# Pacific Island Network – Inventory & Monitoring Program

# Monitoring Plan

Phase 2, Draft last updated: 5 March 2004

**Parks**

Ala Kahakai National Historic Trail (ALKA), Hawaii
American Memorial Park (AMME), Commonwealth of the Northern Mariana Islands
Haleakala National Park (HALE), Hawaii
Hawaii Volcanoes National Park (HAVO), Hawaii
Kalaupapa National Historical Park (KALA), Hawaii
Kaloko-Honokohau National Historical Park (KAHO), Hawaii
National Park of American Samoa (NPSA), Territory of American Samoa
Puuhonua O Honaunau National Historical Park (PUHO), Hawaii
Puukohola Heiau National Historic Site (PUHE), Hawaii
U S S Arizona Memorial (USAR), Hawaii
War in the Pacific National Historical Park (WAPA), Territory of Guam

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## Preface

The network is planning, designing, and implementing its Vital Signs monitoring program. The National Park Service Monitoring Program website, http://science.nature.nps.gov/im/monitor/, provides additional background information on the history, institutional guidance, and current status of the NPS Monitoring Program.

National Park Service monitoring program guidance outlines a Network approach to monitoring (http://science.nature.nps.gov/im/monitor/approach.htm); incorporating a 3-phase planning and design process that will extend over four years. Phase 1 (FY2003), defines goals, and sets preliminary objectives, summarizes existing data and understanding (including evaluating and synthesizing existing data), and develops conceptual ecological models. These first 2 chapters build a foundation for Vital Signs prioritization and selection—fulfilled in the Phase 2 version (FY2004)—and will include an update of material prepared previously. A Phase 3 version (FY2005-FY2006) will encompass a complete monitoring plan.

Currently, this document and other portions of our monitoring plans are in-progress. They should be considered **draft** and not cited.

## Acknowledgements

Contributors include staff from all parks, local US Geological Survey offices, and the Pacific Cooperative Studies Unit. We would especially like to thank our workgroup leads & facilitators: Frank Trusdell (USGS-HVO), Eric Rutherford (PCSU), Grant Kaye (PCSU), Charlotte Forbes Perry (PCSU), Cathleen Bailey (HALE), Tim Tunison (HAVO), Linda Pratt (USGS-PIERC), David Foote (USGS-PIERC), Karl Magnacca (PCSU), Dwayne Minton (WAPA), Sonia Stephens (PCSU), Eva DiDonato (NPSA), Kimber DeVerse (PCSU), Lloyd Loope (USGS-PIERC), Ellen VanGelder (PCSU), Karin Schlappa (PCSU), Jean Licus (PCSU), Sandy Margriter (PISO), Allison Cocke (PCSU), Melia Lane-Kamahele (PISO), and many others who contributed to this report.

## Executive Summary

Will be prepared in 2005

## Chapter 1. Introduction and Background

Knowing the condition of natural resources in national parks is fundamental to the Service's ability to manage park resources "*unimpaired for the enjoyment of future generations.*" National Park managers across the country are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a basis for making decisions and working with other agencies and the public to preserve and protect these resources. For years, managers and scientists have sought a way to characterize and determine trends in the condition of parks and other protected areas to assess the efficacy of management practices and restoration efforts and to provide early warning of impending threats.

The challenge of protecting and managing a park's natural resources requires a multi-agency, ecosystem approach because parks are open systems, with threats such as water pollution and invasive species originating from outside of the park's boundaries. An ecosystem approach is further needed because no single spatial or temporal scale is appropriate for all components and processes; the appropriate scale for understanding and effectively managing a resource might be at the population, species, community, or landscape level, and in some cases may require a regional, national or international effort to understand and manage the resource. National Parks are part of larger ecosystems and natural resources must be managed in that context.

### A. Long-Term Resource Monitoring

Natural resource monitoring provides site-specific information needed to understand and identify change in complex, variable, and imperfectly understood natural systems and to determine whether observed changes are within natural levels of variability or may be indicators of unwanted human influences. Thus, monitoring provides a basis for understanding and identifying meaningful change in natural systems. Monitoring data help to define the normal limits of natural variation in park resources and provide a basis for understanding observed changes; monitoring results may also be used to determine what constitutes impairment and to identify the need for change in management practices. Understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate threats to these systems (Roman & Barrett 1999).

### B. NPS Policy and Mandates for Monitoring

The enabling legislation establishing the National Park Service (National Park Service Organic Act of 1916) and its individual park units clearly mandates, as the primary objective, the protection, preservation and conservation of park resources, in perpetuity for the use and enjoyment of future generations (NPS 1980). National Park Service (NPS) policy and recent legislation (National Parks Omnibus Management Act of 1998) require that park managers know the condition of natural resources under their stewardship and monitor long-term trends in those resources in order to fulfill the NPS mission of conserving parks unimpaired. This act initiated the NPS Natural Resource Challenge which established the framework for fully integrating natural resource monitoring and other science activities in the management processes of the National Park system. In the FY 2000 Appropriations Bill, the Act of 1998 was further strengthened by acknowledging "*the serious commitment of the leadership of the NPS to insist that superintendents carry out systematic, consistent and professional inventory and monitoring programs to ensure that the NPS makes sound resource decisions based on sound scientific* *data*." The 2001 NPS Management Policies updated previous policy and specifically directed the service to inventory and monitor natural systems. Additional details on the Monitoring program established to meet these requirements are available at http://science.nature.nps.gov/im/monitor/ and in 'NPS-75, Inventory & Monitoring (I&M) Guidelines' (http://science.nature.nps.gov/im/monitor/docs/nps75.pdf).

There are numerous legal and policy mandates which support the monitoring program. Some of the most relevant mandates are listed below, with a thorough review and description of relevant laws, policies, and guidance available at http://science.nature.nps.gov/im/monitor/LawsPolicy.htm.

- **National Park Service Organic Act (1916):** establishes the purpose of national parks
- **General Authorities Act of 1970:** unites individual parks into the 'National Park System'
- **Redwood National Park Act (1988):** reasserts system-wide protection standards
- **National Environmental Policy Act of 1969:** requires a systematic analysis of major federal actions
- **Clean Water Act (1972):** designed to restore and maintain the integrity of the nation's water
- **Clean Air Act (1990):** establishes a nationwide program for the prevention and control of air pollution and establishes National Ambient Air Quality Standards
- **Endangered Species Act of 1973:** requires federal departments and agencies shall seek to conserve endangered species and threatened species
- **Coastal Zone Management Act of 1972:** establishes policy to preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone
- **Marine Protection, Research, and Sanctuaries Act of 1972:** intended to improve the conservation, understanding, management, and wise and sustainable use of marine resources; (to) enhance public awareness, understanding, and appreciation of the marine environment; and (to) maintain for future generations the habitat, and ecological services, of the natural assemblage of living resources that inhabit these areas.
- **National Historic Preservation Act of 1966:** includes preserving 'the historical and cultural foundations of the Nation' and preserving irreplaceable examples important to our national heritage
- **Wilderness Act of 1964:** establishes the National Wilderness Preservation System (Wilderness Areas)
- **Geothermal Steam Act 1988:** specifically calls for a monitoring program for certain parks with thermal resources
- **National Parks Omnibus Management Act, 1998:** requires: increased efficiency, provides clear authority for the conduct of scientific study and use of information, appropriate documentation of resource conditions. Encourages: others to use parks for study, publication and dissemination of information derived from studies
- **Executive Order 13112 on Invasive Species (1999):** intended to prevent the introduction of invasive species and provide for their control and to minimize impacts

1. Who is Interested in Monitoring and Why

The program the NPS has implemented has been termed 'Vital Signs' monitoring (see Glossary for definition of Vital Signs and other terms used in this document). This monitoring program simply cannot address all resource management interests, because of limitations of funding, staffing, and logistical constraints. Rather, the intent of Vital Signs monitoring is to monitor a select subset of ecosystem components and processes that reflect the condition of the park ecosystems and are relevant to management issues. Natural systems as well as human activities change over time, and it is extremely challenging to distinguish natural variability and desirable changes in systems from undesirable anthropogenic sources of change to park resources. Cause and effect relationships usually cannot be demonstrated with monitoring data, but monitoring data might suggest a cause and effect relationship that can then be investigated with a research study. As monitoring proceeds, data sets are interpreted, our understanding of ecological processes is enhanced, trends are detected, and future issues will emerge (Roman & Barrett 1999). The monitoring plan, therefore, should be viewed as a working document, subject to periodic review and adjustments over time as our understanding improves and new issues and technological advances arise.

The most widely identified application of monitoring information is that of enabling managers to make better informed management decisions (White & Bratton 1980, Croze 1982, Jones 1986, Davis 1989, Quinn & van Riper 1990). Monitoring provides a tool to address issues that occur at multiple sites in a park or multiple parks within a network, rather than addressing site specific problems individually. Using sound data with careful analysis and interpretation, managers can develop general principles and guidelines that can be applied broadly to a particular type of issue or problem. By gathering data over long periods, correlations between different attributes become apparent, and resource managers gain a better general understanding of the ecosystem.

Another use of monitoring information is to document changes primarily for the sake of familiarity with resources (Halvorson 1984, Croze 1982). Managers must be aware of changes in resources under their stewardship even if no specific management decisions or actions are involved. Such information can also provide good baseline knowledge about system function in the case that future management actions become necessary.

A third use of monitoring information involves convincing others to make decisions benefiting national parks (Johnson and Bratton 1978, Croze 1982). Some aspects of monitoring may focus on documenting specific internal or external threats. Monitoring sensitive species, invasive species, culturally significant species, or entire communities can provide park managers, stakeholders, and the public with an early warning of the effects of human activities before they are noticed elsewhere (Davis 1989, Wiersma 1984). Finally, a monitoring program can provide basic background information that is needed by park researchers, public information offices, interpreters, and those wanting to know more about the area around them (Johnson & Bratton 1978).

Partnerships will be necessary to conduct monitoring and management, and data and information must be made available, at a minimum, to help partners address human health and safety concerns for park neighbors, visitors, staff, and residents. Ideally, exchange of monitoring information with other land managers will facilitate better management of park resources. Given the ecological stressors and future of the Pacific Islands, monitoring will likely include documenting the demise of systems, as well as restoration or maintenance of ecosystems, in order to demonstrate the costs and benefits of management actions. While monitoring of such sensitive resources may demonstrate that they are not easily protected, it may provide important information that can be used to protect more resilient resources, allowing managers from any interested organization to focus protection on preservable resources.

## C. Overview of the Pacific Island Network (PACN)

The Pacific Island Network (PACN) is one of 32 National Park Service I&M networks: groups of parks linked by geography and shared natural resource characteristics. These networks were established to provide baseline resource information and long-term trends in the condition of National Park System resources, to facilitate collaboration and information sharing among parks in ecologically similar regions, and maximize economies of scale in natural resource monitoring and management.

### 1. Geographic, Political, and Biogeographical Setting

The PACN covers an enormous sweep of the Earth (across four time zones, spanning the northern and southern hemispheres, and on either side of the International Date Line) (Figure 1.1). With parks located throughout the tropical Pacific, the PACN is the largest network in the NPS I&M Program in terms of distances between network sites. The tropical Pacific Ocean is commonly divided into the three geographic areas of Polynesia (including Hawaii and American Samoa), Micronesia (including Guam and the Commonwealth of Northern Mariana Islands (CNMI)), and Melanesia (see Loope 1998, Fig. 1). The PACN essentially has 3 overarching geographic regions: the Mariana Islands (Guam and the CNMI), American Samoa, and Hawaii. Resource management policies and practices throughout the network reflect local similarities and differences in island ecosystems and provide a link between the park units and the range of issues both internal and external to the parks. Shared characteristics within the PACN include:

- Relatively small size compared to many continental systems and national parks.
- Island ecosystems, prehistorically isolated from many outside influences, where the presence or absence of certain key taxa can result in important differences in ecosystem ecology from similar continental systems.
- A significant portion of the charismatic fauna, as well as biodiversity, is found in invertebrate taxa.
- Globally recognized endemic ecosystems and biodiversity hotspots (see for example, Mittermeier et al. 1999).
- Five of the 6 unique (of 867 worldwide) ecoregions are classified as 'critical or endangered' for global conservation status, with the remaining one as 'vulnerable' status (Olson et al. 2001).
- Native ecosystems that are all dangerously vulnerable to invasive species.
- Native ecosystems that require active, hands-on management if their unique native biodiversity is to survive.
- Inadequately staffed to address demands of rapidly changing island ecosystems.
- Pacific Islands are recognized as discrete units with great potential for use as models in understanding environmental change, already rapidly occurring in these islands.
- Local community social structures that have retained a significant portion of traditional Polynesian and Micronesian heritage.

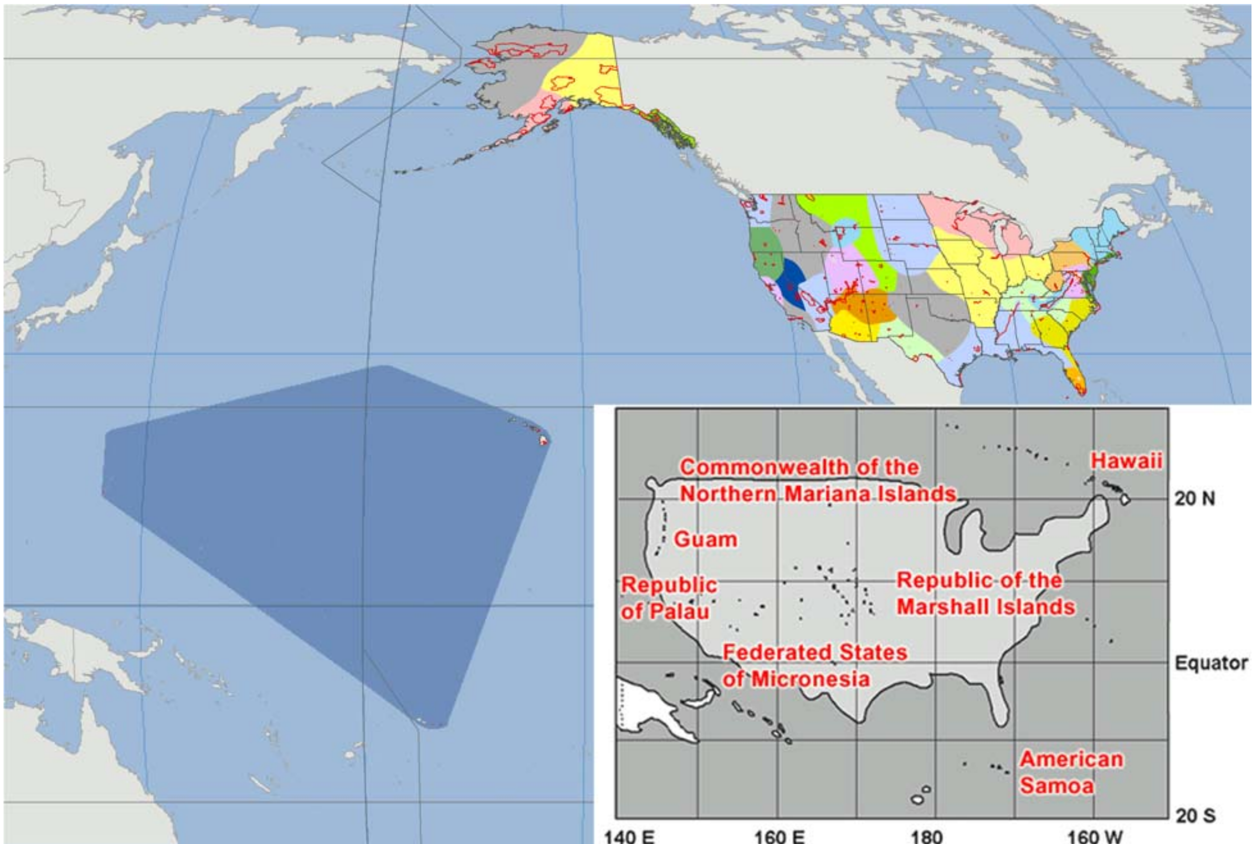



*Figure 1.1. Pacific Island Network (inset perspective to continental US courtesy USGS Water Resources of Hawaii & the Pacific District Office, http://hi.water.usgs.gov/office/pacmap.html).*

With the immense distances within the network also come fundamental geographical differences. The network encompasses a wide range of ecosystems, from submarine to high altitude, and embraces several indigenous systems of resource management as well as Western land management practices. Within Hawaii Volcanoes National Park alone, 4 of the 5 the major Koeppen climate zones are encountered along the slopes of Mauna Loa (Giambelluca & Sanderson 1993). Additionally, disturbance events in the PACN create a unique suite of impacts that varies across the network, including volcanic activity (lava and earthquakes), rising sea levels, floods, hurricanes or typhoons, and tsunami. Examples of additional geographic differences across the Pacific Islands include:

- Alien species issues: invasive alien species in one portion of the network may be native in other portions of the network.
- Biodiversity varies significantly across the PACN network, which encompasses 3 of 14 different global biomes classified by WWF (Olson et al. 2001).
- The distances from external influence (continental or neighboring island groups) vary significantly within the network.
- The influence of external and regional affiliations varies significantly both among and within the Mariana Islands, American Samoa, & Hawaii.
- Indigenous cultures and languages, while related, are significantly different and distinct both between and within the Mariana Islands, American Samoa, & Hawaii.

- Indigenous systems of resource management are still partially or fully practiced in different island groups. In American Samoa, villages or extended families hold land communally and chiefs make decisions about its use in the matai system (O`Meara 1987). In Hawaii, the traditional watershed-based ahupua`a system of land management has been cited in recent years as a tool for improving upon current prevailing Western land management practices. In Guam and Saipan, the traditional system of land tenure was similar to that in Samoa, but has been lost through successive periods of Western colonization (Johnson 1969, McGrath & Wilson 1987).

This diversity provides unique opportunities for long-term monitoring because of the parks' spatial distribution, scale, and range of issues. The network is in the position to provide a national and international leadership role with issues such as tropical island resource management, climate change, and impacts of invasive species on ecosystems.

## 2. Parks of the PACN

The PACN includes 11 parks: War in the Pacific National Historical Park (WAPA) in the Territory of Guam, American Memorial Park (AMME) in the CNMI, National Park of American Samoa (NPSA) in the Territory of American Samoa, and in the State of Hawaii the USS Arizona Memorial (USAR) on the island of Oahu, Kalaupapa National Historical Park (KALA) on the island of Molokai, Haleakala National Park (HALE) on the island of Maui, and on the island of Hawaii Ala Kahakai National Historic Trail (ALKA), Puukohola Heiau National Historic Site (PUHE), Kaloko-Honokohau National Historical Park (KAHO), Puuhonua O Honaunau National Historical Park (PUHO), and Hawaii Volcanoes National Park (HAVO). The geographic relationship of these parks is shown in Figure 1.2.

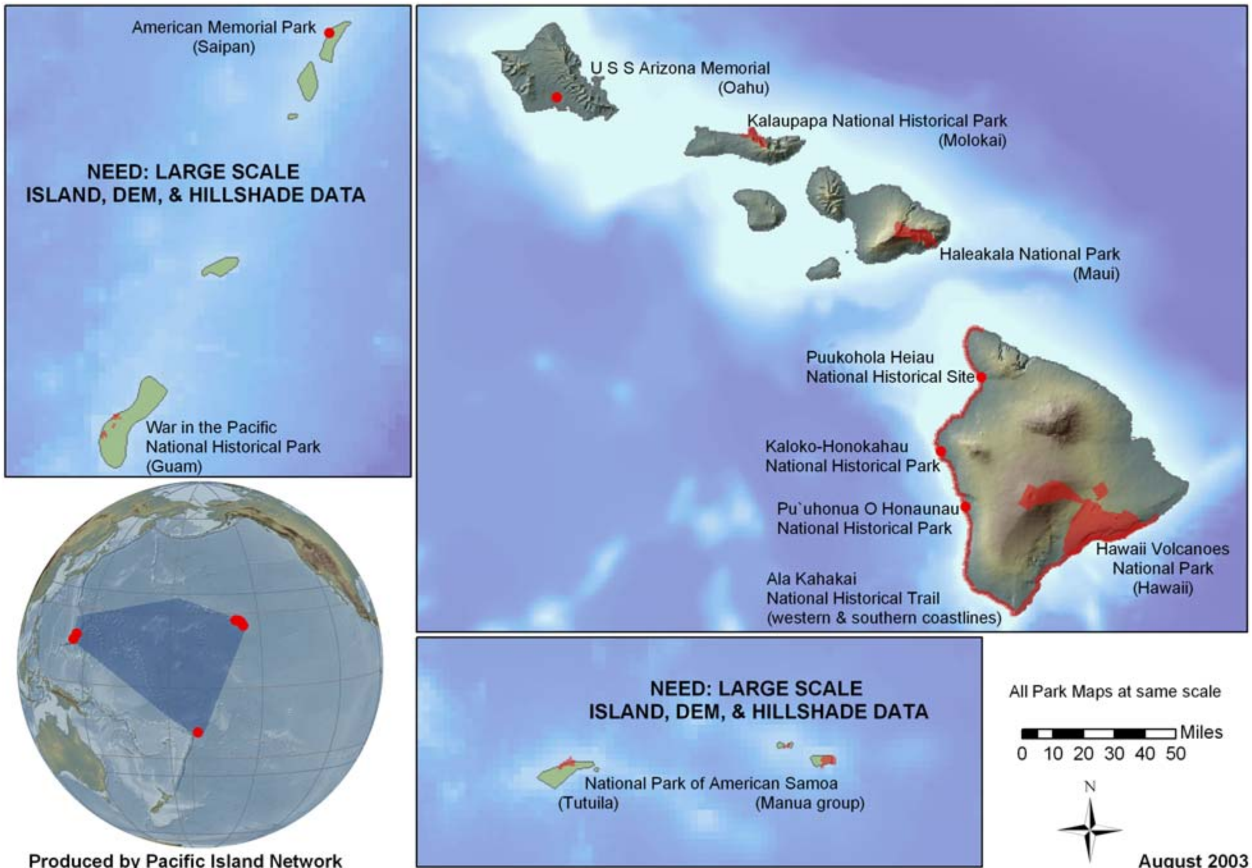



*Figure 1.2. Map of all 11 PACN Parks.*

The differences in designation (National Park, National Historic Site, National Historical Park, Memorial, Memorial Park, National Historic Trail) reflect the variety of purposes for which these different areas were recognized by the United States for inclusion in the National Park system. All parks possess significant natural resources for monitoring. A summary of basic characteristics for each park is shown in Table 1.1 (note that the large number of footnotes suggests that official NPS statistics from NRMap or Lands Division often significantly differ from the local reality faced by park managers). An overview of each park's natural resources is available at http://www.nature.nps.gov/im/units/pacn/resources/. Relevant park natural resource management priorities are identified in the following sections.

*Table 1.1. Summary of Land and Water Characteristics for each park in the PACN.*

| Park | Authorized (year) | Coastline length (mi)[a] | Authorized Marine size (ac)[b] | Authorized Terrestrial size (ac)[c] | Authorized Total Size (ac)[d] | Elevation Range (ft)[e] |
|---|---|---|---|---|---|---|
| **WAPA** | 1978 | 5.8 | 1,006 | 1,031[h] | 2,037[f] | -164–1,042 |
| **AMME** | 1976 | 3.2 | 0[h] | 133[h] | 133[f] | 0–10 |
| **NPSA** | 1988 | 17[h] | 5,260 | 5,260[h] | 10,520 | -164–3,123 |
| **USAR**[i] | 1978 | ?? | 5.5 | 11 | 16.5[f] | -38–75 |
| **KALA** | 1980 | 16[h] | 2,060 | 8,719 | 10,779[f] | -200–4,222 |
| **HALE** | 1916 | 1[h] | 0[h] | 28,969 | 28,969 | 0–10,023 |
| **ALKA** | 2000 | To be determined | To be determined | To be determined | To be determined | To be determined |
| **PUHE** | 1972 | 1[h] | 7 | 79 | 86[f] | -49–0 |
| **KAHO** | 1978 | 2.76 | 536 | 625 | 1,161 | -151–80 |
| **PUHO** | 1961 | 2[h] | 0 | 181[g, h] | 181 | 0–900 |
| **HAVO** | 1916 | 32.7 | 0 | 207,643[g] | 207,643[g] | 0–13,679 |

a Authorized coastline length figures are drawn from NRMap unless otherwise noted.
b Calculated using park boundary GIS data. Identified as 0 where authorized park boundary ends at high tide line. In marine areas within the State of Hawaii neither management nor ownership has been transferred to the NPS (as is also the case in several terrestrial areas throughout the network).
c Determined by subtracting authorized marine size from authorized total size.
d Authorized total size figures are drawn from NRMap unless otherwise noted, includes in-holdings and other areas authorized but where management has not been transferred.
e Determined using figures provided by the NPS Lands division (otherwise using USGS digital elevation models for land surfaces and bathymetry data (when available) for marine areas.
f From park web page.
g For HAVO: does not include 116,000 acre Kahuku addition, for PUHO: does not include Kiilae addition.
h Differs significantly from GIS calculations.
i USAR does not have formal congressional authorization, but operates under an interagency agreement with the US Navy.

*a. Park Natural Resource Management Priorities*

**War in the Pacific National Historical Park (WAPA):** As a historical park, conservation of resources in accord with the World War II setting is a top priority. Natural resource management objectives include managing "...native terrestrial ecosystems in accord with those conditions just prior to the American re-invasion of Guam ...." and to "…preserve and interpret important natural features such as native plant communities and stream and marine bed environments...." (WAPA Resource Management Plan 1997). WAPA is currently in the process of creating a Cultural Landscape Inventory and Management Plan that will provide guidance for terrestrial units. Management of marine areas is intended to conserve the resources in a natural state while allowing for traditional and cultural uses.

**American Memorial Park (AMME):** Due to the park's primary designation as a historic monument, natural resources management priorities center on recreational, environmental, and cultural resources. Nearby to the park, the Puerto Rico dump has been recently closed, although the impact of the dump on the surrounding ecosystems is currently being evaluated (see monitoring projects, below), and this ongoing monitoring is a priority.

**National Park of American Samoa (NPSA)**: A major terrestrial priority is the control and eradication of invasive species, particularly alien plants (over 200 species), as well as feral pigs, marine toads, African snails, rats and others. Other management concerns are the expansion of agricultural plantations within the park and the status of rare species (e.g., sheath-tailed bat, Pacific boa, spotless crake). In the marine environment, the major issue is decreasing the impacts of climate change on coral reefs; increased incidents of coral bleaching and disease are associated with increasing water temperatures. Identification of and research about temperature-tolerant corals (such as those in Ofu lagoon) are needed. Other marine issues include overfishing, crown-of-thorns starfish damage to corals, and the demise of sea turtles.

**USS Arizona Memorial (USAR):** The park has come to commemorate all civilian and military personnel killed in the Pearl Harbor attack, and management efforts focus on the respectful maintenance of the memorial function. There is an undetermined quantity of fuel oil entombed in the hull, which may potentially be catastrophically released. Environmental management for such an event is addressed by the US Navy as part of their regular port operations. The hull is probably the best studied example of metallurgical decay in a marine environment. Park staff monitor basic environmental (marine) parameters as part of their ongoing hull curatory efforts.

**Kalaupapa National Historical Park (KALA):** Top management priorities are preservation and interpretation for present and future generations. Of particular importance is maintaining the lifestyle of Hansen's disease patients as well as to maintain historic structures and traditional sites, values, and natural features. Natural resource management priorities include preservation of native species and control of non-native species. Cooperative management with adjacent land owners and community groups is a major strategy for resource protection.

**Haleakala National Park (HALE)**: The top five management priorities in the park's General Management Plan are: 1) re-establish and perpetuate as nearly as possible the mosaic of ecosystems which would have evolved without the interference of human technology, 2) protect and restore native biota by controlling non-native plants and animals, 3) maintain the human - altered Kipahulu coastal area in its present state with latitude for restoration, 4) isolate and carefully restrict use of upper Kipahulu Valley to ensure perpetuation of the nearly pristine native flora and fauna, and 5) identify and protect cultural sites and remains, and stabilize significant archeological structures.

**Ala Kahakai National Historic Trail (ALKA):** A combined Comprehensive Management Plan and EIS (CMP/EIS) is currently (2003) being developed for the trail. Given the potential impact of trail use on natural and cultural resources located within and adjacent to the trail's coastal corridor, current public scoping data results indicate a need to incorporate culturally appropriate shoreline management prescriptions for public use and resource protection. As such, I&M protocols, appropriately adapted to non-NPS owned trail segments, will be an important resource management tool for ALKA and its non-NPS partners.

**Puukohola Heiau National Historic Site (PUHE):** PUHE has many management issues for both cultural and natural resources. The temple walls and surrounding grounds are becoming overgrown with alien plant species . Erosion is a primary concern to the parks wetland and marine areas. Removal of invasive species, such as Tilapia, and maintenance of the stream and wetlands connection to the ocean is of special importance to native plants and animals in that habitat. Additional management concerns for the marine area include establishment of monitoring programs for turtles, fish, and sharks, and protocols for managing the deposition of sediment on the adjacent reef. Opportunities for management partnerships are being sought through the Hawaiian Charter School , Mauna Kea Soils and Conservation District, and the Royal Court Assembly, an important source of caretaking volunteers.

**Kaloko-Honokohau National Historical Park (KAHO)**: The park's management priorities are water quality (groundwater, marine, and surface waters), threatened, endangered, and rare species, and invasive alien species.

**Puuhonua o Honaunau National Historical Park (PUHO):** The 1991 Statement for Management says that the NPS objective is "to restore and maintain the historic scene of the Pu'uhonua, Palace Grounds, and house complexes in the park to the year 1819." This includes removing alien vegetation and restoring native plants present at the time. A revised vegetation management plan will designate wetland and strand communities as special ecological areas. Several endangered plants are maintained in cultivation. Management concerns include non-native invasive plants, feral predatory mammals, introduced predatory fish in ponds, and upland development and associated impacts on water quality.

**Hawaii Volcanoes National Park (HAVO):** The following goals from the Resource Management Plan express park management priorities for natural resource management: Restore Park ecosystems recently invaded by alien species through removal of key alien species followed by natural recovery; restore highly altered Park ecosystems through a program of active rehabilitation to conditions as natural as practicable; restore lost biodiversity in Park ecosystems by recovering endangered, threatened and rare plant and animal species, and by reintroducing locally extirpated species; develop and maintain an understanding of populations, communities, ecosystems, threats, stressors, and ecosystem health through a systematic, science-based program of inventory and monitoring; maintain, expand Park partnerships for natural resource management, particularly those involving neighboring lands and control of invasive species threatening parklands; reduce the negative impacts of wildfire but use fire as restoration tool when possible; and monitor air quality and composition to protect employee health and understand ecosystem change.

*b. Legal and Management Issues Affecting Parks*

Park enabling legislation, laws, policy, and resource management guidance that provide legal direction for determining the condition of natural resources in parks and specifically guide natural resource management in network parks can be found online at: http://www1.nature.nps.gov/im/units/pacn/pacn_policy.htm. Four significant concerns relevant to monitoring in the PACN are highlighted below.

**Park Enabling Legislation Mandate for Monitoring**: Enabling legislation, where it exists, of an individual park provides insight into the natural and cultural resources and resource values for which it was created to preserve. These values may evolve with time, through evolution of park management and legal interpretations to explicit additions to park enabling legislation. Hawaii National Park (now Hawaii Volcanoes and Haleakala National Parks) enabling legislation provides for “preservation from injury of all timber, birds, mineral deposits, and natural curiosities or wonders within said park, and their retention in their natural conditions as nearly as possible”. The mission of the US Geological Survey’s Hawaii Volcano Observatory (HVO) includes monitoring volcanic and related hazards while increasing general understanding of these systems, and HVO is identified in HAVOs enabling legislation documentation. Also in Hawaii, Kaloko-Honokohau NHP and its advisory committee directed the park to enter into air and water quality agreements with surrounding landowners utilizing the traditional ahupua`a (watershed) concept of land management. In the legislation for the National Park of American Samoa, Congress found: "*Tropical forests contain 50 percent of the world's plant and animal species, contribute significantly to the advancement of science, medicine, and agriculture and produce much of the earth's oxygen. The loss of these forests leads to the extinction of species, lessening the world's biological diversity, reduces the potential for new medicines and crops and increases carbon dioxide levels in the atmosphere contributing to the greenhouse effect that is altering the global climate*". Many PACN parks commemorate conditions from World War II or local Polynesian culture in the late 1700s. Such a mandate in effect freezes ecological conditions, to include culturally introduced species, communities, and landscape characteristics. The cultural components of many PACN parks include mandates to provide park materials in multiple languages, for example, English, Samoan, Chamorro, Hawaiian, or Japanese; in some cases many local residents speak little or no English, but rather one of the many indigenous Pacific rim languages. Several parks are also mandated to employ local residents to develop maintain and administer the park.

**State, Territorial, and Commonwealth Jurisdictions**: Currently, several parks contain leased lands and provide for differing management (and thus monitoring) considerations based on local arrangements. NPSA leases all parks land at 5-year intervals from various local villages (with villages able to opt out at any time). KALA leases lands from the Department of Hawaiian Homelands, and works closely with the Hawaii Department of Health in managing park resources. AMME on Saipan is an affiliated area that is controlled by CNMI (NPS presence is through lease agreements with CNMI via the US Navy). Several other areas have lease or other arrangements for use of or access to lands within authorized park boundaries. Such agreements also provide a foundation for partnerships and leveraging of resources for the joint administration, management and long-term stewardship, inventory and monitoring of resources.

**Submerged Resources**: Unlike emergent, dry, or fast lands, submerged lands and their resources are often not owned, leased, or administered by the NPS. This inconsistency creates unique problems when implementing or enforcing management decisions (or conducting monitoring). Approximately one third of the submerged lands within WAPA are owned by the NPS; the remaining lands are owned by the Territory of Guam, which has ceded administrative control of these lands to WAPA through an MOU (Memorandum of Understanding) with NPS. Submerged lands within the NPSA are owned by the Territory of American Samoa but are administered by the local villages. The State of Hawaii owns and administers the submerged lands below the high tide line within three miles of all fast land within the state. In nearly every park, the NPS does not own or have administrative control over the submerged lands within its boundaries, and in most cases it is currently unclear what agreements, MOUs, or protocols are needed for the NPS to accomplish marine monitoring and conservation management goals.

**Cultural Resource Concerns**: Natural resource monitoring, like numerous other resource management programs, will include work that may directly or indirectly affect protected cultural resources, or involve the collection of natural resource specimens. Cultural resources can be found on land and underwater throughout the network. In most PACN parks, there continues through to the present a connection with local, identifiable individuals and families tied to these resources. Monitoring needs to respect the fact that specific geographic or physical entities are not only held in trust for the people of the U.S., but also represent monitoring of familial artifacts, history, or components of a communities' culture. A cultural sensitivity appropriate to these stewardship concerns must also be reflected in collections, samples, or other activities required for monitoring. What is paramount in working with these collections is the thorough documentation of collection, identification and taxonomy, condition, and storage facility information; along with storage conditions conducive to long-term preservation that are both legally and culturally appropriate.

### 3. Ecological Basis for Monitoring

Ecosystems are loosely-defined assemblages that exhibit characteristic patterns across a range of scales over time, space, and organizational complexity (De Leo & Levin 1997). One of the most difficult aspects of designing a comprehensive monitoring program is integration of monitoring projects so that the interpretation of the whole monitoring program yields information more useful than that of individual parts. Integration involves ecological, spatial, temporal and programmatic aspects, which address many of the facets inherent in the concept of scale.

In order to establish a diverse monitoring program that addresses multiple scales of issues, we strive to identified Vital Signs (and monitoring objectives) in each of the following broad categories:

- Ecosystem drivers that fundamentally affect park ecosystems.
- Stressors or threats and their ecological effects.
- Focal resources of parks.
- Key properties and processes of ecosystem integrity.

Two overarching concepts relevant to the ecological basis for monitoring and monitoring integration are drivers and stressors. Drivers are major external forces of change to ecosystems, both natural and anthropogenic. Stressors are physical, chemical, or biological perturbations to a system that may be either foreign or natural to the system, but applied at an excessive or deficient level (Barrett et al. 1976:192). Together, drivers and stressors influence ecosystem attributes.

- **Ecological Integration** involves considering the ecological linkages among system drivers and the components, structures, and functions of ecosystems when selecting monitoring indicators—marine, freshwater, terrestrial, or atmospheric. An effective ecosystem monitoring strategy will employ a suite of individual measurements that collectively monitor the integrity of the entire ecosystem. One approach for effective ecological integration is to select indicators at various hierarchical levels of ecological organization (e.g., landscape, community, population, genetic; see Noss 1990).
- **Spatial Integration** involves establishing linkages of measurements made at different spatial scales within a park in the network, between individual parks within the network, or over a broader regional context. While in many regards the Pacific Islands present a coherent geographic unit, as often as not the sheer distances, differing continental proximity, and even northern and southern hemisphere parks provide challenges. Nevertheless, spatial integration requires understanding of scalar ecological processes, the co-location of measurements of comparably scaled monitoring indicators, and the design of statistical sampling frameworks that permit the extrapolation and interpolation of scalar data.
- **Temporal Integration** involves establishing linkages between measurements made at various temporal scales. It will be necessary to determine a meaningful timeline for

sampling different indicators while considering characteristics of temporal variation in these indicators. For example, sampling changes in the structure of a tropical forest canopy (e.g., size class distribution) may require much less frequent sampling than that required for detection of changes in the composition or density of herbaceous groundcover. Temporal integration requires nesting the more frequent and, often, more intensive sampling within the context of less frequent sampling.

- **Programmatic Integration** involves the coordination and communication of monitoring activities within and among parks, among divisions of the NPS, other agencies and land management organizations, and the government authorities within the PACN region. At the park or network level, for example, the involvement of a park's law enforcement, maintenance, and interpretative staff in routine monitoring activities and reporting, results in a well-informed park staff, wider support for monitoring, improved potential for involving and informing the public, and greater acceptance of monitoring results in the decision-making process. PACN and park staff also need to coordinate monitoring planning, design and implementation with other agencies to promote sharing of data among neighboring land managers, while also providing context for interpreting the data. The NPS is seen as a model for resource conservation and sustainable development throughout the Pacific.

Regional or global ecosystem analyses, such as the World Wildlife Fund (WWF) terrestrial ecoregions (Olson et al., 2001), provide only generalized overviews that lump the islands into one of several simplified categories (without considering marine or freshwater ecosystems). The tremendous vertical relief, complex and diverse physical and biological systems, combined with comparatively small island areas across the largest ocean on the planet, make scale-related issues difficult to convey. Mauna Loa on the island of Hawaii, for example, hosts lush, moist tropical rain and cloud forest, subalpine shrublands, alpine desert, coastal strand, lowland dry forests, and numerous other habitats, all within a single 300,000+ acre park on one island. Thus, while individual islands or groups may have generic biogeographic or ecoregion descriptions, a *consistent and comparable* large-scale ecoregion product spanning the entire network is lacking.

Temporal and programmatic integration face analogous challenges. The active volcanic nature of several islands continuously provides new geologic substrates, thus continually adjusting the temporal framework parks must manage within. The combination of State, Territorial, and Commonwealth authorities has long necessitated a cooperative management philosophy within the PACN.



### a. Ecological Organization

As with all protected natural areas, there are multiple ecological issues that managers must confront. The Heinz Center's 'State of the Nation's Ecosystems' describes major characteristics of ecosystem condition (The H. John Heinz III Center for Science, Economics & the Environment 2002), these ecological characteristics have been adapted here to include 1) human activities and cultural practices, 2) physical and chemical conditions, and 3) biotic integrity. Within each of these broad characterizations, further refinement helps ensure that the breadth, scope, and scale of monitoring address park management concerns in a scientifically sound manner. These categories are shown in table 1.2 below.

Within an ecosystem it is also imperative to have an understanding of the processes occurring and to know which key species play a role in these processes, while promoting awareness and understanding of overlapping and shared processes among ecological systems. *Appendix A: Topical Workgroup Reports* provides detailed discussions of the factors of geology, air quality and climate, marine systems, water quality, freshwater biology, fauna (both vertebrate and invertebrate), vegetation, and invasive species as they relate to ecological issues in the PACN monitoring program.

*Table 1.2. Organization of ecological characteristics*

| Ecological Characteristic | Vital Sign Category | | |
|---|---|---|---|
| Human activities & cultural practices | Soundscapes | | |
| | Viewscapes / Lightscapes | | |
| | Land Use | | |
| | Use & Activities | | |
| | Management Zones | | |
| Physical and Chemical Conditions | Climate & Air Quality | | |
| | Soil, Water, & Nutrient Dynamics | | |
| | Water Quality | | |
| | Geology | Hazards | |
| | | Landforms | |
| Biotic Integrity | Freshwater Ecosystems | Producers | |
| | | Consumers | Community |
| | | | Population |
| | Terrestrial Ecosystems | Vegetation | Landscape |
| | | | Community |
| | | | Population |
| | | Consumers | Community |
| | | | Population |
| | | Cave Systems | Community |
| | Marine Ecosystems | Benthic | Landscape |
| | | | Community |
| | | | Population |
| | | Intertidal | Community |
| | | | Population |
| | | Water Column (motile) | Community |
| | | | Population |



**Human Activities and Cultural Practices**: Human activity and land use are probably the most significant drivers of change in the Pacific Islands. Yet people and cultural practices are also at the core of why there are national parks in the Pacific Islands. For example, the parks along the Kona coast (PUHO, KAHO, PUHE, and ALKA, island of Hawaii) are all historical, representing specific geographic locations and historical periods. This includes protecting and monitoring biota introduced by early Polynesian peoples, ensuring that continued (yet evolving) traditional as well as contemporary uses and practices (ranging from gift-giving to fishpond restoration to cave use) are monitored such that managers have the information they need to preserve and protect park resources. Similarly, subsistence agriculture in NPSA is an authorized use of park lands. Human activity, namely removal of resources, can put stress on an ecosystem. For example, harvesting of marine resources is a significant environmental stressor, and few parks in the Pacific have not been subject to intense fishing pressure that has already altered, and in several cases already impaired, marine resources. The introduction of new and potentially invasive species has already been demonstrated to have permanently altered many Pacific Island ecosystems. Likewise, NPS management and visitor use activities are yet another significant environmental stressor. Specific details of issues, mandates, and classifications are available in the appropriate workgroup report in Appendix A.

**Physical and Chemical Environment**: Geologic processes, climate, air quality, nutrient cycling, and water dynamics can act as important influences on biological communities. Both typical processes and natural hazards occur within all these categories. Geologic processes include volcanic activity, shoreline dynamics, seismicity, soil formation, and cave dynamics. Climatic conditions, climate change, and extreme events are of grave concern, as sea level rise, coastal erosion, and the shift of climate zones are demonstrated to have immediate and significant local and regional effects on human health, safety, and native biodiversity. Global, regional, and local processes, such as nitrogen enrichment from local volcanic sources versus dust transported from central Asia, represent significant sources of input affecting the ecology of the islands. Air quality considerations in the PACN region reflect the isolated geography of the islands, in that locally generated pollutants are typically left to blow out to sea. Volcanic emissions (especially on the island of Hawaii) are probably the single largest air quality concern. Specific details of issues, mandates, and classifications, such as air quality Class 1 designations, are available in the appropriate workgroup report in Appendix A.

Water-related issues in the PACN are complex, and include both freshwater and marine dynamics, such as location and extent of wetlands, estuarine discharge, nutrient cycling, and water quality. Water quality was singled out for park management relevance, funding, and special congressional reporting as part of the Natural Resource Challenge. Parks in the PACN manage multiple types of water resources, including freshwater, marine, and brackish waters. Several parks have unique and/or pristine water resources which could be considered as Outstanding National Water Resources (ONWR) but are not listed as such due to the deficiency of water quality data and because this standard has not traditionally been applied in the network region. The identification of impaired waters is also limited by the narrow scopes of existing monitoring programs, which are often located outside of park boundaries and limited in scope to a single issue. Details of PACN water quality issues, mandates, and classifications are available in the Water Quality workgroup report in Appendix A.

**Biotic Integrity—Freshwater Ecosystems**: Despite small land areas, several different freshwater habitat types are present in the PACN, some of which are unique globally as well as locally. Habitat types include perennial and intermittent streams, coastal and upland wetlands, montane bogs, coastal and high elevation lakes, man-made brackish fishponds, and seeps. Anchialine pool systems, brackish water features lacking surface connection to the sea, are rare worldwide, and in the PACN are only present in the younger Hawaiian Islands. In general, windward sides of islands have more flowing surface water, while groundwater interactions at the surface are important on drier leeward sides. Freshwater species endemic to the PACN include fish, shrimp, snails, damselflies and other insects, sedges and other flowering plants, and ferns. Freshwater and anchialine biological habitats are a finite resource in the PACN and are often modified or obliterated through land-use practices, including agricultural, residential and commercial development, as well as invasive species introductions. Remaining aquatic habitats are extremely valuable in support of traditional agricultural and gathering practices as well as for their natural ecosystem services. Documenting the historic and contemporary spatial extents of these habitats, along with ecological processes, stressors, and biotic composition, are all significant tasks for monitoring and management. Specific details of issues, mandates, and classifications are available in the appropriate workgroup report in Appendix A.

**Biotic Integrity—Terrestrial Ecosystems**: The Pacific Islands are globally recognized for their terrestrial biodiversity and conservation status by organizations such as the WWF and Conservation International. Additionally, Hawaii, and to a lesser extent other Pacific Islands, are notable for some of the world's highest levels of endemism (uniqueness) in many taxonomic groups, as a result of biological evolution in isolation, with very limited colonization from the outside (Loope 1998). Exemplary groups include the Hawaiian honeycreepers (diverse bird species descended from a finch-like ancestor), Fringillidae, subfamily Drepanidinae (Freed et al. 1987); the Hawaiian silversword alliance, involving the genera Argyroxiphium, Dubautia, and Wilkesia in the plant family Asteraceae (evolved from a common California tarweed ancestor) (Robichaux et al. 1990); and Hawaiian pomace (*Drosophila* and relatives) flies (nearly 1,000 species radiating from one or two colonizing species) (Kaneshiro and Ohta 1982). These and many lesser-known Hawaiian examples (e.g., Gillespie et al. 1994) rival the famed Galapagos finches as textbook examples illustrating the process of evolution. For only Hawaii, roughly 18,000 native species have evolved in place from about 2,000 colonizing ancestors in the Hawaiian Islands. Such facts highlight the importance of structure and composition of plant communities and occurrence and distribution of fauna across landscape and over time. Specific details of issues, mandates, and classifications are available in the appropriate workgroup report in Appendix A.

**Biotic Integrity—Marine Ecosystems**: All parks in the PACN contain significant marine or coastal resources. The vast geographical distribution of the PACN means that parks on opposite sides of the network possess different species and in some cases entirely different marine habitats. For example, native species in one area of the network are highly invasive in another (e.g., mangroves), creating further difficulty when attempting to develop specific network-wide management and monitoring objectives. However, marine ecosystems across the Pacific share many common features, specifically the ecological processes (e.g., dispersal, recruitment, growth, $CaCO_3$ accretion and erosion) that shape them and stressors that alter them. Because of this, process, stressor, and biotic features are all significant facets for monitoring and management. Nearly all stressors on the marine environment have a terrestrial origin, and most are the result of human activity. The majority of parks have land management issues resulting in terrestrial runoff that has been identified as one of the most significant threats to Pacific marine habitats. The importance of invasive species as a significant marine stressor is currently unknown in most PACN parks, but the seriousness of this threat is well demonstrated by several highly visible and very costly examples in Hawaii (Smith et al. 2002). Specific details of issues, mandates, and classifications are available in the appropriate workgroup report in Appendix A.



## D. Network Approach to Planning

Within the PACN, there is a long tradition of sharing, whether it be technical resources, staff expertise, or otherwise, to help all the parks best manage their resources. Thus the network approach is a logical extension of this tradition in many regards. However, geographical, political, ecological, and other resource considerations vary significantly within the network, and a single monitoring plan encompassing all the network parks presents many challenges that the tradition of sharing skills and abilities has not previously addressed (especially in terms of documented common ecological considerations and management concerns in a public, scientific, or peer-review setting).

The NPS Monitoring Program has extensive guidance on the preparation and implementation of this Natural Resource Challenge funded program (see http://science.nature.nps.gov/im/monitor/). This approach includes 7 steps for developing a network monitoring program, and outlines a basic approach to selecting Vital Signs (Figure 1.3).

- Form a network Board of Directors and a Science Advisory committee.
- Summarize existing data and understanding.
- Prepare for and hold a scoping workshop.
- Write a report on the workshop and have it widely reviewed.
- Hold meetings to decide on priorities and implementation approaches.
- Draft the monitoring strategy.
- Have the monitoring strategy reviewed and approved.

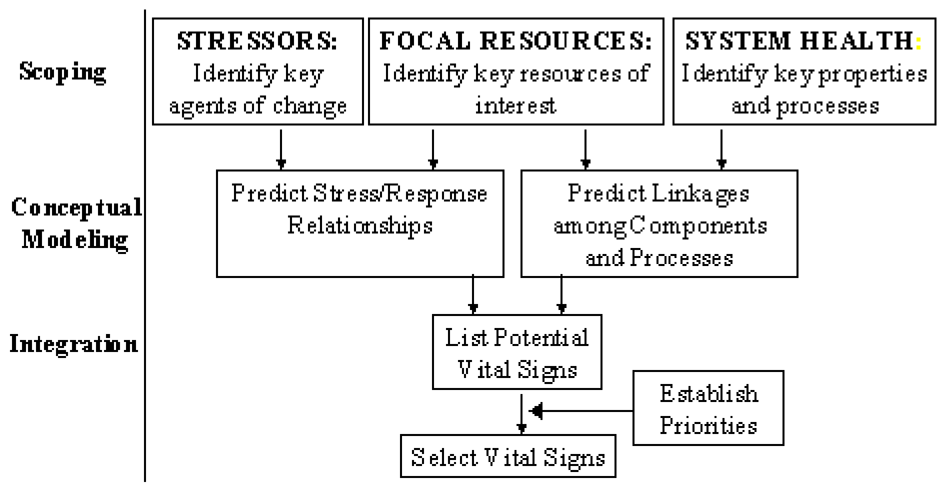



*Figure 1.3. Basic approach to identifying and selecting vital signs for integrated monitoring of park resources (source: K. Jenkins, USGS Olympic Field Station).*

These steps are incorporated into a three-phase planning and design process that has been established for the NPS monitoring program. Phase 1 of the process involves defining goals and objectives; beginning the process of identifying, evaluating, and synthesizing existing data; developing draft conceptual models; and completing other background work that must be done before the initial selection of ecological indicators. Phase 2 is selecting and prioritizing Vital Signs. Phase 3 establishes a complete monitoring plan and initiates implementation. The general scope of work involved in this process is outlined in Table 1.3.

*Table 1.3. Timeline for the PACN to complete the three-phase monitoring program planning and design process.*

| | FY2001 | FY2002 | FY2003 | FY2004 | FY2005 | FY2006 |
|---|---|---|---|---|---|---|
| **Anticipated Funding** | Inventory | Monitoring seed + inventory | Monitoring partial + inventory | Monitoring + inventory | Monitoring | Monitoring |
| **Data gathering internal scoping** | | | | | | |
| **Inventories** | | | | | | |
| **Scoping Sessions** | | | | | | |
| **Conceptual Modeling** | | | | | | |
| **Vital Signs Prioritization and Selection** | | | | | | |
| **Protocol Development Monitoring Design** | | | | | | |
| **Monitoring Plan Due Dates Phase 1, 2, 3** | | | | Phase 1 Oct 03 | Phase 2 Oct 04 | Phase 3 Dec 05 & Oct 06 |

The resulting monitoring plan, prepared in 2006, will be a first edition plan for the parks and network. The process of developing the plan, as well as the inventories and other work that occurs in the elapsed time period will provide a wealth of additional information that must be considered in subsequent updates and revisions to the monitoring plan.

## 1. Network Organization

A Board of Directors, composed of Superintendents from each of the parks plus the General Superintendent for the Pacific West Regional Office in Honolulu, established a network charter (http://www.nature.nps.gov/im/units/pacn/pacn_charter.doc) governing network activities. The network coordinator and Pacific West Regional I&M coordinator serve as non-voting members on the board.

The network charter established a standing Technical Committee comprised of natural resource managers and scientists, including scientists from outside of the NPS who work in the parks and are familiar with park issues, to provide technical assistance and advice to the Board. This Technical Committee, along with the Board of Directors, assisted the network in refining the scope of work involved in preparing this monitoring plan.

Network staff (identified in detail in Chapter 8) includes a network coordinator, data manager, and ecologist. The Pacific West Regional Office in Honolulu ecologist also provides guidance and assistance, including participation in Board of Directors activities.

### *a. Affiliated Offices*

Additional units providing support to the PACN include the **Pacific Cooperative Studies Unit (PCSU)**, started at the University of Hawaii in 1973 as a Cooperative Park Studies Unit (CPSU) of the NPS (with the University of Hawaii, attached to the Department of Botany in the College of Natural Sciences). The unit's primary focus on the conservation of Hawaii's natural resources is protected habitats, such as national parks, wildlife refuges, and the state's natural area reserves. Studies on cultural resources are also conducted particularly where they interface with natural resource management.

The **Pacific West Regional Office in Honolulu (PWRO)** was established in 1970 in Honolulu to conduct area studies, serve as a liaison between the NPS and other federal, state, territorial, and local agencies and governing bodies, and provide support, assistance, and guidance to NPS units. PWRO also is a primary point of contact for NPS with conservation groups and the general public. Staff are presently (2004) distributed throughout the Pacific Island parks, with the majority of staff located in Honolulu, HAVO, and HALE, with additional support office services provided by in-park staff from throughout the region.

The third administrative unit to provide support to the PACN will be the **Pacific Islands Cooperative Ecosystem Studies Unit (CESU)**. This program will provide access to affiliated universities, researchers and programs to further science, research and information exchange in support of biodiversity, resource management, stewardship and education/outreach goals. As of spring 2004, this CESU is still in a formative stage.

### 2. Scoping and Other Workshops

Sessions to determine elements for consideration in the Monitoring Plan were held throughout 2002-2003 by network staff, the Technical Committee, and working groups. In addition, a workshop was held in 2001 at NPSA to identify marine Vital Signs in small parks, (see http://www1.nature.nps.gov/im/units/pacn/monitoring/plan/vs_marine_npsa.pdf). Scoping Workshops were held with each of the PACN parks during 2002 and 2003 to help review and refine the conceptual ecosystem models and monitoring questions, identify drivers and identify candidate attributes to monitor. The Technical Committee as a group remained involved in the sessions to provide continuity and ensure that all issues were considered. Additional workshops were held in 2003 and 2004 to receive input on the content and context of monitoring objectives and questions, Vital Signs, and conceptual models. Additional workshops and meetings were held to facilitate the preparation of conceptual models, refine Vital Signs, and complete other components of the monitoring plan. Table 1.4, below, outlines these developmental meetings, although the process is somewhat fluid, with frequent revision and updates of previous sections.

*Table 1.4. Summary of scoping meetings and other workshops held to solicit input for monitoring plan.*

| Meeting / Workshop | Purpose | Date |
|---|---|---|
| Coral Reef monitoring for NPSA | Evaluate coral reef monitoring from a small park perspective | June 2001 |
| Technical Committee Meeting | Establish monitoring goals and working groups | ??? 2002 |
| Park Scoping (all PACN parks) | Solicit input from parks and cooperators on long-term monitoring | 2002 and 2003 |
| Conceptual Modeling Workshop | Initiate development of conceptual models and identify desired future conditions | March 2003 |
| Water Quality Planning Workshop | water quality components of the monitoring plan and its purpose were considered | August 2003 |
| Technical Committee Meeting: Vital Sign refinement | Identify, review, and improve proposed Vital Signs | November 2003 |
| Vital Sign Workshop | Obtain NPS and external input (review) of proposed Vital Signs and priorities | March 2004 |
| …more to come… | | |

3. Data Mining

Data mining (the collection, analysis, and organization of natural resource information) is vital to the successful identification of issues for the monitoring program. The Technical Committee established working groups in 11 topic areas (data management, air quality/climate, geology, vertebrate fauna, invertebrate fauna, freshwater biology, invasive species, landscape, marine, vegetation, and water quality) to gather information and generate work group reports summarizing in detail the status of monitoring related information (see Appendix A). These workgroups also identify, review, and refine Vital Signs for the parks and network. These workgroups are headed by Technical Committee members and include PCSU facilitators, NPS staff, and outside scientists.

4. Desired Future Conditions

The "unimpairment" criterion of the NPS Organic Act places emphasis on the process of identifying desired future conditions, monitoring the progress of management actions towards those maintaining those conditions, and evaluating the effectiveness of management efforts in preventing further impairment. As stated in Directors Order #2, Park Planning: the goals for park planning and the desired future conditions for a park, should focus on why the park was established and what resource conditions and visitor experiences should be achieved and maintained over time. Explicitly identifying desired future conditions as part of the monitoring program will help smooth the transition from Vital Sign selection to the establishment of specific, measurable objectives and trigger points for management.

Desired future conditions are often defined based on disparate criteria between or even within PACN parks, ranging from World War II memorial conditions, Polynesian landscapes prior to western contact, to 'natural' conditions and processes preserved unimpaired and for the enjoyment of future generations. A pragmatic consideration of ecosystems in the Pacific islands must incorporate the fact that ecosystems are altered (often irrevocably), yet natural processes should be allowed to continue to the extent possible. Various additional considerations such as: ghost communities (result of resource partitioning and character displacement), sliding baselines (the idea that with each subsequent generation the baseline of what is considered natural moves further and further from the true natural state), and distinctions between past and present conditions and management practices, all must be taken into consideration when identifying ecologically relevant desired future conditions.

- General statements for desired ecological future conditions in Pacific Island National Parks include:
- Natural ecosystem processes (functions) continue to operate. "Natural" processes are broadly defined to include those associated with native cultural practices where these are appropriate to a park's mandate.
- Unnatural elements are removed from the system, including alien species control or eradication for the most disruptive species and prevention of additional alien species establishments.
- Extirpated or depleted species (composition), lost ecosystem processes (functions), and missing ecosystems structure(s) are re-established where appropriate.
- Complete watersheds encompass the appropriate range of scales for management. Examples include:
    - Composition: species ranges, diversity, and demographics;
    - Structure: spatial arrangements across multiple scales;

  - Function: typical watershed metrics, e.g., land use practices not impacting sediment and nutrient dynamics.
- Protection of endemic, rare, or endangered biota and ecosystems.
- Recovery or restoration of degraded areas, incorporating environments conducive to the survival and perpetuation of native biological communities.

In addition to general desired ecological conditions, there are a variety of desired future conditions applicable to the monitoring program as a whole. Adaptive monitoring and management approaches are one example, those that provide the flexibility to evaluate and change our techniques based on immediate feedback. A second example is defensible data, including sound database design, documentation and archiving; and the use of appropriate monitoring design. Desired conditions for the network monitoring program include:

- Provide a greater knowledge base, and intrinsically more knowledge.
- Promote scientifically defensible management criteria.
- Monitoring data documents recovery (or lack thereof) in conjunction with management action, and facilitates funding for further management action.
- An integrated, responsive approach of adaptive monitoring and management.
- Encourage and incorporate community involvement in planning and carrying out resource management activities and monitoring; incorporating living cultures (Hawaiian, Samoa, Chamorro) where they do not impair natural resources.
- Education through park-based interpretive programs, as well as education beyond park boundaries and traditional practices.
- Monitoring is consistent with the mission of NPS, resource protection goals, and enabling legislation for individual parks.

## E. Monitoring Goals and Objectives

Monitoring is a central component of natural resource stewardship in the NPS, and in conjunction with natural resource inventories, management, and research, provides the information needed for effective, science-based managerial decision-making and resource protection (Figure 1.4). Natural resource inventories, monitoring, and research are closely-related activities needed for effective science-based management of park resources, and the terms are sometimes confused. In general, monitoring is the tool used to identify whether or not a change occurred and research is the tool to determine what caused the change. While it is often hoped that ecological monitoring can help to explain complex relationships in ecological systems, such understanding often requires a more focused research investment.

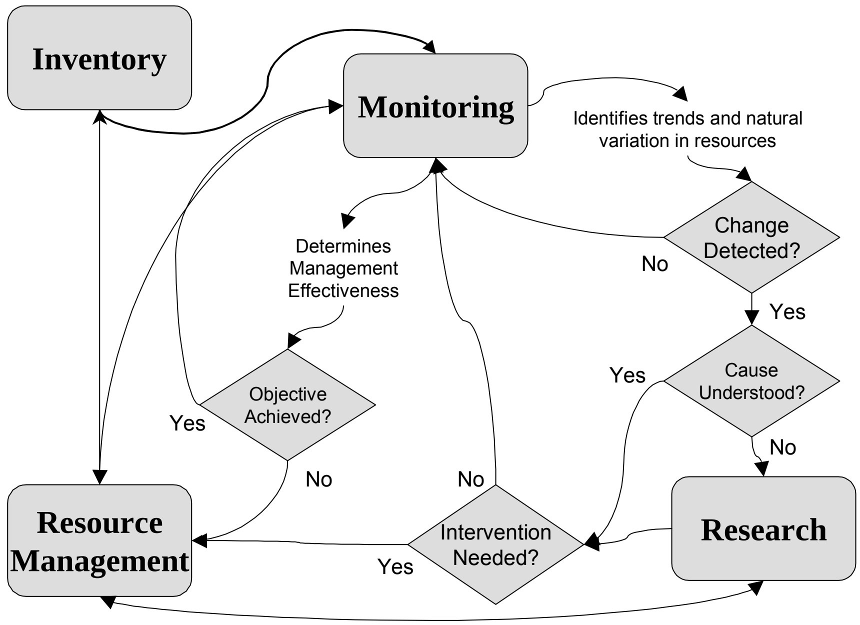



*Figure 1.4. Relationships between monitoring, inventories, research, and natural resource management activities in national parks (modified from Jenkins et al. 2002).*

1. Monitoring Goals

Monitoring program goals for the PACN were adopted directly from the national I&M Program goals, with the addition of a 6th goal addressing shared natural and cultural values (in *italics* below).

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.
- *Provide data to better understand, protect, and manage important resources that share cultural and natural value.*

This sixth goal, related to resources that share cultural and natural value, will permit the network to more fully develop Vital Signs monitoring that address human activities and cultural practices as identified in the ecological organization outlined previously. It will also help us develop a monitoring program that meets the legal considerations and other mandates (also identified previously) that PACN parks must address.

*a. Government Performance and Results Act Goals*

Demonstrated progress towards achieving the NPS monitoring program goal of integrating natural resource monitoring information into NPS practices is pivotal in ensuring the long-term success of the program. The PACN monitoring plan is a significant and specific step towards fulfilling Government Performance and Results Act (GPRA) goal category I (Preserve Park Resources) for the network (see http://www.nps.gov/performance/). This monitoring plan identifies the monitoring indicators or “Vital Signs” of the network and presents our strategy for long-term monitoring to detect trends in resource condition (GPRA Goal Ib3). GPRA goals relevant to the monitoring are listed in Table 1.5. GPRA goals also exist for natural resource inventories, which support the monitoring program. Additionally, the development of partnerships for monitoring with other agencies and organizations will help parks meet other GPRA goals.

*Table 1.5. Government Performance and Results Act Goals for the PACN.*

| Mission Goal | GPRA Goal | Goal # |
|---|---|---|
| Natural and cultural resources restored and maintained in good condition | Disturbed lands restored | Ia1A |
| | Exotic species contained | Ia1B |
| | Improved population status of federally listed T&E | Ia2A |
| | Stable populations of federally listed T&E | Ia2B |
| | Native species of concern at acceptable population levels | Ia2X |
| | Air quality stable or improving | Ia3 |
| | Unimpaired water quality | Ia4 |
| | Cultural landscapes in good condition | Ia7 |
| | Paleontological resources in good condition | Ia9A |
| | Cave floors restored | Ia9B |
| Knowledge about natural resources | Vital signs for natural resource monitoring identified | Ib3 |

## 2. Monitoring Objectives

In many respects, monitoring goals, objectives, and Vital Signs (see Chapter 3), represent the process the network has used to focus the monitoring program. We have identified broad monitoring objectives to help ensure that a full spectrum of ecological and management issues are identified. Subsequent chapters of this monitoring plan will continue to refine this focus through evaluation and selection of explicit objectives for individual Vital Signs, methods, metrics, and analytical techniques. In the interim, the objectives identified below will be refined and focused with feedback received, yet remain broad enough to help facilitate partnerships in accomplishing monitoring.

Formulation of monitoring objectives has been an iterative process: articulating objectives from suites of proposed Vital Signs, adjusting to reflect the categories outlined above, and adding objectives or questions that otherwise seemed to be missing. The following are monitoring objectives organized according to the network’s framework for ecological organization (Section C.3.a).

### *a. Human Activities and Cultural Practices*

| | |
|---|---|
| **Soundscapes** | |
| 1. | Monitor sound sources, frequencies, occurrence, and levels |
| **Lightscapes & Viewscapes** | |
| 1. | Monitor visibility |
| 2. | Monitor landscape/seascape appearance |
| 3. | Monitor light levels and characteristics of light/dark cycles |
| **Land Use** | |
| 1. | Monitor points of entry for invasive species |

2. Monitor water use adjacent to or upstream from park boundaries
3. Monitor land use adjacent to or upstream from park boundaries

**Park Use & Activities**

1. Monitor debris-trash occurrence in coastal, riparian, wetland, and lacustrine habitats; in or near high use areas
2. Monitor patterns of park visitation, use & damage (terrestrial & marine)
3. Monitor incidence and occurrence of bioprospecting
4. Monitor levels of take & harvest of harvested species (marine, freshwater, and terrestrial) or resources (coral, sand)

**Management Zones**

1. Monitor patterns and effects of use and management
2, Monitor effects of management practices on wilderness character

### *b. Physical & Chemical Environment*

**Climate and Air Quality**

1. Track rates of atmospheric deposition
2. Track atmospheric concentrations of particulates and gases, levels of radiation--emphasizing those with known human health or environmental impacts
3. Monitor core weather/climate conditions within each park (on each island)
4. Monitor frequency and intensity (severity) of extreme events (hurricanes, waves, winds, rain, etc.)
5. Identify and monitor spatial patterns of climate, such as trade-wind inversion elevation, lifting cloud level, lapse rates, etc.

**Soil, Water, and Nutrient Dynamics**

1. Monitor cycles of nutrients and elements within soils and water--including carbonate (oceanic), nitrogen, and phosphorous
2. Monitor soil erosion
3. Monitor soil quality trends (physical, toxics/contaminants, other biologic and nutrients)
4. Monitor condition and extent of soil crusts
5. Monitor trends in surface water flow regimes
6. Monitor wetland (incl. anchialine ponds) water flow exchange dynamics, size, and distribution
7. Monitor ground water flow rates and direction of movement (recharge)
8. Monitor physical ocean dynamics--ocean currents, sea level, tides/swell

**Water Quality**

1. Monitor water quality core parameters (temperature, conductance, pH, DO, PAR)
2. Monitor supplemental water quality parameters (nutrients, susp. solids, alkalinity, BOD, flow, ions, TOC, redox)
3. Monitor microbiological water quality parameters
4. Monitor toxic and contaminant levels in water
5. Monitor biological invertebrate communities

**Geology**

Hazards

1. Monitor surface volcanic activity (lava flows, eruption events & ground deformation)
2. Monitor volcanic & non-volcanic seismicity
3. Monitor extent, location, and causes of mass wasting events (e.g. landslides)

Landforms

1. Monitor shoreline dynamics
2. Track dune locations and topography
3. Identify and monitor the extent of permafrost
4. Monitor karst and non-karst cave and lava tube habitat characteristics, topography, and extent

### *c. Biotic Integrity of Freshwater Ecosystems*

**Producers**

1. Monitor community composition, structure, and productivity

**Consumers**

**Community**

| | |
|---|---|
| | 1. Monitor community dynamics, structure, function, and composition |
| | **Population** |
| | 1. Monitor population distribution and demographics (size/age structure, reproduction, recruitment, etc.), including response to restoration efforts |
| | 2. Monitor extent and response to treatment of established invasive species |
| | 3. Monitor occurrence of non-established (incipient) invasive species |
| | 4. Monitor disease incidence and impacts, especially on native species |

### *d. Biotic Integrity of Terrestrial Ecosystems*

| | |
|---|---|
| **Vegetation** | |
| | Landscape |
| | 1. Monitor patterns of distribution & extent of community types |
| | 2. Monitor fire regimes and effect on vegetation |
| | 3. Track insect and disease presence during forest dieback |
| | Community |
| | 1. Monitor community dynamics, structure, function, and composition |
| | 2. Monitor effects of management on native communities |
| | Population |
| | 1. Monitor population distribution and demographics (size/age structure, reproduction, recruitment, etc.), including response to restoration efforts |
| | 2. Monitor extent and response to treatment of established invasive species |
| | 3. Monitor occurrence of non-established (incipient) invasive species |
| | 4. Monitor disease incidence and impacts, especially on native species |
| | 5. Monitor effects of biocontrol on native and invasive species |
| **Consumers** | |
| | Community |
| | 1. Monitor community dynamics, structure, function, and composition |
| | 2. Monitor effects of management on native communities |
| | Population |
| | 1. Monitor population distribution and demographics (size/age structure, reproduction, recruitment, etc.), including response to restoration efforts |
| | 2. Monitor extent and response to treatment of established invasive species |
| | 3. Monitor occurrence of non-established (incipient) invasive species |
| | 4. Monitor disease incidence and impacts, especially on native species |
| | 5. Monitor effects of biocontrol on native and invasive species |
| **Cave Systems** | |
| | Community |
| | Monitor changes in cave communities |



### *e. Biotic Integrity of Marine Ecosystems*

| | |
|---|---|
| **Benthic Communities** | |
| | Landscape |
| | 1. Monitor patterns of distribution and extent of community types |
| | Community |
| | 1. Monitor community dynamics, structure, function, and composition |
| | Population |
| | 1. Monitor population distribution and demographics (including size/age structure, reproduction, recruitment, etc.), including response to restoration efforts |
| | 2. Monitor extent and response to treatment of established invasive species |
| | 3. Monitor occurrence of non-established (incipient) invasive species |
| | 4. Monitor disease incidence and impacts, especially on native species |
| | 5. Track community and population trends in harvested fisheries species |
| **Intertidal Communities** | |
| | **Community** |
| | **1. Monitor community dynamics, structure, function, and composition** |

| | |
|---|---|
| | **Population** |
| | 1. Monitor population distribution and demographics (including size/age structure, reproduction, recruitment, etc.), including response to restoration efforts |
| | 2. Monitor extent and response to treatment of established invasive species |
| | 3. Monitor occurrence of non-established (incipient) invasive species |
| | 4. Track community and population trends in harvested fisheries species |
| | 5. Monitor disease incidence and impacts, especially on native species |
| **Water column (motile) species** | |
| | Community<br>1. Monitor community dynamics, structure, function, and composition |
| | Population<br>1. Monitor population distribution and demographics (including size/age structure, reproduction, recruitment, etc.), including response to restoration efforts<br>2. Monitor extent and response to treatment of established invasive species<br>3. Monitor occurrence of non-established (incipient) invasive species<br>4. Track community and population trends in harvested fisheries species |

## F. Monitoring Strategies

A suite of Vital Signs which integrates multiple attributes of ecosystem composition, structure, and function, while representing several spatial and temporal scales (Holling 1986), is an efficient strategy for monitoring. The PACN monitoring program must also address the interaction of stressors from multiple sources, which occur at a various spatial and temporal scales. Anticipating future natural resource information needs is a daunting task, and past experience has shown that many of the most valuable uses of monitoring information were not anticipated in planning efforts. While not every park will identify nor need the same Vital Signs, monitoring that *can be* coordinated across multiple parks *should be* to gain logistical and financial economies, scientific synergy, and allow for multi-park or regional analyses, which would not otherwise be possible. Two overlapping broad strategies address such concerns: 1) ecosystem health-based monitoring and 2) issue-oriented monitoring.

### 1. Ecosystem Health-Based Monitoring

Ecosystem health or landscape-based monitoring integrates current scientific understanding of ecological structure, function, and composition, known anthropogenic impacts, and essential habitats. It focuses on assessing the ecosystem response to natural and anthropogenic inputs, both the stressors themselves and the resulting impacts on park ecosystems. This is essentially a landscape ecology approach to monitoring, investigating the arrangement of living organisms and ecosystems and the way they interact with each other and change over time. Monitoring of ecosystem health helps meet current natural resource information needs, while providing basic trend information that will help address future, as yet unknown, concerns. Such a broad, ecosystem health-based monitoring program emphasizes:

- Community composition and change.
- Systems, processes, and functions.
- Levels of ecological organization or structure.

Most PACN parks do not have existing ecosystem health-based monitoring. The network monitoring program will focus on this monitoring through formally identifying and prioritizing Vital Signs that address ecosystem health, monitoring a subset of ecosystem health components across the network, using the ecological organization outlined previously to help identify gaps and overlap in the ecological characteristics of Vital Signs, and facilitating additional park-based monitoring.

### 2. Issue-Oriented Monitoring

Issue-oriented monitoring addresses specific and immediate concerns that park managers face. Examples in the PACN include monitoring of threatened and endangered species, fishpond and anchialine pond water and habitat quality, invasive species, and outplanting or restoration effectiveness. While such issue-oriented monitoring may often overlap with ecosystem health-based approaches, it is intended to address specific, immediate, and known concerns.

Most PACN parks already have implemented (either themselves or through partnerships) monitoring that helps address some of the most significant park issues. The network monitoring program will help parks further this monitoring through formally identifying and prioritizing these issues, monitoring a subset of issues common to the network or to groups of parks, and facilitating additional park-based monitoring.

Worth noting is a hybrid concept in the differentiation of 'ecosystem health-based' and 'issue-oriented' monitoring strategies, watershed-based monitoring. The watershed is a key geographic unit in many PACN parks, as a watershed-based view of land management emphasizes the interconnections of ecosystems across the island landscape, from uplands to reef and near-shore marine habitats. Locally, watershed-based management is a traditional cultural means of land and resource management, at least in Hawaii, and thus is an excellent tool for community involvement and interaction. Watershed-based management programs in large geographic areas are often difficult for reasons of scale, whereas Pacific Island watersheds tend to be much smaller, and often fewer stakeholders are involved because land is often proportionately owned by fewer individuals. Applying the logic of ecosystem health-based monitoring within a watershed (using the ecological organization outlined previously to help identify gaps in the ecological characteristics of Vital Signs), will help facilitate linking these 2 strategies.

## Chapter 2. Conceptual Models

A conceptual model is a visual or narrative summary that illustrates the important components of a system and the interactions among them. Conceptual models represent current knowledge of the processes occurring in systems, and as such, are able to illustrate system dynamics, identify the bounds and scope of the systems of interest, and provide a framework for testing hypotheses about how they function. No one "correct" model can be established; conceptual models represent the current best understanding of system dynamics, and should be refined as our understanding of ecosystem processes increases.

### A. Introduction

The process of constructing conceptual models facilitates the organization and communication of information about ecosystem structure, function, and composition, and the understanding gained from defining and testing such models can be applied to park management. A conceptual ecological model also ties the parks in a network together by illustrating their common similarities. The PACN parks share a suite of characteristics that make them unique within the NPS, as well as highly threatened ecologically.

The complexity of natural systems and wide range of scale of factors that influence them makes modeling a highly useful tool at all stages when developing a monitoring program. Differing scales and levels of detail can be incorporated into specific models in order to clarify these factors. The conceptual model also provides an objective and structured framework by which we can select specific attributes (indicators or 'Vital Signs') to monitor.

To accomplish the establishment of a general conceptual ecological model for the Pacific Islands, a workshop was held in March 2003 with the goal of identifying key components, concepts, and cohesive principles for inclusion that could apply to all network parks. This was intended as a first draft of the conceptual model for the PACN parks' Phase 1 monitoring plan. The workshop was attended by an interdisciplinary group of NPS staff, regional NPS cooperators and partners, and university scientists. Input from the PACN Technical Committee and other NPS staff in November 2003 was then used to refine the model's structure and components.

### B. General Conceptual Model

An **ecosystem** is defined as the biotic and abiotic components within a spatially explicit area and the interactions between them. **Ecosystem integrity** implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes (see http://science.nature.nps.gov/im/monitor/Glossary.htm). The overarching goal of the NPS is the restoration and maintenance of ecosystem integrity within park boundaries. The PACN conceptual model combines the concept of ecosystem integrity with the interactive-control ecosystem sustainability model described in the next section.

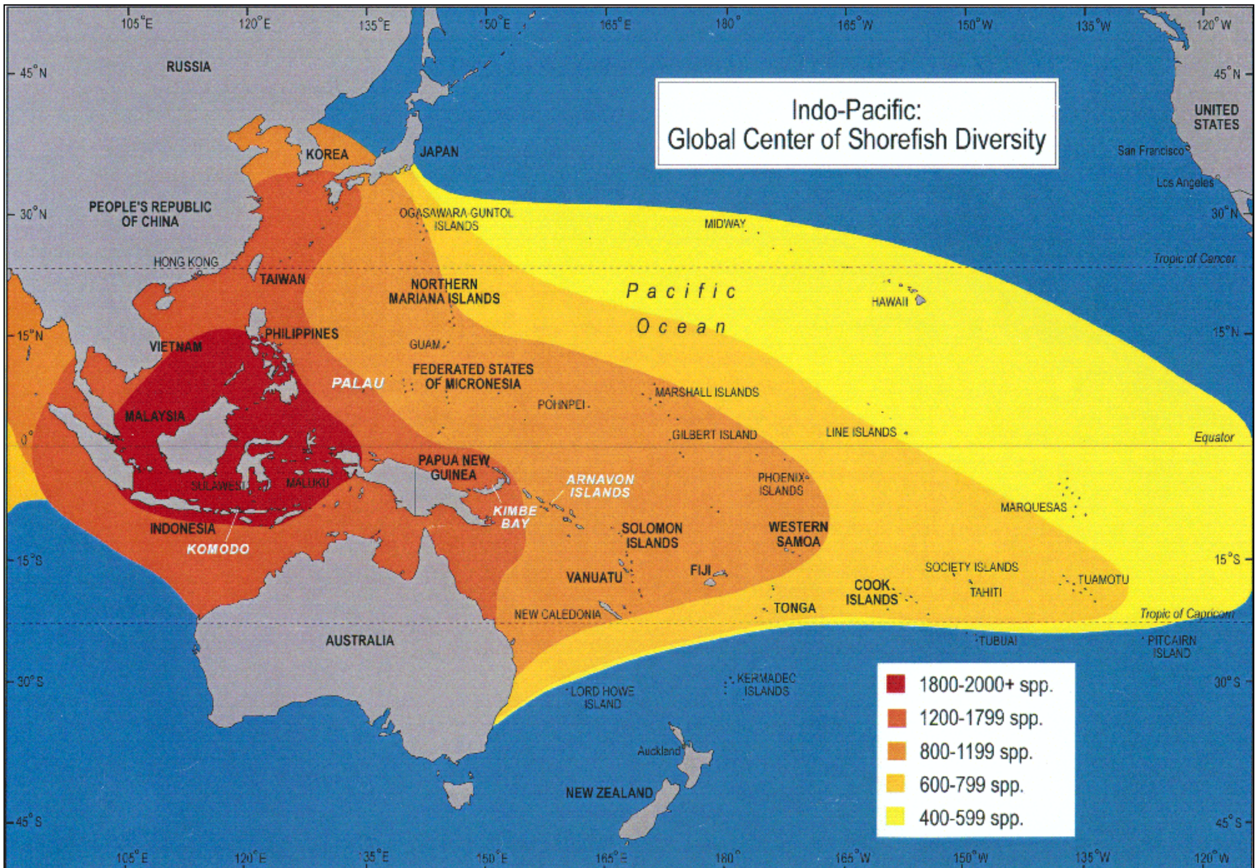
In the most general terms, ecosystem models contain 3 complementary parts: an understanding of ecosystem composition, an understanding of ecosystem structure, and an understanding of ecosystem function. Both stochastic events and successional change contribute to variation in natural systems (Chapin et al. 1996), and it is important when monitoring ecosystem integrity to differentiate between intrinsic variability of natural systems and human-induced changes. Ecosystem stability is maintained when natural variation in ecosystem components is not pushed directionally into a new state by an introduced disturbance, such as addition of nutrients, invasion by an exotic species, or increase in frequency of fire (Chapin et al. 1996). With recent large-scale changes in ecosystems in the Pacific region, questions of stability in ecosystem state are increasingly important.

Natural Pacific Island ecosystems are often considered remarkable for the high levels of endemism exhibited by their flora and fauna. The Hawaiian Islands, for example, have been referred to as “the best ‘natural laboratory’ for evolutionary studies in the world” (Kaneshiro 1989), and contain a high proportion of the natural biological resources of the United States (Loope 1989).

In terrestrial and freshwater habitats in the Pacific Islands, there are often fewer native species or functional groups than are found in most continental regions, because relatively few species have managed to colonize the islands. This phenomenon is also referred to as ‘disharmonic fauna’, where whole groups, such as most mammals or amphibians, are missing from communities. Despite low numbers of colonizing species, a high level of biodiversity is found when many endemic species are present, as in the Hawaiian Islands (Loope & Gon 1989). Older islands tend to have higher levels of endemism than younger islands, and islands farther from source populations tend to have higher levels of endemism than those near source populations. High levels of endemism can arise from both evolution of single species in isolation and from adaptive radiations, where multiple species are derived from a single ancestral species; both of these mechanisms have occurred among the native species of the PACN.

One ‘drawback’ of such high levels of endemism and adaptive radiation is that oceanic islands are exceptionally susceptible to biological invasions. (Loope and Mueller-Dombois 1989, Denslow 2003). There seems to be a strong correlation worldwide between percentage of biotic endemism and vulnerability of the biota to being displaced by biological invaders (Loope and Mueller-Dombois 1989). The presence of underutilized ecological niches, coupled with the ready accessibility of many habitat types from ports of entry and the moderate and stable climate, facilitates the establishment of alien species. In many cases, it seems that new introductions, whether accidental or purposeful, meet less resistance and have proportionately greater negative effects on Pacific Islands than in continental settings.

While these patterns are well documented for terrestrial ecosystems, there are significant differences among ecological and taxonomic groups. In addition, marine systems have analogous but not identical relationships. For example, numbers of Pacific reef fish species are highest near their source populations in Indo-Malaysia (Figure 2.1). Endemism tends to show the opposite pattern, with numbers of endemic species often increasing with distance from a population source. These examples illustrate the importance of understanding biodiversity within the PACN and how impacts from invasive alien species could alter these ecosystems.




Note: Contours represent the maximum number of tropical fish species (reef, inshore, and epipelagic).
Adapted from Stoddart (1992) "Biogeography of the Tropical Pacific", and Springer (1982) "Pacific Plate Biogeography, with Special Reference to Shorefishes", modified by G. Allen. Produced by The Nature Conservancy's Hawaii Natural Heritage Program, September 1995.

*Figure 2.1. Patterns of reef fish biodiversity in the Pacific. Contours represent the maximum number of tropical fish species (reef, inshore, and epipelagic). Adapted from Stoddart (1992) "Biogeography of the Tropical Pacific" and Springer (1982) "Pacific Plate Biogeography, with Special Reference to Shorefishes", modified by G. Allen. (with permission from Hawaii Natural Heritage Program).*

One of the major concerns of resource managers in the Pacific Islands is the invasion of alien species and displacement of native species. Invasive species have the ability to significantly affect ecosystem integrity (Harwell et al. 1999). Changes resulting from introduction of invasive species extend beyond alteration of ecosystem composition and affect ecosystem structure and function as well (e.g., Cuddihy and Stone 1990). In several Pacific Island ecosystems, alien species now form dominant biological components, and restoration of native systems will require a large effort; in cases of extinction (e.g., of lowland forest birds) complete restoration may not be possible.



### 1. Hierarchical Model Structure

In any monitoring program, the issue of scale must be addressed in ecosystem models. The complementary ecological parts of components, structure, and function must be integrated across varying spatial and temporal scales. To aid in this, a nested hierarchy of conceptual models is being developed for the PACN. This organization of conceptual models, illustrated in Figure 2.2, proceeds from a large-scale simple model to smaller-scale detailed models. General models facilitate communication among concerned groups such as scientists, managers, and the public, while specific models are useful both for identifying indicators (Vital Signs) and for local management of particular issues.

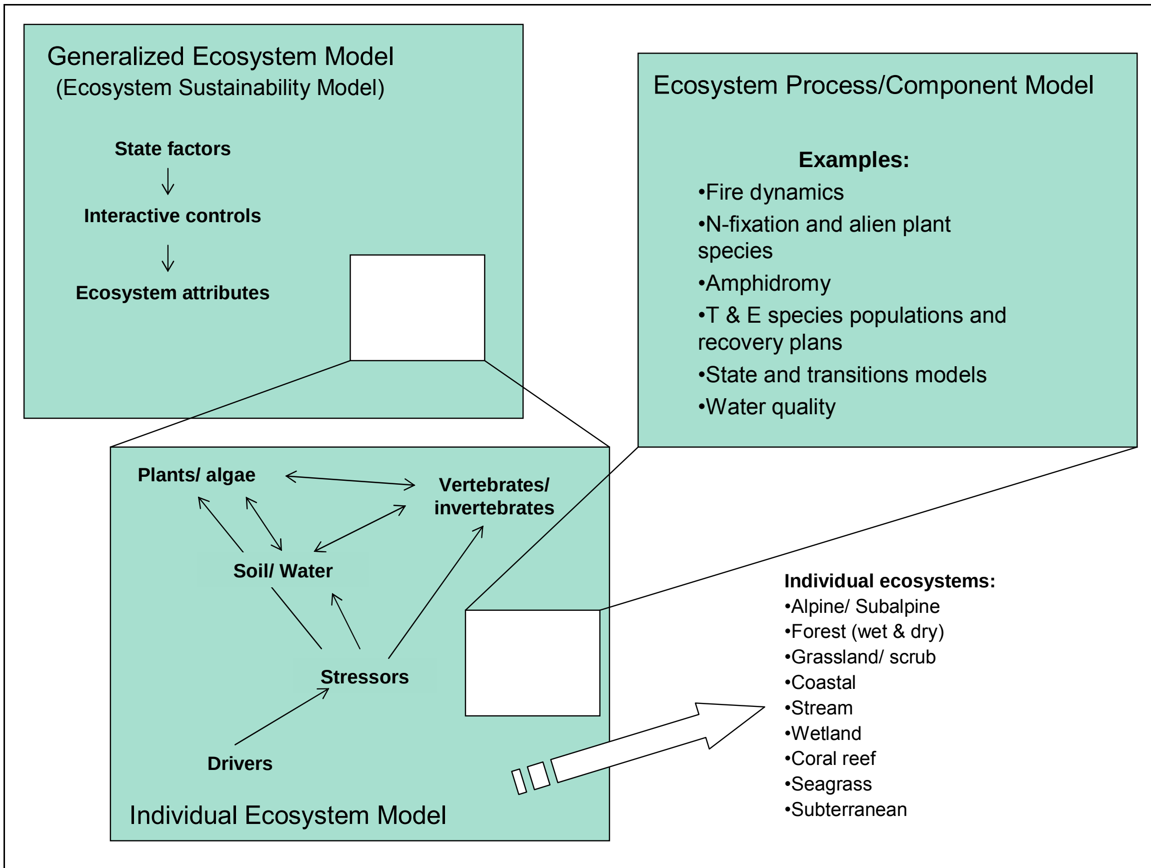



*Figure 2.2. Hierarchical relationships between model types.*

### 2. Ecosystem Sustainability Model

The PACN has adopted a modified version of an ecosystem sustainability model that emphasizes both internal interactions and external factors, called the interactive-control model (Chapin et al. 1996). In it, the hypothesis of Jenny (1941) that five basic categories, or *state factors*, control ecosystem processes is expanded to include secondary *interactive controls*, which both control and respond to ecosystem processes. In the Jenny-Chapin model, state factors include: parent material, time (since disturbance), climate, potential biota, and topography. These factors influence interactive controls, which include local climate, soil (or water) resource supply, functional groups of organisms, and disturbance regime.

This model has been modified by Evenden et al. (2002); replacing the interactive control of *soil or water resource supply* with *soil or water resources and conditions*. This term is more specific when using interactive controls as a basis for selecting Vital Signs for monitoring. The PACN network has also modified the *parent material* state factor to *parent material or water resources* for clarity when considering aquatic ecosystems. Figure 2.3, below, illustrates the modified Evenden et al. model. In this model, *ecosystem processes* include the three factors of composition, structure, and function that operate within an ecosystem (e.g., community composition, successional change, or rate of nutrient cycling).

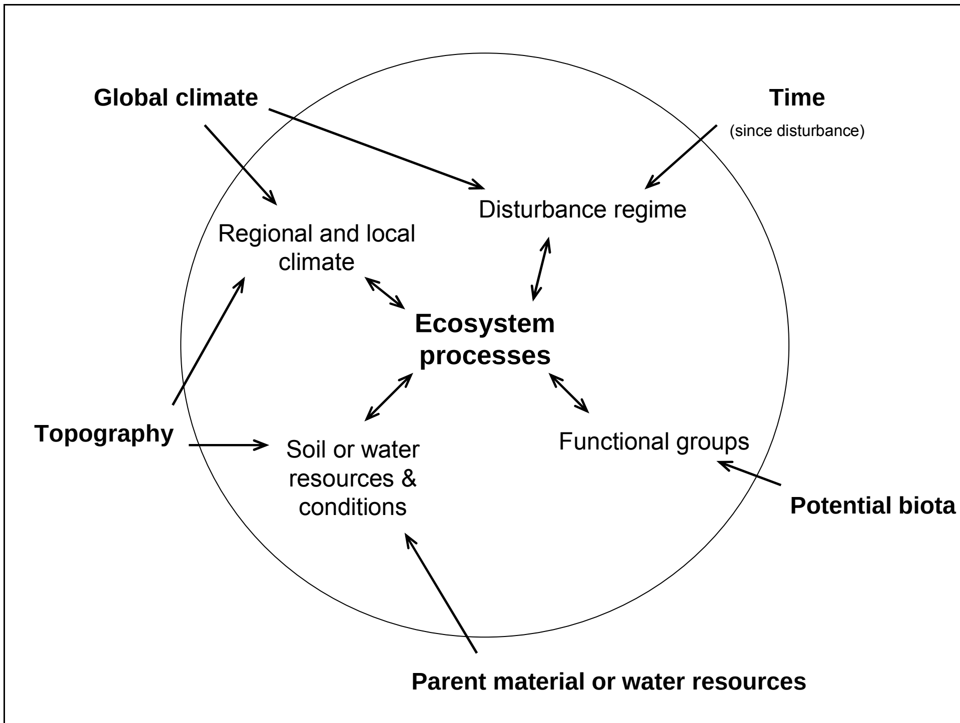



*Figure 2.3. Interactive-control model. State factors outside the circle are variables which operate outside the ecosystem bounds and control ecosystem processes, while interactive controls drawn within the circle are variables which occur within the ecosystem and both control and respond to ecosystem processes. See text for additional details. (Modified from Evenden et al. 2002).*

*a. State Factors*

**State factors** are variables with independent variation which function as ultimate controls on ecosystem structure, function, and processes. They are major forces of change in ecosystems, and may be strongly influenced by human activity. State factors and their expression in the PACN are described below:

- **Global climate** is a factor that accounts for much of the variation in ecosystem structure, productivity, and biogeochemistry (Chapin et al. 1996). There are characteristic patterns of wind direction (trade winds) across the PACN, and a monsoonal climate in the Western Pacific. Other global climate factors include the El Nino-Southern Oscillation (ENSO) cycle, which strongly influences climate on a periodic cycle (e.g., causes a decrease in rainfall in the Hawaiian Islands), and global climate change, which is predicted to cause increased atmospheric and water temperatures, decreased rainfall, and sea level rise in the PACN. Climate change may also lead to shifts in the trade-wind inversion and cloud lifting level as well as increased drought, affecting cloud forests (high-elevation rain forests), an otherwise relatively intact ecosystem type in the PACN region.

  Marine, terrestrial, and atmospheric interactions are tightly coupled, and this state factor includes oceanic climate as well as atmospheric conditions. Oceanic climate influences terrestrial ecosystems as well as near-shore marine ecosystems, through its effect on the atmosphere. Factors include global oceanic circulation patterns, which influence the distribution of organisms, and more localized deep water mixing events, which strongly affect nutrient availability and productivity.

- **Time since disturbance** includes both natural and human-caused disturbances. These include volcanic activity, fire, disease outbreaks, typhoons and hurricanes, as well as forest clearing, chemical spills, and episodes of severe overfishing. Time since disturbance affects processes such as soil and reef formation, colonization by organisms, and recovery of communities from significant stress.

  The history of the Pacific Islands presents an excellent opportunity to monitor the dynamics of ecosystem development over time (Vitousek 1995). For example, the Hawaiian Islands have a clear and well dated age progression; while American Samoa has a complex age matrix within a very small area. In many areas, the influence of human activity is also relatively well dated, allowing comparison of the effects of natural and anthropogenic influences on community succession.

- **Potential biota** is the pool of species from which ecosystems are populated. These may be either native or introduced species. This distinction is significant in the PACN, as non-native species have replaced or threaten to replace natives to a large extent in many areas. In several cases in the Pacific Islands, the number and type of potential species available for colonization was small, so species that did colonize evolved to utilize different ecological niches in a process of adaptive radiation.

  Patterns of native species diversity in several groups in the PACN vary with distance from Southeast Asia and Indonesia. In general, the number of species present within a group decreases with increasing distance from Indonesia, while the number of endemic species increases (see Fig. 2.1). Human activity has broken down geographic barriers to dispersal, so this pattern does not hold for introduced species.

- **Parent material or water resources.** While the islands of the PACN are volcanic in origin (formed by hot spot plumes in Hawaii & American Samoa and plate subduction in the Marianas), chemical composition of their lavas and ash differs (Vitousek 1995). Additionally, the limestone cap found in portions of the Northern Marianas forms a chemically different parent material. Initial substrate composition has a strong effect on soil resources that will eventually form.

  Water resources are the analogous state factor in aquatic ecosystems. Water resources include quantity of water (which determines presence and potential zonation of aquatic ecosystems), its chemical makeup (salty or fresh, acidic or alkaline), and its sources (whether from groundwater or surface flows). Terrestrial parent material influences both freshwater and marine resources as solutes are transported through the system (in marine systems, this process is often strongly affected by groundwater intrusion or surface runoff).

- **Topography** varies significantly across spatial scales, and interacts with the state factors of *time* and *parent material*. For example, the Hawaiian Islands are shield volcanoes formed from variably-textured lava at small spatial scales, and are eroded into complex and rugged topography at broader scales. Landforms eventually erode and subside to form lower relief atoll topography, while in the marine environment, corals build complex structures as islands age.

  Topography influences the interactive control of soil or water resources and conditions by determining such factors as maximum potential soil or water depth, as well as locations of sediment deposition. Regional and local climate is also affected by topography; elevation changes influence patterns of wind, temperature, and rainfall on land, while in aquatic systems current patterns, temperature, and light penetration are affected.

*b. Interactive Controls*

**Interactive controls** generally operate inside the bounds of ecosystems. They respond dynamically to each other and interact with ecosystem processes, but are constrained by state factors. Interactive controls change as processes such as succession occurs, but major changes can lead to significantly different ecosystems (Chapin et al. 1996):

- **Regional and local climate.** The PACN is located within the tropics and subtropics; however, nearly all the world's major climate zones are represented on these islands, due to the interaction of global climate and topography. Global atmospheric circulation generally produces consistent trade winds, and a trade wind inversion layer is formed at approximately 2000 m. These interactions have the effect of producing striking local climatic gradients in temperature, precipitation, and deposition; the spatial and temporal distribution of climatic conditions help drive variation in ecosystems.

  In marine systems, local current regimes influence distribution of organisms, and upwelling conditions or groundwater intrusion affect productivity. Atmospheric climate also influences aquatic conditions; rainfall determines the amount of water available to form freshwater systems, and also has an effect on sediment inputs to aquatic systems as it causes erosion.

- **Disturbance regime.** Within the PACN region, storm events (either hurricanes or typhoons, or periods of brief and intense rainfall) and earthquakes can significantly affect multiple ecosystems. Other natural disturbances which occur within PACN parks include stream flooding, tsunami, landslides, volcanic activity, wildfires, seasonal high wave events, coastal erosion, and drought. Blizzard conditions can occur in HAVO on the summit of Mauna Loa (snow may rarely be present in HALE at the summit of Haleakala). Large-scale disturbances significantly interact with soil and water resources and conditions, as well as regional climate. Localized disturbances such as landslides in a single watershed or the noise from boat motors may have a profound impact on organisms in a single area.

  Frequency and intensity of such events strongly affects community composition and timing of ecosystem processes such as succession (Chapin et al. 1996). Human activity has often modified disturbance regimes on the Pacific Islands, through such activities as diverting streams (reducing timing and severity of floods), introduction of alien grasses (promoting the incidence and scale of fires), and clearing patches of forest for agriculture (changing patterns of nutrient cycling).

- **Functional groups** are able to influence ecosystem processes through modification of soil chemistry (N-fixing organisms), modification of spatial structure (reef-building corals), reduction of water flow (semi-aquatic plants), enhancement of erosion (ungulates), increase in disease occurrence (blood-sucking insects), and predation (carnivores). The presence of functional groups is influenced by local climate, soil and water resources, and disturbance regime (Chapin et al. 1996).

The functional group interactive control does not explicitly distinguish between native and introduced species. However, pre-human Pacific Island ecosystems lacked certain functional groups (e.g., predatory terrestrial mammals, or fire-adapted grasses), whose introduction with human aid has been highly detrimental to native species. The distinction between native and introduced species is a significant factor in the principle of ecosystem integrity, which the PACN is combining with this ecosystem sustainability model.

- **Soil or water resources and conditions.** Soil resources and conditions determine both productivity and maximum structural diversity of plants (Chapin et al. 1996) on land. Resources include nutrient supply and moisture; other conditions include the presence of certain compounds (such as pesticides or heavy metals). Soil resources and conditions are influenced by the state factors of topography and parent material, as well as the presence of N-fixing organisms (Jenny 1941). In the case of volcanic substrates, which comprise much of the land in PACN parks, soil resources are also affected by time since substrate creation.

  In aquatic ecosystems, water resources and conditions are the equivalent interactive control (Chapin et al. 1996), influencing non-photosynthetic organisms as well as algae, aquatic plants, and corals. Water resources and conditions include both water availability and quality, including water flow, quantity of nutrients, light penetration, and presence of pollutants. Water resources and conditions are influenced by the state factors of parent material, water supply and topography.

#### *c. Selection of Ecosystem Components for Monitoring*

While the interactive-control model focuses on interacting ecosystem processes, and thus provides a framework for understanding large-scale ecosystem components, selection of monitoring priorities is not limited to processes. For example, the monitoring of threatened and endangered species will be included, because these organisms have been identified as important resources, either ecologically or culturally. The purpose of the formulation of the PACN conceptual ecological model is to help prepare for the selection of such monitoring priorities.

### 3. Idealized Pacific Island

Parks in the PACN share ecological and historical conditions that make them unique within the NPS. Figure 2.4, below, illustrates the ecosystem zonation of an idealized high-elevation Pacific Island, as it relates to altitude and characteristic rainfall patterns. Most major ecosystem and habitat types are included. The islands of Maui and Hawaii extend into the sub-alpine and alpine zones, while the other PACN islands have elevations that allow them to reach the montane mesic/cloud forest or mid-elevation seasonal/rainforest ecological zones.

Length of human presence on the islands in the PACN varies. The Mariana Islands, including Guam and Saipan, are thought to have been colonized about 3,500 years ago, as were the islands of Samoa. The Hawaiian Islands are thought to have been colonized only about 1,600 years ago. European contact in the Marianas began approximately in the 1650s and in Samoa and the Hawaiian Islands approximately in the 1770s. The history of human activity varies among islands, but all have been significantly influenced by human use.

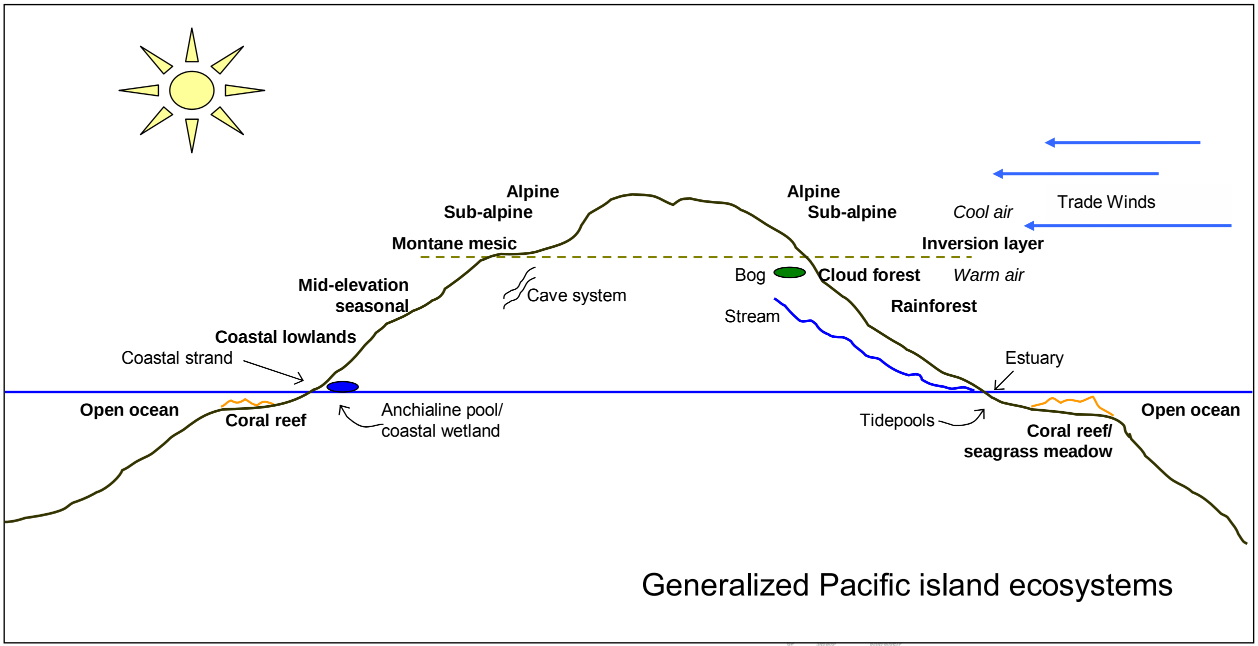



*Figure 2.4: Idealized high-elevation Pacific island (modified from T. Tunison, NPS, and Juvik & Juvik 1998). Most parks occupy only a portion of the idealized island. Lower elevation islands often have windward-leeward regimes with uppermost elevations that extend only into the rain forest/mid-elevation seasonal habitat zones. Cave and lava tube systems may be located at any elevation.*

The lower reaches of the idealized Pacific Island have been heavily impacted from the time of first human colonization, and these impacts continue today at an accelerated rate. All habitat zones were used by native peoples to some degree, although the extent and exact nature of use is not fully known. In many National Parks, traditional uses and practices continue today, although more recent land use practices have for the most part superseded traditional cultural impacts on ecosystem use.

### a. *Pacific Island Stressors*

Pacific Islands share several primary stressors, which arise from their small size and isolation, geological activity, and histories of human occupation. Figure 2.5, below, illustrates common stressors arising from both natural and anthropogenic sources. These stressors are recognized to affect multiple ecosystems, and are often recognized as possible threats to human health or safety. They fall into several broad categories: geological hazards, global climate change, population expansion, and introduction of alien species.

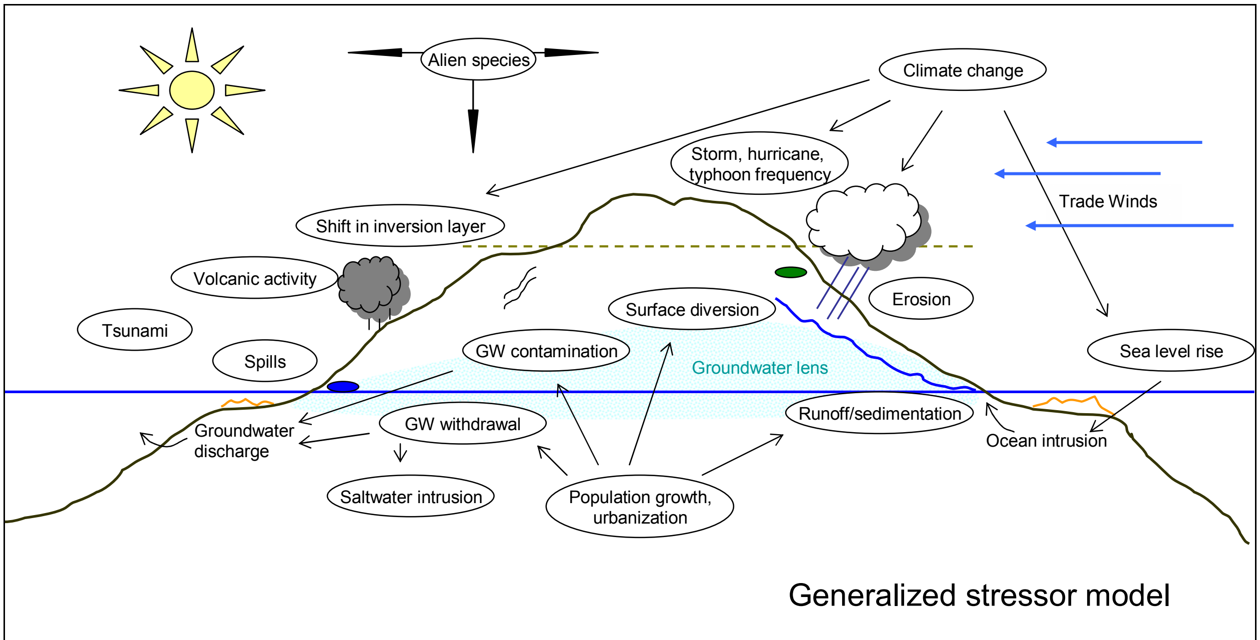



*Figure 2.5: Generalized Stressor Model. Shows stressors shared among most Pacific Islands and Pacific Island ecosystems. Alien species have the potential to impact all ecosystems. Ecosystems illustrated are the same as those in Fig. 2.4.*

Invasive species already present in the islands may comprise the most significant stressors for many if not most ecosystems of Pacific parks. The driver for these stressors is various facets of land use and human activity (basically the breakdown of biogeographic barriers through intentional or unintentional transport of biological organisms by humans). Such transport of organisms by humans does not appear to be slowing down. To the contrary, the process of globalization is in many ways increasing. Therefore, species invasion will only be slowed in the immediate future by measures purposely implemented to prevent, detect, rapidly respond to, and manage invasions (Vitousek et al. 1997; Loope et al. 2001). McGregor (1973) noted that for Hawaii, in spite of normal agricultural quarantine, "(for insects and mites) in the period 1942-72 the rate of colonization per thousand square miles was 500 times the rate of continental United States." Without special attention, invasions will continue to accumulate on Pacific Islands, with devastating results for resources of island parks.

### *b. Atmospheric, Terrestrial, and Marine Interactions*

Links between the atmosphere, land, and marine systems are readily apparent on oceanic islands. Many of the terrestrial-marine linkages are mediated by freshwater systems, for example, transport of nutrients and organic matter from rainforests to coral reefs by streams. All terrestrial systems within the PACN are classified broadly as coastal systems, because of these significant interconnections.

Surface water and ground water systems are highly interconnected as well. Groundwater on Pacific Islands exists in a "lens" floating upon seawater, and all groundwater resources are formed by the percolation of rainwater that does not flow over the island's surface into bedrock. Withdrawal of groundwater for human consumption often reduces the flow of streams and lowers the water table in wetlands, illustrating the interconnectivity of these resources. Additionally, freshwater springs may be found under the ocean surface; these springs provide a source of nutrients to nearby organisms. Figure 2.6 illustrates the interactions between the atmosphere and terrestrial and marine systems.

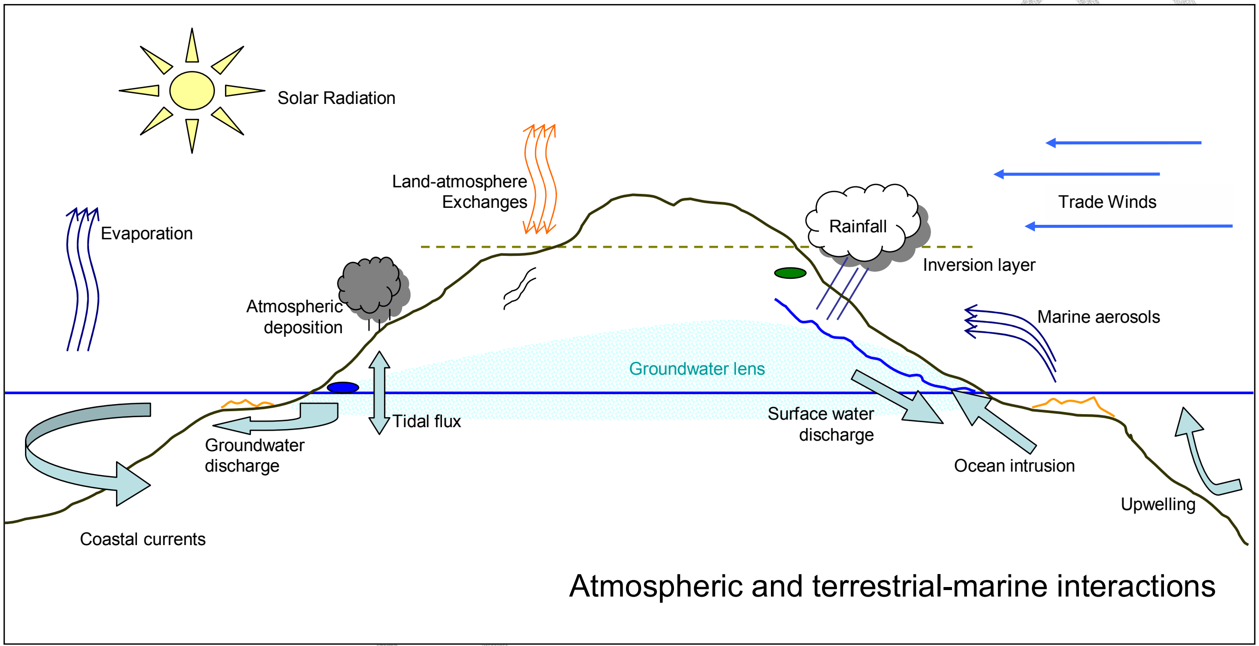



*Figure 2.6: Atmospheric, terrestrial, and marine interactions. Shows key linkages between the atmosphere and marine, freshwater, and terrestrial ecosystems. Ecosystems illustrated are the same as those in Fig. 2.4.*

## C. Ecosystem Models

Within the generalized model of a high Pacific Island, a wide range of ecological and social conditions are present. Climate, topography, geology, human land use patterns, and native species composition vary greatly among islands and within parks. This variation has prompted the establishment of more focused ecosystem-level conceptual models, which can be applied to the appropriate parks.

Not all islands contain all ecosystem types, and not all parks contain habitat representative of all ecosystems on an island. However, parks such as HALE and HAVO contain resources ranging in elevation from alpine desert to the sea, including entire watersheds such as the Kipahulu area of HALE. Traditional management of Pacific Island resources often has a watershed-based perspective (for example, the concept of *ahupua`a* in the Hawaiian Islands), which can be useful as a management tool.

Table 2.1, below, lists ecosystem types located within or immediately adjacent to PACN parks. Ecosystem models are being developed for specific systems as need arises, in order to clarify the prioritization of Vital Signs. They will consist of diagrams and explanatory text, and should be constructed after a thorough literature review. General terrestrial and marine system biological stressor models have been developed as an aid to beginning the process of ecosystem model construction. These models are illustrated in Figures 2.7 and 2.8. An example of an ecosystem-level model is Figure 2.9, which illustrates a conceptual model for stream biology.

*Table 2.1: Ecosystems located within or immediately adjacent to PACN parks, with brief descriptions and parks in which they are found. Resources of ALKA have not been inventoried.*

| Ecosystem Type | Description | Parks |
|---|---|---|
| Alpine & subalpine | High altitude, very low rainfall (above inversion layer). Scrubland and aeolian alpine desert. | HALE, HAVO |
| Forest | | |
| Wet forest | Rain forest & mesic forest below inversion layer, cloud forest at inversion layer. | WAPA, NPSA, KALA, HALE, HAVO |
| Dry forest | Dryland forest, both coastal & montane. | HALE, KALA, KAHO, PUHO, HAVO |
| Scrubland & grassland | Mid- and low-altitude scrubland and grassland. | WAPA, HALE, PUHE, KAHO, PUHO, HAVO, ALKA? |
| Freshwater | | |
| Stream | Flowing-water systems, includes sources, riparian areas, and estuaries. Both perennial and intermittent streams. | NPSA, WAPA, KALA, HALE |
| Wetland | Montane bogs at high elevation, lakes, coastal wetlands and mangrove forest, anchialine ponds, man-made enclosed fishponds, upland & coastal seeps and springs. | AMME, WAPA, KALA, HALE, PUHE, KAHO, PUHO, HAVO, ALKA? |
| Marine | | |
| Coral reef | Coral communities measured from shoreline to pelagic zone. | AMME, WAPA, NPSA, USAR, KALA, HALE, PUHE, KAHO, PUHO, HAVO |
| Seagrass | Seagrass beds are located at Guam, Saipan, and Samoa parks. | AMME, WAPA, NPSA |
| Coastal | Includes sea cliffs, limestone and basalt rocky shores, sand and cobble beaches, and strand vegetation communities. | all parks |
| Subterranean | Cave and lava tube ecosystems. | WAPA, HALE, KAHO, HAVO, ALKA? |



Ecosystems do not exist in isolation, but are linked by movement of air, water, and organisms (Polis et al. 1997). When establishing conceptual models to be used in the National Parks, it is important to make clear that all our parks, even ones that do not contain the full range of components in a model, interact with these components via processes that occur outside park boundaries. For example, coastal wetlands are influenced by zones of human activity outside of park boundaries through the movement of groundwater or streams into park boundaries. In Hawaiian coastal parks, mangrove seeds have been carried by ocean currents from nearby areas, allowing the establishment of this alien species within fishponds. In smaller parks, this landscape-scale view of ecological processes emphasizes the need for interactive management partnerships with outside agencies. None of the PACN parks, with the exception of NPSA however, include an entire watershed from mountain to nearshore. From Table 2.1 above, most of the PACN parks contain only fragments of ecosystems within a watershed, or as in the case of

HAVO, PUHO, HALE, and AMME end at the mean high-tide line and only abut marine ecosystems.

Clearly defined terms are necessary in any model in order to facilitate understanding of its components and their interactions. This is particularly important in establishing conceptual ecological models for the I&M Program, in order to aid in communication among individuals with diverse backgrounds and areas of interest. Terms adopted by the I&M Program as a means of identifying ecosystem processes and components throughout the National Park System are defined in the Glossary. Symbols used to illustrate these components in graphical conceptual models are explained in the Glossary, as well.

### 1. Terrestrial Biology System Model

Illustrated below is a general terrestrial biology system model (Figure 2.7). This model illustrates primary stressors of terrestrial ecosystems (e.g., alpine, wet forest, scrubland) and the pathways by which they affect biological communities. This model includes ecological effects of stressors on communities, and octagons in this model represent general biological groups rather than specific ecosystem attributes.

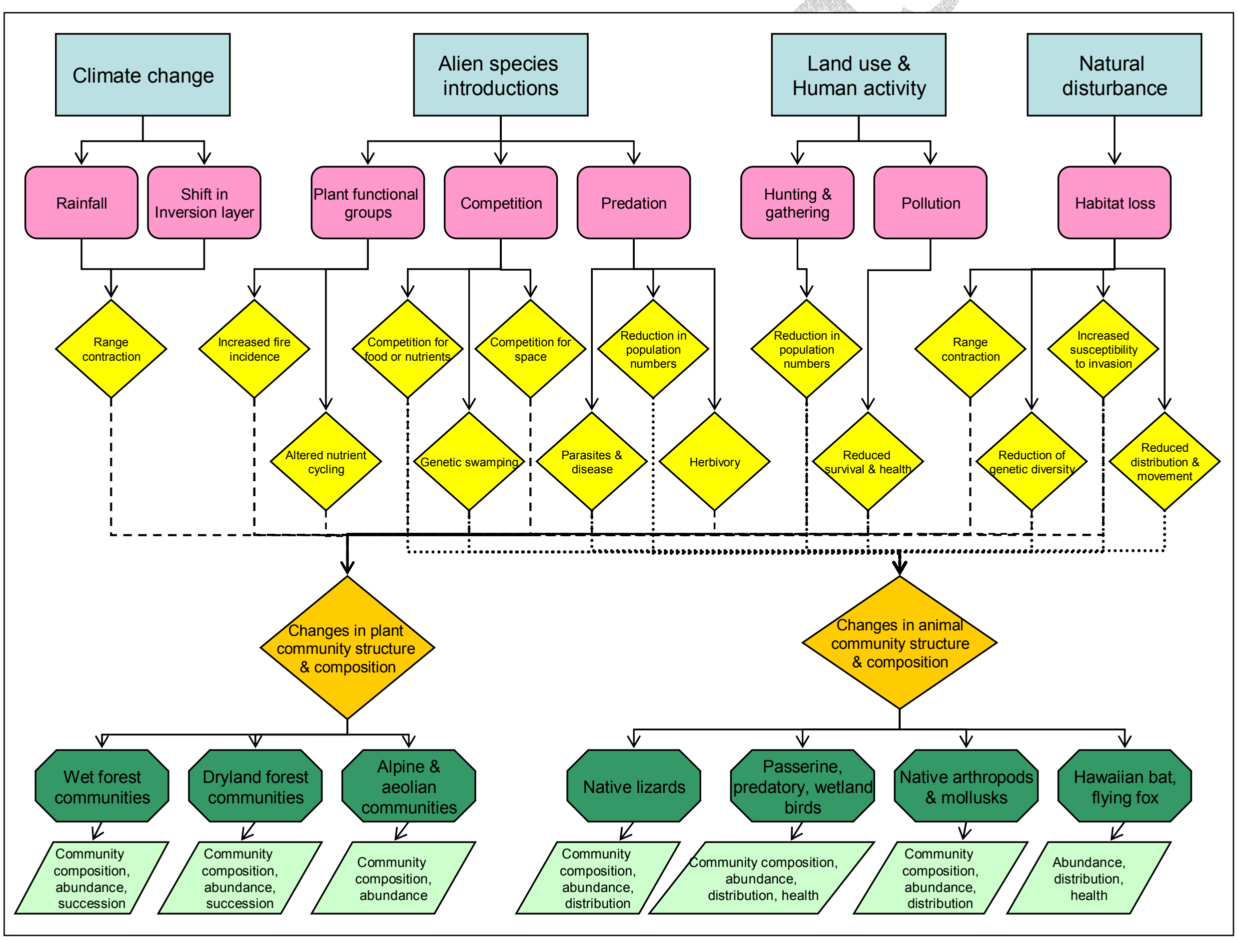



*Figure 2.7: Terrestrial Biology System Model. Dashed lines affect plant communities, and dotted lines affect animal communities. Rectangles represent drivers, rounded rectangles represent stressors, diamonds represent ecological effects of stressors, octagons represent biological groups, and parallelograms represent measures of biological groups. Emphasis is on biological stressors.*

The terrestrial biology system model applies to all terrestrial ecosystems (excluding aquatic and subterranean systems). In general, stressors and their effects do not have equal influence on biological systems, and certain stressors may be more of a concern in certain parks or ecosystems. For example, fire is generally more of a concern in dry ecosystems than in rain forest. The terrestrial biology system model broadly illustrates the drivers and stressors common to terrestrial systems, as well as selected resulting ecological effects.

### 2. Marine Biology System Model

A marine biology system model (Figure 2.8) is constructed similarly to the terrestrial biology system model. Primary stressors of marine ecosystems (including coral reefs, seagrass meadows, and sediment flats) and their ecological effects on biological communities are illustrated. This model applies in general to marine systems, however, certain stressors and their effects impact some systems more than others. For example, changes in coral/ algal dominance are very important in coral reef ecosystems, but not important in coastal mangrove swamps. The marine biology system model broadly illustrates the drivers and stressors common to marine systems, as well as selected resulting ecological effects.

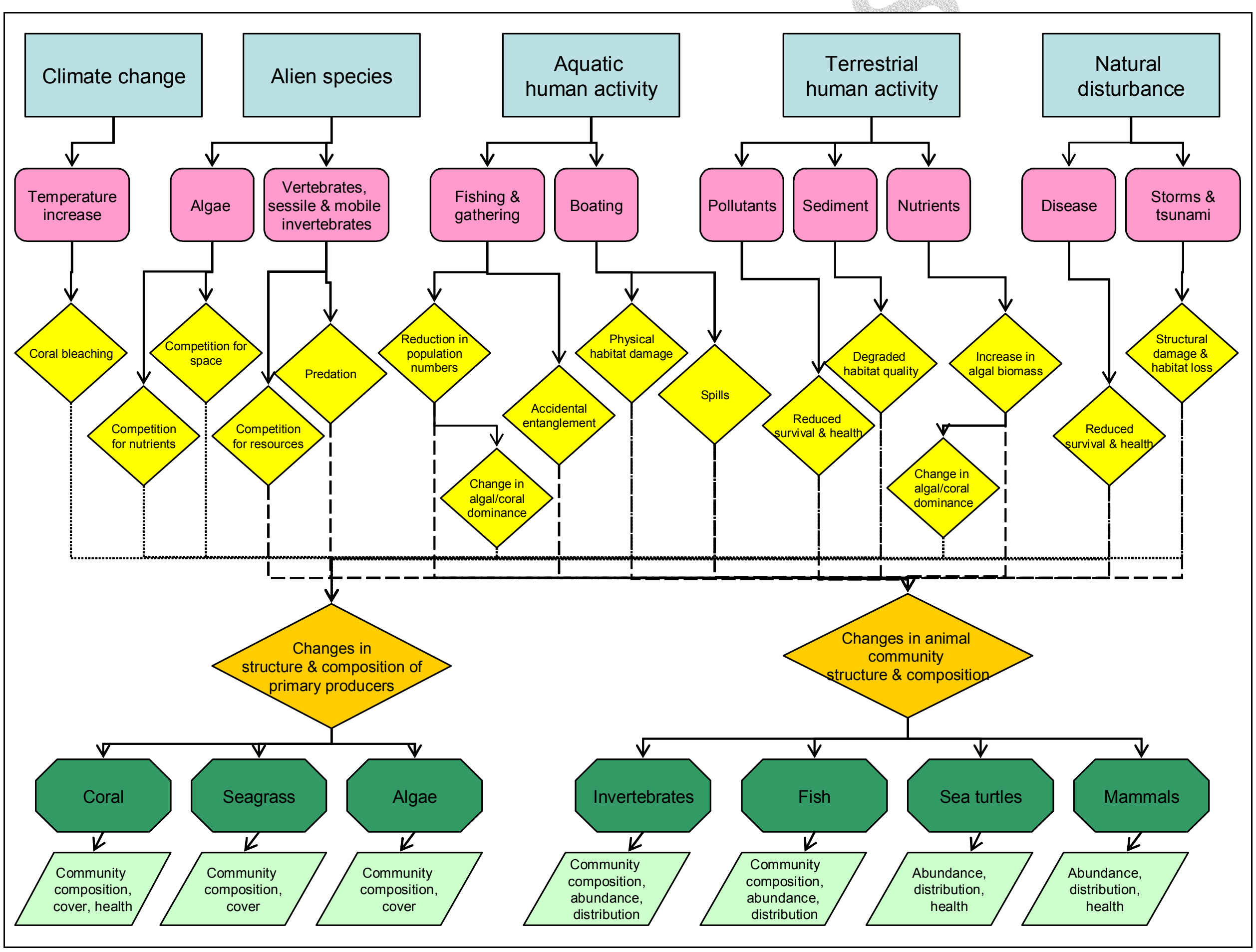



*Figure 2.8: Marine Biology System Model. Dashed lines affect photosynthetic communities, and dotted lines affect animal communities. Rectangles represent drivers, rounded rectangles represent stressors, diamonds represent ecological effects of stressors, octagons represent biological groups, and parallelograms represent measures of biological groups. Emphasis is on biological stressors.*

### 3. Stream Biology Ecosystem Conceptual Model

As an example of an ecosystem model, the stream biology conceptual model is illustrated below (Figure 2.9). This type of model is useful for showing the interactions between ecosystem components and identifying attributes which may be used as Vital Signs. It includes drivers, stressors, ecosystem attributes, and several attribute measures.

This model differs from the two previous system models. Its smaller scale of focus allows the inclusion of more detail, and the endpoints of the model represent ecosystem attributes, rather than biological groups. The inclusion of ecosystem attributes is useful when illustrating how potential Vital Signs fit into the system. Additional ecosystem models will be developed concurrently with Vital Sign selection.

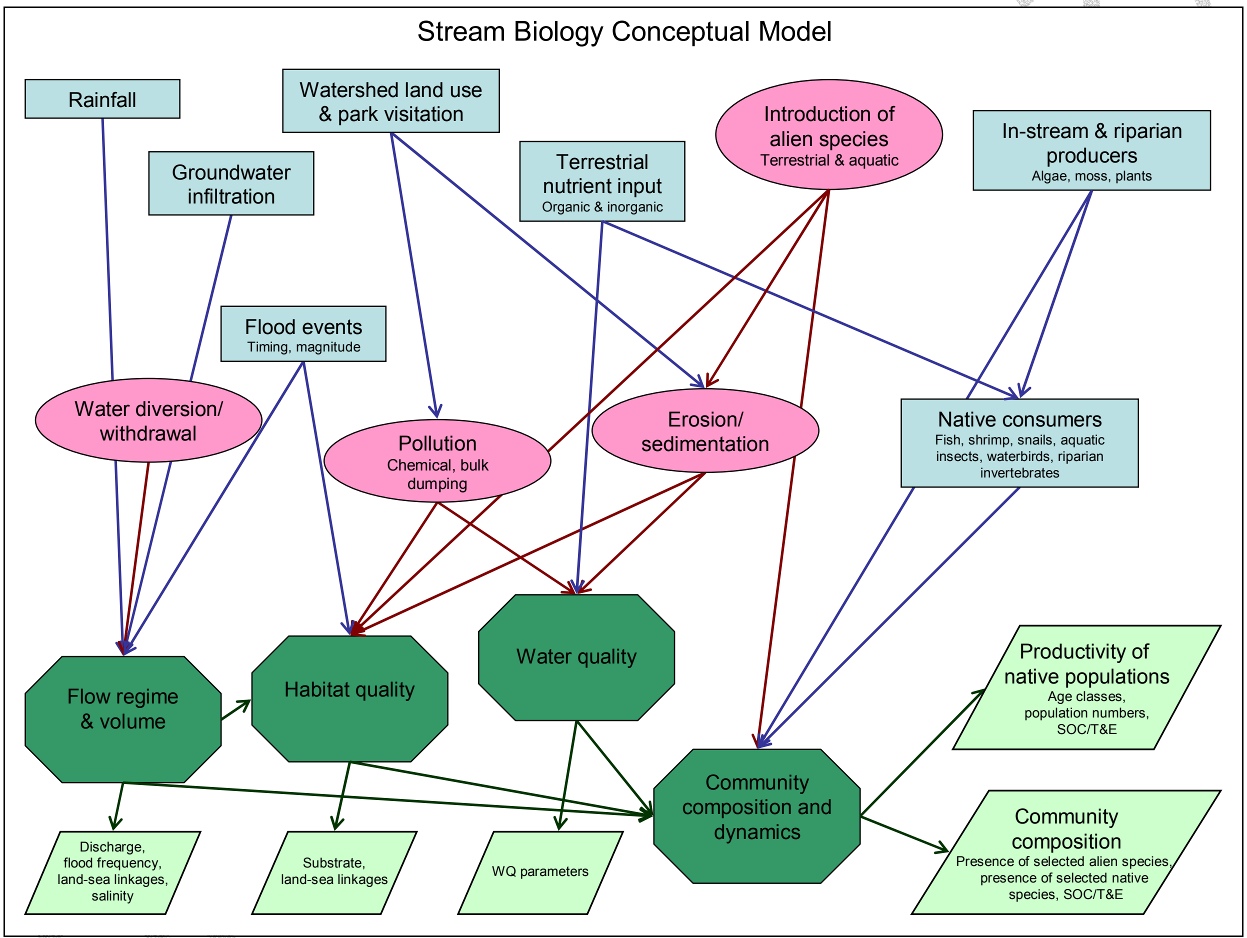



*Figure 2.9: Stream biology ecosystem conceptual model. Rectangles represent drivers, ovals represent stressors, octagons represent attributes, and parallelograms represent measures.*

## D. Ecosystem process/component models

These models present our understanding of selected ecosystem processes and components. They show in detail specific processes at or below the ecosystem level, such as the life histories and habitat uses of focal species or the effect of N-fixing plants on community succession. They are useful for communicating our understanding of specific processes to different audiences, as well as for elaborating on processes which were simplified in depiction of the ecosystem models.

These models will be constructed at the workgroup and park levels as the Inventory & Monitoring Program begins to identify possible Vital Signs. Like ecosystem models, they will consist of diagrams and explanatory text, and should be constructed after a thorough literature review. Examples of three types of ecosystem process/component models follow: an illustration of the amphidromous life history, the effect of alien grasses and fire on vegetation structure, and a model of water quality.

### 1. Amphidromous Life History

An illustration of the amphidromous life history, which is shared by most native Pacific Island stream fish and macroinvertebrates, is shown below (Figure 2.10). This model identifies the key biological and physical components in the life history, and illustrates spatial locations of natural system drivers (rectangles) as well as points of potential anthropogenic disturbance (ovals). This type of diagram is used for illustrating the ecological needs of a specific group of organisms in relation to the different spatial habitats which they utilize during their life cycle. It is primarily useful when selecting strategies to monitor populations of species of concern or biological indicator species.

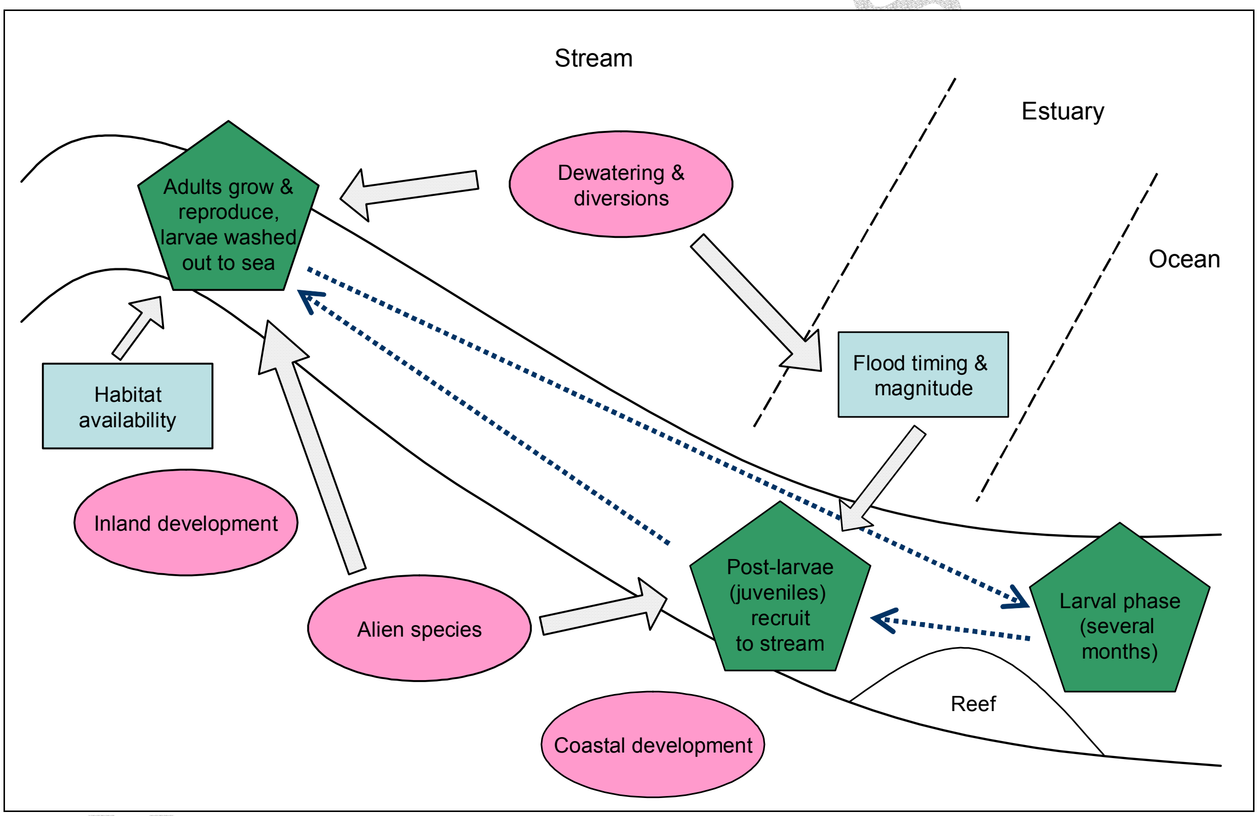



*Figure 2.10: Amphidromy life history model, illustrating habitats in which life history stages occur, natural system drivers, and potential anthropogenic disturbances.*

Amphidromous species migrate between fresh and salt water at two points in their life cycle: from fresh to salt as embryos and from salt to fresh as juveniles (Fitzsimons et al. 2002). Preservation of amphidromous populations requires that a freshwater connection and appropriate ecological conditions and aquatic resources be maintained in a stream from the headwaters to the sea. Presence of alien species, development such as damming or channelization, and withdrawal of water act as stressors at different spatial locations.

2. Effect of Alien Grasses and Fire on Vegetation Structure

The effect of alien grass establishment and modification of the fire regime on vegetation structure is illustrated in Figure 2.11. This type of model is a state-and-transition model, which depicts thresholds between possible vegetation states, or phases, and the mechanisms by which such thresholds are hypothesized to be passed. This type of model is useful when examining the effects of human activity on specific ecosystem processes; such activities may include possible management actions that are necessary to return to a previous state.

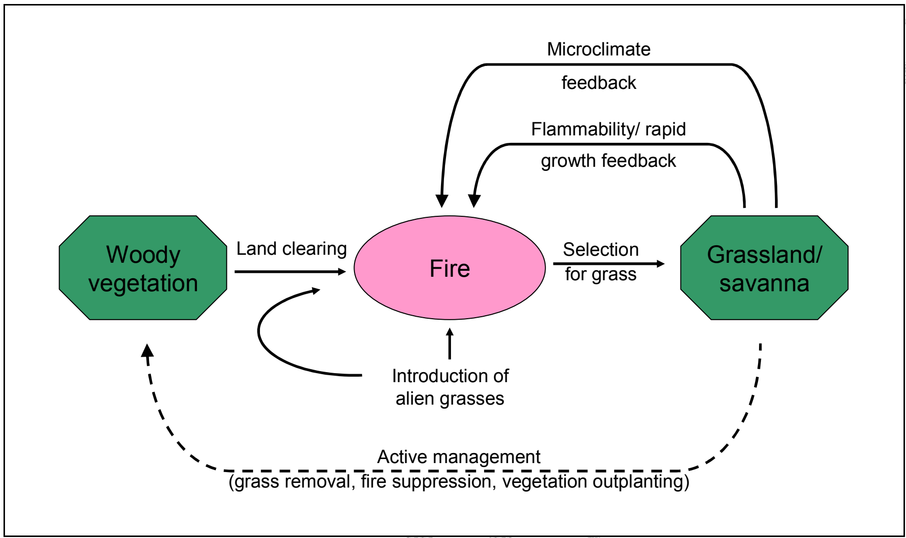



*Figure 2.11: Conceptual illustration of alien grass invasion and fire frequency (modified from D`Antonio & Vitousek 1992).*

In an ecosystem originally dominated by woody vegetation, both land clearing and introduction of alien grasses can lead to an increase in fire occurrence and intensity. Fire leads in turn to a transition to a grassland or savanna ecosystem. This new ecological state is then maintained by ecological feedbacks promoting the continuance of frequent fires (D`Antonio & Vitousek 1992). A transition from the new state (grassland or savanna) to the previous state (woody vegetation) can only be effected by an intensive program of management and restoration.

3. Water Quality Model

The water quality model (Figure 2.12) is intended to help distinguish causal relationships between natural resources, human activity, and water quality. It encompasses water quality for all resource types (fresh, marine, and ground water), so represents a broad illustration of aquatic systems. The relative importance of issues and weight of effects are not demonstrated in the water quality conceptual diagram, but may be added later or used in more detailed models of specific water body types. Development of this model will help to promote expansion of resource conservation from traditional values of human health concerns to include resource sustainability.

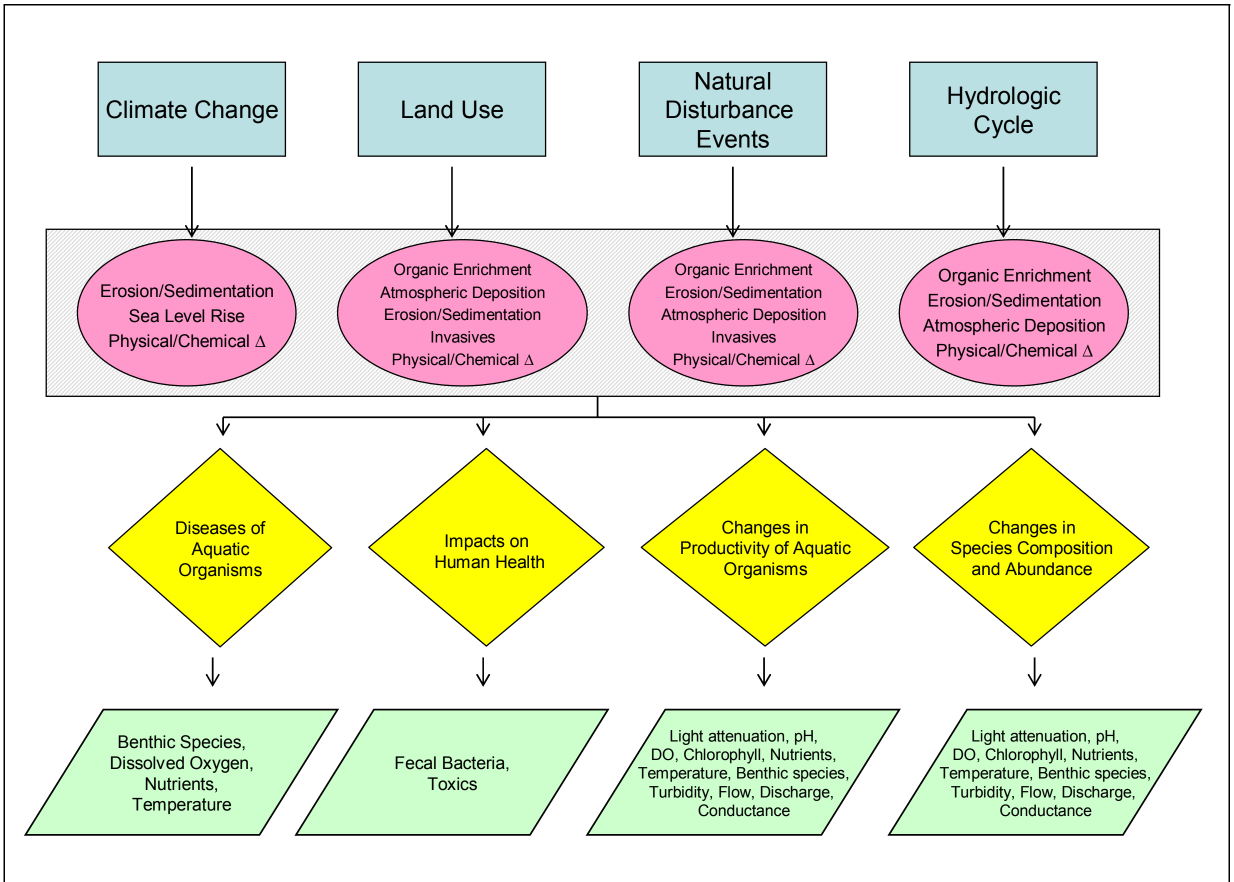



*Figure 2.12: PACN Water Quality model, including marine, surface, and ground water. Rectangles represent drivers, ovals represent stressors, diamonds represent ecological effects of stressors, and parallelograms represent ecological measures.*

In this model, drivers occur independently of one another, but may operate simultaneously, magnifying the effect of associated stressors on the ecosystem. In the water quality model, they include climate change, human use (including both terrestrial and aquatic activities), natural disturbance events, and the hydrologic cycle. Multiple stressors are mediated by a complex set of linkages, as system-specific stressors trigger a suite of ecosystem responses (Cloern 2001). This interaction between stressors and ecosystem responses is indicated in the conceptual model by the inclusion of the stressors in a single box, which then induces several categories of ecological effects. The model endpoints are various ecological measures which can be used to indicate ecological effects.

# Chapter 3. Prioritization and Selection of Vital Signs

Vital Signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes). Because of the need to maximize the use and relevance of monitoring results for making management decisions, vital signs selected by parks may include elements that were selected because they have important human values (e.g., harvested or charismatic species) or because of some known or hypothesized threat or stressor/response relationship with a particular park resource.

Within the definition outlined above, we identified Vital Signs that addressed the following broad categories:

- Ecosystem drivers that fundamentally affect park ecosystems.
- Stressors or threats and their ecological effects.
- Focal resources of parks.
- Key properties and processes of ecosystem integrity.

## A. Identifying, Organizing, and Refining Vital Signs

Vital Signs were initially identified by the various topical working groups in 2003. These initial Vital Signs were differentiated by formulating a monitoring question or questions, articulating related management goal(s), and suggesting methods of measurement for each Vital Sign.

The initial Vital Signs were refined at several points, and the ecological organization and monitoring objectives outlined in Chapter 1, Sections C & E were used to structure the Vital Signs. The process of organizing Vital Signs and reviewing monitoring objectives helped identify areas of overlap as well as gaps in the initial list of Vital Signs, and appropriate additions or deletions were made

## B. Vital Sign Priorities

Vital Signs were initially ranked by each park based on 4 individual criteria (ecological significance, management significance, legal mandate, and cost-effectiveness). Within each Vital Sign, the rankings for the individual criteria were weighted 30% ecological significance, 30% management significance, 20% legal mandate, and 20% cost-effectiveness (Table 3.1). When combined, these weighted priorities provide an overall rank for each Vital Sign (both across all 11 parks in the network, and for only those parks responding to a specific Vital Sign). For details about this prioritization approach see http://science.nature.nps.gov/im/monitor/docs/CriteriaExamples.doc, http://science.nature.nps.gov/im/monitor/docs/PrioritizationExample.doc, and Andreasen et al 2001, Kurtz et al 2001, and Tegler et al 2001.

*Table 3.1. Vital Sign ranking criteria.*

| CRITERIA (Weight) | SUB-CRITERIA | PRIORITIZATION SCHEME |
|---|---|---|
| **Management Significance (30%)** | * There is an obvious, direct application of the data to a key management decision, or for evaluating the effectiveness of past management decisions.<br>* The Vital Sign will produce results that are clearly understood and accepted by park managers, other policy makers, research scientists, and the general public, all of whom should be able to recognize the implications of the Vital Sign's results for protecting and managing the park's natural resources.<br>* Data are badly needed to give managers a better understanding of park resources so that they can make informed decisions.<br>* Monitoring results are likely to provide early warning of resource impairment, and will save park resources and money if a problem is discovered early.<br>* In addition to addressing a specific management decision, data provide information that strongly support other management decisions.<br>* Data are of high interest to the public.<br>* There is an obvious, direct application of the data to performance (GPRA) goals. | VERY HIGH: Strongly agree with all 7 of the statements above.<br>HIGH: Strongly agree with 6 of the statements above.<br>MODERATE: Strongly agree with 5 of the statements above.<br>LOW: Strongly agree with 4 of the statements above.<br>VERY LOW: Strongly agree with 3 of the statements above.<br>NONE: Strongly agree with 2 or fewer of the statements above. Or no opinion.<br>NULL (N/A): Does not apply. !!Vital Sign will not be scored for this Park!! |
| **Ecological Significance (30%)** | * There is a strong, defensible linkage between the Vital Sign and the ecological function or critical resource it is intended to represent.<br>* The Vital Sign represents a resource or function of high ecological importance based on the conceptual model of the system and the supporting ecological literature.<br>* Data from the Vital Sign are needed by the parks to fill gaps in current ecological knowledge.<br>* The Vital Sign provides early warning of undesirable changes to important resources. It can signify an impending change in the ecological system.<br>* The Vital Sign has a high signal to noise ratio and does not exhibit large, naturally occurring variability.<br>* The Vital Sign is sufficiently sensitive; small changes in the Vital Sign can be used to detect a significant change in the target resource or function.<br>* Reference conditions exist within the region, and/or threshold values are specified in the available literature that can be used to measure deviance from a desired condition.<br>* The Vital Sign complements Vital Signs at other scales and levels of biological organization. | VERY HIGH: Strongly agree with all 8 of the statements above<br>HIGH: Strongly agree with 7 of the statements above<br>MEDIUM: Strongly agree with 6 of the statements above<br>LOW: Strongly agree with 5 of the statements above<br>VERY LOW: Strongly agree with 4 of the statements above<br>NONE: Strongly agree with 3 or fewer of the statements above. Or no opinion.<br>NULL (N/A): Does not apply. !!Vital Sign will not be scored for this Park!! |
| **Legal/Policy Mandate (20%)** | This criterion is part of 'Management Significance' but is purposely duplicated here to emphasize those Vital Signs and resources that are required to be monitored by some legal or policy mandate. The intent is to give additional priority to a Vital Sign if a park is directed to monitor specific resources because of some binding legal or Congressional mandate, such as specific legislation and executive orders, or park enabling legislation. The binding document may | VERY HIGH:The park is required to monitor this specific resource/Vital Sign by some specific, binding, legal mandate (e.g., Endangered Species Act for an endangered species, Clean Air Act for Class 1 airsheds), or park enabling legislation.<br>HIGH: The resource/Vital Sign is specifically covered by an Executive Order (e.g., invasive plants, wetlands) or a specific Memorandum of Understanding signed by the NPS (e.g., bird monitoring), as well as by the Organic Act, other general legislative or Congressional mandates, and NPS Management Policies.<br>MODERATE:There is a GPRA goal specifically mentioned for the resource/Vital Sign being monitored, or the need to monitor the resource is generally indicated by some type of federal or state law as well as by the Organic Act and other general legislative mandates and NPS Management Policies, but there is no specific legal mandate for this particular resource.<br>LOW:The resource/Vital Sign is listed as a sensitive resource or resource of concern by credible state, regional, or local conservation agencies or organizations, but it is not specifically identified in any legally-binding federal or state legislation. The resource/Vital Sign is also covered by the Organic Act |

| CRITERIA (Weight) | SUB-CRITERIA | PRIORITIZATION SCHEME |
|---|---|---|
| | be with parties at the local, state, regional, or federal level. | and other general legislative or Congressional mandates such as the Omnibus Park Management Act and GPRA, and by NPS Management Policies.<br>VERY LOW: The resource/Vital Sign is covered by the Organic Act and other general legislative or Congressional mandates such as the Omnibus Park Management Act and by NPS Management Policies, but there is no specific legal mandate for this particular resource.<br>NONE: There is no legal mandate for this particular resource/Vital Sign.<br>NULL (N/A): Does not apply. !!Vital Sign will not be scored for this Park!! |
| **Cost Effectiveness and Feasibility (20%)** | * Sampling and analysis techniques are cost-effective. Cost-effective techniques may range from relatively simple methods applied frequently or more complex methods applied infrequently (e.g., data collection every five years results in low annual cost)<br>* The Vital Sign has measureable results that are repeatable with different, qualified personnel.<br>* Well-documented, scientifically sound monitoring protocols already exist for the Vital Sign<br>* Implementation of monitoring protocols is feasible given the constraints of site accessibility, sample size, equipment maintenance, etc.<br>* Data will be comparable with data from other monitoring studies being conducted elsewhere in the region by other agencies, universities, or private organizations.<br>* The opportunity for cost-sharing partnerships with other agencies, universities, or private organizations in the region exists. | VERY HIGH: Strongly agree with all 6 of the statements above.<br>HIGH: Strongly agree with 5 of the statements above.<br>MEDIUM:Strongly agree with 4 of the statements above.<br>LOW:Strongly agree with 3 of the statements above.<br>VERY LOW:Strongly agree with 2 of the statements above.<br>NONE:Strongly agree with 1 or fewer of the statements above. No opinion, or did not score this attribute<br>NULL (N/A): Does not apply. !!Vital Sign will not be scored for this Park!! |

Following the Vital Signs Workshop (March 2004), the parks revisited the rankings based upon feedback received. These adjusted Vital Sign rankings are presented in Table 3.2 below. A MSAccess database with complete rankings for all Vital Signs (for individual parks, as well as for the network as a whole) is also available at http://www.nature.nps.gov/im/units/pacn/monitoring/plan/vs04/review_materials.htm and in the Vital Signs Workshop summary report. (THIS POST-WORKSHOP REVISION OPPORTUNITY HAS NOT YET OCCURRED, WILL BE COMPLETED AFTER MARCH 2004).

*Table 3.2. PACN Vital Signs and priorities (handouts at the Vital Sign Workshop on 16-18 March 2004 will include this table, with priorities in an easier-to-read format).*

| Ecological Characteristic | Vital Sign Category | Monitoring Objectives | VitalSign Subcategory | Vital Sign | Management Goal | Monitoring Question(s) | Vital Sign Rank |
|---|---|---|---|---|---|---|---|
| Human activities & cultural practices | Soundscapes | Monitor sound sources, frequencies, occurrence, and levels | Soundscape | Alien, Natural, Human Soundscapes | Maintain natural sounds, limit/eliminate alien or human sounds as appropriate to mgmt zones (incl. outside of human audible range) | Are alien species sounds appropriate to management zone? Are naturally present sounds maintained at appropriate frequencies, occurrence, db levels? | |
| | Viewscapes / Lightscapes | Monitor visibility | Viewscape | Visibility | Maintain depth of visibility (marine & terrestrial) | Is sight distance, extinction, and quality reduced? | |
| | | Monitor landscape / seascape appearance | Viewscape | Viewsheds | Maintain historical viewsheds | Are landscapes/seascapes changing? | |
| | | Monitor light levels and characteristics of light / dark cycles | Viewscape | Lightscape, Nightsky, Visibility | Naturally occurring light/dark cycles continue, the prevalence of artificial light minimized | Are natural light/dark cycles maintained as appropriate (eg no inappropriate shading, etc)? Is artificial light restricted to basic human safety needs only? | |
| | Land Use | Monitor points of entry for invasive species | Invasive Species | Points of Entry | Provide early warning of incipient invasions, prevent when possible | What are points of entry for invasive species, ALL taxa? What species are being introduced--reaching the islands? | |
| | | Monitor water use adjacent to or upstream from park boundaries | Water Use | Contemporary Water Use(s) Surrounding Parks | Establish a baseline, track changes, and anticipate future stresses | Which resources are most at risk due to conflicting water uses (withdrawals, diversions, inputs)? | |
| | | Monitor land use adjacent to, or upstream of, park boundaries | Land Use | Contemporary Land Use(s) Surrounding Parks | Establish a baseline, track changes, and anticipate future stressors | What areas are most at risk due to conflicting adjacent changes in land use (e.g. ranching, urbanization)? | |
| | Park Use & Activities | Monitor debris-trash occurrence in coastal, riparian, wetland, and lacustrine habitats; in or near high use areas | Human use | Litter/debris | Reduce or eliminate sources of litter & debris | What are levels of litter within parks? Where is littering/ dumping of trash taking place? What are areas of marine debris deposition? | |
| | | Monitor patterns of park visitation, use & damage (terrestrial & marine) | Human Use | Marine Recreational Activities & Groundings / Anchor Damage | Minimize impacts, maintain natural conditions | Are use levels changing? What are trends? | |
| | | | Human Use | Footprint & Visitor Use Patterns | Maintain human use levels w/appropriate impact-intensities | Are locations and/or intensity in use areas (visitor or management) changing? Are use levels associated w/detectable levels of resource change? | |
| | | | Land Use | Effects of Disturbance from Subsistence Farming / Agriculture | Establish a baseline for future evaluation of impacts; protect primary and secondary forest | What areas are affected by subsistence farming and how are these practices modifying plant communities? | |
| | | Monitor incidence & occurrence of bioprospecting | Human Harvest | Bio-prospecting Harvest | Maintain natural conditions and processes | Are harvest levels changing? What are trends? Is human harvest changing distribution, abundance, or other population characteristics? What are current trends (research activities) in bioprospecting. | |
| | | Monitor levels of take & harvest of harvested species (marine, freshwater, and terrestrial) or resources (coral, sand) | Human Harvest | Coral/Sand Mining Harvest | Maintain natural conditions and processes | Are harvest levels changing? What are trends? | |
| | | | Human Harvest | Culturally Significant Plant Harvest | Determine policy and limits for harvesting, sustain population levels | What impact does gathering of plant materials by humans have on harvested populations? | |
| | | | Human Harvest | Culturally Significant Vertebrate Species | Determine policy and limits for harvesting, sustain population levels | Is human harvest changing distribution, abundance or other population characteristics? Can there be a balance between management goals of sustaining population numbers and culturally important species? | |
| | | | Human Harvest | Reef Fisheries Harvest | Determine policy and limits for harvesting, sustain population levels | Are harvest levels changing? What are trends? Is human harvest changing distribution, abundance, or other population characteristics? Harvest includes legal and illegal take. | |
| | Management Zones | Monitor patterns and effects of use and management | Human Use | Management Zone uses | Maintain human use levels and types w/in appropriate management zones and with appropriate impact-intensities | Are locations, extent and/or intensity in use areas (visitor or management) changing? Are use levels associated w/detectable levels of resource change? | |
| | | Monitor effects of management practices on wilderness character | Wilderness | HAVO, HALE, other Unofficial Wilderness Areas | Ensure management actions and visitor impacts on resources and character do not exceed standards and conditions (potential or designated wilderness) | Monitor to identify the need for, or effects of, management actions | |
| Physical / Chemical Environment | Climate & Air Quality | Track rates of atmospheric deposition | Atmospheric conditions | Deposition: Wet (direct & occult) and Dry | Maintain natural deposition processes and levels | Document differences in Human vs. Volcanic vs. other natural sources | |
| | | Track atmospheric concentrations of particulates and gases, levels of radiation—emphasizing those with known human health or environmental impacts | Atmospheric conditions | Gases: Climate Change Indicators, Human Pollutants, Natural-Volcanic | Understand and track how gases affect: Air Quality, Viewscapes, Odors, Public Safety, Physical Processes, Vegetation & Fauna, etc. Monitor volcanic activity and air quality patterns | How are atmospheric gas concentrations changing and are these changes having ecological or human health impacts? How does volcanic activity influence air quality? | |
| | | | Atmospheric conditions | Marine Aerosols | Maintain natural levels of aerosol influence on landscape | How do marine aerosol levels vary over time and space? | |

| Ecological Characteristic | Vital Sign Category | Monitoring Objectives | VitalSign Subcategory | Vital Sign | Management Goal | Monitoring Question(s) | Vital Sign Rank |
|---|---|---|---|---|---|---|---|
| | | | Atmospheric conditions | Particulates: Climate Change Indicators, Human Pollutants, Natural-Volcanic | Distinguish between human and volcanic sources (incl. catalysts). Track levels for potential effects on human health and nutrient budgets | How are atmospheric particulate species and concentrations changing and are these changes having ecological or human health impacts? | |
| | | | Atmospheric conditions | Solar radiation | Track basic sources of energy input affecting photosynthesis, and other potential impacts such as coral bleaching, genetic mutations, etc | How are solar radiation inputs, UV-B, photosynthetically active radiation, or other wavelengths, fluxes changing? | |
| | | Monitor core weather/climate conditions within each park (on each island) | Weather / Precipitation | Core climate variables | Understand weather & climate conditions within parks | What are ranges of climate parameters within each park? Are they changing? | |
| | | Monitor frequency and intensity (severity) of extreme events (hurricanes, waves, winds, rain, etc.) | Climate | Extreme events (weather & ocean) | Understand & predict effects of extreme events on parks | What are impacts of extreme events? How often do they occur, and at what intensity? What are temporal trends? | |
| | | Identify and monitor spatial patterns of climate, such as trade-wind inversion elevation, lifting cloud level, lapse rates, etc. | Climate-spatial patterns | 2-D and 3-D Climate Representations | Track variations in climate across the landscape (2 & 3 dimensions) | Provide baseline data to help evaluate stability and variability in climate affecting natural populations, processes, and large scale ecological drivers? | |
| | Soil, Water, & Nutrient Dynamics | Monitor cycles of nutrients and elements within soils and water--including carbonate (oceanic), nitrogen, and phosophorous | Biogeochemical Cycles | Nutrient Cycling | Maintain ecological processes at fundamental levels | How are fluctuations changing over time (sounrce, directions, levels of flow)? | |
| | | Monitor soil erosion | Soils | Soil Erosion | Understand patterns of soil erosion, minimize effects on resources | What are causes and locations of soil erosion? | |
| | | Monitor soil quality trends (physical, toxics/contaminants, other biologic and nutrients) | Soils | Soil Quality - Biological | Identify trends in soil quality and evaluate potential for climate change analysis | Are soil communities changing? | |
| | | | Soils | Soil Quality- Chemical | Identify trends in soil quality and evaluate potential for climate change analysis | Are soil buffering and filtering qualities changing? | |
| | | | Soils | Soil Quality- Physical | Identify trends in soil quality and evaluate potential for climate change analysis | Are physical soil properties changing? | |
| | | Monitor condition and extent of soil crusts | Soils | Soil Crust Change (Arid-Semiarid habitats) | Document change and analyze for trend | What are pressures/impacts on soil crusts, and how are they distributed in space and time? | |
| | | Monitor trends in surface water flow regimes | Hydrology | Flowing surface water | Understand patterns in surface water flow regimes & stream dynamics | What are usual rates & range of flow? What is timing & magnitude of floods or droughts? Is erosion occuring, or are flow channels changing? | |
| | | Monitor wetland (incl. anchialine ponds) water flow exchange dynamics, size, and distribution | Hydrology | Wetlands (incl. anchialine pools) | Understand patterns in water flow and recharge in surface features associated w/groundwater | What are freshwater/saltwater recharge rates? What is habitat extent? What are temporal trends in recharge rates and habitat extent? | |
| | | Monitor ground water flow rates and direction of movement (recharge) | Hydrology | Groundwater dynamics | Understand patterns & rates of flow in subsurface groundwater resources | What are rates of subsurface flow? What is level of freshwater/saltwater mixing? What are flow patterns? | |
| | | Monitor physical ocean dynamics—ocean currents, sea level, tides/swell | Hydrology | Ocean/Physical Dynamics: Currents, Sea Level, Tides/Swell | Document variations, identify when conditions are outside normal ranges | If variation is not within normal range? What are temporal trends? | |
| | Water Quality | Monitor water quality core parameters | Ground Water Quality | Core parameters | Keep systems within the normal range of variance, unimpacted by human uses | If variance is not within the normal range, why not? | |
| | | | Marine Water Quality | Core parameters | Keep systems within the normal range of variance, unimpacted by human uses | If variance is not within the normal range, why not? | |
| | | | Surface Water Quality | Core parameters | Keep systems within the normal range of variance, unimpacted by human uses | If variance is not within the normal range, why not? | |
| | | Monitor supplemental water quality parameters | Ground Water Quality | Supplemental parameters | Keep systems within the normal range of variance, unimpacted by human uses | If variance is not within the normal range, why not? | |
| | | | Marine Water Quality | Supplemental parameters | Keep systems within the normal range of variance, unimpacted by human uses | If variance is not within the normal range, why not? | |
| | | | Surface Water Quality | Supplemental parameters | Keep systems within the normal range of variance, unimpacted by human uses | If variance is not within the normal range, why not? | |
| | | Monitor microbiological water quality parameters | Ground Water Quality | Microbiology | Keep systems within the normal range of variance, unimpacted by human uses and safe for human use | If variance is not within the normal range, why not? | |

| Ecological Characteristic | Vital Sign Category | Monitoring Objectives | VitalSign Subcategory | Vital Sign | Management Goal | Monitoring Question(s) | Vital Sign Rank |
|---|---|---|---|---|---|---|---|
| | | | Marine Water Quality | Microbiology | Keep systems within the normal range of variance, unimpacted by human uses and safe for human use | If variance is not within the normal range, why not? | |
| | | | Surface Water Quality | Microbiology | Keep systems within the normal range of variance, unimpacted by human uses and safe for human use | If variance is not within the normal range, why not? | |
| | | Monitor toxic and contaminant levels in water | Ground Water Quality | Toxics & contaminants | Keep systems within the normal range of variance, unimpacted by human uses and safe for human use | If variance is not within the normal range, why not? | |
| | | | Marine Water Quality | Toxics & contaminants | Keep systems within the normal range of variance, unimpacted by human uses and safe for human use | If variance is not within the normal range, why not? | |
| | | | Surface Water Quality | Toxics & contaminants | Keep systems within the normal range of variance, unimpacted by human uses and safe for human use | If variance is not within the normal range, why not? | |
| | | Monitor biological invertebrate communities | Marine Water Quality | Benthic macroinvertebrates | Monitor benthic macroinvertebrate communities as biological indicators. | What are community dynamics of marine & estuarine sediment communities? | |
| | | | Surface Water Quality | Benthic macroinvertebrates | Monitor benthic macroinvertebrate communities as biological indicators. | What are community dynamics of benthic freshwater communities? | |
| | Geology: Hazards | Monitor surface volcanic activity (lava flows, eruption events & ground deformation) | Volcanic Unrest | Ground Deformation | Monitor volcanic activity and ground deformation patterns | What role does volcanic activity and deformation play in maintaining public safety, park facilities, and how do they affect natural processes? | |
| | | | Volcanic Unrest | Lava Flows | Monitor activity; model risks/hazards | What role do lava flows play in maintaining public safety, park facilities, and how do they affect natural processes? | |
| | | Monitor volcanic & non-volcanic seismicity | Seismicity | Seismicity of Non-Volcanic Origin | Monitor activity; model risks/hazards | Can we identify trends and predict hazards? | |
| | | | Seismicity | Seismicity of Volcanic Origin | Monitor activity; model risks/hazards | Can we identify trends and predict hazards? | |
| | | Monitor extent, location, and causes of mass wasting events (e.g. landslides) | Mass Wasting | Mass Geologic Wasting | Document and measure events. Identify threats to habitats, water resources, and humans. | Can we predict slope failure hazards to protect habitats and human safety? Can we monitor or identify causes? What are temporal trends? | |
| | Geology: Landforms | Monitor shoreline dynamics | Erosion / Accretion | Coastal Shoreline Change | Document change and analyze for trends | Where are shorelines advancing, retreating, or stable? | |
| | | Track dune locations and topography | Erosion / Accretion | Dune Change | Monitor dune formation/reactivation and wind erosion patterns | Are drought & desertification influencing topsoil transport and seed/nutrient transport patterns? | |
| | | Identify and monitor the extent of permafrost | Permafrost | Permafrost on Big Island summits | Monitor changes in permafrost | Is extent of permafrost declining? Influence on ground subsidence, slope failure, etc? | |
| | | Monitor karst and non-karst cave and lava tube habitat characteristics, topography, and extent | Caves | Environmental conditions | Ensure integrity of cave systems by maintaining environmental habitats as well as cultural uses and resources | Are cave systems impacted and changing as a result of above ground changes or human activity & cultural practices? Are environmental conditions in caves changing (temp, humidity, light, etc.)? | |
| | | | Caves | Geology: non-karst | Document changes in resource, ensure public safety | What are patterns of mineral accretion? Where & when are collapse/skylight formation or enlargement occuring? | |
| | | | Caves | Geology: karst | Determine trends in karst systems -- growth of caves, declines in groundwater quality, etc. | Are changes in karst systems leading to potential bedrock collapse, well yield disparities, poor groundwater quality, soil instability? | |
| Biotic Integrity | Freshwater Ecosystems: Producers | Monitor community composition, structure, and productivity | Producers | Community dynamics | Understand community composition, productivity, and structure, maintain natural communities | What species & groups are present? What are normal rates of productivity? Where are algal blooms present? | |
| | Freshwater Ecosystems: Consumers: Community | Monitor community dynamics, structure, function, and composition | Biodiversity | Aquatic and Riparian Species (vertebrate and invertebrate) | Early detection of losses and changes in natural biodiversity | Are there long-term changes in selected aquatic native communities? | |
| | Freshwater Ecosystems: Consumers: Population | Monitor disease incidence and impacts, especially on native species | Disease / Pathogens | Disease Impacts to Freshwater Animals | Detect and reduce incidence of disease and pathogens, including parasites. | What is the incidence and level of disease in populations? Are diseases/pathogens affecting populations? What are trends in disease/pathogen? | |
| | | Monitor population distribution and demographics (size/age structure, reproduction, recruitment, etc.), including response to restoration efforts | Native, Focal, or Endemic Taxa | Amphidromous Fauna Size-Age Structure, Reproduction and Recruitment | Variance within normal range, reproduction and recruitment at normal levels | If variance is not within normal range, why not? What are selected short- and long-term trends? Is recruitment at normal levels? | |

| Ecological Characteristic | Vital Sign Category | | | Monitoring Objectives | VitalSign Subcategory | Vital Sign | Management Goal | Monitoring Question(s) | Vital Sign Rank |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Monitor extent and response to treatment of established invasive species | Alien species - Established | Predatory Freshwater Invasives (vertebrate and invertebrate) | Minimize impacts of alien and invasive species on natural system function; eradication; prevent re-introduction, evaluate effects of management | What is the extent of present infestations? What is the impact of predatory invasive species on native species abundance and distribution? What are effective management strategies for invasive species removal? | |
| | | | | Monitor occurrence of non-established (incipient) invasive species | Alien species - Incipient | Predatory Freshwater Invasives (vertebrate and invertebrate) | Minimize impacts of alien and invasive species on natural system function; early detection, prevent establishment, eradicate, or contain | Is species present, if so what is the nature and extent of infestation? What are the most effective strategies for detecting and preventing new invasives species? Where should efforts be focused? What are potential impacts? | |
| | Terrestrial Ecosystems | Vegetation | Landscape | Monitor patterns of distribution & extent of community types | Landscape History | Soil and Pollen | Document the paleo-historical landscapes still present | Are intact paleo landscapes being altered? | |
| | | | | | Landscape | Ecozone Boundaries | Document and track stable vs dynamic terrestrial ecozone boundaries | Are locations of ecotones changing? Are the communities that comprise ecological boundary zones changing? | |
| | | | | | Landscape Level Change | Vegetation: Fragments, Patch Size, Land Cover | Determine landscape level management strategies | How are the distributions of plant communities and land cover inside and immediately outside the Parks changing over time? | |
| | | | | Monitor fire regimes and effect on vegetation | Fire Dynamics | Fire Effects: Vegetation and Landscape Level | Determine appropriate fire management policy, incl. alien plant species control and native plant restoration needs | What is a natural fire frequency? What changes in plant community composition and structure result from fire? What are the biogeochemical effects of fire? | |
| | | | | Track insect and disease presence during forest dieback | Landscape | Forest Dieback | Distinguish between natural and alien-induced dieback; control alien instigators where dieback is not natural. | What percentage of trees in a populations is declining or dying? What proportion are dying by natural vs. non-native influences? What are temporal trends? | |
| | | | Community | Monitor community dynamics, structure, function, and composition | Biodiversity | Terrestrial Plants | Early detection of losses and changes in natural biodiversity | Are there detectable short-term changes in selected native plant communities? | |
| | | | | | Community Dynamics, Structure, and Succession | Long-term Plant Succession | Determine management needs and strategies; Recognize previously unidentified threats | What are long-term trends in plant community composition and structure, regardless of management treatment or land use? | |
| | | | | Monitor effects of management on native communities | Community Dynamics, Structure, and Succession | Recovery/Change of Native Vegetation with Alien Plant Control | Adaptive management with evaulation of trends in vegetation recovery following removal of alien plants | What are trends in plant community composition and structure in response to alien plant control treatments? | |
| | | | | | Community Dynamics, Structure, and Succession | Recovery/Change of Native Vegetation with Feral Ungulate Control | Evaluate management success and determine need for further efforts | What are trends in plant community composition and structure after removal or sustained control of feral ungulates? Are habitats damaged by alien ungulate species restorable? | |
| | | | | | Community Dynamics, Structure, and Succession | Recovery/Change of Native Vegetation with Invasive Alien Invertebrate Control | Evaluate management success and determine need for further efforts | Are native plant species recovering where invasive invertebrates are controlled? What are trends in plant community composition and structure following invasive invertebrate control? | |
| | | | Population | Monitor effects of biocontrol on native and invasive species | Biocontrol | Invertebrate Biocontrol of Plants | Evaluate success in biocontrol efforts using invertebrates, effects on target & non-target plants | What is the long-term impact/efficacy on populations of blackberry, passionflower, & other pests? Are non-target plants, especially natives, being affected? | |
| | | | | | Biocontrol | Plant Pathogen Biocontrol of Plants | Evaluate success in biocontrol efforts using pathogens, minimize non-target impacts | What is the impact/efficacy on populations of control target? Are non-target species being attacked? | |
| | | | | Monitor population distribution and demographics (size/age structure, reproduction, recruitment, etc.), including response to restoration efforts | T, E, S-o-C species | Native Plant Species | Determine need for management; Develop and implement recovery strategies | What are the distribution, abundance, and demographics of threatened, endangered, and rare native plant species?Are plant populations reproducing at self-sustaining levels? | |
| | | | | Monitor disease incidence and impacts, especially on native species | Disease/Pathogens | Disease Impacts to Terrestrial Plants | Detect and reduce incidence of disease and pathogens | What is the incidence and level of disease in populations? Are diseases/pathogens affecting populations? What are trends in disease/pathogen? | |
| | | | | | Disease/Pathogens | Incipient Plant Disease | Prevent disease occurrence or minimize impact within park. | Where are disease locations outside parks? What species are they affecting? What are rates and directions of spread? Identify existing disease/pathogen incidence, impact, and trends? | |
| | | | | Monitor extent and response to treatment of established invasive species | Alien species - Established | Invasive Plant Species | Determine need and feasibility of control; Determine efficacy of control | What is the distribution and abundance of established alien plants? What is the rate of spread of alien plants? | |
| | | | | Monitor occurrence of non-established (incipient) invasive species | Alien species - Incipient | Invasive Plants | Minimize impacts of alien and invasive species on natural system function; early detection, prevent establishment, eradicate, or contain | Is species present, if so what is the nature and extent of infestation? What are the most effective strategies for detecting and preventing new invasives species? Where should efforts be focused? What are potential impacts? | |

| Ecological Characteristic | Vital Sign Category | | | Monitoring Objectives | VitalSign Subcategory | Vital Sign | Management Goal | Monitoring Question(s) | Vital Sign Rank |
|---|---|---|---|---|---|---|---|---|---|
| | | Consumers | Community | Monitor community dynamics, structure, function, and composition | Biodiversity | Terrestrial Invertebrates | Maintenance of endemic biodiversity | What are trends in distribution and abundance of hyper-diverse groups w/in parks? | |
| | | | | | Biodiversity | Terrestrial Vertebrates (including off-shore islets refugia) | Early detection of losses and changes in natural biodiversity | Are there long-term changes in selected native vertebrate communities? | |
| | | | | Monitor effects of management on native communities | Community Dynamics, Structure, and Succession | Recovery/Change of Native Invertebrates with Native Plant Restoration | Restoration of full ecosystem function to areas of restored native vegetation | What native species are recolonizing restored areas? Which ones are not? | |
| | | | | | Community Dynamics, Structure, and Succession | Recovery/change of Native Wildlife habitats (including wetlands) with restoration of native vegetation | Evaluate management success and determine need for further efforts. Restore altered habitat to original state. | What are trends in plant community composition and structure resulting from outplanting and seed-sowing activities? What is the response of native vertebrate and invertebrate populations to plant community restoration? What are priority plant species that should be restored? | |
| | | | Population | Monitor effects of biocontrol on native and invasive species | Biocontrol | Invertebrate Biocontrol of Invertebrates | Minimize undesired impacts of invertebrate biocontrol species on natives, evaluate efficacy of target control | What is the impact of biocontrol agents on native moths, beetles, & parasitoids? What is the impact/efficacy on target populations? | |
| | | | | Monitor population distribution and demographics (size/age structure, reproduction, recruitment, etc.), including response to restoration efforts | Native, Focal, or Endemic Taxa | Forest Birds and Bats (includes T & E spp.) | Maintain and/or increase populations to viable levels | Are distribution, abundance, other population characteristics, or habitat changing? Determine population levels over time. | |
| | | | | | Native, Focal, or Endemic Taxa | Herps | Maintain and/or increase populations to viable levels | Are distribution, abundance, other population characteristics, or habitat changing? Determine population levels over time. | |
| | | | | | Native, Focal, or Endemic Taxa | Invertebrate Charismatic or Species of Concern | Maintain populations and natural systems (e.g. decomposition, pollination, plant & invertebrate community structure) that depend on them | Are distribution, abundance, other population characteristics, or habitat changing? Determine population levels over time. | |
| | | | | | Native, Focal, or Endemic Taxa | Seabirds (including T & E spp.) | Maintain and/or increase populations to viable level | Are distribution, abundance, other population characteristics, or habitat changing? Determine population levels over time. | |
| | | | | | Native, Focal, or Endemic Taxa | Shorebirds and Waterbirds (including T & E spp.) | Maintain and/or increase populations to viable level | Are distribution, abundance, other population characteristics, or habitat changing? Determine population levels over time. | |
| | | | | | Native, Focal, or Endemic Taxa | Terrestrial Invertebrates Associated with Habitat Quality | Maintain quality habitats, ensure restoration achieves desired quality. Persistence of species, pollination, recolonization. | What are trends in invertebrate indicator species? | |
| | | | | | T, E, S-o-C Species | Terrestrial Invertebrate Species Protection | Maintain populations, restore habitat | Are distribution, abundance, other population characteristcs, or habitat changing? | |
| | | | | Monitor disease incidence and impacts, especially on native species | Disease / Pathogens | Disease Impacts to Terrestrial Vertebrates | Detect and reduce incidence of disease and pathogens. Reduce sources of diseases (i.e. mosquitoes, imported alien birds, and pigs). | What is the incidence and level of disease in populations? Are diseases/pathogens affecting populations? What are trends in disease/pathogen? | |
| | | | | | Disease / Pathogens | Incipient Terrestrial Vertebrate Disease | Prevent disease occurrence or minimize impact within park. | Where are disease locations outside parks? What species are they affecting? What are rates and directions of spread? Identify existing disease/pathogen incidence, impact, and trends | |
| | | | | Monitor extent and response to treatment of established invasive species | Alien species - Established | Feral Ungulates | Eradication or control; Determine size of ungulate populations; Evaluate impacts of animals; Evaluate effectiveness of management | What are the relative abundance and population trends of feral ungulates? What are the impacts of feral ungulates? Is competition from invasive spp changing distribution, abundance, etc. of native spp.? | |
| | | | | | Alien species - Established | Invasive Terrestrial Invertebrate Pests of natural systems | Reduce or eliminate impact | How effective is control? What are the abundance, distribution, and seasonal and year-to-year variations in populations? What are trends in impact? | |
| | | | | | Alien species - Established | Predatory Terrestrial Vertebrate Invasives | Reduce or eliminate impacts to native species. Monitor trends in invasive species. | Are predators changing native plant and animal species abundance or distribution? What are trends in invasive species populations? | |
| | | | | | Alien Species - Established | Terrestrial Invertebrate Pests (agricultural) | Reduction or eradication of pests in parks, especially as associated w/culturally significant veg plantings | Monitor population fluctuations to determine when additional control actions are needed | |
| | | | | | Alien species - Established | Terrestrial Invertebrate Pests (human structures) | Reduce or eliminate impact | Characterize extent of impact invertebrate pests are having on historical and other culturally significant structures? | |
| | | | | Monitor occurrence of non-established (incipient) invasive species | Alien species - Incipient | Predatory Terrestrial Vertebrate Invasives | Minimize impacts of alien and invasive species on natural system function; early detection, prevent establishment, eradicate, or contain | Is species present, if so what is the nature and extent of infestation? What are the most effective strategies for detecting and preventing new invasives species? Where should efforts be focused? What are potential impacts? | |

| Ecological Characteristic | Vital Sign Category | | | Monitoring Objectives | VitalSign Subcategory | Vital Sign | Management Goal | Monitoring Question(s) | Vital Sign Rank |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Alien species - Incipient | Fungi | Minimize impacts of alien and invasive species on natural system function; early detection, prevent establishment, eradicate, or contain | Is species present, if so what is the nature and extent of infestation? What are the most effective strategies for detecting and preventing new invasives species? Where should efforts be focused? What are potential impacts? | |
| | | | | | Alien species - Incipient | Invasive Terrestrial Invertebrates | Minimize impacts of alien and invasive species on natural system function; early detection, prevent establishment, eradicate, or contain | Is species present, if so what is the nature and extent of infestation? What are the most effective strategies for detecting and preventing new invasives species? Where should efforts be focused? What are potential impacts? | |
| | | | | | Alien species - Incipient | Invasive Vertebrates | Minimize impacts of alien and invasive species on natural system function; early detection, prevent establishment, eradicate, or contain | Is species present, if so what is the nature and extent of infestation? What are the most effective strategies for detecting and preventing new invasives species? Where should efforts be focused? What are potential impacts? | |
| | | Cave Systems | Community | Monitor changes in cave communities | Community Dynamics, Structure, and Succession | Cave & lava tube communities | Ensure integrity of cave systems by maintain native communities & interactions | Are cave (biotic) communities changing? What are temporal trends? | |
| | Marine Ecosystems | Benthic (sessile) | Landscape | Monitor patterns of distribution & extent of community types | Erosion / Accretion | Coral Growth/Erosion | Maintain/Restore natural systems (hard bottom reefs) | Is net accretion or erosion occuring? What are spatial patterns? | |
| | | | | | Landscape Level Change | Benthic Communities | Determine landscape level management strategies | How are the distributions of benthic communities and coral/algal cover inside and immediately outside the Parks changing over time? | |
| | | | Community | Monitor community dynamics, structure, function, and composition | Biodiversity | Benthic Marine Invertebrates, and Algae | Early detection of losses and changes in natural biodiversity | Are there long-term changes in composition of selected native communities? | |
| | | | | | Community Dynamics, Structure, and Succession | Subtidal - Hard Bottom (coral reef, colonized basalt, etc.) | Maintain natural conditions with variance within normal range | If variance is not within normal range, why not? What are selected short- and long-term trends? | |
| | | | | | Community Dynamics, Structure, and Succession | Subtidal - Soft Bottom (sand flat, seagrass bed) | Maintain natural conditions with variance within normal range | If variance is not within normal range, why not? What are selected short- and long-term trends? | |
| | | | Population | Track community and population trends in harvested fisheries species | Native, Focal, or Endemic Taxa | Benthic Reef Fisheries | Prevent over-harvest. | What are effects of human harvest on fished or gathered species? | |
| | | | | Monitor population distribution and demographics (size/age structure, reproduction, recruitment, etc.), including response to restoration efforts | Native, Focal, or Endemic Taxa | Benthic Marine Invertebrates and Algae | Maintain populations within normal ranges of variation | Is population variation within normal range? What are population trends? | |
| | | | | | Native, Focal, or Endemic Taxa | Coral Growth/Size and Age Structure, and Recruitment | maintain natural conditions with variance within normal range | If variance is not within normal range? What are selected short- and long-term trends? | |
| | | | | Monitor disease incidence and impacts, especially on native species | Disease / Pathogens | Disease Impacts to Corals (including bleaching) | Detect and reduce incidence of disease and pathogens. | What is the incidence and level of disease in populations? Are diseases/pathogens affecting populations? What are trends in disease/pathogen? | |
| | | | | | Disease / Pathogens | Incipient Coral Disease | Prevent disease occurrence or minimize impact within park. | Where are disease locations outside parks? What species are they affecting? What are rates and directions of spread? Identify existing disease/pathogen incidence, impact, and trends | |
| | | | | Monitor extent and response to treatment of established invasive species | Alien species - Established | Benthic Marine Invasives | Minimize impacts of alien and invasive species on natural system function, eradication | Can we detect changing trends in alien and invasive species? What are effects of alien and invasive species on communities? What is response to treatment? | |
| | | | | Monitor occurrence of non-established (incipient) invasive species | Alien species - Incipient | Benthic Marine Invasives | Minimize impacts of alien and invasive species on natural system function; early detection, prevent establishment, eradicate, or contain | Is species present, if so what is the nature and extent of infestation? What are the most effective strategies for detecting and preventing new invasives species? Where should efforts be focused? What are potential impacts? | |
| | | Water column (motile) | Community | Monitor community dynamics, structure, function, and composition | Biodiversity | Water Column Marine Vertebrates and Invertebrates | Early detection of losses and changes in natural biodiversity | Are there long-term changes in selected native communities? | |
| | | | Population | Track community and population trends in harvested fisheries species | Native, Focal, or Endemic Taxa | Water Column Reef Fisheries | Prevent over-harvest. | What are effects of human harvest on fished or gathered species? | |
| | | | | Monitor disease incidence and impacts, especially on native species | Disease / Pathogens | Disease Impacts to Marine Animals (other than turtles) | Detect and reduce incidence of disease and pathogens, including parasites. | What is the incidence and level of disease in populations? Are diseases/pathogens affecting populations? What are trends in disease/pathogen? | |
| | | | | | Disease / Pathogens | Disease Impacts to Sea Turtles | Detect and reduce incidence of disease and pathogens. | What is the incidence and level of disease in populations? Are diseases/pathogens affecting populations? What are trends in disease/pathogen? | |

| Ecological Characteristic | Vital Sign Category | | | Monitoring Objectives | VitalSign Subcategory | Vital Sign | Management Goal | Monitoring Question(s) | Vital Sign Rank |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Monitor extent and response to treatment of established invasive species | Alien species - Established | Water Column Marine Invasives | Minimize impactsof alien and invasive species on natural system function, eradication | Can we detect changing trends in alien and invasive species? What are effects of alien and invasive species on communities? What is response to treatment? | |
| | | | | Monitor population distribution and demographics (size/age structure, reproduction, recruitment, etc.), including response to restoration efforts | Native, Focal, or Endemic Taxa | Water Column Marine Invertebrates and Fish | Variations within normal ranges | If variation is not within normal range? What are temporal trends? | |
| | | | | | Native, Focal, or Endemic Taxa | Fish Growth/Size and Age Structure, and Recruitment | Maintain natural conditions with variance within normal range | If variance is not within normal range? What are selected short- and long-term trends? | |
| | | | | | T, E, S-o-C species | Marine Species | Variations within normal ranges | If variation is not within normal range? What are temporal trends? | |
| | | | | Monitor occurrence of non-established (incipient) invasive species | Alien species - Incipient | Water Column Marine Invasives | Minimize impacts of alien and invasive species on natural system function; early detection, prevent establishment, eradicate, or contain | Is species present, if so what is the nature and extent of infestation? What are the most effective strategies for detecting and preventing new invasives species? Where should efforts be focused? What are potential impacts? | |
| | | Interidal (both) | Community | Monitor community dynamics, structure, function, and composition | Biodiversity | Intertidal Marine Vertebrates, Invertebrates, and Algae | Early detection of losses and changes in natural biodiversity | Are there long-term changes in selected native communities? | |
| | | | | | Community Dynamics, Structure, and Succession | Intertidal - Hard Bottom | Maintain natural conditions with variance within normal range | If vaiance is not within normal range, why not? What are selected short- and long-term trends? | |
| | | | | | Community Dynamics, Structure, and Succession | Intertidal - Soft Bottom (sand beach, mudflat, mangrove) | Maintain natural conditions with variance within normal range | If vaiance is not within normal range, why not? What are selected short- and long-term trends? | |
| | | | Population | Track community and population trends in harvested fisheries species | Native, Focal, or Endemic Taxa | Intertidal Reef Fisheries | Prevent over-harvest. | What are effects of human harvest on fished or gathered species? | |
| | | | | Monitor population distribution and demographics (size/age structure, reproduction, recruitment, etc.), including response to restoration efforts | Native, Focal, or Endemic Taxa | Intertidal Marine Invertebrates, Fish and Algae | Variations within normal ranges | If variation is not within normal range, why not? | |
| | | | | Monitor extent and response to treatment of established invasive species | Alien species - Established | Intertidal Marine Invasives | Minimize impactsof alien and invasive species on natural system function, eradication | Can we detect changing trends in alien and invasive species? What are effects of alien and invasive species on communities? What is response to treatment? | |
| | | | | Monitor occurrence of non-established (incipient) invasive species | Alien species - Incipient | Intertidal Marine Invasives | Minimize impacts of alien and invasive species on natural system function; early detection, prevent establishment, eradicate, or contain | Is species present, if so what is the nature and extent of infestation? What are the most effective strategies for detecting and preventing new invasives species? Where should efforts be focused? What are potential impacts? | |

With park staff ranking individual Vital Signs, priorities for the PACN reflect park staff understanding of each Vital Sign's management significance, ecological significance, legal/policy mandate, and cost effectiveness and feasibility. The criteria identified above are somewhat lengthy and required a significant time investment when ranking, many Vital Signs were in draft form at the time. The rankings identified are therefore tentative, and the network rankings are presented in this document as they reflect the combined input of park staff. Actual selection of Vital Signs will reflect a practical combination of inputs, including individual park priorities, using these rankings as a starting point for discussion. Figure 3.1 presents a visual schematic of how park, network, and regional or NPS-wide Vital Signs priorities may actually be reflected in implementation.

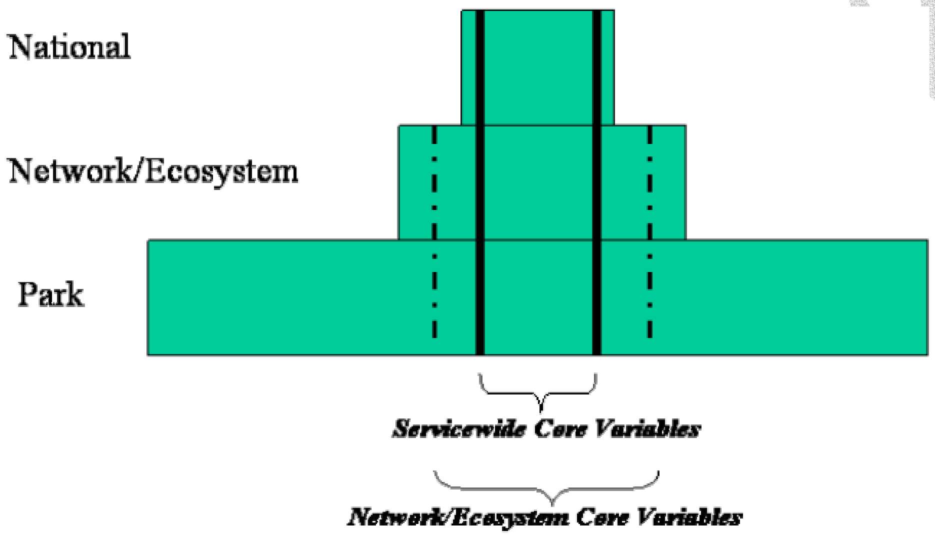



*Figure 3.1. Schematic of Vital Sign priorities and implementation at park, network, and regional or NPS-wide levels.*

## C. Selected Vital Signs

To be completed in Spring 2004.

### 1. Vital Sign Selection Criteria

To be completed in Spring 2004.

### 2. Selected Vital Sign Organization

To be completed in Spring 2004.

Figure 3.2. TENTATIVE—Selected Vital Signs within the framework of PACN ecological organization.

Figure 3.3. TENTATIVE—Selected Vital Signs within the framework of the PACN conceptual model.

Figure 3.4. TENTATIVE—Selected Vital Signs within the 4 broad categories of Vital Signs: 1) ecosystem drivers, 2) stressors or threats, 3) focal resources, 4) key properties and processes.

### 3. Brief Vital Sign Descriptions

To be completed in Spring 2004.

## D. Vital Signs Not Selected

To be completed in Spring 2004.

## Chapter 4. Sampling Design
Will be prepared in 2005

## Chapter 5. Sampling Protocols
Will be prepared in 2005

## Chapter 6. Data Management
Will be prepared in 2005

## Chapter 7. Data Analysis and Reporting
Will be prepared in 2005

## Chapter 8. Administration/Implementation of the Monitoring Program
Will be prepared in 2005

## Chapter 9. Schedule
Will be prepared in 2005

## Chapter 10. Budget
Will be prepared in 2005

## Literature Cited


Andreasen, J.K., O'Neill, R.V., Noss, R., and Slosser, N.C. 2001. Considerations for the development of a terrestrial index of ecological integrity. *Ecological Indicators*, 1: 21-35.

Chapin, F. S. III, Torn, M. S., and Tateno, M. 1985. Principles of ecosystem sustainability. *American Naturalist* 148: 1016-1037.

Cloern, J. E. 2001. Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology. Progress. Series.* 210: 223-253.

Croze, H. 1982. Monitoring within and outside protected areas. *pp*.628-633 *in* J.A. McNeely and K.R. Miller, *eds*. National Parks, Conservation and Development: The Role of Protected Areas in Sustaining Society. Proceedings of the World Congress on National Parks, October 11-22, 1982, Bali, Indonesia. Smithsonian Institution Press. Washington D.C.

Cuddihy, L.W. and Stone, C.P. 1990. Alteration of native Hawaiian vegetation; effects of humans, their activities and introductions. Cooperative National Park Resources Studies Unit, Hawaii. 138pp.

Davis, G.E. 1989. Design of a long-term ecological monitoring program for Channel Islands National Park, California. Natural Areas Journal 9:80-89.

D`Antonio, C. M. and Vitousek, P. M. 1992 Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology and. Sysematics.* 23: 63-87.

De Leo, G.A. & Levin, S. 1997. The multifaceted aspects of ecosystem integrity. *Conservation Ecology* 1:3. http://www.ecologyandsociety.org/vol1/iss1/art3/

Denslow, J.S. 2003. Weeds in Paradise: Thoughts on the Invasibilty of Tropical Islands. *Annals of the Missouri Botanical Garden* 90:119-127.

Evenden, A., Miller, M., Beer, M., Nance, E., Daw, S., Wight, A., Estenson, M., and Cudlip, L.. 2002. Chapter III. Conceptual models. Northern Colorado Plateau Vital Signs Network and Prototype Cluster plan for natural resources monitoring. Phase I. National Park Service, Moab, Utah.

Fitzsimons, J. M., Parham, J. E., and Nishimoto, R. T. 2002. Similarities in behavioral ecology among amphidromous and catadromous fishes on the oceanic islands of Hawai`i and Guam. *Environmental Biology of Fishes* 65: 123-129.

Freed, L.A., S. Conant, and R.C. Fleischer. 1987. Evolutionary ecology and radiation of Hawaiian passerine birds. *Trends in Ecology and Evolution* 2:196-203.

Giambelluca, T. and Sanderson, M. 1993. The Water Balance and Climatic Classification. pp 56-72. *In*: *Prevailing Trade Winds: climate and weather in Hawaii*. M. Sanderson, *ed*. University of Hawaii Press, Honolulu, HI.

Gillespie, R.G., H.B. Croom, and Palumbi, S.R.. 1994. Multiple origins of a spider radiation in Hawaii. *Proceedings of the National Academy of Sciences* 91:2290-2294.

The H. John Heinz III Center for Science, Economics & the Environment. 2003. *The state of the nation's ecosystems: Measuring the land, waters, and living resources of the United States*. Washington, DC. http://www.heinzctr.org/ecosystems/report.html

Halvorson, C.H. 1984. Long-term monitoring of small vertebrates: a review with suggestions. *pp*.11-25 *in* J.L. Johnson, J.F. Franklin, and R.G. Krebill, coordinators. Research Natural Areas: Baseline Monitoring and Management. Proceedings of a Symposium, March 21, 1984, Missoula, Montana. USFS General Technical Report INT 173. Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah. 84 pp.

Harwell, M.A., Myers, V., Young, T., Bartuska, A., Gassman, N., Gentile, J. H., Harwell, C.C., Appelbaum, S., Barko, J., Causey, B., Johnson, C., McLean, A., Smola, R., Templet, P., and Tosini, S. 1999. A framework for an ecosystem integrity report card. *BioScience* 40: 543-556.

Holling, C.S. 1973. The resilience of terrestrial ecosystems; local surprise and global change. pp.292-317 *In*: W.C. Clark and R.E. Munn, *eds*. Sustainable Development of the Biosphere. Cambridge University Press, Cambridge, U.K.

Jenkins, K., Woodward, A., and Schreiner, E. 2002. A framework for long-term ecological monitoring in Olympic National Park: Prototype for the coniferous forest biome. Forest and Rangeland Ecosystem Science Center, US Department of the Interior and US Geological Survey. Prepared in cooperation with Olympic National Park. 96p.

Jenny, H. 1941. Factors of soil formation: a system of quantitative pedology. McGraw-Hill, New York.

Johnson, J.A. 1969. *Land Ownership in the Northern Mariana Islands*. Mariana Islands District, Trust Territory of the Pacific Islands. 67 pp.

Johnson, W.C. and Bratton, S.P. 1978. Biological monitoring in UNESCO biosphere reserves with special reference to the Great Smoky Mountains National Park. *Biological* Conservation 13:105-115.

Jones, K.B. 1986. The inventory and monitoring process. *pp*.1-9 *in* A.Y. Cooperrider, R.J. Boyd, and H.R. Steward, *eds.* Inventory and Monitoring of Wildlife Habitat. USDI Bureau of Land Management. Service Center. Denver, Colorado. 858 pp.

Juvik, S.P. and Juvik, J.O. 1998. Atlas of Hawai'i,3rd ed. Department of Geography, University of Hawaii press, Honolulu, HI.

Kaneshiro, KY., and Ohta, A.T. 1982. The flies fan out. *Natural History*: 91:54-59.

Kaneshiro, K.Y. 1989. The uniqueness of Hawaii's Biota. pp. 7-10 in: *Conservation Biology in Hawaii*, C.P. Stone & D.B. Stone, *eds*. University of Hawaii Press, Honolulu, HI.

Kurtz, J.C., Jackson, L.E., and Fisher, W.S. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. *Ecological Indicators*, 1: 49-60.

Loope, L.L. 1989. Island ecosystems. pp. 3-6 *in*: *Conservation Biology in Hawaii*, C.P. Stone & D.B. Stone, *eds*. University of Hawaii Press, Honolulu, HI.

Loope, L.L. 1998. Hawaii and Pacific Islands. pp. 747-774 *in* M.J. Mac, P.A. Opler, C.E. Puckett Haecker, and P.D. Doran, *eds*. *Status and Trends of the Nation's Biological Resources, Volume 2.* U.S. Department of the Interior, U.S. Geological Survey, Reston, VA.

Loope, L.L. and Gon, S.M. III. 1989. Biological diversity and its loss. pp. 109-117 *in*: *Conservation Biology in Hawaii*, C.P. Stone & D.B. Stone, *eds*. University of Hawaii Press, Honolulu, HI.

Loope, L.L., Howarth, F.G., Kraus, F., and Pratt, T.K. 2001. Newly emergent and future threats of alien species to Pacific landbirds and ecosystems. *Studies in Avian Biology* (Cooper Ornithological Society) No. 22:291-394.

Loope, L.L. and Mueller-Dombois, D. 1989. Characteristics of invaded islands. pp. 257-280 *in* J.A. Drake, H.A. Mooney, F. di Castri, R.H. Groves, F.J. Kruger, M. Rejmanek, and M. Williamson, *eds*., *Ecology of Biological Invasions: a Global Perspective*. John Wiley & Sons, Chichester, U.K.

McGrath, W.A. & Wilson, W.S. 1987. The Marshall, Caroline and Mariana Islands. Ch. 9 *in* Ron Crocombe, *ed. Land Tenure in the Pacific*. University of the South Pacific, Suva, Fiji. 420 pp.

McGregor, R.C. 1973. The Emigrant Pests. A report to Dr. Francis Mulhern, Administrator, Animal and Plant Health Inspection Service. Berkeley, California. 167 p. (Unpublished report on file at Hawaii Department of Agriculture, Honolulu, Hawaii.)

Mittermeier, R.A., Myers, N., and Mittermeier, C.G. 1999. Hotspots: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. CEMEX and Conservation International. 431p.

National Park Service. 1997. Resource Management Plan War in the Pacific National Historical Park. 143 pp.

National Park Service. 1980. Supplemental Appropriations Act, FY 1979, PL 96-38.

Noss, R.F. 1990 Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology 4:355-364.

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D. Powell, G.V.N., Underwood, E.C., D'Amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C. Loucks, C.J., Allnutt, T.F., Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P., and Kassem, K.R. 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth. *Bioscience*. 51: 993-938.

O`Meara, J.T. 1987. Samoa. Ch. 5 *in* Ron Crocombe, *ed. Land Tenure in the Pacific*. University of the South Pacific, Suva, Fiji. 420 pp.

Polis, G.A., Anderson, W. A., and Holt, R. D. 1997. Toward an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs. *Annual Review of. Ecology and Systematics.* 28: 289-316.

Quinn, J.F. and van Riper, C. 1990. Design considerations for national park inventory databases. *pp*.5-14 *in* C. van Riper III, T.J. Stohlgren, S.D. Veirs, Jr., and S.C. Hillyer, *eds*. Examples of Resource Inventory and Monitoring in National Parks of California.

Proceedings of the Third Biennial Conference on Research in California's National Parks, September 13-15, 1990, University of California, Davis, California. 268 pp.

Robichaux, R.H., Carr, G.D., Liebman, M., and Pearcy, R.W. 1990. Adaptive radiation of the silversword alliance (Compositae: Madiinae): ecological, morphological, and physiological diversity. *Annals of the Missouri Botanical Garden* 77:64-72.

Roman, C.T. & Barrett, N.E. (1999) Conceptual framework for the development of long-term monitoring protocols at Cape Cod National Seashore. USGS Patuxent Wildlife Research Center, Cooperative National Park Studies Unit, Narragansett, Rhode Island.

Smith, J.E., Hunter, C.L., & Smith, C.M. (2002) Distribution and reproductive characteristics of nonindigenous and invasive marine algae in the Hawaiian Islands. *Pacific Science* 56: 299-315.

Springer, V.G. 1982. Pacific plate biogeography, with special reference to shorefishes. *Smithsonian Contributions to Zoology*: 367:1-182.

Stoddart, D.R. 1992. Biogeography of the tropical Pacific. *Pacific Science* 46:276-293.

Tegler, B., Sharp, M., and Johnson, M.A. 2001. Ecological Monitoring and assessment network's proposed core monitoring variables: an early warning of environmental change. *Environmental Monitoring and Assessment*, 67: 29-56.

Vitousek, P.M. 1995. The Hawaiian Islands as a model system for ecosystem studies. *Pacific Science* 49:2-16.

Vitousek, P.M., D'Antonio, C.M, Loope, L.L., Rejmanek, M., and Westbrooks, R. 1997. Introduced species: a significant component of human-caused global change. *New Zealand Journal of Ecology* 21:1-16..

Wiersma, G.B. 1984. Integrated global background monitoring network. Presented at Symposium: Research and monitoring in circumpolar biosphere reserves. Waterton Biosphere Reserve, Waterton Lakes, Alberta, Canada, August 27-31.

White, P.S. and Bratton, S.P. 1980. After preservation: the philosophical and practical problems of change. *Biological Conservation* 18:241-255.

## Glossary

**Adaptive Management** is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form employs management programs that are designed to experimentally compare selected policies or practices, by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed.

**Attributes** are any feature or process of the environment that can be measured or estimated and that may provide insight into the state of the ecosystem. Attributes are selected to represent the overall health of the system, known or hypothesized effects of stressors, or elements that have important human values. Examples include: diversity of native species, presence of alien species, and sediment in the water column. In PACN models, they are represented by an octagon.

**Composition** is defined as the identity and variety of elements within an ecosystem, including species present and their population structure, abundance, and genetic diversity (Noss 1990).

**Drivers** are major external forces of change to ecosystems, both natural and anthropogenic, including state factors. Examples of drivers include storm frequency and sea level rise, fire cycles, climate, and hydrological cycles. In PACN models, they are represented by a rectangle.

**Ecological effects** are the physical, chemical, biological, or functional responses of ecosystem attributes to drivers and stressors. In PACN models, they are represented by a diamond.

**Ecosystem integrity** implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes.

**Function** refers to how ecosystem parts interact with each other. Ecosystem functions include flow of nutrients or energy between ecosystem components and succession of biological communities after disturbance.

**Indicators** are a subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2002). They are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system.

**Interactive controls** as defined in the interactive-control ecosystem sustainability model are drivers that generally operate inside the bounds of ecosystems. They respond dynamically to each other and interact with ecosystem processes, but are constrained by state factors (Chapin et al. 1996). They include: disturbance regime, biological functional groups, soil or water resources and conditions, and regional and local climate.

**Measures** are the specific variables used to quantify the condition or state of an attribute (or vital sign). These are specified in definitive sampling protocols. One example is stream flow as an attribute, while discharge measurements in cubic feet per second are the measure. In PACN models, they are represented by a parallelogram.

**State factors** as defined in the interactive-control ecosystem sustainability model are variables with independent variation which function as ultimate controls on ecosystem structure and function (Chapin et al. 1996). They are considered ecosystem drivers. They are major forces of change in ecosystems, and may be affected by human activity. State factors include: time since disturbance, potential biota, parent material or water resources, topography, and global climate.

**Stressors** are physical, chemical, or biological perturbations to a system that may be either foreign or natural to the system, but applied at an excessive or deficient level (Barrett et al. 1976:192). Stressors often move the ecosystem away from desired future conditions through forcing change in ecosystem composition, function, or structure. Examples include: air pollution, water pollution, water withdrawal, pesticide use, land-use change, and introduction of invasive terrestrial, marine, and aquatic species. Stressors act together with drivers to influence ecosystem attributes. In PACN models, they are represented by an oval.

**Structure** is the physical organization or spatial patterns of organisms and habitats (i.e., the arrangement of species in space). Structure can be seen at widely divergent spatial scales, from the micro-scale structure in a patch of moss growing on a stream boulder to the landscape-scale three-dimensional profile of a coral reef system as measured from sandy shore to outer reef.

**Vital Signs** are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes). Because of the need to maximize the use and relevance of monitoring results for making management decisions, vital signs selected by parks may include elements that were selected because they have important human values (e.g., harvested or charismatic species) or because of some known or hypothesized threat or stressor/response relationship with a particular park resource.