NATIONAL MARINE SANCTUARIES™

A Monitoring Framework for the National Marine Sanctuary System

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National Marine Sanctuaries

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Synopsis

This document describes a new approach to monitoring for the system of 14 U.S. National Marine Sanctuaries. The primary purpose of System-Wide Monitoring (SWiM) is to ensure the timely flow of data and information to those responsible for managing and protecting resources in the ocean and coastal zone, and to those that use, depend on, and study the ecosystems encompassed by the sanctuaries. It does this by enabling marine sanctuaries to develop effective ecosystem-based monitoring programs that address management information needs. SWiM provides a design process that can be applied in a consistent way at multiple spatial scales and to multiple resource types. It also provides a reporting strategy to enable the evaluation of status and trends in protected resources and activities that affect them. Finally, SWiM integrates information from partner monitoring efforts to enhance its utility, improve local efforts, apply it to broader issues and scales, and contribute to multi-site, regional and national research and monitoring activities.

SWiM's begins with tailored monitoring at the local (sanctuary) level to track the status and trends of natural resources and human uses (allowable and prohibited) as they affect water, habitat, and living resource quality. It focuses on information critical to management while contributing to and benefiting from other local, regional, and national monitoring programs. In so doing, SWiM will also be a building block for the Nation's Integrated Ocean Observing System (IOOS) and contribute significantly to the goals established for the marine protected area network of the U.S.

SWiM has three principal characteristics. Its foundation is an ecosystem framework that can be applied and adapted to any marine sanctuary, and serves as the basis for design of monitoring programs and reporting of information. Second, the design steps for SWiM can be applied to create or improve a monitoring program for a sanctuary, a group of sanctuaries, or even for specific types of natural resources (e.g., marine mammals) or issues (e.g., marine reserve effectiveness). Third, SWiM provides a flexible strategy for reporting resource status and trends at multiple spatial scales (individual sanctuaries, networks of sites, and the entire sanctuary system).

The design process for monitoring has three phases. The first, "Requirements," uses a sanctuary's management objectives to generate specific questions based on existing threats to resources. In addition, 14 "system questions" are considered. These apply to all sanctuaries and relate generally to the quality of water, habitats, and living resources - the three principal ecosystem components common to all marine sanctuaries that protect natural resources. Once the appropriate questions are posed, specialists identify priority threats and the most likely environmental responses to those threats. The outcome of this phase is a "requirements matrix" that lists priority resources and specific assessments that must be made for each.

The requirements matrix is the starting point of the second planning phase, "Protocols." Sanctuary staff and selected experts consider temporal and spatial aspects of existing programs, as well as resolving capabilities, as required by resource managers. Appropriate sampling protocols are selected, considering field capabilities, prioritization of key variables, sampling and statistical requirements, and cost. Pilot efforts may be necessary to obtain information on characteristics such as expected densities, diversity, and temporal and spatial variance. Implementation options are then proposed, identifying sampling intensity, expected detection capabilities, partners, timelines, milestones, and costs.

The third phase, "Observing," involves field sampling, analysis, and reporting. Periodic reports to managers provide detailed results on the status of protected resources and, in some cases, the outcomes of specific management actions. In addition, cooperative planning and information management will allow regional and national reports on environmental conditions at larger scales. Feedback at every scale can then be used to inform decision-making and guide policy.

Introduction

The National Marine Sanctuary Program (NMSP) of the National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS) manages marine areas in nearshore and open ocean waters that range in size from less than 1 to over 5,000 square miles. Protected habitats include rocky coasts, kelp forests, coral reefs, sea grass beds, estuarine habitats, hard and soft bottom habitats, and segments of whale migration routes. Some also contain cultural artifacts. The mission of the NMSP is to serve as trustee for the Nation's marine protected areas to conserve, protect, and enhance the biodiversity, ecological integrity, and cultural legacy of these ecosystems. Yet, while resource protection is the primary goal of the program, multiple use of the marine environment is allowed as long as it is compatible with this goal.

Sanctuary managers and staff have a variety of tools at their disposal to help them protect site resources. Most sanctuaries have regulations that limit activities such as collecting, destructive fishing techniques, discharges of pollutants, and looting of cultural sites. Many have formal agreements with other agencies or have on-site staff to enforce sanctuary regulations. Sanctuaries also guide or participate in numerous educational and outreach activities that enhance public awareness of the need for environmental protection. They also conduct or facilitate issue-directed research to provide knowledge that informs decisions.

With few exceptions, nearly all conservation measures employed to protect sanctuary resources involve managing human activities as opposed to direct intervention in natural systems. Vessel traffic lanes are strategically located to minimize impact. Mooring buoys are installed to reduce anchor damage to sensitive benthic habitats. Some fishing techniques are prohibited because they destroy critical habitat. Spill contingency plans are developed to provide the most effective response measures, given the nature of resources in the area. Therefore, the majority of enforcement, education, research and monitoring related to sanctuary resources is of an applied nature, as it is primarily directed at reducing threats posed by human populations interested in experiencing or extracting sanctuary resources, or simply passing through the sanctuary.

Fundamental to accomplishing the Program's mission is the development and consistent application of a rigorous, objective, and applied scientific foundation for understanding ecosystem structure and function, evaluating environmental condition, and implementing effective, sustainable, and adaptive management strategies. The NMSP uses the mission-oriented, multi-disciplinary approach of conservation science for understanding, protecting, assessing, monitoring, maintaining, and restoring cultural and natural resources under its stewardship (Gittings et al., 2003). The approach has contributed both to a better understanding of fundamental aspects of natural systems and to the decisions that must be made to control threats to those systems.

The enabling legislation for the NMSP was Title III of the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA;16 U.S.C. 1431). Title III contained no specific provisions requiring research or monitoring. Subsequent reauthorizations, including that in 2000, have significantly affected the manner in which many aspects of sanctuary management are addressed, including provisions "...to support, promote, and coordinate scientific research on, and long-term monitoring of, the resources in these marine areas." (see Appendix 3 for a more complete legislative history).

The 2000 reauthorization also directed the NMSP to place additional emphasis on issues related to the entire system of sanctuaries, and implies the need for greater consistency among conservation programs throughout the system. Attention to ecosystems regardless of sanctuary boundaries, and connectivity among sanctuaries are thus focus areas for sanctuary science. Monitoring programs also need to consider not only individual site priorities, but also regional and national issues and questions. In so doing, the Program will improve its ability to address increasing levels and varieties of use in the Nation's coastal waters, and endeavor to prevent problems before they affect sanctuary resources.

The Expanding Role of Monitoring

Resource managers are being increasingly challenged to defend their decisions with scientifically credible data. Monitoring the changing condition of resources, with or without direct management, is critical to effective decision-making. Of course, even greater capacity is gained when targeted research programs address cause-and-effect relationships among sanctuary resources and the factors that affect their condition. Thus, appropriate links between monitoring and other conservation science programs are very important.

A marine sanctuary's regulatory, advisory, science, education, outreach, and enforcement activities are conducted in accordance with the site's management plan. Current management plans are being developed using a model that calls for response to threats using management actions with established "desired outcomes" (Fig. 1). Success and failure are assessed by monitoring specific performance measures.

The design for monitoring at a site should be consistent with this model, particularly with regard to identifying and addressing priority information needs and selecting appropriate indicators to evaluate the effectiveness of management actions. Performance measures for monitoring would establish development, implementation, and reporting milestones.

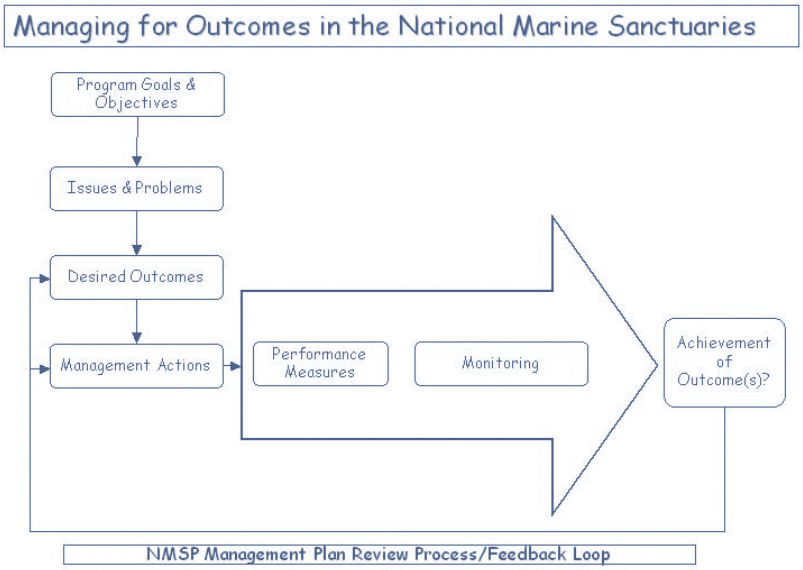

Figure 1. Key steps in the process of addressing specific issues and problems in a marine sanctuary. Note the critical role of monitoring to assess performance in the process and to provide feedback that could influence management actions.

In the past, monitoring in the sanctuaries proceeded primarily on a site-by-site basis, with independent development of monitoring programs tailored to address some, but not all of the priority information needs of the sanctuaries. Most efforts have been directed at selected "key resources," and few sites have had the means to monitor across a broad range of physical, biological and chemical regimes. At times, site monitoring has been designed to address specific issues, such as the impacts of groundings, spills, cable installations, hydrocarbon development, or the benefits derived from restricting use in certain areas (zoning).

Monitoring in the sanctuaries has generally been characterized by substantial dependence on federal, state, and local governmental partners, academia, and volunteers, both for project funding and field support. Unfortunately, inconsistent funding and changing mechanisms for the distribution of funds have affected program stability, leaving at risk our knowledge of the natural and cultural resources the program is directed to protect. Furthermore, most current monitoring in the NMSP is not coordinated regionally or nationally, either among the sites, or between the sites and germane non-sanctuary programs. One result has been the inability to generate long-term data sets that would otherwise contribute important information on regional environmental changes.

Each sanctuary has its own concerns and requirements for environmental monitoring. Yet the sanctuaries are located within most of the major coastal biogeographic regions of the contiguous U.S., in Hawaii, and in American Samoa, and they have a long-term commitment to resource protection and management programs in these regions. Thus, they can and should contribute to an assessment of the effectiveness of the Nation's coastal resource protection efforts. In these and other ways, they strongly support the goals of the National Marine Protected Area (MPA) Initiative (see http://mpa.gov/) and should be considered an integral part of that initiative.

Sanctuaries can also contribute, to various extents, to the assessment of coastal environmental quality on a nationwide basis. In fact, marine sanctuaries are located within eight of the nine regions of the Integrated Ocean Observing System (IOOS) along the coastal U.S. (Figure 2), making them significant components of that system as well. The ability of sanctuaries to facilitate sustained measurements at fixed locations in real-time or near real-time makes them ideal locations to support the plans for a regionally-implemented IOOS. Sanctuaries and IOOS also have mutual goals, including improvement of capabilities to detect and forecast ocean phenomena, promoting safe marine operations, effectively managing ocean resources, and preserving and restoring healthy marine ecosystems.

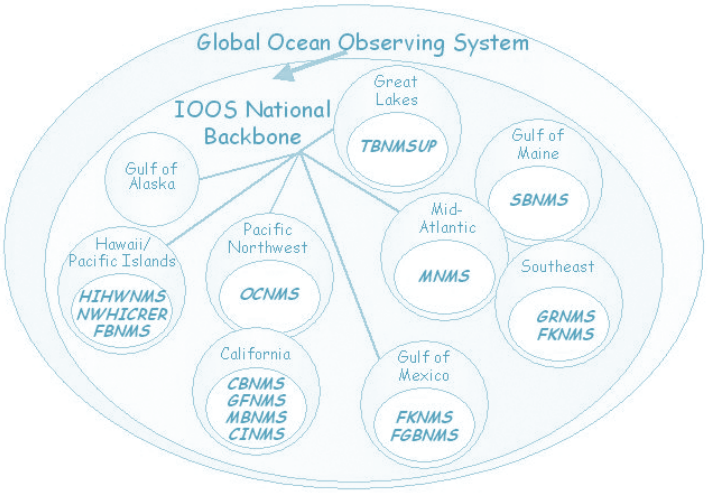

Figure 2. Regional structure proposed for the Integrated Ocean Observing System (IOOS), which is a component of the Global Ocean Observing System. Acronyms for the sanctuaries and reserves in the NMSP are shown for each region as follows: NMS in all cases is National Marine Sanctuary, HIHW - Hawaiian Island Humpback Whale, NWHICRER - Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve, FB – Fagatele Bay, OC - Olympic Coast, CB – Cordell Bank, GF – Gulf of the Farallones, MB – Monterey Bay, CI – Channel Islands, TBNMSUP – Thunder Bay NMS and Underwater Preserve, M – Monitor, FK – Florida Keys, FGB – Flower Garden Banks, SB – Stellwagen Bank, GR – Gray's Reef.

At present, the system of marine sanctuaries is limited in what information it contributes at larger scales. Additionally, connections among sites, and between sites and other coastal waters, are not well understood. Thus, adequate comparisons cannot be made among sanctuaries, nor can it be objectively determined whether certain sanctuaries are representative of broader regional habitats, or how they influence each other. Thus, while it is essential to build site-based monitoring programs that target priority needs, which vary by site, it is important to recognize the necessity and opportunity to contribute to and benefit from larger spatial and issue-based initiatives.

By establishing monitoring programs with both local and wide-ranging applicability to the Nation's important marine conservation issues, the marine sanctuaries would serve as places where significant research initiatives can be securely conducted, coordinated, and supported by an existing infrastructure, as well as baseline and long-term data. A system-wide monitoring program should therefore strive to represent a model for development and support of local, regional, and national marine resource monitoring efforts (Fig. 3).

Appropriately conceived and implemented, a System-Wide Monitoring Program (SWiM) within the NMSP would enhance credibility for the program in the public eye, establish a legacy for sanctuaries as places for sustained and purposeful observations of natural systems and, most importantly, improve efforts to effect change in public attitudes about and behavior in the coastal environment.

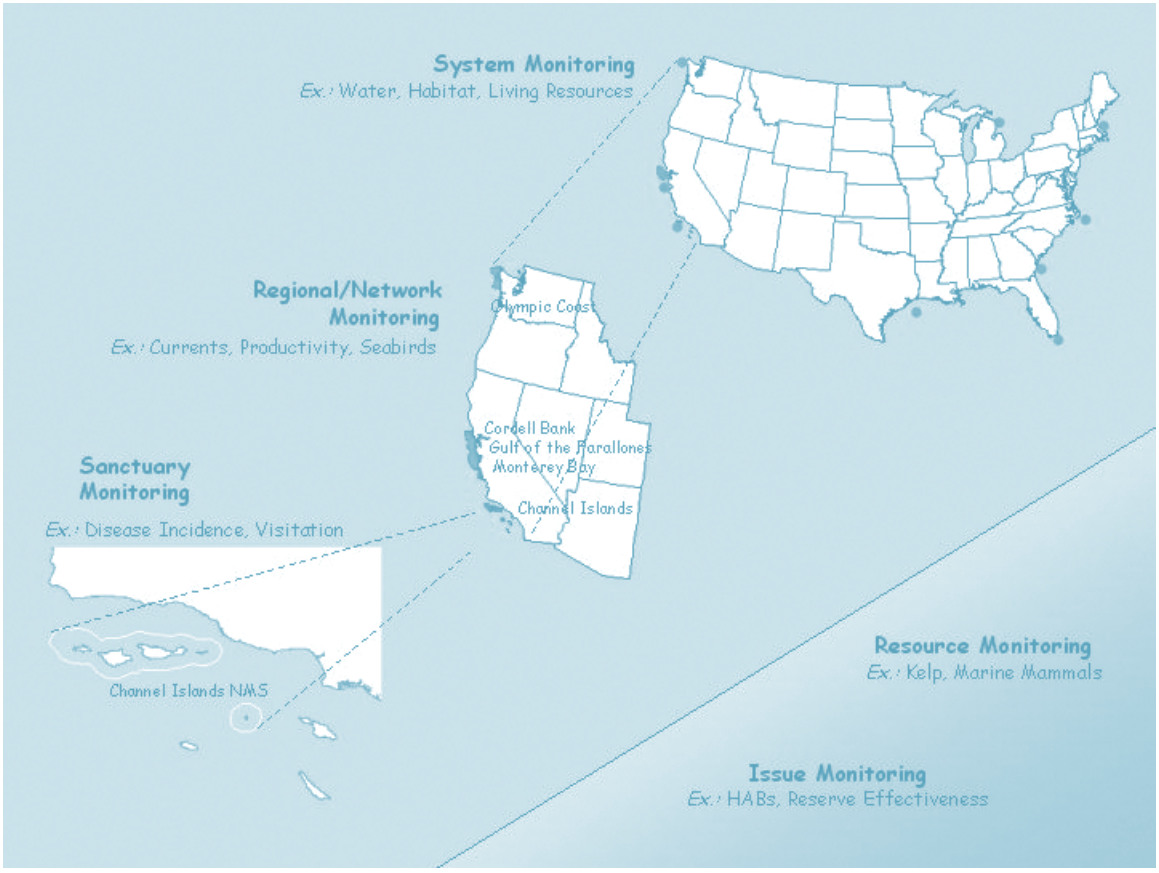

Figure 3. Application of System-Wide Monitoring Program at multiple spatial scales and for multiple purposes within the National Marine Sanctuary System. Blue circles indicate only sanctuaries along the continental U.S. coast and not those in Hawaii or American Samoa. For each monitoring category, examples of the types of data that might be collected are provided.

Other Constituencies

The need for development of a system-wide program for monitoring in the NMSP is driven by additional factors as well, each associated with certain constituencies. For example, the American public is encouraged to participate in the development and revision of management plans for marine sanctuaries. Understanding the condition of sanctuary resources and the ability of managers to address the increasingly complex issues facing them is critical to generating useful public input. Monitoring data are also vital to adapting to defending decisions and actions when challenged by the public, other management authorities, Congress, and the legal system. Furthermore, in providing scientifically credible data and proven management tools, the NMSP often influences the conservation and regulatory actions of other Federal, State, and local management authorities in the U.S. and abroad.

Monitoring and other conservation science programs also support research and other monitoring studies occurring at a variety of spatial scales, as well as teaching and training in local, regional and national education programs at all academic levels. The outreach activities of public and private institutions are also frequently supported. Finally, science programs provide important information as a community service to recreational and commercial users (e.g., weather and sea conditions in real time and the status of natural resources of interest to various users).

Approach

SWiM enables marine sanctuaries to develop effective, ecosystem-based monitoring programs that address management information needs using a design process that can be applied in a consistent way at multiple spatial scales and to multiple resource types. It is, however, important to note that the role of consistency, as applied here, is not necessarily to conduct the same monitoring at all sanctuaries; here it refers primarily to the application of a set of design, implementation, and reporting principles for all monitoring in the NMSP. Of course, consistent protocols and procedures may be implemented, but only when the design process indicates they are appropriate.

Ecosystem Framework

Each of the marine sanctuaries established to protect natural resources has characteristics that make it unique as well as affect and control the way ecosystems function. It can be argued in a general sense, however, that the ecosystem structure and function in all sanctuaries have similarities and are influenced by analogous factors that interact in comparable ways. Furthermore, the human influences that affect the structure and function of marine sanctuaries are similar in a number of ways.

The ecosystem framework in Figure 4 depicts these relationships for a generalized marine ecosystem. The framework is useful for ensuring that a system-wide monitoring program accounts for the most important aspects of ecosystem structure and function. It can also be modified for individual sanctuaries by adding site-specific detail based on conceptual, functional, and/or numerical models, thereby identifying particularly significant resources and processes for monitoring.

The framework shows three primary ecosystem components common among marine sanctuaries – water, habitats, and living resources (though the atmosphere could be considered as an ecosystem component, SWiM focuses on the marine environment, and therefore recognizes the atmosphere as a driver and source affecting sanctuary conditions rather than a separate component). Aspects of each component must be monitored to identify deviations from acceptable conditions. Water quality is, in general, monitored by tracking variation caused by natural drivers and indicators of certain types of human activity. The evaluation of both habitat and living resources requires assessment of the quantity and quality of resources as well as certain aspects of resource production and loss. Selected human influences must also be tracked, either through quantifying the levels of activities themselves or by tracking their outcomes (e.g., the occurrence of non-indigenous species).

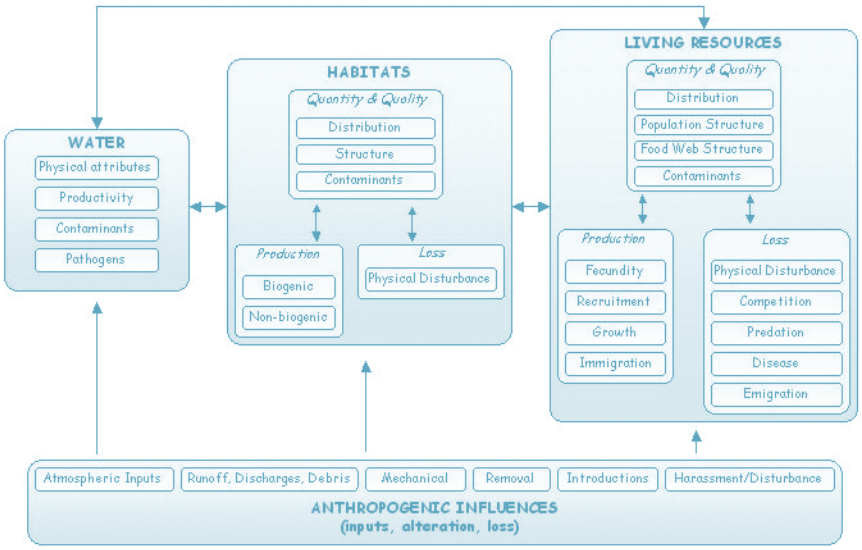

Figure 4. Conceptual framwork for a generalized marine ecosystem, including common resources and processes that affect ecosystem integrity.

System Questions

Assuming that a common marine ecosystem framework can be applied to all sanctuaries, it follows that there may be a number of questions that can be posed at all sites. The questions below derive from both the generalized ecosystem framework and from the NMS Program mission. They are widely applicable across the system of marine sanctuaries. Any sanctuary could ask much more specific questions at the local scale, but these 14 "system questions" should be considered in the course of developing site-based monitoring programs in all sanctuaries. Because the questions are fairly broad, they are likely to include all questions posed at any finer scales. Furthermore, they represent useful reporting categories for the synthesis of more extensive and detailed findings at the sanctuary, issue, resource, network, or regional scales. The system questions are:

Water

- Are specific or multiple stressors, including changing oceanographic and atmospheric conditions, affecting water quality?
- What is the eutrophic condition of sanctuary waters and how is it changing?
- Do sanctuary waters pose risks to human health?
- What are the levels of human activities that may influence water quality and how are they changing?

Habitats

- What is the distribution of major habitat types and how is it changing?
- What is the physiological condition of biologically-structured habitats and how is it changing?
- What are the contaminant concentrations in sanctuary habitats and how are they changing?
- What are the levels of human activities that may influence habitat quality and how are they changing?

Living Resources

- What is the status of biodiversity and how is it changing?
- What is the status of extracted species and how is it changing?

· What is the status of non-indigenous species and how is it changing?
· What is the status of key species and how is it changing?
· What is the condition or health of key resources and how is it changing?
· What are the levels of human activities that may influence living resource quality and how are they changing?

Design Process

Figure 5 depicts a design process by which monitoring programs can be developed to track the condition of marine ecosystems in the NMSP. It can be used by individual sanctuaries or by groups of sanctuaries. It can also be used to develop tailored monitoring programs, or address single issues or particular resource types.

The process has three phases. "Requirements" involves clarifying priority issues, objectives, and information needs based on the collective experience of sanctuary staff and advisors, and knowledge of national program issues and policies. Questions related to these issues and information needs are generated and posed at appropriate spatial scales, either within a sanctuary (and when appropriate, areas beyond sanctuary boundaries), a network of sanctuaries, a region, or the entire sanctuary system. The first phase ends with the compilation of a "requirements matrix," which identifies the most pertinent resources and the most appropriate measures to address particular questions.

"Protocols" involves the steps required to implement field sampling programs focused on the most pertinent variables associated with the resources of priority interest.

"Observing" includes the fieldwork, analysis, and reporting steps necessary to inform management and guide future monitoring efforts. Information from individual sanctuaries can be summarized for reports directed at different audiences. It can also contribute to monitoring programs designed for larger spatial scales, including networks of sanctuaries, regions, and the sanctuary system, or those addressing specific natural resource types or issues. The development of monitoring programs for any of these scales or purposes can utilize the same design process. In addition, coordination with and among regional monitoring efforts will be important to ensure better exchange of data as well as compatibility among data sets.

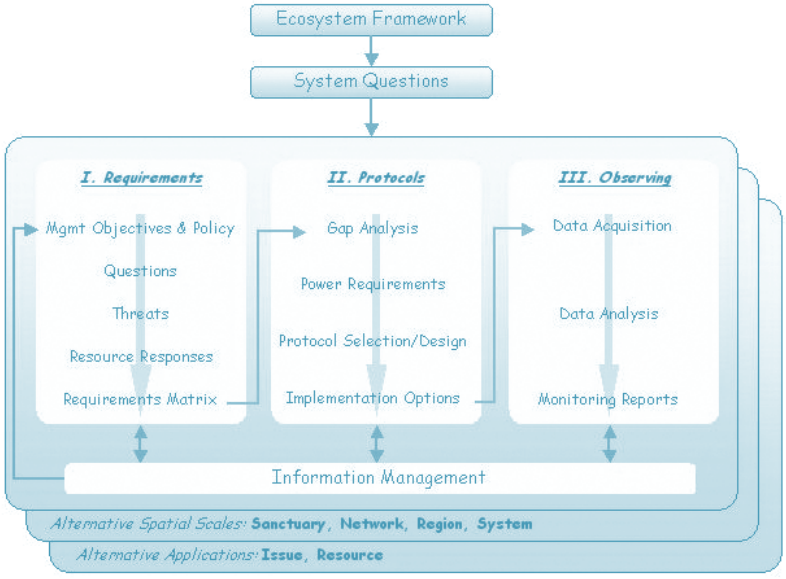

Figure 5. Design process for System-Wide Monitoring (SWiM) in the National Marine Sanctuary Program, showing the key phases and steps used to develop monitoring at selected spatial scales, and the feedback of monitoring information to resource managers and policy makers.

"Requirements" Phase

The "Requirements" phase requires a clear understanding of the site's management objectives. Specific questions are posed, based on existing or anticipated threats to priority resources, or on specific management actions. Priority questions, once developed, are organized within the context of the 14 broader, system-level question described above. Thus, the system questions serve as reporting categories for site-based monitoring data.

For any sanctuary, the best way to identify and prioritize issues, questions, and threats is tapping the knowledge of local and regional resource managers and constituents most familiar with the ecosystems and problems facing them. Supporting documents may include the sanctuary management plan, which contains sanctuary objectives and planned actions, documents supporting management plan reviews (e.g. public scoping summaries), and science and education plans and summaries. There are also a number of documents produced with a national perspective that may be relevant, including program-wide science needs assessments (e.g., Gittings et al., 2002), policy statements, and plans for new initiatives. For monitoring at the network and regional scale, or for specific issues or resources, information needs and questions may be identified from a number of sources, including sanctuary documents, conference proceedings, workshop summaries, and expert consultation.

The ecosystem framework, as well as more specific ecosystem models prepared for the region of interest, can also provide guidance for the development of questions.

How questions are specifically addressed will vary considerably among sanctuaries, particularly because the nature and temporal and spatial scales vary for relevant pressures, threats and potential responses. Operationally, this design phase would involve posing the priority questions in a forum that includes sanctuary management staff, key advisors and researchers, and selected individuals with regional and national expertise on management and/or conservation science issues. For each question, the group would identify current or anticipated natural or anthropogenic threats most relevant to the question, the resources potentially affected by the threats, and the potential responses most likely to be observed should an effect occur. For example, a question about exploited reef fish populations is likely to require knowledge about threats posed by commercial and recreational fishing, predator/prey interactions, and/or particular diseases. Potential response variables include reduced abundances, changes in the trophic structure of the assemblage, or changes in disease incidence. Some of the other indicators potentially relevant to the three major resource categories are shown in Table 1. Among the sanctuaries, differing single measures, or multiple measures may be deemed appropriate to track particular responses. On a coral reef, one alga may be a key species for which cover is tracked. In another sanctuary, kelp canopy cover might be a more appropriate measure of living resource condition. For water quality, measures related to turbidity may be selected to track priority threats at one site while a suite of organic contaminants and metals may be monitored at another.

Compiling this information results in a "requirements matrix" that contains a list of priority resources and the variables that must be assessed to determine their status and how it changes through time (see Davis et al., 1994 for an example). The concept of a requirements matrix is similar to, and based on, the approach used in the National Park Service to develop natural resource monitoring programs (Davis, 1993; Davis et al., 1994). The resources listed may include aspects of the physical (e.g., water, atmosphere, habitat) or biological environment (e.g., species or other taxonomic levels of interest). The variables may be physical attributes (e.g., temperature, turbidity, grain size characteristics), demographics (presence/ absence, status and trends in abundance and distribution), or measures of condition (e.g., growth and mortality rates, fecundity). To the extent possible, temporal and spatial needs for sampling are also identified in the matrix. The requirements matrix constitutes the final product of the first phase of monitoring program design.

Table 1. Variables often used to assess the condition of water, habitat, and living resources.

Category		Common Measures
Water	Status and trends	Temperature Salinity Dissolved oxygen Currents Nutrients Turbidity/water clarity Primary production/HABs Organic contaminants Heavy metals
	Human activity	Point source discharges Non-point source pollution Land use patterns/levels Vessel traffic levels/types Development activities
Habitats	Status and trends	Sediment contaminants Structure/distribution Biogenic aspects Storm freq./intensity/impacts Climatic events Seasonality
	Human activity	Mechanical disturbance Extraction levels Debris accumulation
Living Resources	Status and trends	Biodiversity measures Key species measures Extracted species measures Non-indigenous species Vital rates (e.g., reproduction, recruitment, mortality) Condition indices
	Human activity	Extraction modes and rates Invasion mechanisms Level of disturbance

"Protocols" Phase

The second phase of the design process involves all steps necessary to provide the required data streams. It identifies the required mix of platforms, in situ and remote sampling gear, and measurement protocols needed to meet the data requirements. It would be most effective using a working group that includes experts experienced in ecological studies and monitoring. One or more design workshops would be necessary to complete the phase.

Beginning with the requirements matrix, the working group must determine which variables are already being assessed in the desired manner and which are not. This evaluation requires clear understanding of detection needs of resource managers, which determine the spatial and temporal sampling requirements. Higher levels of certainty or the ability to confidently detect smaller levels of change require more intense sampling (Green, 1989). Determining whether adequate sampling is already occurring may require analysis of the statistical power of existing data. Changes in sampling intensity can then be recommended.

For variables not currently being assessed, appropriate protocols must be selected, and decisions regarding spatial and temporal sampling must be made. Due consideration must be given to statistical design in order to achieve desired confidence levels and to provide managers with an understanding of the power of the data available to support decisions (Fairweather, 1991). Knowledge of expected sample variance is required to allow for power analyses. If no variance estimates exist, it may be necessary to conduct pilot field studies prior to completing the second phase of design (Davis, 1993).

Appropriate sample design is also considered. For certain monitoring, repeated measures designs (Green, 1993) that incorporate stratified random samples (i.e. repeated sampling at locations initially selected randomly within selected habitats, zones, or other categories) are useful. These allow for comparatively robust short-term assessment of temporal change and the determination of probable causative factors (particularly in the case of diseases and some human activities).

Ultimately, sampling designs will continue to vary according to the information needs of each sanctuary. Generally speaking, however, sampling of a variety of different ecological indicators is recommended to support "weight of evidence" assessments of condition. In addition, one continuing goal will be making data comparable among monitoring programs within the context of the multi-site, regional and national reporting framework. Compatibility is also critical to ensuring data accessibility for regional observing initiatives like those planned for IOOS.

The outcome of this phase is a series of implementation options. These should outline alternative variables and protocols under different funding scenarios, the roles and responsibilities of partners participating in the program, and milestone schedules for data collection, analysis, and reporting. The options may include the requirements for three levels of monitoring: 1) a program that utilizes only existing resources, 2) one that improves upon existing programs, resulting in

minimally acceptable monitoring that meets the most important objectives and addresses the most important questions defined in the first phase of design, and 3) a wide-ranging program that implements protocols and variables related to all priority resources.

"Observing" Phase

The third phase of monitoring involves the collection, processing, and reporting of data in order to make it useful for the continued protection and management of resources. It results in periodic reports on the status and trends of priority resources and human activities at relevant space and time scales. These results must be presented in a way that clearly conveys whether management objectives are being achieved. The information needs to be accurate, timely, and defensible. In addition, conclusions need to convey, to the extent possible, the level of confidence with which they are presented.

The specificity of resulting data streams and monitoring reports will depend on the needs of those who require them. Site level monitoring generally requires the highest level of detail, as the information supports day-to-day management decisions focused on site-specific activities. At larger spatial scales, including the system level, vastly differing resources and settings make such reporting unnecessary, and conclusions must be more general.

Data and reports will target different audiences. Site reports will be primarily for sanctuary staff, other local managers, academic partners associated with the sites, and advisory committees and work groups. They will impact local management decisions, monitoring, research, education, outreach, and enforcement programs primarily, though not exclusively. Location-specific data will also be made available to appropriate coastal observing networks. The reports will be produced by the lead partners involved in monitoring in each sanctuary, and may include site staff, agency and academic partners, and/or contractors. The reports will be specific with regard to findings related to all relevant questions and variables.

Network or regional reports will be tailored to management authorities operating at larger spatial scales, including state governmental representatives, other federal agencies, and non-governmental organizations. Many scientists and educators can make use of such information as well.

A national report on the status and trends of program resources will synthesize information from reports generated at smaller spatial scales. Its specificity will have to be much reduced due to the highly differing nature of resources among the sanctuaries. Questions that can be addressed by all sanctuaries are relatively few, and they are generally broad compared to those of an individual site. Nevertheless, answers to questions posed at the national level provide an indication of how well the National Marine Sanctuary Program is fulfilling its mission to safeguard these valuable marine resources. Audiences for this type of summary are agencies working on agencies that are national in scope (e.g., NOAA, National Park Service, U.S. Geological Survey, Environmental Protection Agency), advocacy groups, and Congressional oversight committees and individual members of Congress.

One goal of the program is to prepare reports that summarize the findings of various studies in a way that is easy to understand for audiences of a more general nature. Relatively simple "report cards" will be used to provide summaries of studies at different spatial scales. Thus, while the primary target audience of monitoring reports is sanctuary management, some or all of the results from sanctuary-based reports will contribute to reports at the larger spatial scales, as well as those relating to specific resources or issues.

For summary reports that target audiences with only a general interest in sanctuary resources, a series of symbols is being developed. The symbols are modified from, but similar in nature to those used in the National Coastal Condition Report (EPA, 2001). Each represents one of the 14 proposed "system questions" in the three reporting categories (water,

habitat, and living resources; see Fig. 6). Sanctuary staff will be asked to summarize their findings with regard to each relevant question. The symbol for each question will be color-coded (red, yellow, or green) to indicate the current status (good, fair, or poor, respectively), based on the judgment of those interpreting the data. Each symbol will also have one of three orientations. Upward pointing triangles imply an improving trend. Downward pointing triangles imply a deteriorating condition. Squares imply that no trend exists, or that not enough data are available to determine whether a trend exists. Some triangles may have a gradation in color, suggesting that the condition is apparently changing from one status category to another (e.g., from good to fair).

Information Management

An efficient system for the management of information is essential to the success of a system-wide approach to monitoring. Among other things, it establishes appropriate pathways for data delivery and reporting by participating partners, assures data quality, security, and accessibility, and facilitates statistical and non-statistical analysis. It must accommodate historical data as well as information gathered by investigators working at various scales under different agreements and using different platforms. Then it must facilitate the integration of information for reporting results at selected spatial scales ranging from individual sanctuaries to the system, as suggested in Figure 5. It must have established tracking procedures, and ensure data quality and timely access for reporting. A number of other functions must also be developed, particularly with regard to ensuring compliance with protocols for acquisition, handling, serving, and reporting, and the application of metadata standards to enable inter-comparability. Versatility must be incorporated in a way that allows handling of and long-term access to diverse data sets.

The Data Management and Communications (DMAC) Steering Committee for IOOS is developing a strategy that integrates marine data streams across disciplines, institutions, time scales, and geographic regions. This is one of three subsystems for IOOS, the other two being the Observing Subsystem and the Modeling and Analysis Subsystem. The plan for DMAC (Hankin et al., 2003) calls for the establishment of a data and communications infrastructure that consists of standards, protocols, facilities, and software. It will support needs for metadata, as well as data searches, visualization, transport, manipulation, and storage. Virtually all these needs apply to SWiM, and many standards and capacities may be adopted directly. Considerable coordination will be necessary as well to ensure mutual access to required data streams and to minimize duplication of effort.

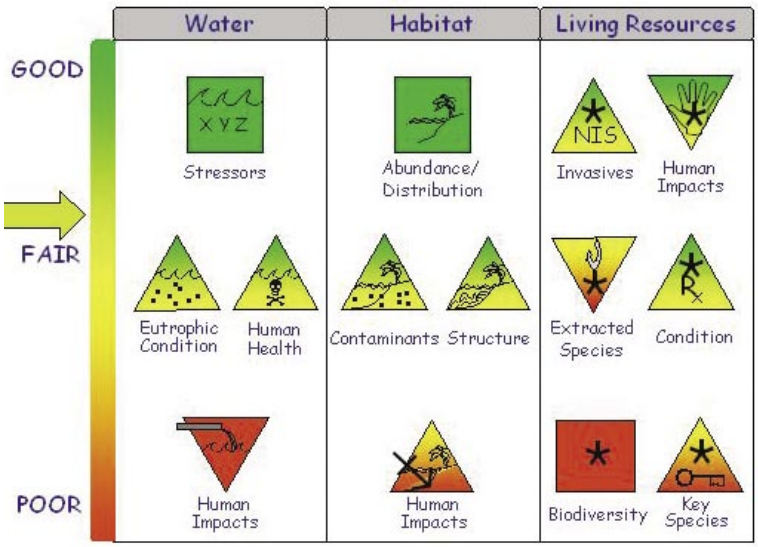

Figure 6. Symbols proposed to report the status and trends for the 14 questions within the NMSP. Any symbol can be re-colored or reconfigured to represent the appropriate status and trend.

Strategy for Implementation

As already mentioned, a substantial amount of monitoring already occurs within the National Marine Sanctuary System. The plan for implementing SWiM will build on existing strengths, adjusting activities when necessary, and add capacities that allow for consistent program design, information handling, and reporting at appropriate spatial scales. Key activities will include 1) conducting development workshops, 2) coordinating with key partners and programs within and outside NOAA to develop operational capabilities for field sampling and information management, and 3) establishing program review capacities. Each of these is supported by activities focusing on individual sanctuaries, networks of sites, and the sanctuary system.

Development Workshops

Monitoring program development workshops for the marine sanctuaries will help each site address priority information needs while providing consistency in the approach to program design. Many sites have monitoring programs that already address many of their information needs, but gaps exist in each. By analyzing existing programs at these sites, the gaps can be identified, and improved monitoring programs can be designed, providing targets for enhancement for the sanctuaries and their monitoring partners. A recent workshop at the Flower Garden Banks NMS allowed the site and its funding partner, the Minerals Management Service, to prepare for the issuance of a new monitoring contract. At a workshop in Hawaii, priority information needs for the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve were identified, many of which related to resource monitoring. The monitoring framework outlined here will be used to develop a strategy to address these needs. At the Channel Islands, where a preliminary design process was tested in 2002, the sanctuary will soon initiate a series of workshops to develop a monitoring plan to evaluate the effectiveness of marine reserves planned for that site.

NMSP staff will schedule site-based development workshops to coincide with each marine sanctuary's review of its management plan, a process scheduled every five years. The activity will contribute not only to a monitoring plan for the site, but also its overall science plan.

Development workshops will also focus on specific resources. A marine mammal and seabird monitoring workshop was recently conducted for the west coast and involved each of the region's five marine sanctuaries. A fish census workshop was conducted at Gray's Reef to improve monitoring protocols for those priority resources. In both cases, the results will contribute to efforts to enhance consistency among sanctuaries tracking these natural resources.

Three marine sanctuaries on the west coast – Monterey Bay, Gulf of the Farallones, and Cordell Bank – are conducting a joint review of their management plan. One proposal is to design a monitoring plan for this network of sites. If this plan is approved, the design process proposed here will be applied to these sanctuaries.

The design process will also be applied to specific issues of concern to sanctuary management. A monitoring program is being developed to address and track the recovery of mechanically damaged coral reefs. Depending on severity and the nature of damage and restoration efforts, specific types of monitoring can be initiated. The effort will also support case settlement and litigation by providing cost estimates using techniques incorporated into the design procedure.
Other regional and theme-based workshops will also be considered to support the development of SWiM. In regional workshops, resource managers and experts in ecological studies and monitoring would consider regional information needs and advise the program on the development of network monitoring programs. Theme-based workshops would focus on particular topic areas, such as water quality, fisheries, marine reserves, or others, in order to identify priority information needs and the most appropriate indicators and protocols to address them.

Partnerships and Coordination

Numerous partnership opportunities will be formalized during implementation of SWiM. Priority will be given to making optimal use of NOAA investments and expertise within and outside the NMSP. In addition, we will strengthen existing strategic partnerships and develop new ones, creating linkages and integration with existing monitoring initiatives and activities to enhance program development and data acquisition, management, and dissemination.

Some of the key NOAA partnerships are likely to include the National Centers for Coastal Ocean Science, the National Data Buoy Center, the National Environmental Satellite, Data and Information Service, the National Marine Fisheries Service, and the National Estuarine Research Reserves. Other Federal agencies, particularly the Environmental Protection Agency, National Park Service, Minerals Management Service, U.S. Fish and Wildlife Service, and U.S. Geological Survey may also play important roles in the development and support of monitoring programs. Coordination is essential with programs such as Ocean.US and the Regional Associations implementing IOOS, the National Coastal Assessment Program, EPA's Environmental Monitoring and Assessment Program, and the Census of Marine Life.

Many partnerships at the local level are already active and will need to be continued and strengthened. Programs like the South Florida Ecosystem Restoration Task Force, Texas Automated Buoy System, Southern California Coastal Water Research Project, Partnership for Interdisciplinary Studies of Coastal Oceans, California Cooperative Oceanographic Fisheries Investigation, Georgia Coastal Analysis Partnership, Puget Sound Ambient Monitoring Program, and certain sites within the US Long-Term Ecological Research (LTER) Network either already do, or could enhance marine sanctuary monitoring efforts. In addition, there are several volunteer-based programs supported by sanctuaries (e.g., BeachWatch and SEALS), and independent organizations focused on coral reef assessments (Global Coral Reef Monitoring Network) and fish censuses (Reef Environmental Education Foundation). Such programs may be called on to implement appropriate monitoring within SWiM.

The NMSP recently worked with the National Estuarine Research Reserve Program and the Smithsonian Environmental Research Center to initiate a monitoring program focused on invasive species in the sanctuaries and reserves on the U.S. west coast. NOAA and the National Fish and Wildlife Foundation provided funding and the program is currently underway.

Gray's Reef NMS is working with the National Data Buoy Center to develop buoy systems that will accommodate sensors required to monitoring water conditions at that sanctuary. The new design will allow for meteorological and oceanographic measurements as well as input from external sensors, all of which will be transmitted to shore in near real-time. System engineering is complete for the buoys and installation is planned for 2004. Once tested, it is possible that similar systems will be installed in other sanctuaries, allowing for greater consistency in water quality assessments, yet enabling requisite flexibility for customized measurements.

The NMSP is also working with EPA on two significant activities related to SWiM. In 2003, EPA's Environmental Monitoring and Assessment Program (EMAP) conducted a sampling cruise along the U.S. west coast, collecting benthic and water column samples at 150 locations, a third of which were in marine sanctuaries. The results will provide the first statistically robust comparison of environmental conditions within and outside marine sanctuaries in this region. EPA, in cooperation with NOAA and other Federal agencies, is also updating its National Coastal Condition Report. The NMSP contributed a short description of SWiM and a preliminary report on one sanctuary.

The NMSP continues to coordinate with a number of non-governmental organizations to enhance their efforts in support of SWiM. The Reef Environmental Education Foundation (REEF) currently conducts fish censuses using standardized methods in eight of the 11 sanctuaries that protect natural resources. They are also working with the program to modify the protocols to better address questions about fish community dynamics.

Perhaps one of the most challenging aspects of developing SWiM will be to establish a robust information management system. Virtually all aspects of the program require efficient information management. Planning activities, data acquisition, translation, tracking, analysis, and reporting all must work in an integrated manner that considers all relevant spatial and temporal scales of assessment. For example, sanctuary-specific information will need to be compared among sites and reported collectively to document the status of networks or the status of particular issues or resources. To accomplish this, consistency among data sets and reporting protocols is necessary. In addition, Federal requirements related to database design and accessibility, and metadata must be considered.

Developing the necessary information management capabilities will require a combination of internal capacities and strategic partnerships. The NMSP is working with the National Oceanographic Data Center (NODC) on information management support activities for the Sanctuary Integrated Monitoring Network (SIMoN), an ongoing effort to coordinate regional monitoring in the Monterey Bay NMS and central California region. Coordination activities relate to needs assessment, data mining, policy compliance, and facilitating data ingest, processing, and dissemination. The initial website for SIMoN was posted in October 2003 and contains habitat information, interactive maps, graphs, real-time data, and up-to-date information on current monitoring projects (www.mbnms-simon.org). It is hoped that the capabilities developed in this pilot effort will be transferable to other sanctuaries and support both network and system-wide monitoring.

On a larger scale, the Data Management and Communications Plan to support IOOS is in development. It will be critical to coordinate SWiM and DMAC efforts to enable data quality, access and sharing. Other key NOAA partners on developing information management capacities are likely to include the Coastal Services Center and the National Coastal Data Development Center (part of NODC). Existing initiatives such as the Coral Information System (CORIS) and Coast Watch may also service some of the needs of the program.

Oversight and Review

Credibility of a monitoring program depends on the quality of design and the utility of results. The NMSP will seek periodic review of SWiM with these measures in mind. Review panels will be convened periodically to provide expert evaluation and guidance. Consisting of resource managers and monitoring experts, the groups will have broad geographic representation, a balance of expertise in physical, biological and chemical sciences, and experience with the application of science to resource management. The panels may suggest changes to such program components as the design process or reporting system, or recommend partnerships to enhance SWiM. Their recommendations should be based primarily on the need to ensure that 1) conclusions remain scientifically defensible and 2) information is accessible and useful to resource managers. Separate comment and review may also be solicited from selected members of Sanctuary Advisory Committees, research panels established by individual sites, and monitoring panels working on related programs (e.g., SIMoN).

Conclusion

SWiM is a critical component of the National Marine Sanctuary Program's conservation science efforts. It will work together with other characterization and research activities to provide a greater understanding of what constitutes healthy ecosystems and what it takes to keep them that way. But full realization of SWiM will require a focused effort that builds on existing monitoring within marine sanctuaries, collaborates with complementary marine protected area networks, and taps into the resources and capabilities of other ocean observing initiatives. New field sampling, new technologies and new partnerships must all work in concert to enable the U.S. to remain a leader in the science, protection, and restoration of coastal ecosystems and to ensure the legacy of our treasured marine environment.

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Appendix 1. Definitions of selected terms used in this document.

Issue – topic or area of concern for which effective management of natural resources requires specific information.

Monitoring –The repeated collection and analysis of observations or measurements to evaluate changes in the condition and progress toward meeting a management objective. For marine sanctuaries it is more specifically a process to document the status and trends of resources and activities for which the NMSP has statutory authority.

Network – a combination of marine sanctuaries with functional ecological connections.

Region – a large area of the marine environment encompassing more than one marine sanctuary, regardless of whether discernible functional connections exist among the sites; the next larger scale of observation needed to understand local phenomena of interest.

Research – studies of ecosystem function and the relationships between resources and the factors that control their condition.

Resource – elements of the natural environment or cultural history contained within a marine sanctuary.

Resource Characterization – identifying natural and cultural resources and characterizing relationships among them.

Site or sanctuary – an individual national marine sanctuary.

System – collectively, all marine sanctuaries.

Appendix 2. Organizations, programs, and acronyms mentioned in this document.

Acronym (if relevant)	Organization or Program
CalCOFI	California Cooperative Oceanographic Fisheries Investigation
COML	Census of Marine Life.
CORIS	Coral Information System
DMAC	Data Management and Communications Steering Committee for IOOS
AMAP	EPA's Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
GCAP	Georgia Coastal Analysis Partnership
GCRMN	Global Coral Reef Monitoring Network
IOOS	Integrated Ocean Observing System
LTER	Long-Term Ecological Research Network
MPRSA	Marine Protection, Research, and Sanctuaries Act of 1972
MPA	Marine Protected Area
MMS	Minerals Management Service (U.S. Dept. of Interior)
NCCOS	National Centers for Coastal Ocean Science (NOAA)
NCAP	National Coastal Assessment Program
NCDDC	National Coastal Data Development Center (NOAA)
NDBC	National Data Buoy Center (NOAA)
NESDIS	National Environmental Satellite, Data and Information Service (NOAA)
NERRS	National Estuarine Research Reserve Program (NOAA)
NFWF	National Fish and Wildlife Foundation
NMFS	National Marine Fisheries Service (NOAA)
NMSA	National Marine Sanctuaries Act
NMSP	National Marine Sanctuary Program (NOAA)
NOS	National Ocean Service
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center (NOAA)
NPS	National Park Service (U.S. Dept. of Interior)
PISCO	Partnership for Interdisciplinary Studies of Coastal Oceans
PSAMP	Puget Sound Ambient Monitoring Program
REEF	Reef Environmental Education Foundation
SEALS	Sanctuary Education Awareness and Long Term Stewardship
SIMoN	Sanctuary Integrated Monitoring Network
SERC	Smithsonian Environmental Research Center
SFER	South Florida Ecosystem Restoration Task Force
SCCWRP	Southern California Coastal Water Research Project
SWiM	System-Wide Monitoring
TABS	Texas Automated Buoy System
FWS	U.S. Fish and Wildlife Service (U.S. Dept. of Interior)
USGS	U.S. Geological Survey (U.S. Dept. of Interior)

Appendix 3. Legislative history of science in the National Marine Sanctuary Program.

The enabling legislation for the NMSP was Title III of the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA;16 U.S.C. 1431). The stated purposes for the program included "...preserving and restoring... areas for their conservation, recreational, ecological, or esthetic values." No provisions were made for aspects of conservation science related to research or monitoring within marine sanctuaries in the original Act. Substantial provisions for both research and monitoring were made, however, in Title II of the same Act (related to the effects of ocean dumping), suggesting the authors recognized the differences between the two and did not intend to include them in Title III. Nevertheless, such provisions were added to Title III incrementally over the next three decades.

None of the language in annual authorizations by Congress prior to 1980 changed the original Act substantively. The first mention of research came in amendments made in 1980, which included the following; "The Secretary shall conduct such research as is necessary and reasonable to carry out the purposes of this title." (P.L. 96-332) Still, monitoring was not provided for, at least not without broad interpretation of the word "research," which was probably not the intent of the authors, as mentioned above.

Amendments made in 1984 greatly expanded the scope of the National Marine Sanctuary Program, first by increasing the number of attributes that may be considered in selecting areas for sanctuary designation to include "...conservation, recreational, ecological, historical, research, educational, or esthetic qualities..." (P.L. 98-498). Further, the "Purposes and Policies" section of the amendment directed the Program to "...support, promote, and coordinate scientific research on, and monitoring of, the resources of these marine areas." This was the first mention of monitoring in any legislation related to marine sanctuaries.

Amendments in 1988 authorized the Secretary to "...take such action...to promote and coordinate the use of national marine sanctuaries for research purposes including – (1) requiring that NOAA...give priority to research including national marine sanctuaries; and (2) consulting with other Federal and State agencies to promote use [of sanctuaries]...for marine research." (P.L. 100-627)

In 1990, the Florida Keys National Marine Sanctuary and Protection Act (16 U.S.C. 1433) required the "...establishment of a comprehensive water quality monitoring program..." This was the first such requirement for an individual sanctuary. Significant changes to the Program occurred again in 1992, including a change in the name of Title III, as amended, to the National Marine Sanctuaries Act (NMSA). It was also directed that the Florida Keys NMS "...establish a long-term ecological monitoring program..." and the Hawaiian Islands Humpback Whale NMS "...identify research needs and establish a long-term ecological monitoring program with respect to humpback whales and their habitat." Further, the House report accompanying this Act specifically mentioned the need to "...strengthen the role of research and monitoring as components of sanctuary management." (H.R. 102-565)

The most recent reauthorization of the Act in 2000 affected the manner in which many aspects of sanctuary management are addressed, including monitoring, by directing that the sanctuaries be "...established as the National Marine Sanctuary System." Further direction was provided: "...to support, promote, and coordinate scientific research on, and long-term monitoring of, the resources in these marine areas."

The 2000 reauthorization thus directs the NMSP to place additional emphasis on issues related to the entire system of sanctuaries, and implies the need for greater consistency among conservation programs throughout the system. Attention to ecosystems regardless of sanctuary boundaries, and connectivity among sanctuaries are thus focus areas for sanctuary science. Monitoring programs also need to expand to consider not only individual site priorities, but also regional and national issues and questions. In so doing, the Program will improve its ability to address increasing levels and varieties of use in the Nation's coastal waters, and endeavor to prevent problems before they affect sanctuary resources.


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