-scientists can understand them and the trends they document.

Recognizing the resource and logistical limitations of monitoring a large, remote area such as the NWHI, ecosystem monitoring must focus on a set of sensitive indicators that collectively serve as the proxy for total ecosystem behavior. Monitoring must be both spatially and temporally rigorous, the former being statistically robust to present an unbiased characterization of the various habitats, and the latter accounting for all key parameters during each sampling event to capture the degree of temporal variability in these systems. The remoteness of the NWHI will require some reliance on remotely sensed indicators because of the cost of transportation, on-island accessibility, and the limited seasonal windows for safe ship-based field activities. As the understanding of ecosystems improves, new parameters, indicators, and technologies will emerge to increase the scope, power, predictability, and implications of monitoring.

Understanding how various components of the NWHI connect with each other, and how they link the NWHI with the MHI and other parts of the Pacific, is a particularly important consideration for monitoring. A critical component is measuring the rates, scale, and spatial structure of exchange, or connectivity, among subpopulations of species and communities. It is also important that monitoring protocols be established and followed to ensure that information is reliable and comparable over time. The key ecosystem and ecological processes that require monitoring include:

- Oceanographic processes (physical and chemical)
- Passive transport of nutrients, living resources, and contaminants/pollution
- Active transport and movement of living resources
- Population dynamics and genetic structure
- Resilience

The expected outcome is development of parameters and indicators that enable useful, effective, and efficient monitoring of the ecosystems and ecological processes of the NWHI, including connectivity and resilience, building on and integrating existing monitoring programs as much as possible.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF RELEVANCE TO ECOLOGICAL PROCESS METRICS RESEARCH AND MONITORING

Understanding and Interpreting the NWHI: Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Current knowledge

Monitoring programs have addressed a wide range of weather, water quality, and chemistry parameters, circulation patterns, and oceanographic characteristics through a variety of means. In particular, a number of studies have been undertaken to understand oceanographic processes and transport in the NWHI using buoy arrays, drifters, and remote sensing. Monitoring oceanic characteristics has demonstrated spatial patterns in transport and ocean productivity. Much of the work on ecological processes is described in Section 3.2.1 of this report.

Deep-Ocean Assessment and Reporting of Tsunamis or DART® bouys during maintenance.

Photo: NOAA

Research needs and opportunities

Table 14. Prioritized list of research needed to further understanding of ecosystem and ecological processes in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Indicators and Monitoring of Ecosystem Change				
Ecosystem and ecological process metrics and monitoring				
Determine how energy and nutrients transfer through ecosystems, enabling managers to identify important habitats or food sources that drive communities.	High	1 to 5 years	Conserving Wildlife and Habitats	MCS-1.1 MCS-1.2 TES-1.2
Determine species interactions within and between ecosystem components.	High	1 to 5 years	Conserving Wildlife and Habitats	MCS-1.1 MCS-1.2 TES-1.2

3.4.2 Biodiversity and habitat metrics and monitoring

Central to the conservation and management of the NWHI is a goal to maintain the health of its biological diversity, populations of living resources, and marine and terrestrial habitats. Within this context, it is critical for managers to understand changes in the area's species and habitats.

An appropriate suite of parameters and indicators is an essential requirement for effectively detecting changes in species and habitats over time. Differentiating between natural and human impacts on biodiversity and habitats is also important. Metrics must be scientifically robust and relevant, while also being practical and sensitive to the trends they are intended to document. Monitoring must be able to characterize the status and changes in biodiversity and habitats, at appropriate spatial and temporal resolutions, and provide sufficient information to guide remedial efforts, if needed.

Documenting the status of species and habitats, and understanding how the distribution and abundance of NWHI biodiversity is related to the MHI and other parts of the Pacific are particularly important considerations for monitoring. Assessing the rates, scale, and spatial structure of exchange among populations of species and the communities is a key aspect, as is focusing on areas and issues that threaten the ecosystems. It is also important that monitoring protocols be followed or established to ensure that information is reliable and comparable over time. The key biodiversity components that require appropriate parameters, indicators, and monitoring include:

- Status and trends of habitats
- Status and trends of native species (genetic, taxa, and populations)
- Specially protected species (genetic, taxa, and populations)
- Health, disease, and contamination

The expected outcome is an understanding of ecosystem health over broad spatial and temporal scales. Models will be developed that enable the status of species and populations within the NWHI to be projected in relation to specific short-term impacts or long-term environmental changes. Studies and modeling of priority species and populations across a gradient of environmental stress conditions and stress agents will lead to a robust capacity for projecting the response of taxa and populations to likely changes. Where specific threats are at hand, monitoring can also serve to substantiate and design management measures to reduce or eliminate those threats.

Strategies in the Monument Management Plan of Relevance to Biodiversity and Habitat Metrics Research and Monitoring

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.

Current knowledge

Several existing programs are gathering data related to species and habitats. These efforts are especially well developed and long standing for specially protected and endangered species, including the Hawaiian monk seal, five species of baleen whales, at least 19 other species of whales and dolphins, marine turtles (green, hawksbill, loggerhead, and leatherback), migratory birds (such as the Laysan and black-footed albatross and other seabirds), five bird species that are

Photo: Kittipong Janthasang

Laysan albatross.

An expanse of blue at Pearl and Hermes Atoll.

listed under the ESA, and six plant species known historically from the NWHI that are listed as endangered. Seabird abundance and nesting distribution are monitored, and work is proposed to develop a revised standardized monitoring plan.

In the marine environment of the NWHI, NOAA Fisheries has conducted quantitative monitoring of reef fishes as part of the Monk Seal Forage Base Study. The NOWRAMP/ NWHI RAMP cruise series was established in 2000 to assess the biodiversity and resources of all 10 emergent reefs and shallow (less than 20 meter) shoals. *The Draft Atlas of the Shallow-Water Benthic Habitats of the NWHI* (NOAA 2003) and the *Bathymetric Atlas of the NWHI* (Miller et al. 2004) describe the marine habitats and bathymetry of the NWHI and establish important baseline information for monitoring programs. NWHI RAMP cruises continue to monitor the marine ecosystem an annual basis.

NOAA's Biogeography Branch joined with the Monument to design and implement a biogeographic assessment. The almost 400-page report contains dozens of maps, figures, and tables with up-to-date research results on oceanographic and geologic processes, marine and terrestrial living resources, and major environmental concerns. Chapters on connectivity and management emphasize that the work was undertaken to provide direct support to the research and management needs of the Monument (Friedlander et al 2009).

Scientists at HIMB have joined 11 NOAA cruises since 2005 to initiate a variety of studies on coral (*Acropora, Montipora capitata, Pocillopora*), fishes (moray eels, yellow tang, butterflyfish, parrotfish, and sharks) and mammals (monk seal, spinner dolphin). Topics include genetics, behavior, foraging ecology, statistical modeling, and other primary research.

Terrestrial habitats of the NWHI have been prioritized in terms of their importance to native and specially protected species. Past research on health and disease at the NWHI includes work on coral and reef fish disease and avian botulism.

Research needs and opportunities

Table 15. Prioritized list of research activities needed to further understanding of biodiversity and habitat metrics in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Indicators and Monitoring of Ecosystem Change				
Biodiversity and habitat metrics and monitoring				
Determine the distribution patterns of cetacean species within the Monument boundaries.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES-2.1
Continue annual monitoring and modeling of threatened and endangered species populations to evaluate population trends and progress towards recovery.	Critical	1 to 5 years	Conserving Wildlife and Habitats	TES-1.2
Use a combination of optical and diver data collection techniques to gather ecosystem monitoring data for evaluation of population trends of fishes, corals and other invertebrates.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.4
Monitor changes in the species composition and structure of terrestrial habitats.	Critical	1 to 5 years	Conserving Wildlife and Habitats	HMC-3.1 HMC-4.7 HMC-5.2
Use a combination of optical and diver data collection techniques to detect coral bleaching and/or disease outbreaks.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3
Track changes that occur in the deep water ecosystems (>30 meters) and evaluate how these habitats are linked to shallow reef as feeding grounds or possible areas of refuge.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.4
Determine the most efficient and accurate statistical sampling design for the reef monitoring program to effectively survey the reefs of the NWHI efficiently, within the constraints of accessibility, to provide for accurate abundance measures for corals, fish and invertebrates and track changes in their numbers through time.	Medium	1 to 5 years	Understanding and Interpreting the NWHI	MCS-2.2

3.4.3 Human impact metrics and monitoring

Although the NWHI are remote and largely uninhabited, they are subject to a wide range of anthropogenic stressors, from within the area as well as from external sources. Management of the NWHI will require regular information on the sources, types, magnitude, and effects of human interaction with the NWHI ecosystem. Determining the incidence, rates, scale, and spatial and temporal aspects of human activities is essential to this effort. Monitoring protocols must therefore be in place to ensure that information is reliable and comparable over time.

An appropriate suite of parameters and indicators is an essential requirement of effectively tracking human activities and impacts over time at useful spatial and temporal resolutions. Metrics must be scientifically robust and relevant, yet also practical and simple so that non-scientists can understand them and the trends they document. A full understanding of the impacts of human activities, both land-based and marine, is essential to support ecosystem-based conservation and management. The anthropogenic sources that require appropriate parameters, indicators, and monitoring are related to:

- Human activities, resource use, and waste disposal
- Invasive species
- Climate change
- Ship groundings and fuel spills
- Residual fishing impacts
- Toxic and hazardous military and LORAN waste
- Research
- Marine debris
- Illegal fishing

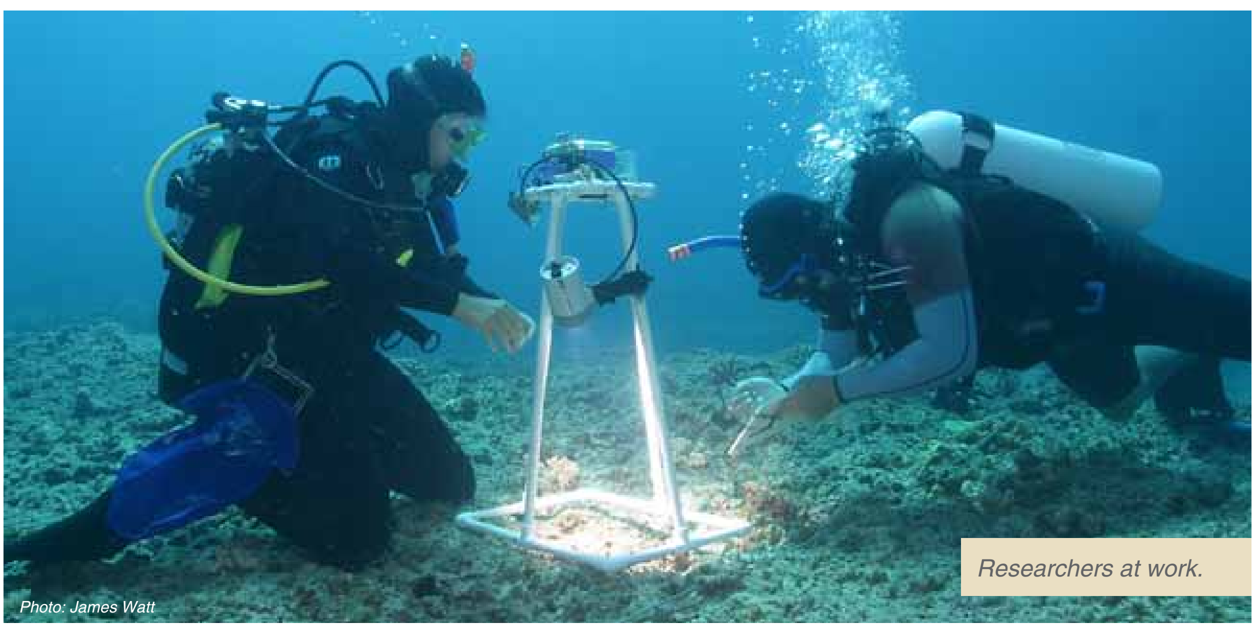


Photo: James Watt

Researchers at work.

In addition, it will be necessary to monitor the effects of management actions and research activities that are undertaken in the NWHI, both to verify that these activities have achieved their desired outcomes and to decide whether there are unintended impacts from management interventions.

The expected outcome is the ability to minimize human impacts by monitoring changes caused by human activities and management actions in the NWHI. Parameters and indicators will be developed that enable useful, effective, and efficient monitoring to be implemented.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF RELEVANCE TO HUMAN IMPACTS METRICS RESEARCH AND MONITORING

Understanding and Interpreting the NWHI:
Marine Conservation Science Action Plan

- MCS-1: Continue and enhance research, characterization, and monitoring of marine ecosystems for the life of the plan, as appropriate.
- MCS-2: Assess and prioritize research and monitoring activities over the life of the plan.

Conserving Wildlife and Habitats:
Threatened and Endangered Species Action Plan

- TES-8: Ensure protection of threatened and endangered species by facilitating Endangered Species Act consultations for Monument activities throughout the life of the plan.

Migratory Birds Action Plan

- MB-2: Minimize the impact of threats to migratory birds such as habitat destruction by invasive species, disease, contaminants (including oil), and fisheries interactions for the life of the plan.
- MB-3: Monitor populations and habitats of migratory birds at a level sufficient to ascertain natural variation and then to detect changes in excess of that variation that might be attributed to human activities, including anthropogenic climate change.

Reducing Threats to Monument Resources:
Marine Debris Action Plan

- MD-1: Remove and prevent marine debris throughout the life of the plan.
- MD-2: Investigate the sources, types, and accumulation rates of marine debris within 5 years.
- MD-3: Develop outreach materials regarding marine debris within 2 years.

Maritime Transportation and Aviation Action Plan

- MTA-1: Increase awareness of navigational hazards and ecological sensitivity of the Monument.
- MTA-2: Conduct studies to identify potential aircraft and vessel hazards and adopt measures to prevent adverse impacts.

Managing Human Uses:
Permitting Action Plan

- P-2: Track and monitor permitted activities and their impacts.

Current knowledge

Monitoring human activities and their impacts has been undertaken in a variety of ways in the NWHI, usually in relation to specific physical developments, resource uses, species introductions, or rehabilitation efforts. Examples include the efforts to study and address historical coastal developments and disturbances, such as naval base construction at Midway and FFS, LORAN stations, and conversion of abandoned buildings. Studies have documented contamination in soil, sediment, and biota at FFS, Kure, and Midway. Marine pollution from land-based or sea-based human activities in the form of point-source discharges, groundwater discharges, ingestion by wildlife, or nonpoint-source runoff have been monitored in some parts of the NWHI. Accumulation of marine debris is a significant anthropogenic impact on the NWHI ecosystem. A multi-agency effort to remove and recycle derelict fishing gear and other marine debris has been in place since 1996 and has tracked the amount of debris that is accumulating.

There is considerable amount of data on terrestrial invasive species at the NWHI, which include grasses, annual plants, the house mouse, 19 species of ants and wasp, the grey bird locust, and two introduced mosquito species. Marine invasive species surveys have identified 11 alien marine invertebrate, fish, and algal species in the NWHI, with the highest concentrations at Midway Atoll.

Research needs and opportunities

Table 16. Prioritized list of research activities needed to further understanding of human impact metrics in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Indicators and Monitoring of Ecosystem Change				
Human impact metrics and monitoring				
Characterize and monitor terrestrial alien/invasive species.	Critical	1 to 5 years	Reducing Threats to Monument Resources	AS-1.2 AS-2.1 AS-5.1 AS-8.2
Determine the current extent of alien/invasive presence in the NWHI, and follow the populations through time to inform/enhance decisions to either attempt eradication or mitigate the effects on native species.	Critical	1 to 5 years	Reducing Threats to Monument Resources	AS-1.2 AS-2.1 AS-2.2 AS.7.2 AS-8.1
Monitor the residual carbofuran contamination on Laysan Island.	Medium	6 to 10 years	Conserving Wildlife and Habitats	HMC-2.6

3.5 Modeling and Forecasting of Ecosystem Change

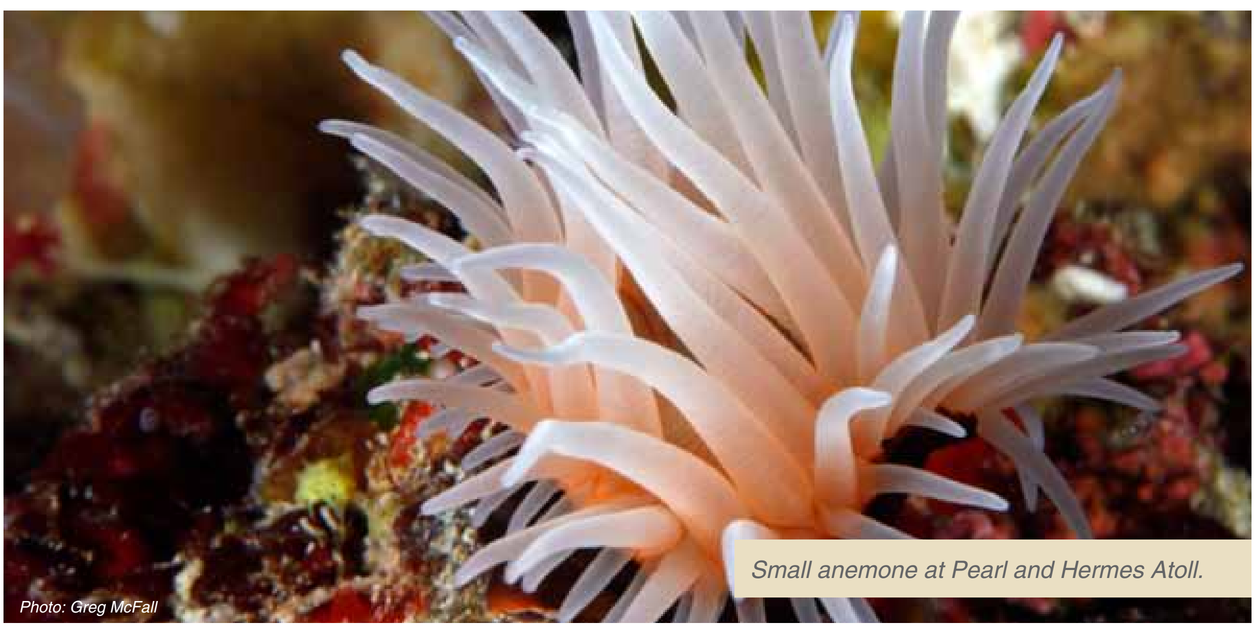
Modeling is a tool to understand or predict changes in the ecosystem or its individual parts. Ecological models can benefit resource managers in understanding complex functional linkages and relative benefits and risks to Monument resources from various management decisions. As such, and if viewed as a tool rather than an end goal, the broad research theme of modeling relates to nearly all strategies outlined in the Management Plan.

A solid understanding of ecological processes, habitat and biological diversity, and human activities of the NWHI, along with robust monitoring, provides inputs to modeling that can predict impacts and support more effective management. This understanding creates the potential to develop models within these themes for specific issues (such as larval recruitment linked to current patterns, changes in populations of protected species, impacts of management interventions, and projected effects of climate change). Broader integration of data and monitoring results on ecosystem and ecological processes, habitats and biodiversity, and human activities makes possible the development of models for individual components, as well as broad-scale models of the NWHI that capture and describe processes in the whole Monument ecosystem.

Incorporating measures of climate change, such as sea temperature, sea level, and carbon dioxide concentrations, into models of ecosystem processes makes the models more complex but also more representative of conditions at the Monument. Data from around the world suggest variables that may be important to include. For example, one predicted result of climate change is the large-scale redistribution of global fisheries catch potential from tropical to higher-latitude regions within the next 50 years as a result of increased water temperature, altered ocean currents and changes in coastal upwelling (Cheung et al. 2009). Models are tested and improved by inputs of site-specific data collected during boundary events. The Science Plan recognizes that rare or extreme climatic events may occur unexpectedly, and scientists must remain ready to launch surveys and other data collecting activities whenever the need arises. The Plan was developed to be flexible so that opportunities for collaboration can be implemented as more scientists turn their attention to the effects of climate change on the Monument's resources.

3.5.1 Modeling the ecosystem and ecological processes

Ecosystem models and forecasting are based on sufficient understanding of ecological processes and characteristics, including patterns, linkages, and resilience. Good modeling of ecological processes allows forecasting of significant changes in the ecosystem to be anticipated or predicted and action taken to minimize impacts. Understanding priority parameters and indicators at a variety of levels — genetic, taxa, populations, habitat, processes, and stressors — supports development of effective models that are sensitive to the scale, resolution, and frequency of sampling. The ecological linkages and patterns of the complex mosaic of ecosystem components of the NWHI need to be understood at an appropriate scale that can be used to monitor, manage, and model the system. The modeling of ecological patterns and linkages improves over time with an increased understanding



Small anemone at Pearl and Hermes Atoll.

Photo: Greg McFall

of the spatial and temporal variation in physical and biological characteristics. Ecosystem modeling and forecasting can provide the means to project the resilience of natural systems in responding to potential short-term impacts and long-term change, with ecosystem changes anticipated or predicted and management actions taken to help ensure that ecosystem resilience is maintained, so that the ecosystem is best able to absorb or recover from disturbance and change.

The expected outcome is development of comprehensive ecosystem models that include ecological linkages and patterns, and ecosystem resilience. Studies and modeling across a range of priority components and across a gradient of environmental stress conditions and stress agents will lead to a robust capacity for projecting the reactions of an ecosystem to likely changes.

Numerous efforts are under way to develop models for parts of the NWHI ecosystem functions and processes. Example models involve oceanographic circulation, trophic levels, transport, productivity, and carrying capacity. Similarly, efforts are ongoing to document ecological linkages within the archipelago, both biotic (for example, movement of adult organisms) and abiotic (such as passive transport of larvae). These are the first steps to broader modeling of ecological linkages and patterns in support of more comprehensive ecosystem models and forecasting. Genetic analyses of species distribution have shown strong differentiation in the absence of obvious geographic barriers that would suggest more restricted movement of larvae and the possibility that local adaptation may be an important driver in the ecosystem.

Research needs and opportunities

Table 17. Prioritized list of research activities needed to further modeling of ecosystem and ecological function in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Modeling and Forecasting of Ecosystem Change				
Modeling the ecosystem and ecological processes				
Understand how physical processes drive biological communities to enhance management of communities with respect to current patterns, upwelling, etc.	Critical	1 to 5 years	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.5
Understand how physical processes impact island structure and function.	Critical	1 to 5 years	Conserving Wildlife and Habitats	HMC-3.1 HMC-3.2

3.5.2 Modeling biodiversity and habitats

Protecting, preserving, and enhancing the native biodiversity of the marine and terrestrial environment are core functions in managing the NWHI. Understanding and projecting likely trends in the status of the species and habitats that make up the biodiversity of the area would enable managers to better protect these resources. Modeling requires information on the distribution and abundance of species populations and the processes that affect their distribution and abundance. In the NWHI, understanding and modeling passive and active transport of flora and fauna are of particular importance. Related is the need to understand the connectivity of the NWHI's species and habitats to those of the MHI and other parts of the Pacific.

Information on existing and likely human impacts, including climate change, and the response of flora and fauna to short- and long-term changes is also important in being able to model future scenarios for biodiversity. Appropriate parameters and indicators must be selected at a variety of levels, such as genetic, taxa, population, habitat, process, and stressor, to support the development of effective models. With these kinds of data, modeling species, populations, and habitats can allow for forecasting significant changes, allowing managers to take preemptive action to minimize impacts on the diversity of the NWHI ecosystems.

The expected outcome is the development of models that enable the status of species, populations, and habitats within the NWHI to be projected in relation to specific short-term impacts or long-term environmental changes. Studies and modeling of priority species, populations, and habitats across a gradient of environmental stress conditions and stress agents will lead to a robust capacity for projecting the response of flora and fauna to likely changes.

Large number of Galapagos sharks at Maro Reef.

Photo: James Watt

Current knowledge

Much of the previous research on biodiversity and habitats of the NWHI will contribute to the development of models for these areas. Some studies more specifically generate information directly related to modeling the conditions of species and population or habitat dynamics. For example, research on the genetics of species distribution have shown differentiation in the absence of obvious geographic barriers, suggesting more restricted movement of larvae and the possibility that local adaptation may be an important driver in some species.

Research needs and opportunities

Table 18. Prioritized list of research activities needed to further modeling of biodiversity and habitats in the NWHI:

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Modeling and Forecasting of Ecosystem Change				
Modeling biodiversity and habitats				
No stated project needs in the next 5 years.				

3.5.3 Modeling human impacts and management

A variety of short-term and long-term impacts from human activities are the greatest threat to the integrity and future of the resources and biodiversity of the NWHI ecosystem. Short-term impacts include marine debris, ship groundings, and potential oil spills from maritime traffic. Long-term impacts include invasive species and more diffuse, complex impacts such as chronic pollution and climate change. In addition, management actions and research themselves have impacts that need to be considered and addressed. Modeling human activities and their impacts enables managers to identify the species, populations, habitats, and processes at risk. These models will allow for the possibility of identifying and implementing preventative management actions, as well as to develop response action plans. With a good knowledge of the kind and level of human activities likely to affect the NWHI, models could be developed to forecast the location and extent of impacts under various change scenarios.

The expected outcome is the development of models that enable the impacts of human activities and management actions to be understood and addressed preventatively or through development of response action plans.

Current knowledge

The efforts to document the sources of human use and impacts on the NWHI ecosystem will contribute to development of models that project the effects of these threats. Some studies more specifically generate information directly related to modeling human impacts, particularly those that have to do with oceanographic circulation, transport models, and carrying capacity models.

Current efforts are underway to quantify the impacts of research to sites in the NWHI. Data collected from permitted activities, including sites visited and numbers of collections, will provide information necessary to model and evaluate potential human-based stressors, both direct and indirect, on NWHI habitats and resources.

Research needs and opportunities

Table 19. Prioritized list of research activities needed to further modeling of human impacts in the NWHI.

Research and Monitoring Activity	Average Rating	Timeframe (years)	Priority Management Need	Management Plan Activity
Modeling and Forecasting of Ecosystem Change				
Modeling human impacts and management				
Advance knowledge of possible alien species invasion locations to enhance early detection fan allow for advance planning for mitigation in the case of possible invasions.	High	1 to 5 years	Reducing Threats to Monument Resources	AS-1.2 AS-2.3 AS-7.2 AS-8.1 AS-8.2

Susan Middleton sifts through debris inside the carcass of 'Shed Bird,' Kure Atoll

Photo: Cynthia Vanderlip

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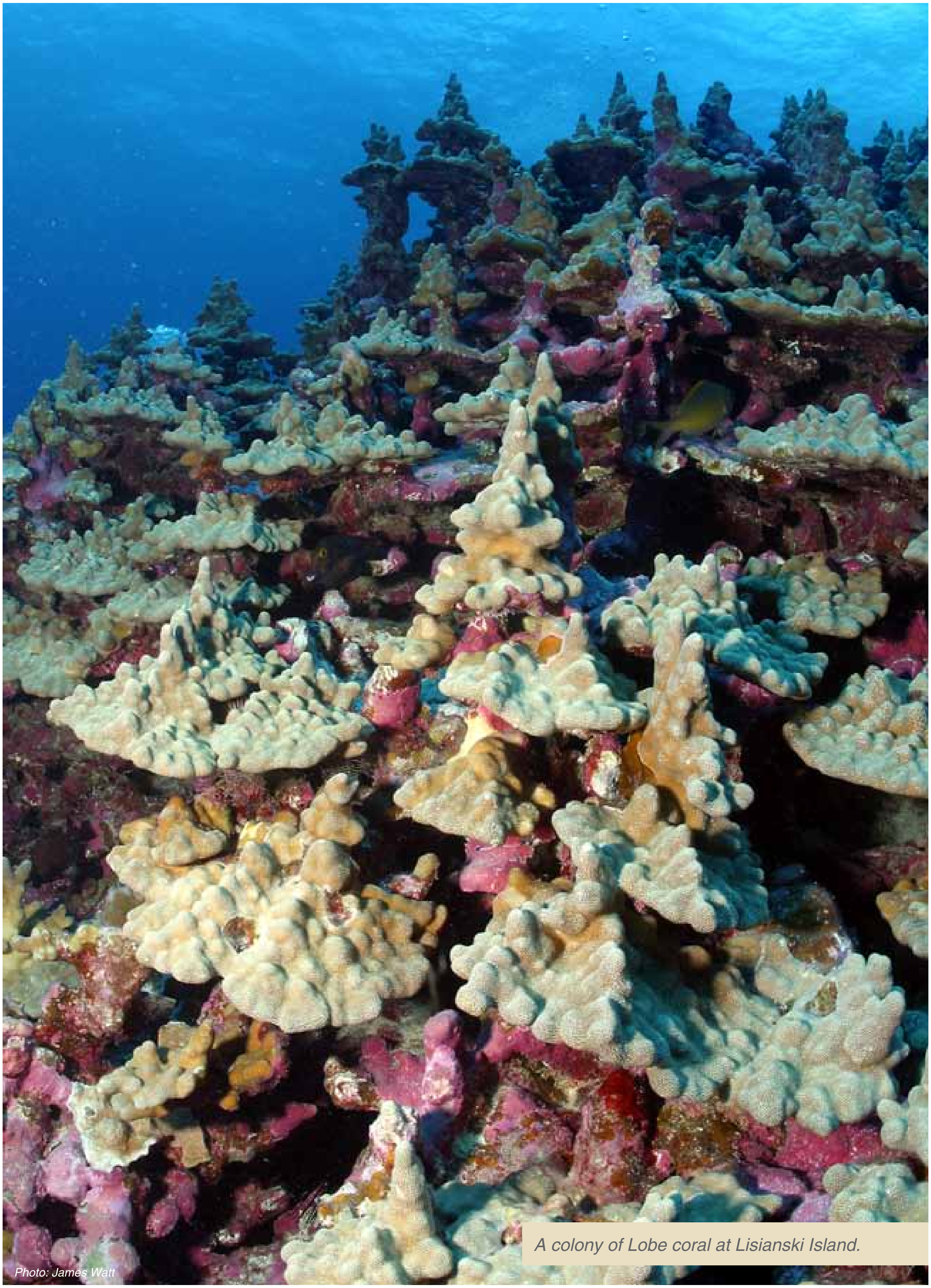

Photo: James Watt

A colony of Lobe coral at Lisianski Island.

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