PAPAHĀNAUMOKUĀKEA MARINE NATIONAL MONUMENT

NATURAL RESOURCES SCIENCE PLAN

DRAFT

Contents

Figures

Tables

Acronyms

DLNR	State Department of Land and Natural Resources
ESA	Endangered Species Act of 1973
FFS	French Frigate Shoals
FWS	U.S. Fish and Wildlife Service
HAMER	Hawai‘i Archipelago Marine Ecosystem Research
km	kilometers
LORAN	U.S. Coast Guard Long-Range Aid to Navigation
Management Plan	Monument Management 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
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
NWHI RAMP	Northwestern Hawaiian Islands Reef Assessment and Monitoring Program
ONMS	Office of National Marine Sanctuaries
PCBs	polychlorinated biphenyls
Science Plan	Papahānaumokuākea Natural Resources Science Plan
USCG	U.S. Coast Guard

1.0 Introduction

The Papahānaumokuākea Marine National Monument (Monument), established on June 15, 2006, by Presidential Proclamation 8031, created one of the world's largest marine protected areas in the Northwestern Hawaiian Islands (NWHI), managed to protect ecological integrity. This Proclamation is the most recent in a series including executive orders issued by six U.S. Presidents and a Governor of the State of Hawai'i to protect the NWHI over the last 100 years. Globally, the NWHI are a natural and cultural treasure of outstanding scientific, conservation, and aesthetic value. The establishment of the Monument builds on the long-standing efforts of state and federal agencies, nongovernmental organizations, stakeholders, and the public to provide for long-term protection of the marine and terrestrial ecosystems of the NWHI and the preservation of cultural and historic heritage resources. Today, the responsibility for management of the Monument is shared by the State of Hawai'i, 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. Co-Trustee agencies, in cooperation with the Office of Hawaiian Affairs, manage the Monument through the Monument Management Board.

The Monument Management Plan (Management Plan), completed in December 2008, describes a comprehensive and coordinated management regime to achieve the vision, mission, and guiding principles of the Monument and to address six priority management needs over the next 15 years. Each of these six priority management needs is expanded into issue or resource-based action plans, further divided into strategies, used to develop specific activities to achieve long-term ecosystem protection for the Monument. Although activities within the Management Plan are appropriately focused on achieving specific management goals (such as to eradicate an established invasive species), many of them require supporting science to achieve their goals.

This 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 is linked to the Management Plan both through the critical role science plays in effective management and because scientific research is one of the primary activities occurring within the Monument.

The Science Plan establishes a 15-year research and monitoring framework to advance ecosystem science through research and monitoring practices to improve management of the natural resources in the Monument over the next 5 years. The Science Plan was developed through the collective efforts of scientists, resource and Monument managers, and other stakeholders from a variety of agencies and organizations, including the Monument's Co-Trustee agencies, academic and research institutions, and other partners. This Science Plan is organized into four sections as follows:

- Section 1 provides an overview of the Monument, describes the purpose and scope of the Science Plan, and defines stakeholders.
- Section 2 describes the planning process as well as and information and data sources used to develop the Science Plan.

- Section 3 describes research focus areas under five research themes and their association to the Management Plan.
- Section 4 presents a list of prioritized research and monitoring activities that will provide information and data needed to improve management of the Monument over the next 5 years.

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.

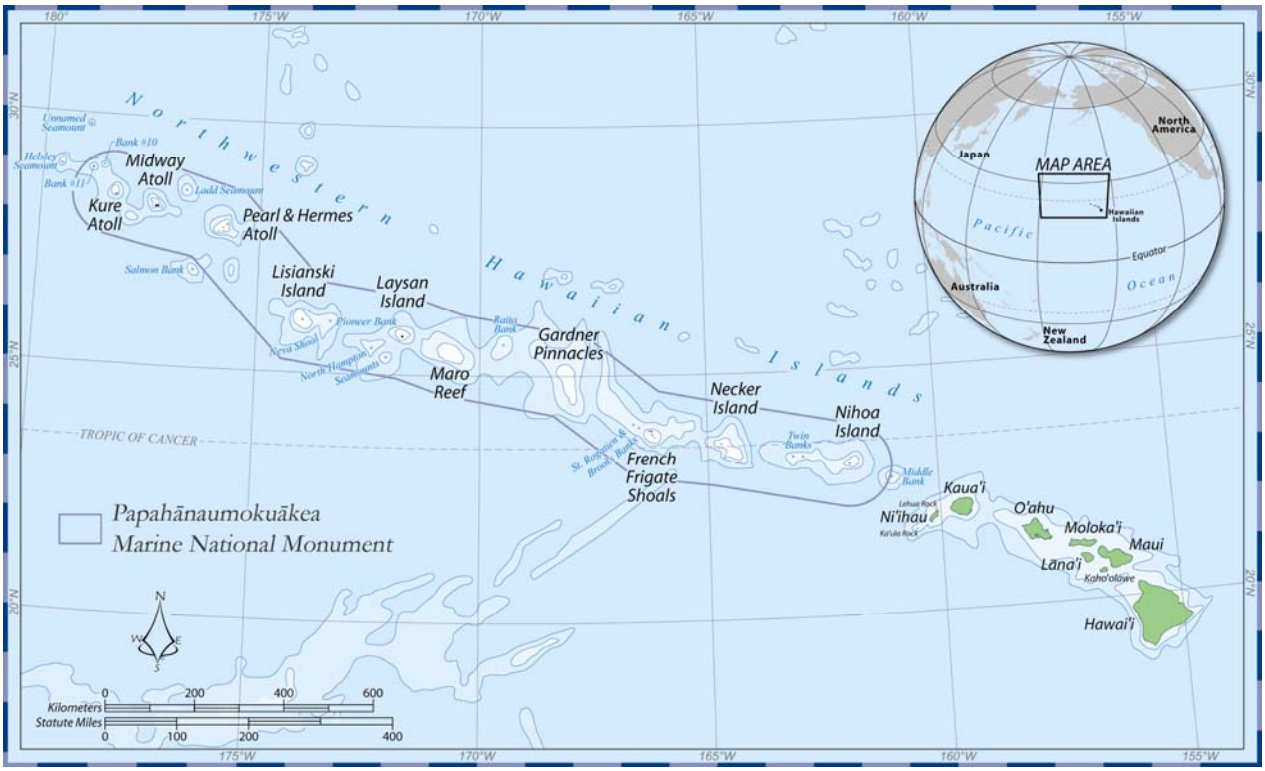

Figure 1. Map of the Papahānaumokuākea Marine National Monument

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 meeting applicable criteria provided by relevant state statutes and regulations.

In addition, the Co-Trustees signed a Memorandum of Agreement (MOA) on December 8, 2006, establishing roles and responsibilities as well as coordination bodies and mechanisms for managing the Monument. 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 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 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.

The Science Plan characterizes research needs and activities to achieve these goals over the next 15 years and outlines priorities for the next five years (2009 to 2013). These priorities include research and monitoring needed on terrestrial and marine resources throughout the Monument.

The Science Plan is not considered a static document. 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.

1.3 Stakeholders

The Science Plan serves as a guide for a broad range of stakeholders, including scientists, resource managers, the Monument Management Board (MMB), the public and Monument's Co-Trustee representatives. The Science Plan provides the Monument scientists and resource managers the means to direct scientific research towards 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 serves as a guide for the MMB to review and evaluate permit applications for research in the Monument. Public review and comment on the Science Plan's planning process also serves to inform the public about the types and extent of research that will

occur in the Monument and provides an opportunity to take public comments into account when writing the final draft of the Science Plan.

2.0 Summary of Planning Process

The Science Plan builds on extensive discussions, planning, and prioritization efforts conducted over the last 5 years. Resource managers, scientists, the academic community, and representatives of non-governmental organizations and other stakeholder groups have defined the research needs and opportunities for informing management decision-making in the Monument. Information and data used to develop the Science Plan were drawn from the review and synthesis of published literature, reports, planning documents, the Monument permit database, input from the public and other concerned agencies and from extensive coordination during development and approval process leading up to the development of the final Management Plan. Key components of the planning process to develop the Science Plan included the following activities:

- Development of a 15-year research and monitoring framework including themes and focus areas for the Science Plan building on the Hawai‘i Archipelago Marine Ecosystem Research (HAMER) Plan and a comprehensive review of reports, published literature, planning documents, and other sources of information.
- Public review and comment on the 15-year research and monitoring framework for the Science Plan
- Development of research profiles on the range of ongoing and potential new research and monitoring activities based on input from scientists and managers and review of past and ongoing permitted research and monitoring activities
- Identification of research and monitoring gaps and needs based on priority management needs, strategies, and activities identified in the Management Plan
- Prioritization of research and monitoring activities based on management needs

A science planning team (Science Plan Team) composed of Monument managers, scientists, and other designated Co-Trustee representatives and their staff, were engaged in all aspects of draft plan development including the review and input on the research and monitoring framework, identification of gaps and information needs, and prioritization of research and monitoring activities.

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 archipelago. The HAMER Plan was drafted, reviewed and approved by the Co-Trustees and other key agencies, with an external review by an expert panel. Although it was modeled after the HAMER Plan, the science plan 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 in the development of the science plan include:

- Papahānaumokuākea Monument Management Plan (2008)
- Quarterly Progress Reports of the Hawai‘i Institute of Marine Biology – Office of National Marine Sanctuaries (ONMS) Pacific Region Partnership (2006 – ongoing)
- 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, Inc. 2008). 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 Hawai‘i’s statutory environmental impact review process. In addition to these requirements, the scoping process’s objectives also included:

- Helping public, elected officials, and agencies gain a clear understanding of the purpose of the Science Plan.
- Developing preliminary focus themes of this Science Plan.
- Identifying opportunities for needed research that would contribute to better management of the Monument.
- Developing two-way communication with the public and science community to facilitate information sharing.
- Providing a “user-friendly” approach to obtaining public and agency input, suggestions, and mitigation options for consideration in the Science Plan.
- Complying fully with Council on Environmental Quality and the State of Hawai‘i’s Office of Environmental Quality’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 by 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. Comments 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, Inc. 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 to 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. There were only a few comments that provided clear suggestions as to the types of research that should be conducted within the Monument.

The report 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.

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
- 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, Center for Coastal Monitoring and Assessment), the University of Hawai‘i (Hawai‘i Institute of Marine Biology, Botany, Zoology, Oceanography, Hawai‘i Undersea Research Laboratory), 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 were reviewed and prioritized by a panel of MMB agency representatives (Science Plan Panel). This panel was composed of individuals selected by their respective agency to represent that agency in the review and prioritization process.

2.5 Prioritization of Research and Monitoring Activities

The list of 157 research and monitoring activities was reviewed and prioritized by the Science Plan Panel in January and February 2009. 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
- Providing the public with information on priority information and data needed to manage the natural resources of the Monument

The Science Plan Panel was tasked to rate each activity, on a scale from 1 to 10, on that activity's importance to the future protection and conservation of resources of the Monument. Points were added to the initial rating if the activity supported a legal mandate of one of the Co-Trustees or directly supported endangered species recovery. Points were also added if the activity supported a single or multiple strategies of the Management Plan. An overview of the prioritization process is provided in Figure 2.

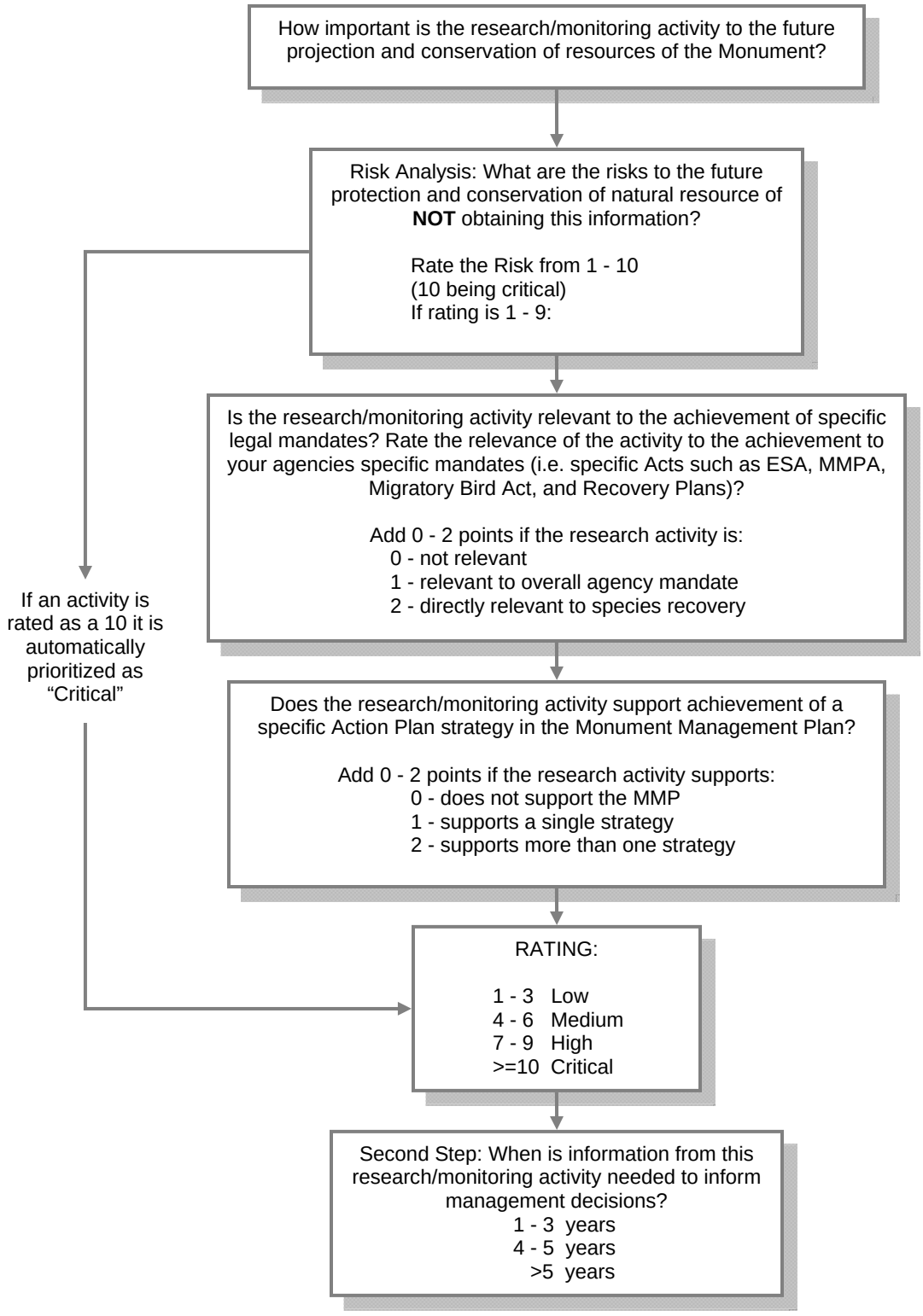

Figure 2. Prioritization Process Used for the Science Plan

The Science Plan Panel met on February 12 and 13, 2009 to prioritize research activities for inclusion in the Science Plan. Each member of the panel reviewed the generalized list of research and monitoring activities and rated each activity individually. Initial ratings were based on a scale from 1 to 10, with 1 to 3 corresponding to a low priority, 4 to 6 for a medium priority and 7 to 9 as a high priority. Any initial rating of 10 was immediately prioritized as a critical need, and was not subject to further assessment. For the remaining activities, the highest potential rating was 13, but any activity that accumulated a score of at least 10 was also prioritized as critical. Science Plan Panel members were encouraged to conduct their own information needs assessment, as done by Monument staff prior to the meeting, and write them in a similar scientific question format. This led to several additional proposed research activities.

After each of the Science Plan Panel completed their initial rating, scores for each activity were compiled and discussed among the entire group. Activities that received similar scores from all participants were reviewed and ratings of low, medium, high or critical were confirmed. Activities that did not have similar scores were discussed among the team. Each agency's representative was given the opportunity to explain the rationale for their ranking, which led to a consensus rating by all agencies. The activities, their rating, time frame in which the information is needed, and the link to the Management Plan needs and activities are included in Table 2 of Section 4.

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 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 of 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 2). All of these factors assist in the central objective to conserve and manage Papahānaumokuākea.

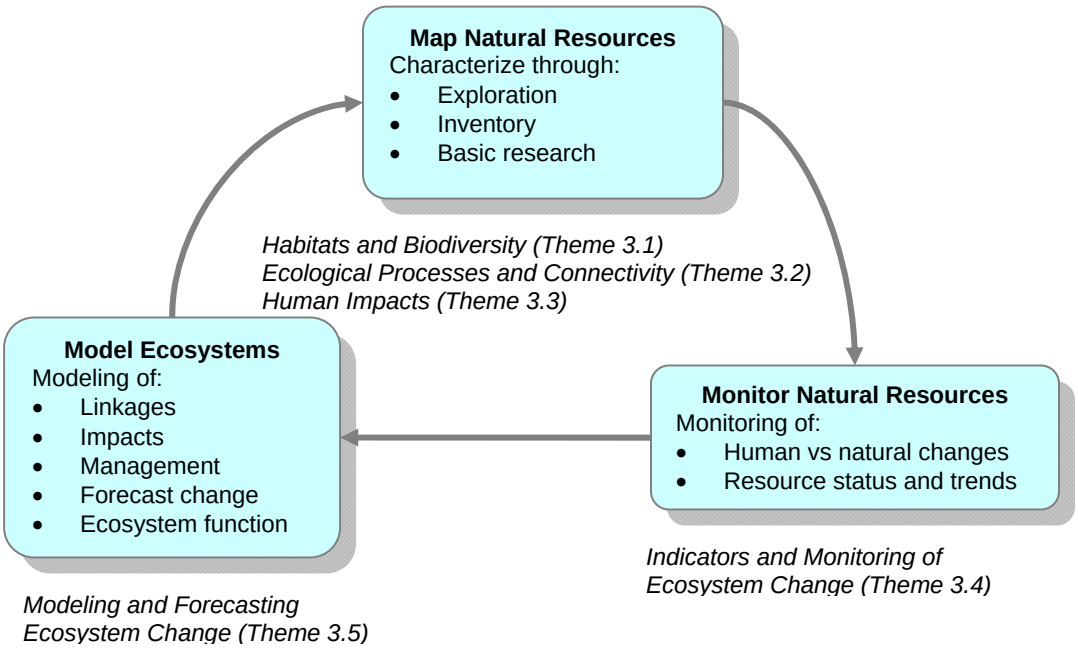

Figure 3. Research and Monitoring Process and Related Themes for the Science Plan

3.1 Habitats and Biodiversity

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. Because of the intimate interconnections between habitats and biodiversity, science in the Monument should also be designed to consider the linkages between these two ecosystem components. Biodiversity studies will 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, or both. Special focus will be given to research on native and protected species. This work will require 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 degree of exploration and research accomplished within it to date.

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. This will allow characterization of the diversity of habitats within the Monument. Understanding the diversity, distribution and abundance of habitats available at the NWHI will provide a baseline that can be used to identify changes in habitat composition, the causes of such change (for example, climate change, invasive species, and human use), and the potential implications of these habitat alterations. It will also form the basis for a habitat stratification scheme for marine monitoring. Identifying and protecting habitats in decline will in turn inform our management of biodiversity in the Monument and promote the ability to properly manage the ecosystems as a whole.

Why is this focus area important?
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 done to date, most of the NWHI remains relatively unexplored, not only deep water habitats, but also many shallow water habitats.

Questions addressed by focus area

This focus area provides insights into the diversity of habitats in the NWHI. Key questions this research activity is expected to address include:

- What is the pre-Western contact baseline distribution of marine and terrestrial habitats?
- How are current conditions different from conditions before human contact?
- What is the current distribution of habitats in the Monument? How is this current habitat baseline changing?
- What habitats are sensitive to human use?
- How does human use affect NWHI habitats?
- What habitats are essential for rare or endangered species?

- What are the basic processes that underlie the maintenance and functioning of Monument 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 by 2009.

Development of a geo-referenced catalog of terrestrial and marine habitats will provide a baseline for assessing the distribution and abundance of the diversity of habitats within the Monument. This tool will facilitate management and permitting decisions related to specially protected species, ecosystem monitoring, and research site selection. Additionally, it will allow objective and quantitative assessment of changes in habitat composition and distribution within the NWHI over time.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF POTENTIAL RELEVANCE TO HABITAT RESEARCH AND MONITORING

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.

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.

Examples of research needs and opportunities

A geographic information system-based biogeographic assessment of NWHI living species and their associated habitats will describe the spatial and temporal relationships of species within and among habitats and between marine and terrestrial habitats, to the extent information is available. This product will also provide the spatial resource information necessary to support ecosystem-based decision making. Additional specific research opportunities include:

- Conducting field work to validate and update existing habitat maps and bathymetry. This work will build on remote sensing data originally collected in developing the *Draft Atlas of the Shallow-Water Benthic Habitats of the NWHI* and the *Bathymetric Atlas of the NWHI*, Draft. The updated dataset, maps, and images, together with additional information on new species, will provide a framework for an improved understanding of biogeography.
- Researching methods to facilitate restoration of Southeast Island at Pearl and Hermes Atoll. This research is of great importance for the survival of several native plant populations at the northern end of the archipelago and for a small translocated population of the endangered Laysan finch (*Telespyza cantans*). Similarly, research to reverse the loss of habitat at several islets at French Frigate Shoals (FFS) is important, as they make up the largest pupping habitats for the endangered Hawaiian monk seal and nesting habitat for the threatened green turtle in Hawai‘i.
- Developing an understanding of the range of natural variability caused by weather in the simple but dynamic vegetation communities of the NWHI as a basis for better management actions.
- Identifying historic and prehistoric locations of freshwater wetlands or seeps and, based on these data, identifying suitable locations for freshwater wetland restoration for native species that use fresh water and developing techniques to create the wetlands at these locations.
- Surveying the distribution of seabirds at sea and monitoring annual and seasonal changes in seabird diets as they relate to ocean conditions.

Selected previous and ongoing studies

The Northwestern Hawaiian Islands Reef Assessment and Monitoring Program (NOWRAMP/NWHI RAMP) was initiated 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 cruises are typically multi-agency, collaborative partnerships (NOAA, FWS, and DLNR’s Division of Aquatic Resources, and others) consisting of quantitative diver surveys of fish, coral, algae, and invertebrate communities, supplemented by towed diver surveys, 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 draft *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.

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. 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 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 some or most of them cannot be executed.

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, 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.

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. 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 so may require protection. Understanding the ecological role of key native species at the NWHI and safeguarding this biodiversity will help maintain ecosystem stability. At some point, exploration would also need to extend to deep-water habitats.

Why is this focus area important? 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 those of deep-water communities.

Questions addressed by focus area

This focus area provides insights into the marine and terrestrial biodiversity of the NWHI and the ecological role of native species in the area. Key questions this research activity is expected to address include:

- What is the current distribution and status of native biodiversity in the NWHI?
- What is the historical distribution of native biodiversity?
- What native species play key ecological roles in the NWHI?
- Which native species are endemic and which are rare?
- Which native species need additional protection?
- What habitats need additional protection to maintain robust populations of native species?
- What habitats are essential for reproductive (adult) segments of populations, particularly those of species that are major economic and ecological resources?
- What are the key habitat linkages for just-settled and older juvenile reef fishes and other benthic resources?
- What are the effects of climate change on native biodiversity in the NWHI?
- What management actions could minimize climate change effects?
- What effects, sublethal and acute, occur or may occur to native biodiversity from contamination?

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. For marine species, this research will provide information for the Census of Marine Life, a worldwide effort to catalogue all marine species. 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.

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

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.

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.

Examples of research needs and opportunities

Overall, there is a need for basic information on all living resources of the NWHI. Taxonomic studies should provide information on all species present to develop a baseline and facilitate identification of new species records. Life history studies are needed to provide information on essential habitat requirements (reproduction, recruitment, and feeding) in all life stages, environmental tolerance, larval dispersal mechanisms and other parameters (age structure, growth, and mortality) for key native species. Specific research needs include:

- Conducting baseline flora and fauna surveys of all terrestrial and marine habitats within the Monument, with particular initial emphasis on poorly-known taxa such as terrestrial arthropods and shallow water marine cryptofauna and marine algae.
- Identifying and describing new species, their habitats and status.
- Developing a comprehensive catalog of native species that includes geographic distribution, ecological requirements, geo-referenced habitat use during different life

stages, and life history metrics (population age and size distributions, growth rates, size and age of maturity, and mortality rates).

- Comparing native species habitats and ecological requirements with those of invasive species present in the NWHI.
- Comparing native species habitats and ecological requirements with a catalog of anthropogenic threats to identify native species vulnerable to anthropogenic stress.
- Developing comparative life history studies between NWHI and MHI to determine anthropogenic effects on growth, maturation, and reproductive success of native species.
- Documenting the trophic dynamics of key native species.
- Evaluating distribution and availability of habitat, especially that which is essential to reproduction, recruitment, and feeding.
- Characterizing the genetic structure of specific populations.
- Determining the functional ecological roles of native species.
- Identifying management activities that would conserve key habitats and species.

Selected previous and ongoing studies

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 Hawai‘i for decades. The Monument is home to one of the largest and most important assemblages of tropical seabirds in the world, with approximately 14 million birds (6 million breeding annually) representing 23 species.

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).

3.1.3 Specially protected species

Why is this focus area important?
Understanding the status and needs of species already specially protected is critical to maintaining the health of their populations and promoting their recovery.

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 albatrosses — 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 albatrosses, Laysan ducks, 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.

Questions addressed by focus area

This focus area provides insights into the status of protected species in the NWHI. Key questions this research activity is expected to address include:

- What is the population status and trend of specially protected species?
- What are the geographic distributions of these species?
- What is the critical habitat for each protected species?
- What anthropogenic activities affect protected species' critical habitat?
- What non-threatened species do protected species depend on?
- What are the sublethal effects of contaminants, such as polychlorinated biphenyls (PCBs), on specially protected species?
- What are the effects of climate change on specially protected species populations in the NWHI?

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 POTENTIAL RELEVANCE TO SPECIALLY PROTECTED SPECIES RESEARCH AND MONITORING

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.

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.

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.

Examples of research needs and opportunities

It is important to develop and regularly update a database of population structure and dynamics for protected species. The database will help managers make effective decisions and determine the effect of previous decisions or events (climate events, management decisions, research programs, and disease outbreaks, for example). In light of the ever-worsening crisis for the Hawaiian monk seal population, a great deal of management-driven research will be conducted to reverse this trend. The Recovery Plan for the Hawaiian Monk Seal (NMFS 2007) lists 11 short-term management actions, many of which will benefit from additional research. These actions include investigating factors affecting food limitation, researching methods to reduce shark predation on monk seals, researching methods to minimize exposure and spread of infectious disease, and investigating and developing response to biotoxin impacts, among others. In addition to this focus, other opportunities include research to improve the understanding of:

- The essential habitats and ecological requirements of specially protected species, to minimize anthropogenic threats and the effect of catastrophic events.
- Developing translocation techniques and requirements for Nihoa finches (*Telespyza ultima*) and Nihoa millerbirds (*Acrocephalus familiaris kingi*) so their populations can be expanded to other islands within the NWHI to facilitate recovery of these endangered species.
- The diet and foraging behavior of the Hawaiian monk seals throughout their different life stages to understand the effect of food availability on the population.
- Time budgets, diving, and movement characteristics and energetics, stratified by representative sub-populations, age, and sex classes of the Hawaiian monk seal.
- An appropriate and sensitive assay for biotoxins and metabolites in tissues of monk seals and prey species.
- The effect of climate change on the nesting sites of specially protected species.
- The Allee effect (that for smaller populations, the reproduction and survival of individuals decrease) and thresholds for phase shift.
- Appropriate techniques for translocation of endemic songbirds to establish additional populations.
- The potential to establish additional populations of endangered land plants.

Selected previous and ongoing studies

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. 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).

Cetaceans: In the NWHI, sightings and acoustic recordings of whales as well as dolphins have been documented. Five species of baleen whales and one toothed whale are listed as "Endangered" under the ESA, and as "Depleted" under the MMPA. In addition to these six 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. 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, olive ridley, 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, 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. 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 nonbreeding 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 21 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.

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 December 2008, the population numbers approximately 350 ducks. 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 ‘ōhai, *Sesbania tomentosa*, is present on Nihoa and Necker Islands. *Mariscus pennatiformis* 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.

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. The distribution and change in disease will enable managers to identify trends and vectors of disease and their impact on the NWHI ecosystem and its function. 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.

Why is this focus area important?
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.

Questions addressed by focus area

This focus area provides insights into effect of disease on NWHI biodiversity. Key questions this research activity is expected to address include:

- What is the baseline or current status of disease in the NWHI?
- Which invasive species act as vectors for introduced disease into NWHI?
- What is the potential impact of disease on the biodiversity and ecosystem stability of the area?
- What (if any) disease eradication strategies are possible and should be adopted?
- Once detected, what are the most effective mechanisms to minimize spread into the greater population?
- What are the potential diseases entering the NWHI, and the response to the diseases?
- What (if any) disease prevention strategies are possible and should be put in place?

Research on health and disease at the NWHI is expected to help maintain biodiversity by establishing a baseline for the pretenses 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 POTENTIAL RELEVANCE TO HEALTH AND DISEASE RESEARCH AND MONITORING

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.

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.

Examples of research needs and opportunities

It is important to obtain a baseline and maintain a disease monitoring program for the NWHI to identify and mitigate future disease outbreaks. General research needs are to establish

epidemiology by type of disease, including life history, vectors and pathways; evaluate the likelihood for establishment of diseases; and evaluate the impact of diseases. Specific research opportunities include:

- Establishing a baseline for types, diseases, prevalence, morbidity, and mortality.
- Identifying protocols for removal of coral disease from infected colonies with minimal impact.
- Characterizing threats according to likelihood of exposure and susceptibility.
- Identifying disease threats to highly endangered species.
- Determining techniques to eradicate mosquitoes from Midway Atoll to limit the effects of avian pox and other diseases on native birds and seals.
- Evaluating the efficacy of habitat management and vaccination for prevention of botulism in Monument waterbirds.

Selected previous and ongoing studies

Past research on marine health and disease at the NWHI included but, was not limited to, work on coral and reef fish disease and avian botulism (Work et al. 2004; Aeby 2006a, b). Aeby (2006b) 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).

Ongoing research on health and disease issues includes studies on the effect of *Acropora* white syndrome and *Acropora* growth anomalies on *Acropora* reproductive output (Aeby and Work 2007); an assessment of 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). Stat and Gates (2007) have identified an association between *Symbiodinium* clade A and a higher incidence of disease. The upside down jellyfish, *Cassiopeia* spp., an introduced species to Hawai‘i, is a possible vector for *Symbiodinium* clade A. Active research on fish diseases includes studies on native goatfish from Johnston Atoll (not yet invaded by ta‘ape), and found no nematode infections, providing further evidence that nematode disease was introduced into Hawai‘i by ta‘ape.

Work et al. (in preparation) 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.

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 the effective management of the Monument.

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-surface temperature, acidity, and other parameters of 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.

Why is this focus area important?
The movement of water masses in and out of the NWHI and vertically (upwelling) and extreme ocean and atmospheric events are major drivers of ecosystem health and productivity, especially as a result of the transport of nutrients and living resources, such as larvae. Weather patterns and atmospheric conditions also influence geological processes and biological cycles. Understanding oceanic and atmospheric factors is essential for understanding and predicting the effects of climate change and their relation to potential management actions to conserve species and habitats.

Questions addressed by focus area

This focus area provides insights into the hydrodynamics of the NWHI and the ability to address fundamental management issues related to the temporal and spatial patterns, quality and movement of water masses and the occurrence of important ocean and atmospheric events. Key questions that this research activity is expected to address include:

- What are the temporal and spatial patterns, quality, and movement of water and air masses that drive connectivity within the NWHI and between the NHWI and the MHI and other parts of the Pacific?
- Are there oceanographic features or processes that create ecological sub-units within the NWHI and how do these sub-units vary over time?
- What are the sources and sinks for important imports brought into the NWHI by water masses, such as larvae, nutrients, contaminants, and marine debris?

- How do seasonal changes in current, upwelling patterns, and weather conditions affect surface productivity and the distribution, abundance, and health of species, populations, and habitats in the NWHI?
- How are currents and upwelling influenced by changes or fluctuations in the regional and global oceanographic situation and climate conditions?
- How are perturbations to the large and meso-scale structure of currents affecting marine biota and endangered species in the NWHI?
- What are the kinds, patterns, and predictability of extreme oceanographic and atmospheric events that have a major impact on the NWHI ecosystem, and on species and 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.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF POTENTIAL RELEVANCE TO OCEANOGRAPHIC AND ATMOSPHERIC RESEARCH AND MONITORING

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.

Marine Debris Action Plan

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

Examples of research needs and opportunities

Overall, there is a need for basic information on spatial and temporal patterns of water movement, atmospheric conditions, and water quality characteristics within the NWHI at a range of scales. Moving forward, it is important for resource managers to have a unified hydrodynamic model to describe connectivity, identify seasonal areas of oceanographic productivity, detect and predict change in the pattern and scales of movement, dispersal, abundance, and recruitment of living resources at various life stages, identify and document variability in larval and nutrients sources, and understand debris dispersal and establish management units within the NWHI. Specific opportunities include research to improve the understanding of:

- Carbon, nitrogen, and phosphorus in the ecosystem and the transfer to higher trophic levels.
- Community changes that will result from alterations to reef structure by major ocean and atmosphere events.
- Discerning anthropogenic impacts from natural variability of the physical ocean environment.
- Pacific Decadal Oscillation and El Niño/Southern Oscillation events and effects.
- Geomorphological and sedimentological processes affecting reefs and terrestrial areas.
- Dispersion patterns of key pollutants.

- Physical and biological effects of extreme events on the ecosystem.

Selected previous and ongoing studies

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. Research efforts have used a variety of methods, including buoy arrays, drifters, and remote sensing.

3.2.2 Passive transport of nutrients and living resources

Why is this focus area important?
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 movement of water masses into, out of, and within the NWHI plays a major role in ecosystem health, functioning, biogeography, and biodiversity. The passive transport of nutrients and living resources that results from horizontal currents and vertical water movements (upwelling) is fundamental to the 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-surface 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. Larval dispersal and the role of larval sources and sinks are particularly important.

Questions addressed by focus area

Numerous management issues depend on an understanding of the movement of water masses as a means for the transport of nutrients and biota. Key questions that this research area can address include:

- What are the temporal and spatial patterns of passive transport provided by the movement of water masses within the NWHI?
- What are the temporal and spatial patterns of passive transport into the NWHI and between the MHI and other parts of the Pacific region?
- What are the sources and sinks for the nutrients and larvae that are transported by these water masses?
- Do seasonal changes in current and upwelling patterns affect surface productivity and the distribution and abundance of species, populations, and habitats in the NWHI?
- Do the oceanographic features and water movement create sub-units within the NWHI, such as eddies that provide larval retention?

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 POTENTIAL RELEVANCE TO PASSIVE TRANSPORT OF NUTRIENTS AND LIVING RESOURCES RESEARCH AND MONITORING

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.

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.

Examples of research needs and opportunities

To understand passive transport, there is a need for basic information on spatial and temporal patterns of water movement, quality and characteristics within the NWHI at a range of scales to assess the general patterns of passive transport for nutrients and living resources. Building on an understanding of oceanographic processes, specific examples of research needs and opportunities include efforts to:

- Determine the transport pathways and patterns for the larvae of key organisms.
- Identify the sources and sinks of larval dispersal for key organisms.
- Define the sources and patterns of primary productivity resulting from upwelling sites and occurrences and nutrient input to the NWHI.
- Undertake applied research into the design of protected areas in support of ecosystem resilience based on passive transports processes, patterns, and pathways.

Selected previous and ongoing studies

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 demonstrated clear spatial patterns in ocean productivity but has been unable to trace the path of nutrients and energy flow into the ecosystem. Although transport models have been developed and have identified large-scale patterns in ocean circulation, they have not yet been able to establish the sources and sinks for larval populations.

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 movements and migration patterns of target species may occur in relation to various biological and environmental variables (prey abundance, temperature, moon, sun and tidal cycles, thermoclines, and bottom topography, for example). Other movements may

Why is this focus area important? Understanding the movement processes and patterns for important native and specially protected species is critical to effectively managing these populations in the NWHI.

be more episodic, for example as a result of extreme weather events. There may be critical habitat or resources that are an important determining factor in 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.

Questions addressed by focus area

Information on the transport and movement patterns of key species and the drivers to this movement of organisms is essential for management of the species and populations in the NWHI. Key questions that this research area is expected to address include:

- What key species (such as native or protected) actively migrate between the NWHI and the MHI?
- What habitats are used by key species in the NWHI and what is their distribution?
- What are the predictable migration and movement patterns that can be used to minimize anthropogenic impacts to these species and their habitats and optimize management?
- How are migration and movement patterns of key species influenced by changes or fluctuations in global and regional climate conditions?

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.

Examples of research needs and opportunities

Overall, there is a need for systematic information on the active transport and movement of biota into, out of, and within the NWHI. This work can be extended to important applications such as discrete population identification, population dynamics, and species interactions. All of these efforts should be undertaken in a way that contributes to the development of models that can predict movement patterns at multiple spatial and temporal scales to address questions of connectivity, especially the linkages between the NWHI and the MHI. Specific opportunities include:

- Identifying and understanding the important species that have regular or episodic active movement or migration into the NWHI.
- Determining the life stages of species that are involved in active transport.
- Identifying critical habitats for different life stages of species that transport themselves into the NWHI.
- Understanding the effects of extreme events and anthropogenic activity on movements and migrations and survival.
- Determining which habitats and migrating species combinations are at risk, such as sea turtles and nesting beach habitat, and identify management actions to minimize risk.

STRATEGIES IN THE MONUMENT MANAGEMENT PLAN OF POTENTIAL RELEVANCE TO ACTIVE TRANSPORT AND MOVEMENT OF LIVING RESOURCES RESEARCH AND MONITORING

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.

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.

Permitting Action Plan

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

Selected previous and ongoing studies

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 satellites 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 albatrosses (Naughton et al 2007) as well as spinner dolphins (Karczmarski et al. 2005) and satellite tracking of endangered species (monk seals) (Parrish and Abernathy 2006) and top predators (sharks and jacks) (Lowe et al. 2006). 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 albatrosses and red-tailed tropicbirds Kure Atoll, Midway Atoll, and FFS to understand breeding and non-breeding season movement patterns of these birds (J. Klavitter pers. comm.). In addition to albatrosses with far-ranging distribution, most breeding seabird species 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, NOAA's Southwest Fisheries Science Center). 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.

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 terrestrial and marine 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

Why is this focus area important? Understanding the genetic diversity of species groups, and the reasons and ways the area's plant and animal populations change, is critical to conservation management.

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 allow for comparisons of population dynamics and understanding the connectivity within the NWHI and between the NWHI and the main Hawaiian Islands 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.

Questions addressed by focus area

Information on the genetic structure of species groups and the dynamics of populations provide fundamental input into managing these organisms. Key questions include:

- Are there genetically distinct subpopulations of flora or fauna between the MHI and the NWHI or within the NWHI?
- What are the reproductive population pools of key species that are critical for their management?
- What is the value of the NWHI populations as a source to repopulate the MHI?
- What is the relative resilience or fragility of individual species to natural and anthropogenic stress?
- How does the isolation of the terrestrial flora and fauna affect the genetic structure and population dynamics of these organisms?
- Is it possible to identify taxa that will serve as proxies for ecosystem genetic connectivity and to develop sampling regimes that will identify genetic management units?
- How does the connectivity resulting from passive transport via larval dispersal affect genetic structure and population dynamics?
- How do patterns of genetic connectivity for biota in the Monument differ between taxa?
- What is the genetic and population impact of invasive species from the MHI to the NWHI?
- How have reductions in number of protected species affected their genetic diversity?

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 POTENTIAL RELEVANCE TO POPULATION DYNAMICS AND GENETIC STRUCTURE RESEARCH AND MONITORING

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

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.

Examples of research needs and opportunities

As the understanding of most of the species and populations in the NWHI is at the most basic level (identification of species and groups), genetic studies have the capability to enhance the understanding of the ecosystem, including distribution, dispersion rates, and connectivity or isolation among plant and animal populations in the NWHI. Specific research opportunities include:

- Characterizing the genetic structure of key species and populations.
- Identifying genetically distinct subpopulations of flora or fauna between the MHI and the NWHI.
- Determining the value of selected species in the NWHI for repopulating MHI populations that are overexploited or subject to major impacts.
- Determining the importance of MHI populations for maintaining populations in the NWHI.
- Applying genetic techniques to key populations across the stress gradient of the archipelago to detect pools of individuals with a genetic makeup that keeps them from being filtered out by the environmental stressors.
- Studying individual species' response to natural and anthropogenic stress, for example, determining which coral symbionts are more heat tolerant and can withstand coral bleaching.
- Identifying key species that may be at risk from the genetic influence of invasive species.
- Identifying pilot taxa to serve as proxies for ecosystem genetic connectivity.
- Exploring the potential of a "founders' effect" in island microbial communities that could result in limited capability of degraded contaminants.
- Measuring the genetic diversity of the Laysan duck populations on Laysan Island and Midway Atoll to determine whether additional ducks should be translocated from Laysan to Midway Atoll to maximize genetic diversity of Midway's new population and to determine if ducks produced at Midway should be used for future translocations without supplementation from Laysan.

Selected previous and ongoing studies

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. 2006). 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.

3.2.5 Resilience

Why is this focus area important?
Understanding ecosystem resilience — the ability of a system 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 the ability of the NWHI ecosystem to absorb or recover from disruption and change and maintain its functions and services will provide critical input to management of the area. Understanding ecosystem resilience is important in knowing how well natural systems will respond to short-term impacts and long-term 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 and 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.

Questions addressed by focus area

A fundamental management issue is determining how species, populations, habitats, and processes respond when confronted with environmental stress. Questions about resilience include:

- How well can ecosystem components acclimate to change?
- Can whole communities acclimate to change?
- What is the level of genetic adaptation at which species are predisposed to better deal with changing environmental conditions?

- Which environmental and physiological or genetic conditions allow particular species or individuals to better survive in substandard conditions?
- What is the role of community composition and morphology in supporting resilience?
- Is ecosystem health a factor in the ecosystem's recovery from periodic disturbance?
- What are the key drivers and components of ecosystem resilience that are critical to modeling and forecasting?

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 POTENTIAL RELEVANCE TO RESILIENCE RESEARCH AND MONITORING

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

Threatened and Endangered Species Action Plan

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

Examples of research needs and opportunities

Management decision making will be improved by knowledge on a variety of specific ecosystem resilience issues. Information is needed on resilience pathways, such as acclimation to stress, adaptation to stress, the role of the environment, and the role of the community. Specific examples of research opportunities include activities to determine:

- The key aspects that affect ecosystem stability and resilience, such as rates of energy flow, oceanographic and atmospheric conditions, nutrient levels, and recruitment.
- The degree that variability in an ecosystem may control its capacity for resilience.
- How ecosystem acclimation to change varies among taxa and in relation to survival and the ability to effectively reproduce.
- How genetic makeup enhances the ability of taxa to recover from some kinds of stress.
- The environmental conditions, such as temperature, current flow, and geomorphology, which have a mitigating influence on survival in a changed environment.
- The extent to which the reduction or expansion of one or more segments of the community assemblage results in competitive top-down pressure or an increase in bottom-up production.
- How the rebound of an ecosystem depends on maintaining established pathways of energy flow that provide the system a stable means of recovery rather than risk a transition to a different state of equilibrium.
- The extent to which reducing fish populations of the MHI ecosystem has undermined or realigned energy flow and trophic stability, by making comparisons to the NWHI.
- Whether self-seeding systems are capable of resilience.

Selected previous and ongoing studies

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.

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 will remain 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 because 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.

3.3.1 Human activities

Why is this focus area important? 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. Despite its remote location and largely uninhabited condition, the NWHI are subject to a wide range of environmental and anthropogenic stressors. Marine pollution, dredging, invasive species, fishing, and vessel groundings are some of the factors that have affected or may harm the resources of the NWHI. Several activity types have been identified as priorities: un-permitted activities, permitted activities, activities that occur within the NWHI, activities outside of the Monument boundaries, and management and remediation activities. A full understanding of the impacts of these human activities (both land-based and at-sea) on the NWHI ecosystem is essential for any realistic ecosystem-based science and management.

Questions addressed by focus area

This focus area provides insights into the impact of anthropogenic changes on the NWHI marine and terrestrial ecosystem. Key questions this research activity is expected to address include:

- What habitats are sensitive to human activities?
- How do direct, indirect, and cumulative human activities affect the habitats of the NWHI?
- What are the effects of commercial fishing outside the NWHI on resources within?
- What are the impacts to natural communities from the historical uses at Kure, Midway, Pearl and Hermes, Laysan, FFS, Mokumanamana, and Nihoa?
- What is the impact of permitted activities?
- What is the number, location, and duration of current un-permitted activities?

- What is the impact of post-Monument un-permitted activities?
- What are some of the management actions plausible to restore resources or mitigate the impacts of humans on the Monument?

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

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.

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.

Permitting Action Plan

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

Examples of research needs and opportunities

It is important to understand the full scope of anthropogenic impact on the NWHI to make sound management decisions. General topics of interest include developing a geo-referenced database and maps of impacts and threats to the NWHI; developing forecasting tools to anticipate anthropogenic impacts, the potential impacts from illegal fishing within the NWHI, the impacts of offshore fisheries on NWHI fish populations and the ability to repopulate the MHI; and assessing potential threats from vessel activity within and outside the area boundaries, including pollution, introduction of invasive species, and groundings. Specific research topics include:

- Determining the effects of contaminants obtained at sea from fish and squid (such as mercury and PCBs) on seabird productivity and survivorship.
- Understanding the impacts and status of remaining contamination in Coast Guard landfills at Kure Atoll (such as PCBs).
- Developing technology to detect un-permitted activity in the NWHI.
- Developing a real-time tracking system for all vessel activity within the NWHI.
- Determining the level and possible impact of vessel underwater noise.
- Assessing the cumulative effects of anchoring and evaluate the effectiveness of establishing permanent mooring buoys.
- Understanding the effect of vessel discharge on NHWI resources to establish discharge protocols.
- Using satellite imagery to survey and track marine debris in the north Pacific.
- Evaluating the MHI areas that need management to minimize the input of marine debris to the NWHI.
- Using oceanographic models for forecasting marine debris accumulation sites.
- Mapping areas of past fisheries, high scientific use, and high vessel traffic.
- Understanding the effects of permitted impacts to the NWHI.
- Estimating the total capacity of scientific and other collections for the NWHI.
- Understanding and employing the best practices to eradicate terrestrial non-native invasive species.
- Monitoring islands and human activities to ensure no non-native species are introduced.
- Determining the extent of all the past military use and remaining debris and landfills.
- Characterizing the fate of landfill contaminants.
- Understanding the sublethal effects of contaminants on native species and any management actions to take to minimize the effects.

Selected previous and ongoing studies

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 Mokumanamana, and construction and maintenance of U.S. Coast Guard Long-Range Aid to Navigation (LORAN) station at Kure and FFS. FWS continues to monitor contaminant levels in and around buildings at Midway and remediate lead contamination that causes “droop wing” and mortality of fledging albatrosses. Through active management, island habitats are being restored through eradication of invasive species at Kure, Laysan, FFS, and Midway. These coastal development activities have, to greater or lesser extents, also altered current flow, temperature regimes, and shoreline configuration, and they have significantly altered coastal erosion patterns.

Reef disturbance caused by storm or human activities is believed to create favorable environments for formation of ciguatera toxin in marine life (Lehane and Lewis 2000; Van Dolah 2000; Ruff 1989; Kaly and Jones 1994).

Additionally, contamination at some of these sites includes offshore and onshore debris such as batteries (lead and mercury), transformers with PCBs, capacitors, and barrels. Debris washing ashore is another source of contamination on the islands. Studies have also shown up to 30 percent of the material consumed by foraging seabirds to be soil (Hui and Beyer 1998, Beyer et al. 1994). If the consumed soil is contaminated, it can result in direct intake of toxic substances by these foraging birds. For example, ingestion of sand contaminated by carbofuran, a pesticide washed ashore with marine debris on Laysan, caused the deaths of endangered Laysan finches until FWS identified and removed the source (Campbell et al. 2004, David et al. 2001).

Investigations by the U.S. Navy during the Base Realignment and Closure of Midway, the U.S. Army Corps of Engineers for removal of underground storage tanks as part of its Formerly Used Defense Sites, and the U.S. Coast Guard (USCG) for remediation of former LORAN stations have documented and in some cases remediated contamination in soil, sediment, water, reefs, and marine and terrestrial biota. Additional studies by the FWS, University of Hawai‘i, Rutgers University, University of Michigan, University of California-Davis, and University of California-Santa Cruz, have investigated the fate and effects of various contaminants in several Monument ecosystems and biota.

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 Hawai‘i 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 albatrosses.

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.

3.3.2 Alien and Invasive species

Why is this focus area important?
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.

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. 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.

Questions addressed by focus area

This focus area provides insights into the biology and distributions of alien marine and terrestrial organisms to understand possible invasive threats. Key questions this research activity is expected to address include:

- What is the baseline or status of invasive species in the NWHI?
- Which invasive species compete with endemic species, and how do they compete?
- What are the limiting resources for which they compete?
- What are the major pathways for introduction of invasive species into NWHI and how should they be managed?
- What are the potential impacts of individual alien species, and which ones should be given priority for management?
- What eradication strategies should be adopted?
- What alien species prevention strategies should be implemented?
- What alien species not currently present are most likely to become introduced to the NWHI in the near future?

- What is the pattern of succession for invasive species on the hulls of ships that periodically or routinely visit the NWHI? How often do the hulls need cleaning? What special eradication and quarantine procedures are required? From where do the invasive and alien species come? Are some harbors "clean" and others "contaminated" with alien and invasive species?
- Should the use of experimental fishing gears such as traps, nets and lines used in the NWHI be limited to new gear or that exclusively used in the NWHI?
- What research is needed to facilitate eradication of non-native species that threaten both the native flora and fauna?

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.

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

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.

Examples of research needs and opportunities

Overall, there is a need for basic information on all living resources in the NWHI and for research to develop monitoring protocols to ensure early detection and response to invasive species. Knowledge of vector pathways, major hubs, the biology of alien species, and a geospatial threat analysis of alien species found within the NWHI are also needed to establish effective eradication strategies and protect endangered and endemic species. Knowledge of environmental conditions that might cause an alien species to become an invasive threat is

needed to estimate the potential impact and prevent an invasive event. Specific research opportunities include:

- Cataloging invasive species, their range of habitats, environmental tolerance, and dispersal capabilities.
- Prioritizing all non-native organisms in the NWHI by threat level, invasiveness, and practicality of eradication or control.
- Mapping the presence, abundance, and rate of spread of current alien species in the NWHI.
- Mapping areas of high vessel traffic to identify areas that may require more intensive management.
- Documenting life history information to ensure control agents are selected that present no toxicity to nontarget organisms and that are specifically delivered to the invasive organism.
- Determining correlations between moisture and temperature conditions and grasshopper abundance to allow better advance prediction of high locust populations.

Selected previous and ongoing studies

There is considerable body of existing work on terrestrial invasive species in the NWHI (Conant and Rowland 1994; Nishida 1998, 2002; Wanless et al. 2007). Some of the species identified as invasive include the introduced grass *Cenchrus echinatus*; the invasive annual plant *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.

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.

3.3.3 Climate change

Changes in the global climate are being brought about by three factors: increasing concentrations of carbon dioxide and other gases in the atmosphere, commonly referred to as the greenhouse effect; alterations in the biogeochemistry of the global nitrogen cycle; and ongoing change in land use and land cover. These changes are expected to increase average global temperatures, cause a rise in the sea

Why is this focus area important?
Global climate change is affecting the NWHI ecosystems, and these effects and others will continue. Understanding the changes in climate and the effects on species, communities, and habitats will help managers make effective ecosystem-based conservation decisions in relation to these changes.

level, and change chemical concentrations in the world's oceans. The four areas of impact linked to global climate change that may have the greatest potential effect on the NWHI ecosystem are extreme weather events, increased sea surface temperature, sea level rise, and change in oceanic chemical composition. Understanding and forecasting these effects will help managers identify native species and habitats that are at risk and take steps for their continued conservation.

Questions addressed by focus area

Research in this focus area will help managers understand and forecast the effect of climate change on the NWHI. Key questions that this research activity is expected to address include:

- Which ecosystems are most and least vulnerable to threats, and on what time scales?
- What habitats and species will be affected by sea level rise?
- Which species will be affected by changes in ocean chemistry (acidification)?
- How can we monitor the health of organisms that depend on calcification?
- What areas will be most affected by extreme weather events?
- How will change in sea level effect water current and upwelling patterns, surface productivity, and the distribution and abundance of species, populations, and habitats in the NWHI?
- What are the kinds, patterns, and predictability of extreme oceanographic and atmospheric events that have a major impact on the NWHI ecosystem and on individual species, populations, and community structure and function?

Research in this area is expected to help resource managers identify ecosystems within the NWHI that will be most vulnerable to climate change. Forecasting climate change will help managers mitigate its effects on the NWHI ecosystems.

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

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.

Examples of research needs and opportunities

A comprehensive and adaptive understanding of the effects of climate change on the NWHI is needed to provide managers with the information and tools needed to manage for ecosystem integrity and to mitigate their impacts. Specific attention should be given to the effect on habitats critical to native and specially protected species. Specific research opportunities include:

- Determining the effect of climate change on the nesting sites of specially protected species.
- Determining and understanding specific habitats, community and populations structures and function affected by global climate change (such as ocean acidification, sea level, temperature, chlorophyll fronts, and population shifts).
- Understanding habitat changes that will result from sea-level rise.

- Understanding effects to species from changes in ocean chemistry (acidification).
- Developing and employing tools and methods to monitor the health of organisms that depend on calcification.
- Mapping areas that will be most affected by extreme wave events and sea-level rise.
- Discerning anthropogenic impacts from natural variability of the physical environment.
- Describing the geomorphological and sedimentary processes that affect reefs and terrestrial areas.
- Projecting the physical and biological effects of extreme events on the ecosystem.
- Projecting effects of climate change on the fate and effects of contaminants (pH changes that affect bioavailability or UV effects on compound reactivity).

Selected previous and ongoing studies

Scientific understanding of anthropogenic warming and cooling influences on climate has improved in the last few years, leading to high confidence that the global average net effect of human activities since 1750 has been warming (Intergovernmental Panel on Climate Change 2007). Recent modeling indicates that melting could occur faster than the Intergovernmental Panel on Climate Change predicted, however (Overpeck et al. 2006). Increase in sea level will affect low-lying equatorial islands and atolls such as are present at the NWHI. Shoreline erosion and saltwater intrusion into subsurface freshwater aquifers have been noted throughout the Pacific (Shea et al. 2001).

Regional predictions for the North Central Pacific Gyre area within the life of the Management Plan are for increases of surface temperature of 0.5 to 1.0 °C, which is a smaller increase than was predicted for the Arctic and Northern hemisphere continental areas. 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.

Weather alterations such as reductions in the amount of precipitation and changes in soil moisture and temperature will affect vegetation communities and the reproductive capabilities of land birds and insects. Increased frequency and intensity of storms will have impacts on coral health by direct damage caused by breakage and smothering as sand moves around and on terrestrial systems when islands are over-washed.

Anomalies in the sea surface temperature that would result from regional and global-scale climatic phenomenon are believed to cause 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.

The magnitude of sea level rise by 2090 from thermal expansion of water and melting of land-based ice sheets appears to be the projection with the least certainty, but ranges from 0.18 meters

to 0.59 meters. A rise of that magnitude (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).

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 change, biodiversity and habitat change, and change caused by human activities. Ongoing monitoring using these parameters provides the basis for identifying the process and patterns of change over time and space and the amount of variability intrinsic to the system as a basis for improved conservation and management.

3.4.1 Ecological process metrics and monitoring

Why is this focus area important? Ecological processes and human impacts drive ecosystem change. It is essential to understand and monitor natural processes to separate out and manage human effects. Effective monitoring requires appropriate parameters and measures of change.

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 the various components of the NWHI connect with each other and 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

Questions addressed by focus area

Documenting the changes in ecological processes and ecosystems is fundamental to management. Key questions in relation to ecosystem metrics and monitoring include:

- What are the parameters and indicators most useful, effective, and efficient for monitoring change in the ecological processes and ecosystems of the NWHI?
- Are the existing parameters, indicators, and sampling programs appropriate and sufficient, and can they be integrated into a comprehensive ecosystem monitoring program?
- What changes to the ecosystem or ecological processes may be anticipated or predicted though monitoring?
- Can monitoring provide information to understand ecosystem resilience and support management based on the ability of a system to absorb or recover from disturbance and stress?
- What are the other key parameters and indicators of ecosystem resilience?
- Can monitoring programs track dynamic changes in the environment and support modeling and forecasting?

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 POTENTIAL RELEVANCE TO ECOLOGICAL PROCESS METRICS RESEARCH AND MONITORING

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.

Examples of research needs and opportunities

Monitoring programs require research to select priority parameters and indicators to be measured for changes to ecosystems and ecological processes. Research also needs to indicate the scale, resolution, and frequency of sampling that will contribute to meaningful monitoring and the kinds of tools and technology that can best obtain the desired data. There are key gaps in development and implementation of monitoring programs, including the need to determine:

- The variables, scale, and spatial and temporal resolution that will be used to monitor ecological processes and connectivity to support management needs.
- The existing parameters and indicators of existing monitoring programs and to identify gaps as the basis for more comprehensive monitoring of ecosystem change.
- The spatial and temporal basis of ecological processes to identify ecological boundaries between sub-regions.

Key research issues have been identified as important for monitoring and modeling, including:

- The environmental conditions — such as temperature, flow, and geomorphology — that have a mitigating influence on survival in a changed environment.
- To what extent the reduction or expansion of one or more segments of the community assemblage results in competitive top-down pressure or an increase in bottom-up production.
- How ecosystem acclimation to change varies among taxa and in relation to both survival and the ability to effectively reproduce.
- The degree to which variability in an ecosystem may control its capacity for resilience.
- How the rebound of an ecosystem depends on maintaining established pathways of energy flow that provide the system a stable means of recovery rather than risk a transition to a different state of equilibrium.
- To what extent reducing fish populations of the ecosystem undermines or realigns energy flow and trophic stability, by making comparisons between the relatively low fishing effort in the NWHI and that of the MHI.
- The other key aspects that affect ecosystem stability and resilience need to be identified, for example, rates of energy flow, oceanographic conditions, nutrient levels, and recruitment.
- The spatial and temporal patterns of plankton and larval dispersal, sources, and sinks.
- The size, location and effectiveness of closed areas, such as Marine Protected Areas (MPAs).

It is also essential to monitor specific environmental issues that threaten ecosystems, habitats, and species to justify and design restorative measures (for example, alien species eradication, plastic pollution, removing grounded vessels, and rare habitats threatened by global climate change).

Selected previous and ongoing studies

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.

3.4.2 Biodiversity and habitat metrics and monitoring

Ensuring that the biological diversity, populations of living resources, and habitats of the marine and terrestrial environment of the NWHI remain healthy is central to its conservation and management. It is therefore critical to know the species, their status, where they live, the habitats, and changes in their status over time to enable managers to better protect these resources.

Why is this focus area important?
Monitoring the status and trends of species, populations, and the habitats that support them in the NWHI is an essential component of conserving and managing the ecosystem. Effective monitoring requires appropriate parameters and measures of change.

An appropriate suite of parameters and indicators is an essential requirement of effectively detecting changes in species and habitats over time. Differentiating between natural and human

impacts on biodiversity and habitats is also important. Metrics must also be scientifically robust and relevant. However, metrics must be practical and simple so that non-scientists can understand them and the trends they 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 connectivity within the NWHI with the MHI and other parts of the Pacific are particularly important consideration 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

Questions addressed by focus area

The process for monitoring biodiversity and habitats to detect change must be developed in a way to address key long term management questions, including:

- What are appropriate species and habitats to monitor as indicators for ecosystem health?
- What are the stresses effecting changes in the indicators species and habitats?
- What are the ecological effects (from individuals to ecosystems) of the stressors?
- What are the limits of acceptable change?
- What management or restoration actions could be used to minimize the effects of the stressors and stay within those limits?
- What are the other key drivers and components of change in the health of species populations and habitats that are critical to monitoring?
- What parameters are most important for discerning trends in the status of species populations and habitats?
- Are the parameters, indicators, and sampling programs of existing monitoring efforts appropriate or do they need to be expanded or improved to create adequate monitoring programs?
- What monitoring of species and habitats helps determine the interaction of populations and habitats within the NWHI and between the NWHI and the MHI and other areas?
- Will monitoring be able to detect significant changes or trends in the status of species and habitats that allows action to be taken to minimize impacts from short-term and long-term changes from natural and anthropogenic impacts?
- What are the impacts of specific suspected threats and stress to habitats and species? Is remediation warranted?

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 POTENTIAL RELEVANCE TO BIODIVERITY AND HABITAT METRICS RESEARCH AND MONITORING

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.

Examples of research needs and opportunities

As with monitoring of ecosystems and ecological processes, there is a need for research on the parameters and indicators most appropriate and practical for measuring changes to species populations and habitats. Research needs to address both marine and terrestrial biodiversity and communities and seek to identify the scale, resolution, and frequency of sampling that will contribute to meaningful monitoring of flora and fauna, as well as the most useful tools and technology for gathering the data. Important gaps in developing and implementing monitoring programs include the need to determine:

- The variables, scale, and spatial and temporal resolution that will be used to monitor biodiversity and habitats to support management needs.
- The existing parameters and indicators of existing monitoring programs and to identify gaps as the basis for more comprehensive monitoring.
- The spatial and temporal parameters that distinguish sub-populations of species or differentiate habitats in the NWHI.

Specific research issues have been identified as important for monitoring biodiversity and habitats, including the need to:

- Identify the priority species and habitats to monitor as indicators for ecosystem health, especially in relation to anticipated short- and long-term impacts and change (including from management actions).
- Identify the stresses effecting changes in the indicators species and habitats and the ecological effects (from individuals to ecosystems) of the stressors.
- Establish the limits of acceptable change to the indicator species and habitats and the management or remediation actions that could be used to minimize the effects of the stressors and stay within those limits.
- Document “hot spots” of adult population abundance.
- Understand the changes of indicator species’ body burdens of selected contaminants.
- Determine the movement of key species into and out of the NWHI, and within the NWHI.
- Assess priority species populations as a basis for monitoring and developing recovery models and projections of future population levels.
- Undertake life history studies for all priority species to provide information on essential habitat requirements (reproduction, recruitment, and feeding) for all life stages.

- Ascertain essential habitat and ecological requirements of protected species to minimize anthropogenic threats and the effect of catastrophic events.
- Determine which likely effects of climate change on protected species are priorities for monitoring, such as the effect of sea level rise on nesting sites of green sea turtles, Hawaiian monk seals, and seabirds.
- Evaluate existing and potential diseases that affect priority species and habitats of the NHWI and develop appropriate methods to monitor the presence and impact of these diseases on terrestrial and marine biodiversity.

Selected previous and ongoing studies

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, one species of toothed whales, at least 19 other species of whales and dolphins, marine turtles (green, hawksbill, loggerhead, olive ridley, and leatherback), migratory birds (such as the Laysan and black-footed albatross and other seabirds), five bird species that are 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.

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.

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.

Why is this focus area important?
Human impacts on the biodiversity and ecosystems of the NWHI are the key issues that affect the future of the area. Monitoring the appropriate parameters and measures of the sources, types, magnitude, and effects of human interaction with the NWHI ecosystem is essential for management.

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

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.

Questions addressed by focus area

Documenting the changes caused by human use and interventions in the NWHI is fundamental to management of the ecosystems. Key questions related to the metrics and monitoring of human impacts include:

- What are the parameters and indicators most useful, effective, and efficient for monitoring human impacts in the NWHI?
- Are the existing parameters, indicators, and sampling programs appropriate and sufficient and can they be integrated into a comprehensive monitoring of human impacts?
- Is it possible to adequately monitor impacts originating from sources outside the NWHI?
- Can significant impacts be anticipated or predicted though monitoring?
- Is monitoring useful for anticipating impacts from complex, dynamic human-induced changes in the environment, such as climate change and the introduction of alien species?
- Are different metrics and monitoring needed to address the evaluation of management interventions for effectiveness and unintended impacts?

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 POTENTIAL RELEVANCE TO HUMAN IMPACTS METRICS RESEARCH AND MONITORING

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.

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.

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.

Permitting Action Plan

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

Examples of research needs and opportunities

Research is needed on metrics and monitoring human activities, impacts, and management interventions. As with other kinds of monitoring, there is a need for research on the parameters and indicators that are most appropriate and practical. Research needs to address both marine and terrestrial biodiversity and communities and seek to identify the scale, resolution, and frequency of sampling and the tools and technology. Developing and implementing monitoring programs include the need to understand:

- The variables, scale, and spatial and temporal resolution of monitoring programs.
- The existing parameters and indicators of existing monitoring programs and identify gaps as the basis for more comprehensive monitoring.
- The spatial and temporal parameters important in monitoring human activities, impacts, and management interventions.

Specific research issues have been identified as important for monitoring human activities, impacts, and management interventions, including the need to:

- Understand the impacts of past fishing in the NWHI.
- Understand and track the impacts from illegal fishing in the NWHI.
- Measure and monitor the impacts of offshore fisheries on NWHI fish populations.
- Understand the distribution of landfills, dumps, and other sources of contamination from past military and Coast Guard use, as well as their impacts.

- Monitor the impact from vessel activity, including pollution, introduction of invasive species, and groundings, and developing forecasting tools to anticipate anthropogenic impact.
- Monitor the level and impact of anthropogenic underwater noise.
- Develop the use of remote sensing technology to obtain systematic surveys of marine debris in the north Pacific.
- Monitor biological communities for early detection and response to invasive species.
- Monitor the effectiveness of efforts to eradicate alien species and whether there are unintended impacts from eradication methods and activities.

Selected previous and ongoing studies

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.

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.

3.5.1 Modeling the ecosystem and ecological processes

Why is this focus area important? Ecosystem models that reflect the complexity and dynamics of the NWHI will support more effective management that can be proactive and can predict and minimize impacts.

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 — for example, genetic, taxa, populations, habitat, processes, and stressors — supports development of effective models with important considerations 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 the 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 of the spatial and temporal variation in physical and biological characteristics. Ecosystem modeling and forecasting can provide the means to predict 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 to be taken to help ensure that ecosystem resilience is maintained, so that the ecosystem is best able to absorb or recover from disturbance and change, while maintaining its functions and services.

Questions addressed by focus area

Understanding how ecological processes and ecosystems respond when confronted with environmental change is a fundamental management question that can be addressed by incorporating ecological patterns, linkages, and resilience into ecosystem modeling and forecasting. Key questions in relation to ecosystem modeling include:

- What are the physical, chemical, and biological parameters that are most important for applied ecosystem modeling and forecasting?
- Can existing models, and their parameters, indicators, and sampling programs, be integrated into a comprehensive ecosystem model?
- Is it possible to model ecosystem linkages and patterns within the NWHI and between the NWHI and the MHI and other areas?
- Can models result in forecasting of significant changes in the ecosystem to be anticipated or predicted and action taken to minimize impacts from short-term and long-term changes and for a range of natural and anthropogenic impacts and the effects of management actions?
- Can ecosystem modeling address resilience, for example, in terms of the environmental conditions that allow taxa to better survive in substandard conditions; the role of community composition and morphology in supporting resilience; and the importance of natural variability to the resilience of an ecosystem?
- What are the other key drivers and components of ecosystem resilience that are critical to modeling and forecasting?

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.

Examples of research needs and opportunities

Research is needed to support establishing such comprehensive models by identifying the priority parameters and indicators to be measured for applied ecosystem modeling and forecasting, and the scale, resolution, and frequency of sampling that will contribute to meaningful models. There are key gaps in the development and implementation of ecosystem models capable of forecasting, including the need to:

- Identify the variables, resolution, and scale of the ecosystem models. It is important to set the appropriate scale and the spatial and temporal resolution that can be used to identify and monitor physical and biological processes that best deliver forecasting that responds to management needs.
- Review existing models and identify gaps. Current models being used in the archipelago are the first steps to broader ecosystem modeling, and many of the models currently under development could form the basis of a more comprehensive ecosystem model and forecasting efforts.
- Select the parameters and validate the model. Specific research is needed to develop the parameters for an ecosystem model and address the gaps in the current portfolio of modeling efforts with the suite of variables that respond to ecosystem management needs. Targeted studies are also needed to assess the validity of the ecosystem models that emerge. The research would provide some appraisal of confidence in the model results so that the managers understand the risks.
- Develop the capability for ecosystem forecasting. Many of the current models are static and largely conceptual in nature. They need to be converted to track dynamic changes in the environment, as temporal change is inherent in forecasting and represents the primary challenge to selecting viable indicators that effectively detect changes with documented implications for ecosystem change.

Examples of specific opportunities for research in relation to ecosystem modeling include:

- How ecosystem acclimation to change varies among taxa and in relation to both survival and the ability to effectively reproduce.
- Which environmental conditions, such as temperature, flow, geomorphology, have a mitigating influence on survival in a changed environment.
- To what extent the reduction or expansion of one or more segments of the community assemblage results in competitive top-down pressure or an increase in bottom-up production.
- The degree that variability in an ecosystem may control its capacity for resilience.
- How the rebound of an ecosystem depends on the maintaining established pathways of energy flow that provide the system a stable means of recovery rather than risk a transition to a different state of equilibrium.
- To what extent reducing fish populations of the ecosystem undermine or realign energy flow and trophic stability, by making comparisons between the relatively low fishing effort in the NWHI and that of the MHI.

- The other key aspects that affect ecosystem stability and resilience need to be identified, such as rates of energy flow, oceanographic conditions, nutrient levels, and recruitment.
- Spatial and temporal patterns of plankton and larval dispersal, sources, and sinks.
- Size, location and effectiveness of closed areas, such as MPAs.

Selected previous and ongoing studies

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, ongoing are efforts 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.

3.5.2 Modeling biodiversity and habitats

Why is this focus area important?
Modeling the future status of species and habitats will enable more effective, proactive management to ensure these species and the habitats that support them remain healthy and diverse in the face of projected impacts.

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 species and habitats of the NWHI to the MHI and other parts of the Pacific that are included in the range areas of species found in the NWHI. 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.

Questions addressed by focus area

Key questions in relation to the modeling the response of biodiversity and habitats to change include:

- What parameters are most important for modeling and forecasting trends in the status of species populations and habitats?
- Can existing models, and their parameters, indicators, and sampling programs, be expanded or improved to create adequate models?

- Is it possible to model the linkages and patterns of species distribution and populations within the NWHI and between the NWHI and the MHI and other areas?
- Can models anticipate significant changes in the status of species, populations, and habitats so that action taken to minimize impacts can be undertaken for a range of natural and anthropogenic effects, and for the effects of management interventions?
- What are the other key drivers and components of trends in the status of species, populations, and habitats that are critical to modeling and forecasting?

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.

Examples of research needs and opportunities

As with ecosystem modeling, research is needed to establish the priority parameters and indicators and the scale, resolution, and frequency of sampling needed for credible modeling and forecasting the status and trends in biodiversity and habitats. Specific opportunities include research for modeling to:

- Select the variables, resolution and scale needed for modeling.
- Identify parameters, validate models, and address gaps in the current portfolio of modeling efforts with the suite of variables that respond to the management needs for biodiversity and habitats.
- Undertake targeted studies to assess the validity of the models that emerge.
- Develop the capability for forecasting the response of species, populations, and habitats to anticipated short-term impacts (including management interventions), and long-term change.
- Project the genetic impact of potential introduced species in both the marine and terrestrial environment.
- Understand and project recruitment success of key marine species across the NWHI.
- Understand and predict "hot spots" of adult population abundance.
- Track likely movement of species groups into the NWHI and within the NWHI.
- Develop discrete population recovery models and projections of future population levels.
- Determine how genetic makeup enhances the ability of taxa to recover from some kinds of stress and whether susceptibility to stress is less for taxa that are chronically exposed to some stress.

Selected previous and ongoing studies

Much of the previous research on biodiversity and habitats of the NWHI will contribute to the development 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.

3.5.3 Modeling human impacts and management

Why is this focus area important? Human activities threaten the biodiversity and ecosystem of the NWHI. Modeling these impacts improves the potential for appropriate management responses and better understanding of the effects of management actions themselves on the biodiversity and ecosystem.

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.

Questions addressed by focus area

Key questions in relation to the modeling the impact of human activities and management actions include:

- What are the kinds and levels of human activities that may impact the NWHI and the likelihood of impacts occurring?
- What are the critical vectors and pathways for impacts, such as invasive species, and how are they changing over time?
- What are the priority high-risk human activities that may affect the NWHI?
- What kinds of management actions are undertaken in the NWHI that may affect species, populations, habitats, and processes?
- What parameters are most important for modeling and forecasting impacts from human activities and management actions?
- Is it possible to model complex, long-term impacts such as climate change in ways that are useful for management?

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.

Examples of research needs and opportunities

Research is needed to determine the priority parameters, the indicators needed for modeling and forecasting the impacts of human activities and management actions. Specific research opportunities in relation to modeling include:

- Identifying the variables, resolution, and scale needed for modeling a range of short-term and long-term human impacts.
- Developing the capability for forecasting the response of priority species, populations, habitats, or ecological processes to specific short-term impacts, management actions, or long-term changes.

- Conducting targeted studies to assess the validity of the models that emerge.
- Identifying the pathways and impacts of invasive species that have reached the MHI, or are projected as likely to reach the MHI.
- Determining the risk of spread and the effects of invasive species, including changes in the trophic web, competition between natives, and the possible changes in vector pathways over time.
- Determining the effects of commercial fishing and of sustenance and subsistence fishing and the demand for fish products in the state by making comparisons between the relatively low fishing effort in the NWHI and that of the MHI.
- Predicting the ecosystem effects of management actions that treat invasive species.
- Projecting loss of habitat from sea level rise and its impact on protected species.

Selected previous and ongoing studies

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.

4.0 Research and Monitoring Activities

Research and monitoring activities included in this section were reviewed and prioritized by managers charged with implementing the Management Plan. The universe of research and monitoring activities subjected to the prioritization process (described in Section 2) represented a fairly focused range. A majority of the activities include previous and ongoing research solicited by management agencies. As such, the range of activities was designed to meet both agency mandates and the findings as listed in the Monument regulations. Subsequent listed activities were incorporated as the result of several review and gap analysis processes in accordance with the Management Plan. As a result, most of these activities were rated as high or critical, as they were already identified as priorities for managers. Examples of specific ongoing and past research and monitoring projects are provided in the Monument's Permit Report document (www.hawaiireef.noaa.gov).

Research and monitoring priorities are listed in Table 2 by Science Plan theme and focus area. The table includes the activity rating, the time frame when information from the activity is needed by managers, and references to one or more Management Plan activities that requires information from the Science Plan activity. An overview of priority research and monitoring activities is provided below by theme.

Habitats and Biodiversity
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. Special focus will be given to research on native and protected species. Some critical activities include indentifying new species and records for the NWHI, identifying threats to reproductive potential of protected species, determining the relationship between protected species (marine and terrestrial) and their habitat, and quantifying the effects of disease and contaminants on focal species. Data from these activities will inform management decisions about habitat protection, development of potential translocation sites for protected species, and disease eradication activities.

Ecological Processes and Connectivity
The islets, reefs, and atolls that make up the NWHI cannot be considered as completely isolated units; nor can the NWHI be considered in isolation from the MHI. Understanding the ecological processes that affect and connect these two ecosystems is fundamental to the effective management of the Monument. Some critical activities include quantifying passive transport of biota and nutrients via currents and other oceanographic processes, and active transport of animals via active movement and migration. Other activities include determining connectivity through genetic structure and identifying the major drivers of the health, productivity and resilience (the ability of ecosystems to absorb and recover from change) of these ecosystems.

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 Monument. 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 critical activities include mapping contaminated areas, determining the effects of contaminants, invasive species and marine debris on the NWHI ecosystem, and assessing the effects of historical and ongoing human activities. A number of critical activities focus on determining the effects of climate change, a relatively new anthropogenic threat to the Monument.

Indicators and Monitoring Ecosystem Change

Long-term monitoring is an essential tool for scientists to detect and understand changes in the ecosystem. Understanding ecosystem change is critical to modeling future conditions and identifying management needs. Many of the critical activities under this theme focus on monitoring individual components of biodiversity at the Monument. Results from each activity can then be combined and analyzed to understand changes at the ecosystem level. One of the critical activities addresses the need to compare each monitoring program's protocol. This is essential to ensure compatibility of results and establish uniform protocols that are followed over time.

Modeling and Forecasting Ecosystem Change

Modeling and forecasting change and potential impacts is essential for effective ecosystem management. Activities under this theme include modeling effects of physical processes on community structure, modeling effects of climate change on biodiversity and creating predictive models of alien species invasions. Integrating monitoring results and data from previous themes is essential for creating accurate models.

New research and monitoring needs are expected to emerge with the implementation of the Management 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 achieve the goals of the Monument and for effective implementation of the Management Plan.

Table 2. Research and Monitoring Activities Organized by Research Theme and Focus Area

Research and Monitoring Activity	Priority Rating[1]	Timeframe[2] (years)	Related Monument Management Plan Needs and Activities	
			Priority Management Need	Management Plan Activity
Habitats and Biodiversity				
Habitats				
▪ Characterize intertidal zone habitats/ communities	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1
▪ Map terrestrial habitat distribution	Critical	1-3	Conserving Wildlife and Habitats	HMC-3.1 HMC-3.2
▪ Quantify protected species/habitat relationships	Critical	1-3	Conserving Wildlife and Habitats	TES-1.3 TES-3.2 TES-3.3 TES-6.1 HMC-3.1
▪ Quantify terrestrial species/habitat relationships	Critical	4-5	Conserving Wildlife and Habitats	TES-6.1 TES-7.5 MB-1.2 HMC-4.2 HMC-4.5 HMC-4.7 HMC-5.2
▪ Evaluate potential and impacts of development of additional freshwater sources at potential translocation sites of the Laysan duck, Nihoa finch, Laysan finch, and Nihoa millerbird	Critical	+5	Conserving Wildlife and Habitats	HMC-7.1
▪ Characterize and map shallow water benthic communities/habitats (<30m)	High	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2
▪ Characterize and map deep water benthic communities/habitats (>30m)	High	1-3	Understanding and Interpreting the NWHI	MCS-1.3 MCS-1.4
▪ Characterize and map deep water fish communities/habitats (>30m)	High	1-3	Understanding and Interpreting the NWHI	MCS-1.3 MCS-1.4
▪ Characterize and map deep water invasive species communities/habitats (>30m)	High	1-3	Understanding and Interpreting the NWHI	MCS-1.3 MCS-1.4
▪ Characterize reef community in mid depth (60-150m) reef habitat	High	1-3	Understanding and Interpreting the NWHI	MCS-1.3 MCS-1.4
▪ Quantify marine species/habitat relationships	High	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4
▪ Quantify terrestrial plant/habitat relationships	High	+5	Conserving Wildlife and Habitats	TES-7.5
Native species				
▪ Assess fish population characteristics	High	1-3	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.5
▪ Identify key habitats for sensitive life-stages (e.g., recruitment habitats for juvenile reef fishes)	High	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.4
▪ Identify new terrestrial species and records for the NWHI	High	1-3	Conserving Wildlife and Habitats	HMC-5.1
▪ Identify new marine species and records for the NWHI	High	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-2.1
▪ Assess lobster population characteristics	High	1-3	Understanding and Interpreting the NWHI	MCS-1.2
▪ Monitor salinity, parasites, contaminants, and native arthropods associated with freshwater seeps and ponds	High	1-3	Conserving Wildlife and Habitats	HMC-7.1
▪ Characterize terrestrial microbial biodiversity	High	4-5		
▪ Conduct terrestrial invertebrate demographic	High	+5	Conserving Wildlife and Habitats	HMC-5.1

Table 2. Research and Monitoring Activities Organized by Research Theme and Focus Area

Research and Monitoring Activity	Priority Rating[1]	Timeframe[2] (years)	Related Monument Management Plan Needs and Activities	
			Priority Management Need	Management Plan Activity
research				
▪ Conduct terrestrial plant demographic research	High	+5	Conserving Wildlife and Habitats	TES-7.1 TES-7.2 TES-7.3 TES-7.4 TES-7.5 HMC-4.7 HMC-5.2
▪ Assess terrestrial invertebrate population characteristics	High	+5	Conserving Wildlife and Habitats	HMC-5.1 HMC-7.1
▪ Assess terrestrial plant population characteristics	High	+5	Conserving Wildlife and Habitats	TES-7.1 TES-7.2 TES-7.3 TES-7.4 TES-7.5 HMC-4.7 HMC-5.2
▪ Assess marine invertebrate population characteristics	Medium	4-5	Understanding and Interpreting the NWHI	MCS 1.2 MCS 1.5
Specially protected species				
▪ Evaluate methods to reduce predation on monk seals	Critical	1-3	Conserving Wildlife and Habitats	TES-1.2 TES-1.6
▪ Develop tools to increase monk seal female survival (juvenile & adult) to salvage reproductive potential	Critical	1-3	Conserving Wildlife and Habitats	TES-1.2
▪ Model potential effects of climate change on protected species	Critical	1-3	Conserving Wildlife and Habitats	TES-1.3 TES-3.2 TES-3.3
▪ Characterize feeding areas, define diet and monitor prey abundance for monk seals	Critical	1-3	Conserving Wildlife and Habitats	TES-1.2
▪ Characterize and monitor green turtle populations	Critical	1-3	Conserving Wildlife and Habitats	TES-3.1
▪ Analyze habitat use of monk seals	Critical	1-3	Understanding and Interpreting the NWHI Conserving Wildlife and Habitats	MCS-1.5 TES-1.2 TES-1.3
▪ Determine whether prey selection is limiting monk seal population growth, investigate resource competition with other top predators, evaluate potential competition with fisheries	Critical	1-3	Conserving Wildlife and Habitats	TES 1.2
▪ Conduct research on food resource limitation of monk seals	Critical	1-3	Conserving Wildlife and Habitats	TES 1.2
▪ Conduct monk seal contaminant research	Critical	1-3	Conserving Wildlife and Habitats	TES 1.2
▪ Conduct Laysan duck demographic research	Critical	4-5	Conserving Wildlife and Habitats	TES 6.1
▪ Investigate translocation potential for threatened and endangered species and develop associated techniques	Critical	4-5	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
▪ Conduct studies to support increased population numbers and distribution of *Amaranthus brownii*, *Pritchardia remota* and *Schiedea verticillata*	Critical	4-5	Conserving Wildlife and Habitats	TES-7.2 TES-7.3 TES-7.5
▪ Conduct landbird demographic research	Critical	+5	Conserving Wildlife and Habitats	TES 6.1 TES 6.2
▪ Assess seabird population characteristics	Critical	+5	Conserving Wildlife and Habitats	MB 3.1
▪ Characterize seabird trophic interactions	Critical	+5	Conserving Wildlife and Habitats	MB-3.1 MB-3.2

Table 2. Research and Monitoring Activities Organized by Research Theme and Focus Area

Research and Monitoring Activity	Priority Rating[1]	Timeframe [2] (years)	Related Monument Management Plan Needs and Activities	
			Priority Management Need	Management Plan Activity
▪ Determine cetacean habitat preferences	High	1-3	Conserving Wildlife and Habitats	TES-2.1
▪ Assess shorebird population characteristics	High	4-5	Conserving Wildlife and Habitats	MB-3.3
▪ Measure reproductive performance and diet composition in seabirds	High	4-5	Conserving Wildlife and Habitats	MB-3.2
▪ Assess population size and trends of migratory birds	High	4-5	Conserving Wildlife and Habitats	MB-3.3
▪ Conduct seabird life history research	High	+5	Conserving Wildlife and Habitats	TES-4.2 MB-3.1
▪ Assess seabird foraging energetics	High	+5	Conserving Wildlife and Habitats	MB-3.2
▪ Devise and implement methods for monitoring population size and reproductive success in tree-nesting seabird species.	High	+5	Conserving Wildlife and Habitats	HMC-8.2
Health and disease				
▪ Evaluate use of vaccines for high-risk diseases	Critical	1-3	Conserving Wildlife and Habitats	TES 1.2
▪ Investigate green turtle disease	Critical	1-3	Conserving Wildlife and Habitats	TES 3.1
▪ Develop disease eradication techniques	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1
▪ Describe disease impact on marine communities	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.2
▪ Describe methods of marine disease transmission	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.4 MCS-2.1
▪ Describe methods of native bird disease transmission	Critical	1-3	Conserving Wildlife and Habitats	MB-2.1
▪ Research parasite impacts on seabirds	High	4-5	Conserving Wildlife and Habitats	MB-2.6
Ecological Processes and Connectivity				
Oceanographic processes				
▪ Understand marine primary productivity	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4
▪ Operate and obtain data from tide stations	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1
▪ Operate and obtain data from weather stations	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1
Passive transport of nutrients and living resources				
▪ Determine ocean current patterns	High	1-3	Understanding and Interpreting the NWHI	MCS-1.1
▪ Determine ocean upwelling patterns	High	1-3	Understanding and Interpreting the NWHI	MCS-1.1
Active transport and movement of living resources				
▪ Assess marine turtle movements	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.5
▪ Assess monk seal movements	Critical	1-3	Conserving Wildlife and Habitats	TES 1.2
▪ Quantify seabird foraging/movement patterns	Critical		Understanding and Interpreting the NWHI Conserving Wildlife and Habitats	MCS-1.5 MB-3.2
▪ Identify habitat utilization patterns of sharks to inform monk seal mortality mitigation	Critical	1-3	Understanding and Interpreting the NWHI Conserving Wildlife and Habitats	MCS-1.5 TES-1.2 TES-1.6
▪ Quantify Laysan duck movement patterns	Critical	+5	Conserving Wildlife and Habitats	TES 5.1
▪ Assess apex predatory fish movements	High	1-3	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.5
▪ Assess fish movements	High	4-5	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.5
▪ Quantify shorebird movement patterns	High	+5	Understanding and Interpreting the NWHI Conserving Wildlife and Habitats	MCS-1.5 MB-3.3

Table 2. Research and Monitoring Activities Organized by Research Theme and Focus Area

Research and Monitoring Activity	Priority Rating[1]	Timeframe[2] (years)	Related Monument Management Plan Needs and Activities	
			Priority Management Need	Management Plan Activity
▪ Quantify terrestrial invertebrate movement patterns	High	+5	Conserving Wildlife and Habitats Reducing Threats to Monument Resources	HMC-5.1 AS-5.1 AS-5.4
Population dynamics and genetic structure				
▪ Assign pups to mothers using genetic analysis	Critical	1-3	Conserving Wildlife and Habitats	TES 1.2
▪ Assess turtle population dynamics and genetic structure	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.5
▪ Assess marine connectivity throughout Hawaiian Archipelago	High	1-3	Understanding and Interpreting the NWHI	MCS-1.5
▪ Assess cetacean population dynamics and genetic structure	High	1-3	Understanding and Interpreting the NWHI Conserving Wildlife and Habitats	MCS-1.5 TES-1.2 TES-1.3 TES 2.1
▪ Assess coral population dynamics and genetic structure	High	1-3	Understanding and Interpreting the NWHI	MCS-1.5
▪ Assess shorebird population dynamics and genetic structure	High	+5	Understanding and Interpreting the NWHI Conserving Wildlife and Habitats	MCS-1.5 MB-3.3
▪ Assess terrestrial invertebrate population dynamics and genetic structure	High	+5	Conserving Wildlife and Habitats	HMC-5.1
▪ Assess terrestrial plant population dynamics and genetic structure	High	+5	Conserving Wildlife and Habitats	TES-7.1 TES-7.2 TES-7.3 TES-7.4 TES-7.5 HMC-4.7 HMC-5.2
▪ Assess seabird population dynamics and genetic structure	High	+5	Understanding and Interpreting the NWHI	MCS-1.5
▪ Assess marine invertebrate population dynamics and genetic structure	Medium	+5	Understanding and Interpreting the NWHI	MCS-1.5
Resilience				
▪ Investigate mechanisms influencing fish health and diversity	High	4-5	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.5 MCS-1.4
▪ Investigate mechanisms influencing coral health and diversity	High	+5	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.5 MCS-1.4
Human Impacts				
Threat assessment and mapping				
▪ Locate, investigate and evaluate effects of contamination in terrestrial and nearshore areas	Critical	1-3	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
▪ Examine the correlation between reproductive success and contaminant loads	High	4-5	Conserving Wildlife and Habitats	TES-4.2 MB-2.2
▪ Study contaminant levels in birds and their habitats	High	4-5	Conserving Wildlife and Habitats	MB-2.2 HMC-2.1
▪ Conduct risk assessment to determine safe levels of lead in soils	High	+5	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

Table 2. Research and Monitoring Activities Organized by Research Theme and Focus Area

Research and Monitoring Activity	Priority Rating[1]	Timeframe[2] (years)	Related Monument Management Plan Needs and Activities	
			Priority Management Need	Management Plan Activity
Human activities and impacts				
▪ Monitor and evaluate cumulative effects of all activities and actions on Monument resources	Critical	1-3	Managing Human Uses	P-2.2 VS-1.3
▪ Assess effects of ongoing human use on terrestrial habitat	Critical	1-3	Managing Human Uses	VS-1.3
▪ Assess effects of ongoing human use on marine habitat	Critical	1-3	Conserving Wildlife and Habitats	HMC-1.1 HMC-1.2 VS-1.3
▪ Assess the impacts of field activities on NWHI natural resources	Critical	1-3	Achieving Effective Monument Operations	CFO-2.3
▪ Assess the impacts of visitors and other users on natural resources	Critical	1-3	Managing Human Uses	VS-1.3
▪ Investigate the integrity of known landfills and dumps	Critical	1-3	Conserving Wildlife and Habitats	HMC-2.2
▪ Assess commercial fishing impacts	Critical	1-3	Understanding and Interpreting the NWHI	MCS-2.1
▪ Survey marine debris and assess removal efforts	Critical	1-3	Reducing Threats to Monument Resources	MD-2.1 MD-2.2
▪ Assess impacts of historical land use	Critical	+5	Conserving Wildlife and Habitats	HMC-2.1 HMC-2.2 HMC-2.3 HMC-2.7 HMC-3.2
▪ Assess impacts of marine debris on living resources	High	1-3	Reducing Threats to Monument Resources	MD-2.1 MD-2.2
▪ Research effects of manmade structures on beach and reef habitat.	High	1-3	Conserving Wildlife and Habitats	HMC-3.2
▪ Research historic disposal sites and investigate them for contamination	High	1-3	Conserving Wildlife and Habitats	HMC-2.3
▪ Conduct seabird contaminant research	High	4-5	Conserving Wildlife and Habitats	MB-2.2 MB-2.3 HMC-2.1 HMC-2.6 HMC-2.7
▪ Characterize and monitor the effects of marine debris on cetaceans in the Monument	High	4-5	Conserving Wildlife and Habitats Reducing Threats to Monument Resources	TES-2.3 MD-2.1 MD-2.2
▪ Investigate effects of anthropogenic iron sources on marine resources	High	4-5	Conserving Wildlife and Habitats	HMC-2.4
▪ Conduct studies on potential aircraft and vessel hazards and impacts	High	4-5	Reducing Threats to Monument Resources	MTA-2.1
▪ Monitor and fingerprint oil found washed ashore	High	+5	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
Invasive species				
▪ Survey terrestrial alien/invasive species	Critical	1-3	Conserving Wildlife and Habitats	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

Table 2. Research and Monitoring Activities Organized by Research Theme and Focus Area

Research and Monitoring Activity	Priority Rating[1]	Timeframe[2] (years)	Related Monument Management Plan Needs and Activities	
			Priority Management Need	Management Plan Activity
▪ Investigate competitive interactions between alien/invasive and native species	Critical	1-3	Reducing Threats to Monument Resources	AS-1.2 AS-7.1 AS-7.2 AS-8.1
▪ Develop a method to control and eradicate *Schistocerca nitens*	Critical	1-3	Reducing Threats to Monument Resources	AS-5.4
▪ Conduct research on invasive species prevention and control methods	Critical	1-3	Reducing Threats to Monument Resources	AS-1.2 AS-5.3 AS-5.4 AS-6.1 AS-6.2 AS-6.3 AS-6.4 AS-7.1 AS-7.2 AS-8.2
▪ Identify and map distribution of social Hymenopterans	Critical	4-5	Reducing Threats to Monument Resources	AS-5.1
▪ Investigate eradication techniques for all social Hymenopterans	Critical	4-5	Reducing Threats to Monument Resources	AS-5.2
▪ Assess alien/invasive species population characteristics	High	1-3	Reducing Threats to Monument Resources	AS-2.1 AS-7.1 AS-7.2 AS-8.1
Climate change				
▪ Assess effects of climate change on biodiversity	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4
▪ Model climate change effects on coral population demographics	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.5
▪ Model the effects of sea level rise on terrestrial resources.	Critical	1-3	Conserving Wildlife and Habitats	MB-3.1 HMC-3.1 HMC-3.2
▪ Model the effects of sea level rise and currents on marine resources	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4 MCS-1.5
▪ Model the effects of increasing sea surface temperature on terrestrial resources	Critical	1-3	Conserving Wildlife and Habitats	MB-3.1 HMC-3.1 HMC-3.2
▪ Model the effects of increasing sea surface temperature on marine resources.	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4 MCS-1.5
▪ Model the effects of ocean acidification and ocean chemistry on marine resources.	Critical	1-3	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	1-3	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
▪ Model the effects of changes in precipitation on terrestrial resources.	Critical		Conserving Wildlife and Habitats	HMC-7.1 HMC-7.2
▪ Quantify historical climate change	High	4-5	Understanding and Interpreting the NWHI	MCS-2.1
Indicators and Monitoring of Ecosystem Change				
Ecosystem and ecological process metrics and monitoring				
▪ Investigate trophic level interactions	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 TES-1.2
▪ Monitor water level, salinity, and other water quality	High	1-3	Conserving Wildlife and Habitats	HMC-6.1

Table 2. Research and Monitoring Activities Organized by Research Theme and Focus Area

Research and Monitoring Activity	Priority Rating[1]	Timeframe[2] (years)	Related Monument Management Plan Needs and Activities	
			Priority Management Need	Management Plan Activity
parameters of Laysan Lake, and document any loss of lake area.				
Biodiversity and habitat metrics and monitoring				
▪ Compare monitoring program protocols	Critical	1-3	Conserving Wildlife and Habitats	MCS-2.2
▪ Monitor cetacean distribution	Critical	1-3	Conserving Wildlife and Habitats	TES-2.1
▪ Monitor landbird populations	Critical	1-3	Conserving Wildlife and Habitats	TES 6.1
▪ Continue annual monitoring and modeling of threatened and endangered species populations	Critical	1-3	Conserving Wildlife and Habitats	TES-1.2
▪ Characterize and monitor marine invertebrate species	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.4
▪ Monitor coral reef communities	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4
▪ Characterize and monitor fish species	High	1-3	Understanding and Interpreting the NWHI	MCS-1.2 MCS-1.4
▪ Characterize and monitor algal populations	High	1-3	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	High	1-3	Conserving Wildlife and Habitats	HMC-3.1 HMC-4.7 HMC-5.2
▪ Monitor coral disease	High	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3
▪ Monitor coral bleaching	High	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2
▪ Conduct terrestrial plant population surveys	High	1-3	Conserving Wildlife and Habitats	TES-7.1 TES-7.2 TES-7.3 TES-7.4 TES-7.5 HMC-4.7 HMC-5.2
▪ Monitor avian disease outbreaks	High	4-5	Conserving Wildlife and Habitats	MB-2.1
▪ Implement monitoring program for deep-water (>30 meter) ecosystems	Medium	1-3	Understanding and Interpreting the NWHI	MCS-1.4
Human impact metrics and monitoring				
▪ Map and monitor invasive red algae	Critical	1-3	Reducing Threats to Monument Resources	AS-7.1
▪ Characterize and monitor terrestrial alien/invasive species	Critical	1-3	Reducing Threats to Monument Resources	AS-1.2 AS-2.1 AS-5.1 AS-8.2
▪ Characterize and monitor marine alien/invasive species	Critical	1-3	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	High	1-3	Conserving Wildlife and Habitats	HMC-2.6
Modeling and Forecasting of Ecosystem Change				
Modeling the ecosystem and ecological processes				
▪ Model effects of physical processes on community structure	High	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.5
Modeling biodiversity and habitats				
▪ Modeling effects of climate change on biodiversity	Critical	1-3	Understanding and Interpreting the NWHI	MCS-1.1 MCS-1.2 MCS-1.3 MCS-1.4
Modeling human impacts and management				

Table 2. Research and Monitoring Activities Organized by Research Theme and Focus Area

Research and Monitoring Activity	Priority Rating[1]	Timeframe [2] (years)	Related Monument Management Plan Needs and Activities	
			Priority Management Need	Management Plan Activity
▪ Create predictive models of alien species invasions	High	1-3	Reducing Threats to Monument Resources	AS-1.2 AS-2.3 AS-7.2 AS-8.1 AS-8.2

1 - Priority rating based on research activity prioritization review process described in Section 2.0.
2 - Timeframe over which information from the research and monitoring activities are needed for management decision-making.

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