National Park Service
U.S. Department of the Interior

Pacific Island Network
Vital Signs Monitoring Plan

Appendix H: Conceptual Models and Ecological Overview of Pacific Island Network Ecosystems

Sonia Stephens and Raychelle Daniel (HPI-CESU), Editors

Pacific Island Network (PACN)

Territory of Guam
War in the Pacific National Historical Park (WAPA)

Commonwealth of the Northern Mariana Islands
American Memorial Park, Saipan (AMME)

Territory of American Samoa
National Park of American Samoa (NPSA)

State of Hawaii
USS Arizona Memorial, Oahu (USAR)
Kalaupapa National Historical Park, Molokai (KALA)
Haleakala National Park, Maui (HALE)
Ala Kahakai National Historic Trail, Hawaii (ALKA)
Puukohola Heiau National Historic Site, Hawaii (PUHE)
Kaloko-Honokohau National Historical Park, Hawaii (KAHO)
Puuhonua o Honaunau National Historical Park, Hawaii (PUHO)
Hawaii Volcanoes National Park, Hawaii (HAVO)

http://science.nature.nps.gov/im/units/pacn/monitoring/plan/

Suggested citation:

Stephens, S. H, and R. G. Daniel (Eds.). 2006. Appendix H: Conceptual models and ecological overview of Pacific Island Network ecosystems *In:* HaySmith, L., F. L. Klasner, S. H. Stephens, and G. H. Dicus. Pacific Island Network vital signs monitoring plan. Natural Resource Report NPS/PACN/NRR—2006/003 National Park Service, Fort Collins, Colorado.

Last revision: 10 September 2006

Organization contact information:

National Park Service, Inventory and Monitoring Program, Pacific Island Network, PO Box 52, Hawaii National Park, HI 96718, phone: 808-985-6180, fax: 808-985-6111, http://www.nature.nps.gov/im/units/pacn/index.htm

Hawaii-Pacific Islands Cooperative Ecosystems Studies Unit, University of Hawaii at Manoa, 3190 Maile Way, St. John Hall #408, Honolulu, HI 96822-2279

Acknowledgements:

This appendix was prepared with assistance from the Hawaii-Pacific Islands Cooperative Ecosystems Studies Unit (HPI-CESU), Task Agreement Numbers: J8080040032 and J8080050039.

ACKNOWLEDGEMENTS

Gail Ackerman (CESU), John Gross (NPS, I&M), Sam Gon (TNC), Bryan Harry (retired NPS), Leslie HaySmith (NPS, PACN), Fritz Klasner (NPS, PACN), and Dwayne Minton (NPS, WAPA) provided helpful reviews of this material.

Several Cooperative Park Studies Unit/Hawaii-Pacific Islands CESU facilitators contributed sections to this report, including Gail Ackerman, Kimber DeVerse, Jean Franklin, Kelly Kozar, Grant Kaye, Karl Magnacca, Eric Rutherford, and Karin Schlappa.

Conceptual Models: Vital Sign protocol Primary Investigators and CESU facilitators that contributed to the conceptual model section include Gail Ackerman (Frugivorous Bats and Seabirds), Alison Ainsworth (Terrestrial Plants), Rick Camp (USGS, Land birds), Peter Craig (NPS, Fish and Fisheries), Kimber DeVerse (Water Quality), Eva DiDonato (NPS, Water Quality), Page Else (Landscape Dynamics), Heather Fraser (Insectivorous Bats), Leslie HaySmith (NPS, Bats, Terrestrial Plants, Invasive Species), Frank Howarth (Bishop Museum, Caves), Darcy Hu (NPS, Seabirds), Jim Jacobi (USGS, Terrestrial Plants), Tahzay Jones (NPS, Water Quality and Freshwater Animal Communities), Penny Latham (NPS, Invasive Plants), Lloyd Loope (USGS, Invasive Plants), Karl Magnacca (Terrestrial Invertebrates), Dwayne Minton (NPS, Erosion-Deposition), Jeff Perreault (USGS, Groundwater), Karin Schlappa (Climate), and Joan Yoshioka (Invasive Plants).

We would also like to thank Peter Vitousek (Stanford University) for assistance with initiating our conceptual model development. We also thank Tim Tunison (NPS, HAVO) for generating the basis of the island model used extensively by the PACN. We would especially like to thank the Northern Colorado Plateau and Southeast Coast I&M Networks for their work on conceptual models from which we borrowed concepts and material extensively (Miller et al. 2003, DeVivo 2005). Symbols for some of the conceptual model diagrams were provided courtesy of the Integration and Application Network (http://ian.umces.edu/).

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INTRODUCTION

Development of conceptual models is an important step in the design of the Inventory and Monitoring Program. Conceptual models provide a framework for clarifying meaningful monitoring strategies, which enables us to progress from more general to more specific monitoring questions (Gross 2003). Monitoring efforts must be based on a fundamental understanding of how an ecosystem functions, which conceptual models provide. In addition, conceptual models promote communication among scientists, managers, and the public, providing a means for evaluation and discussion of ecosystem components. In two sections of the PACN Monitoring Plan, Chapter two and Appendix H, we present conceptual models developed to guide the design of the Network's long-term monitoring program.

A conceptual model is a visual or narrative summary that illustrates the important components of a system and the interactions among them. Conceptual models can play four important roles in a monitoring program: (a) represent current knowledge of the processes occurring in systems, (b) illustrate system dynamics, (c) identify the bounds and scope of the systems of interest, and (d) provide a framework for testing hypotheses about how they function. No single "correct" conceptual 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.

One of the purposes of conceptual models is to facilitate communication among various stakeholders, including park staff, researchers, and the general public. Conceptual models are "caricatures of nature" (Holling et al. 2002) designed to describe and communicate ideas about how nature works. Conceptual models can take a variety of forms from narrative descriptions to schematic box-and-arrow diagrams. Regardless of form, the success of a model depends on its ability to share viewpoints and develop a common understanding based on multiple viewpoints.

ORGANIZATION OF APPENDIX H

Appendix H is organized into four sections. The first section consists of a general holistic network model (also presented in Chapter 2, HaySmith et al. 2006) stating major factors and processes controlling the composition, structure, and function of network ecosystems. The second section introduces ecosystem conceptual models that articulate ecosystem composition, structure, and function. The second section also conveys our understanding of how natural ecosystem drivers and major agents of change influence key structural components, functional relationships, interactions, and system dynamics. The third section contains narrative descriptions of major agents of change affecting the network that are integrated on a landscape level. The fourth section of the appendix contains conceptual models specific to individual Vital Signs. These models will be expanded within protocols as they are developed. Further details about model elements may be found in the topical reports in Appendix E: Supporting Documents, as well as Appendix I: Water Quality Report.

CHAPTER ONE: PACIFIC ISLAND NETWORK ECOSYSTEMS

The Pacific Island Network (PACN) is the most widespread network in the Inventory and Monitoring Program, spanning four time zones and crossing both the International Date Line and the equator. The islands that make up the network are remote and extensively separated, and their vertical relief has led to the evolution of a variety of ecosystem types (Figure 1.1). PACN parks contain resources ranging from alpine desert to tropical coral reefs. The wealth of diversity they contain has led to the challenge of creating a unified conceptual framework for the network. The process of defining this framework has involved considerable discussion, with parks, agency scientists, and others. The early effort to frame the significance of ecological composition, structure, and function provides the foundation for a strategic ecological framework for monitoring.

Figure 1.1. Example of elevational gradients typical to many PACN islands: Sunuitao Peak, Ofu Island, NPSA

The suite of individual Vital Signs for an Inventory and Monitoring Program is ideally selected to provide a wide range of information about the condition of the network's ecosystems (See Chapter 3, HaySmith et al. 2006). The PACN defines an ecosystem as a community of organisms living in and interacting with a physical and chemical environment, which may be characterized by energy and matter flows between the different elements (which includes human interactions). Ecosystems are fundamental resources of PACN parks. A premise of the PACN Vital Signs monitoring program is that conservation of the many species and landscapes valued by NPS staff, visitors, and society at large requires an ecosystem focus.

An ecosystem-based perspective is centered on practical and theoretical considerations. Walker (1995) noted "Given our inadequate understanding and knowledge of how many and which kinds of species occur in an ecosystem, the best way to approach the problem of conserving them all is to ensure that the system continues to have the same overall structure and function." This practical view is shared by many conservation biologists (Noss 1990, Franklin 1993, Noon et al. 1999). Contemporary ecological theory further suggests that conservation should emphasize the maintenance of ecosystem processes because ecosystems and ecosystem components are inherently dynamic both in space and time, and thus cannot be conserved as static entities (Pickett et al. 1992, Christensen et al. 1996). The process-based perspective for ecosystems is equally important to other levels of organization including populations, species, and landscapes. Ecosystems are interconnected through flows of materials, energy, and organisms in spatially structured landscape mosaics (Turner et al. 2001). Thus, landscape-level considerations are encompassed by the ecosystem approach of the PACN.

Ecosystems and landscapes can be represented conceptually in many different ways along continua of simplicity to complexity, with specificity. For purposes of Vital Signs monitoring, we will begin with a simple, general model that summarizes ideas about ecosystem sustainability. This general model will provide the theoretical framework for aspects of the monitoring plan related to ecosystem structure and function.

PACIFIC ISLAND NETWORK HOLISTIC MODEL

The PACN has adopted a modified version of the interactive-control model of Miller and colleagues (2003) as a general holistic network model (Figure 1.2). This holistic model illustrates ecological similarities across the network. It also provides a general framework describing factors and processes controlling the composition, structure, and function of network ecosystems. Jenny's (Jenny 1941, 1980) state-factor approach has been widely applied as a framework for examining temporal and spatial variations in ecosystem structure and function (Figure 1.2) (Walker and Chapin 1987, Vitousek 1994, Seastedt et al. 2001). Chapin and colleagues (1996) extended Jenny's framework with ecosystem sustainability, describing it as: "...one that, over the normal cycle of disturbance events, maintains its characteristic diversity of major functional groups, productivity, and rates of biogeochemical cycling" (Chapin et al. 1996) (Figure 1.2B). By substituting water quality and quantity for soil resources in the model, the interactive-control model can be applied to aquatic as well as terrestrial ecosystems (Chapin et al. 1996). In the PACN interactive-control model, the concepts of water and soil quality will be used interchangeably with the more descriptive concepts of water and soil resources, and conditions. Climate, as represented in this model, includes the broader concept of atmospheric resources and conditions. Climate also encompasses climatic variables such as temperature or precipitation, as well as atmospheric drivers and stressors (e.g., gaseous or particulate matter).

A key aspect of the interactive-control model is the associated hypothesis that interactive controls must be conserved for an ecosystem to be sustained. Large changes in any of the four interactive controls are predicted to result in a new or modified ecosystem with different characteristics than the original system (Chapin et al. 1996). For example, major changes in soil resources (e.g., through erosion, salinization, fertilization, or other mechanisms) can greatly affect productivity, recruitment, and competitive relations of plants. These changes could lead to changes in the structure and function of plant communities and higher trophic levels. Changes in vegetation structure or herbivore abundance can affect the ecosystem's disturbance regimes (e.g., through altered fuel characteristics or increased herbivory). These factors and processes in combination can result in a fundamentally different type of ecosystem.

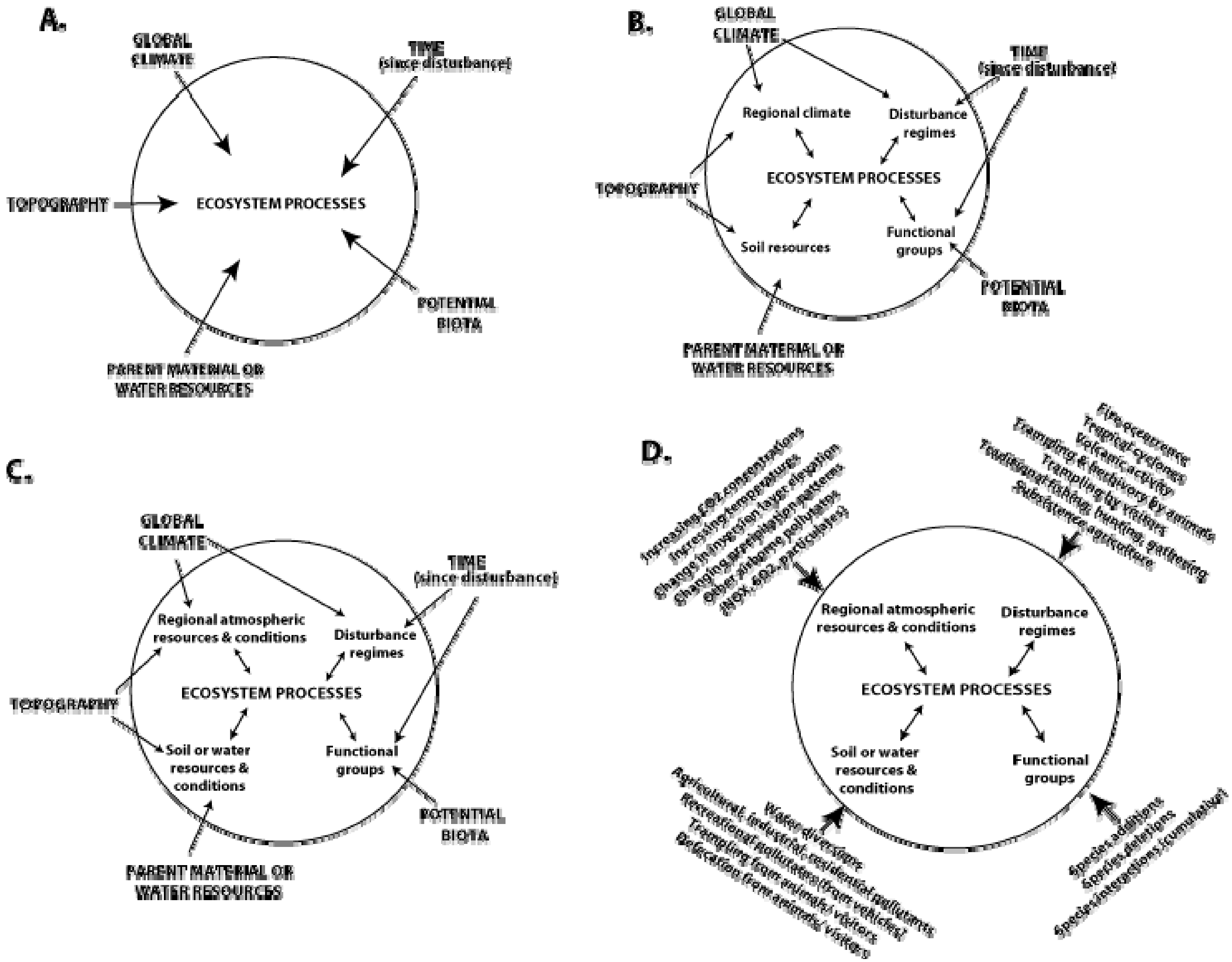

Figure 1.2. Relationships (A) between Jenny's (1941) state factors and ecosystem processes, and (B) among state factors, interactive controls, and ecosystem processes. The circle represents the boundary of the ecosystem (Chapin et al. 1996). Modified version (C) of the interactive-control model for the PACN, and (D) the array of stressors affecting PACN ecosystems arranged in the model in relation to their first-order effects (modified from Miller et al. 2003).

CHAPTER TWO: ECOSYSTEM MODELS

In this second section, we present key ecosystems found within the PACN network. Each ecosystem description provides an overview of abiotic and biotic composition. The overview is followed by a synopsis of major agents of change and how they influence key components, functional relationships, and system dynamics. Each description concludes with a conceptual model. The ecosystem models aim to describe our understanding of general ecosystem dynamics in the PACN.

Classification of PACN ecosystems was based on the representative ecosystem types present in the parks. We also considered the relevance of these broad categories across the network. The ecosystem groupings we present in this appendix differ slightly from those developed for the State of Hawaii by the Nature Conservancy and the Hawaii Gap Analysis Project (GAP) which use the National Vegetation Classification Standard (NVCS) (Juvik and Juvik 1998). The classification of Hawaiian terrestrial ecosystems in Pratt and Gon (1998) is based on elevation, moisture regime, dominant life forms and predominant vegetation present in Hawaii alone (Figure 2.1).

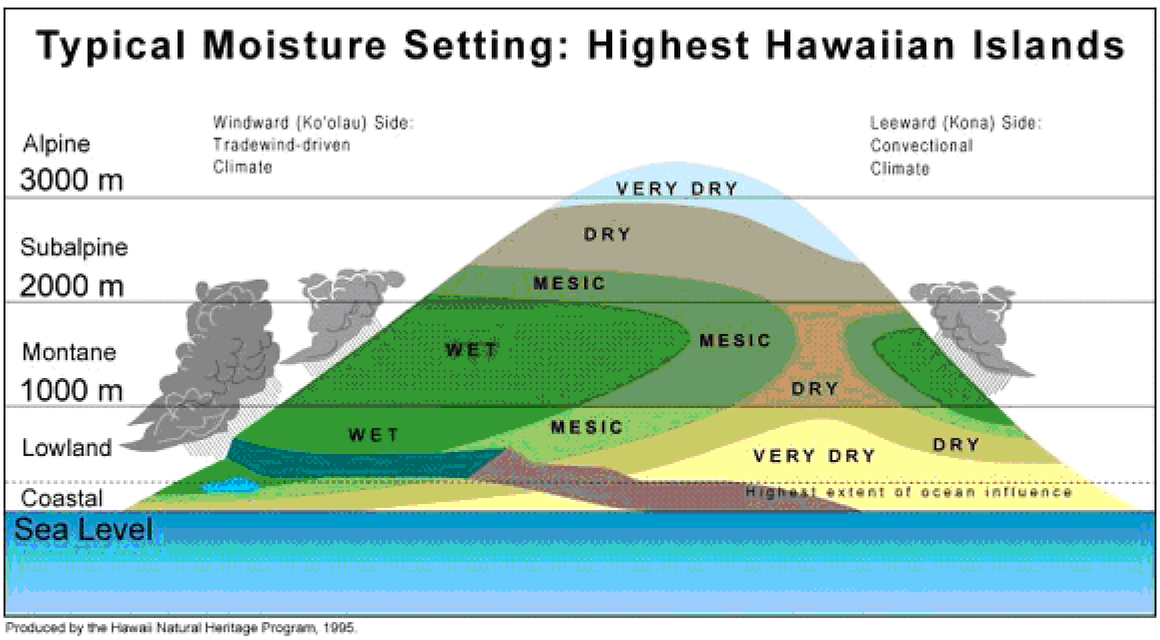

Figure 2.1. Diagram depicting the effect of tradewinds on high-elevation islands, causing wet, windward slopes and dry, leeward flanks, along with dry alpine zones (from Pratt and Gon 1998).

The Pacific Island Network has identified six key ecosystem groupings: scrub land; forest and shrubland; subterranean; stream; coastal; and nearshore marine (Figure 2.2).   These ecosystem groupings were based predominantly on ecosystem interactions as well as similarities of dominant life forms, elevation, and moisture regime across the network.

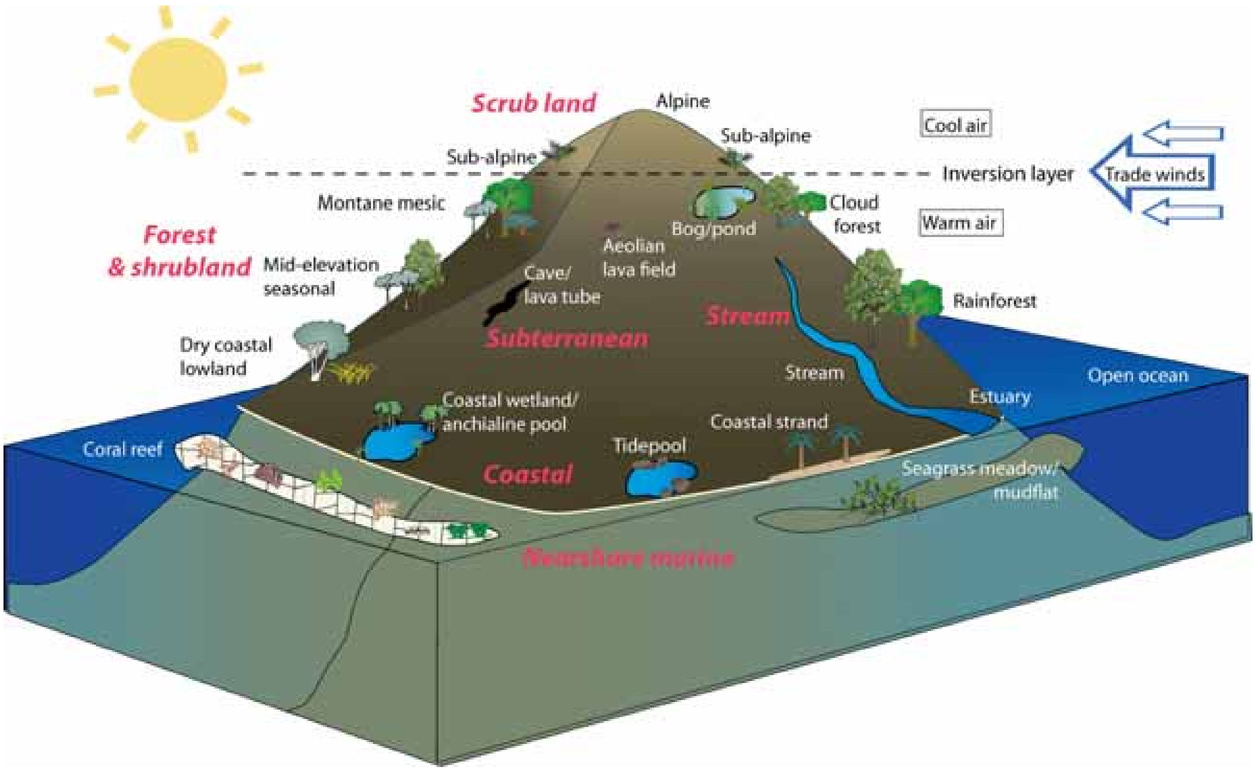

Figure 2.2. Idealized high-elevation Pacific island showing typical ecosystem zonation and the Pacific Island Network's six key ecosystem groupings.

Each ecosystem group described in this appendix includes several "layers" of models as follows:

- In all cases, we have identified the primary biotic and abiotic resources found within the ecosystem and described their relationships to one another. We discuss the major stressors, or agents of change, affecting each ecosystem.
- We provide narratives and models of distinctive systems (e.g., anchialine pools).
- We conclude with an ecosystem dynamics model that depicts the major agents of change, interactions among those agents, and the resources that they affect.

Each system is discussed in both a regional and a network or park-specific context. For further explanatory information on components of each ecosystem, a review of the agents of change and Vital Sign models are included in the section following the ecosystem models (*Agents of Change and Vital Sign Conceptual Models*). Information on specific park and network resources can be found in park resource overviews in Appendix A and topical reports in Appendix E: Supporting Documents and Appendix I: Water Quality Report.

The following sub-sections describe key PACN ecosystems (Figure 2.2) and conceptual models.

SCRUB LAND ECOSYSTEM

(modified from Mueller-Dombois and Fosberg 1998 and Ricketts et al. 1999)

Scrub land ecosystems in the PACN include three distinctive systems: alpine desert, subalpine scrubland, and non-alpine desert and lava fields. Alpine desert and subalpine scrubland ecosystems are rare in the tropics. Within the PACN, only HALE and HAVO contain alpine and subalpine systems, due to the height of their volcanic peaks. Subalpine vegetation is found in a zone between the upper level of the cloud zone and the nocturnal ground frost line. Alpine desert is found above the nocturnal ground frost line. Both boundaries oscillate about a median elevation unique to each mountain (see Figure 2.3). The stature of flora is limited by sparse precipitation, and solar radiation is intense. Frost occurs nightly almost year round in the alpine desert zone.

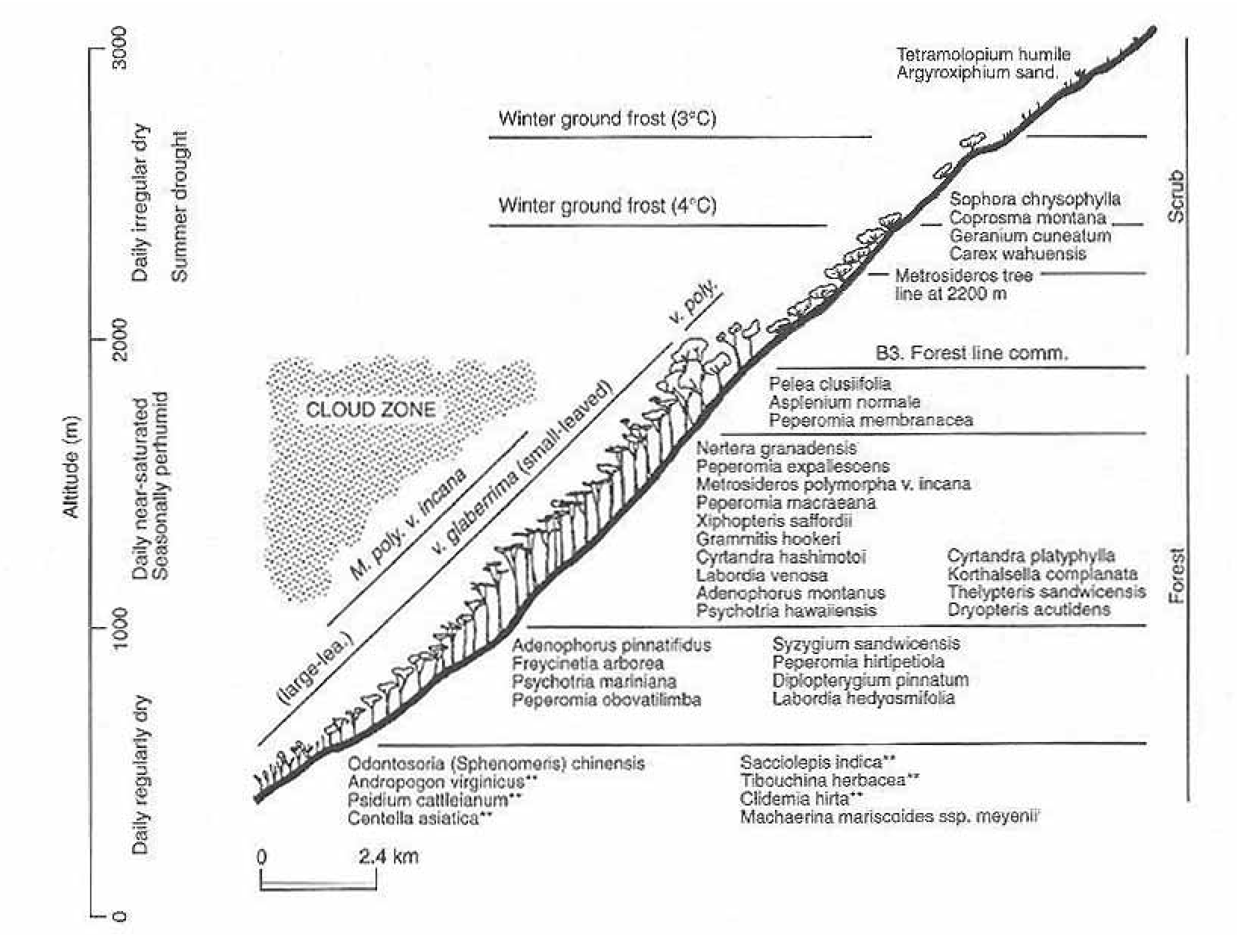

Figure 2.3. Vegetation profile on an altitudinal transect on the windward slope of Haleakala, Maui, showing the transition between forest and scrub vegetation. Species with two asterisks are alien, those with one asterisk are indigenous, and the rest are endemic (Mueller-Dombois and Fosberg 1998).

Alpine and Subalpine

The occurrence and composition of subalpine communities vary on each of the high mountains (Mauna Loa [HAVO], Mauna Kea [not in a park], and Haleakala Mt. [HALE]). Several recognized natural subalpine vegetation communities include open forest/savanna dominated by mamane (*Sophora chrysophylla*) and naio (*Myoporum sandwicensis*), pukiawe (*Styphelia tameiameiae*)-dominated heath scrub, aweoweo (*Chenopodium oahuense*)-dominated scrub, and xerophytic tussock grassland.

On Mauna Loa, the highest zone is primarily an aeolian (wind-supported) desert with little or no vegetation. Successively lower zones support a sparse alpine moss desert with scattered grasses and ferns and, lower, a pukiawe (*S. tameiameiae*)/ ohelo (*Vaccinium reticulatum*)-dominated sparse alpine low heath-scrub with the same grasses and ferns. The summit of Haleakala Mt. is alpine desert. Below summit elevation is heath-shrub desert characterized by pamakani (*Tetramolopium humile*), *Dubautia menziesii*, and the Haleakala silversword (*Argyroxiphium sandwicense* ssp. *macrocephalum*) (Figure 2.4).

Figure 2.4. Subalpine vegetation at HALE, including the endangered Silversword (*Argyroxiphium sandwicense* ssp. *Macrocephalum*).

Three endangered birds are found in these ecosystems: the nene or Hawaiian goose (*Branta sandvicensis*), uau or Hawaiian dark-rumped petrel (*Pterodroma phaeopygia sandwichensis*), and palila (*Loxioides bailleui*). Several endemic arthropod species are found in alpine systems, including a group of highly specialized aeolian species which are dependent on wind-blown debris (Figure 2.5). These include several species of beetle, most notably the candidate endangered wekiu bug (*Nysius wekiuicola*) on Mauna Kea, a flightless moth (*Thyrocopa apatela*) on Haleakala, several species of wolf and web-building spiders, and several mite species (Edwards 1987, Howarth 1997).

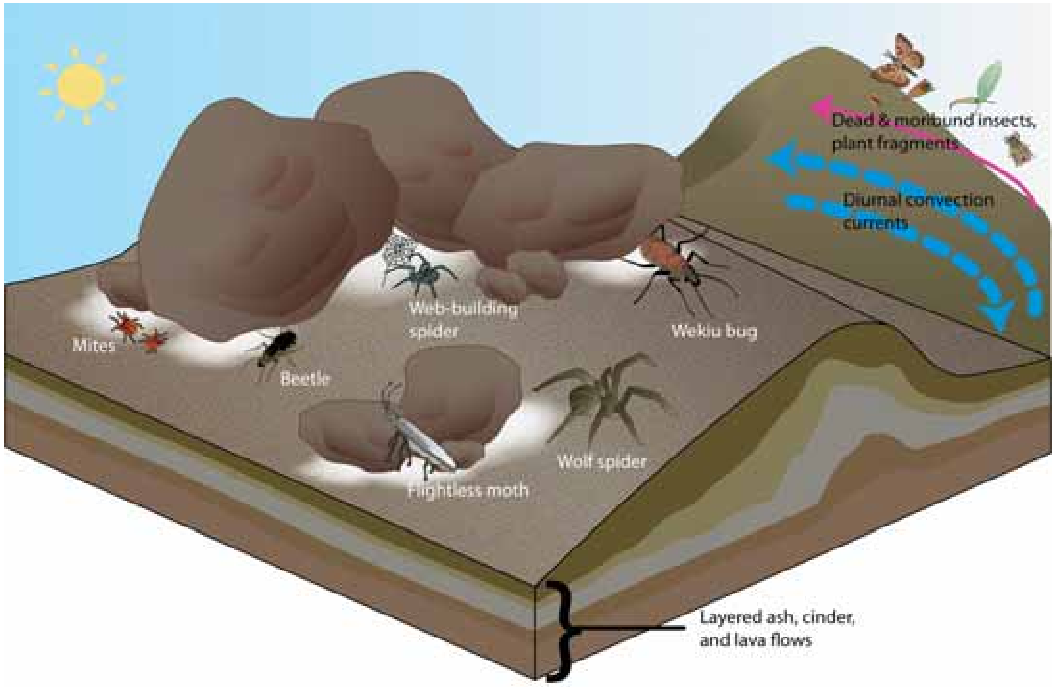

Figure 2.5. Invertebrate communities in the aeolian zone are almost entirely supported from windblown debris.

Non-Alpine Desert and Lava Field

Non-alpine, aeolian desert, found in HAVO, supports a range of dryland vegetation and animal species, including several rare insects and plants (Figure 2.6). It is maintained by tradewinds, low rainfall, and emissions of volcanic gasses on a dry cinder substrate (Howarth 1987). Lava fields are examples of successional ecosystems. A new lava flow may require many months to cool sufficiently to allow invasion of vegetation. In Hawaii, the general native successional sequence typically begins with colonization by blue-green algae. Mosses, ferns, and lichens then begin to establish, followed by ferns such as kupukupu (*Nephrolepis* spp.), then flowering plants, which are ultimately succeeded by a forest or grassland ecosystem. In Samoa, a mat-forming fern (*Dicranopteris linearis*) and a club moss are the first colonizers on volcanic soils.

Figure 2.6. Lava field with sparse vegetation at HAVO.

Scrub land Ecosystem Stressors

Although some large blocks of relatively intact high shrublands and alpine deserts still exist, overgrazing by domestic and feral livestock, wildfires, trampling from recreational activities, competition from introduced plants, removal of plants such as silverswords, and introduced ants that kill native invertebrate pollinators all pose significant threats to native species and communities (Gagne and Christensen 1985, Sohmer and Gustafson 1987). The introduced spider *Meriola arcifera* is a concern for the aeolian invertebrate fauna on Mauna Kea (Ziegler 2003). Alpine grasslands have been reduced in range (Sohmer and Gustafson 1987), but still occupy more than 50 percent of their presumed original range. The World Wildlife Fund classifies Hawaiian high shrublands (including alpine and subalpine ecosystems) as having bioregionally outstanding biological distinctiveness and a vulnerable conservation status (Ricketts et al. 1999, World Wildlife Fund 2001).

Scrub land Ecosystem Model

Figure 2.7 is the conceptual model of ecosystem dynamics in alpine and subalpine ecosystems of PACN parks. Rectangles indicate prominent agents of change and circles represent major components of the ecosystem. Large pink arrows link agents of change to the entire ecosystem, including biotic, physical, and chemical components. The dark green area indicates those agents of change or resources that are actively managed by the National Park Service.

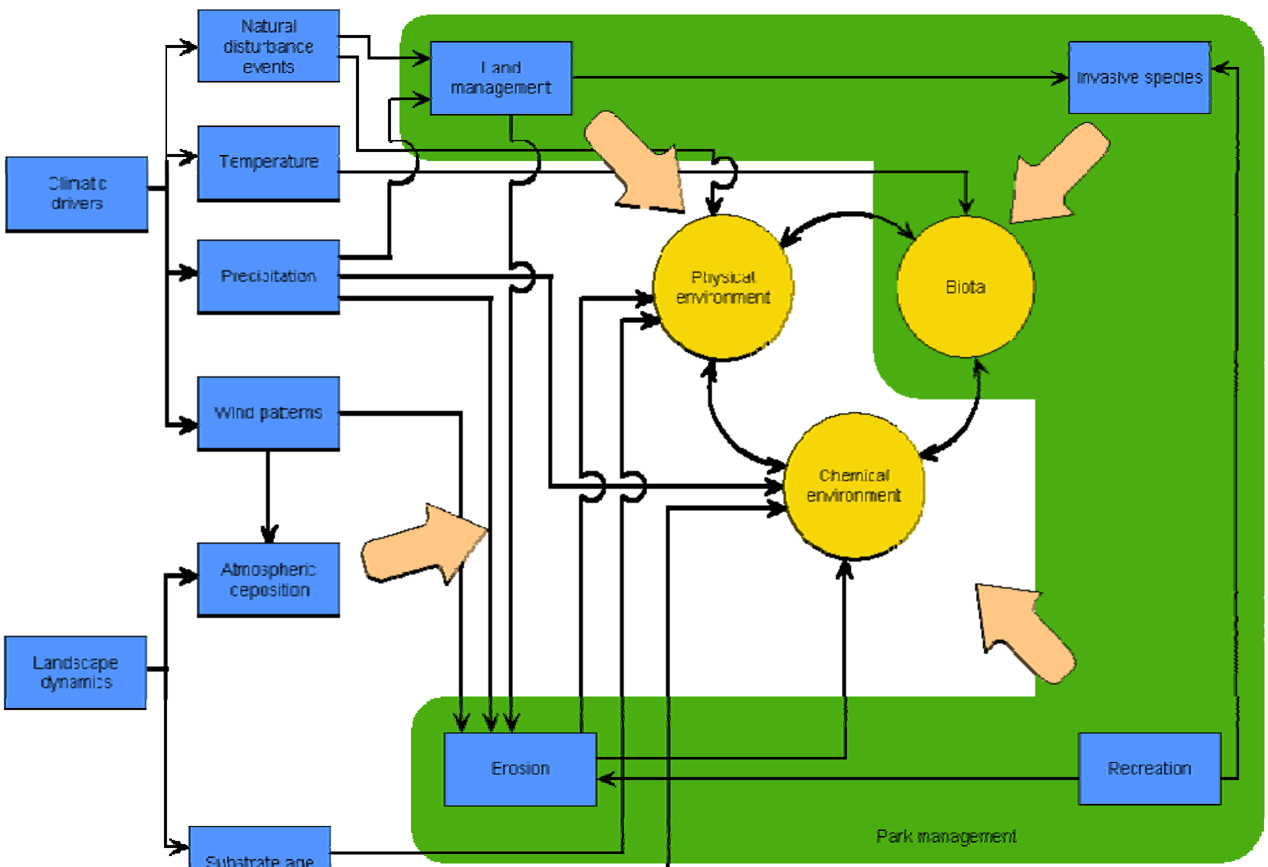

Figure 2.7. Conceptual model of ecosystem dynamics in alpine and subalpine ecosystems of PACN parks.

FOREST AND SHURBLAND ECOSYSTEM

(Partly modified from Loope and Giambelluca 1998, Mueller-Dombois and Fosberg 1998, Ricketts et al. 1999, and World Wildlife Fund 2001)

Forest and shrubland Ecosystems across the network show a diversity of vegetation communities. Forest and shrubland ecosystems occur in WAPA, NPSA, KALA, HALE, ALKA, PUHE, KAHO, PUHO, and HAVO. Distinctive communities found within the Forest and shrubland ecosystem include rain forest, cloud forest, montane bog and pond, Hawaiian mesic, Marianas limestone, Hawaiian dry forest and grassland, and Mariana Island savanna systems.

Pacific Island rain forests include both montane cloud forest and montane and lowland rain forests, all recognized as globally rare ecosystems. On most Pacific Islands, rain forests and cloud forests were more extensive before human colonization, but are now only remnants. The relatively low relief of the Samoan Islands, coupled with their geographic location, have not created a trade wind-generated rain shadow effect as in the Hawaiian Islands, and it is believed that the Samoan Islands, including American Samoa, were primarily covered with lowland and montane rainforest and high-elevation cloud forest before human colonization (Mueller-Dombois and Fosberg 1998). In the Hawaiian Islands, the wet forest differs from most continental climax assemblages in that the dominant species are largely the original colonizing species (Figure 2.8).

Figure 2.8. Forest ecosystem in KALA, with *Metrosideros polymorpha* and fern species.

In Hawaii, coastal and lowland dry shrublands occur on the lowest leeward slopes of the higher Hawaiian Islands, and on all but the summit regions of the islands of Lanai, Kahoolawe and Niihau. Native tropical dry forests typically occur on the leeward side of the main islands and once covered the summit regions of the smaller islands (Gagne and Cuddihy 1990). Most native lowland forests of Hawaii are either seasonal or sclerophyllous to some degree and more mesic transition forests occur where conditions are favorable. These transition forests include mixed mesic forests that often contain patches and elements of dry forest communities. See Figure 2.3 for an illustration of the major vegetation zones in the Hawaiian Islands.

The low reliefs of Saipan and Guam, coupled with their location, have not created a trade wind-generated rain shadow effect as in the Hawaiian Islands. Even though these islands receive high rainfall, water typically runs off or percolates into the subterranean environment quickly (though wetlands are often found in depositional areas). It is believed that areas with limestone substrate were thickly forested prior to human settlement. Areas with volcanic substrate may have supported grassland or savanna vegetation, with forested ravines, valley bottoms, and slopes, but it is uncertain to what degree grassland/savanna vegetation has been facilitated by human use of fire (Mueller-Dombois and Fosberg 1998).

Rain Forest

NPSA, KALA, HALE, and HAVO contain native dominant rainforests or rainforest remnants dominated by alien vegetation. In the Hawaiian Islands, rain forests are largely dominated by the tree *Metrosideros polymorpha*, with other wet forest tree species commonly present (e.g., *Cheirodendron Ilex*, *Antidesma*, *Melicope*, *Syzygium*, *Myrsine*, *Psychotria*, *Tetraplasandra*), and tree ferns (*Cibotium* spp.) and a variety of shrubs and epiphytic plants covering the forest floor and tree surfaces. *Clermontia*, *Cyanea*, *Gunnera*, *Labordia*, *Broussaisia*, *Vaccinium*, *Phyllostegia*, and *Peperomia* are other typical non-canopy plant genera. Numerous ferns and mosses, as well as Hawaii's three native orchids, also occur in the rain forest (Sohmer and Gustafson 1987).

Many of the Hawaiian honeycreepers, an endemic group of birds that displays many specialized adaptations to different food and plant resources, were found in mesic and wet forests. Hawaiian moist forest is the main habitat for other forest birds including the Hawaiian hawk (*Buteo solitarius*), Hawaiian crow (*Corvus hawaiiensis, now only in captivity*), Hawaiian honeyeaters (now extinct), and Hawaiian thrushes. This ecoregion was the center for adaptive radiation in honeycreepers, many plant species, Hawaiian Drosophila, and other invertebrates.

The National Park of American Samoa preserves the only mixed-species paleotropic rainforest in the U.S. Native fruit-bearing tree species are important as food sources for rare flying foxes (*Pteropus samoensis* and *P. tonganus*) and uncommon many-colored fruit doves (*Ptilinopus perousii*). Montane and lowland rainforest are distinguished from each other by dominant canopy tree species. In lowland rainforest, these include *Diospyros samoensis, D. elliptica, Dysoxylum samoense*, *Pometia pinnata*, *Syzigium inophylloides*, and *Planchonella samoense*. Montane rainforest is dominated by *Dysoxylum huntii*, with other associated species. Rainfall is higher in the montane rainforest than in the lowland forest.

Cloud Forest

Cloud forests are found in NPSA and HALE. The tropical montane cloud forest (TMCF) is composed of forest ecosystems of distinctive floristic and structural form. It typically occurs as a relatively narrow altitudinal zone where the atmospheric environment is characterized by persistent, frequent, or seasonal cloud cover at the vegetation level (Figure 2.3). Enveloping clouds or wind-driven clouds influence the atmospheric interaction through reduced solar radiation and vapor pressure deficit, canopy wetting, and general suppression of evapotranspiration. The net precipitation (throughfall) in such forests is significantly enhanced (beyond rainfall contribution) through direct canopy interception of cloud water (horizontal precipitation or cloud stripping) and low water use by vegetation.

In comparison with lower altitude tropical moist forest, the stand characteristics generally include reduced tree stature and increased stem density. Canopy trees usually exhibit knarled trunks and branches; dense, compact crowns; and small, thick, and hard (sclerophyll) leaves. TMCF is also characterized by having a high proportion of biomass as epiphytes (bryophytes, lichens, and filmy ferns) and a corresponding reduction in woody climbers. Soils are wet and frequently waterlogged and highly organic in the form of more humus and peat (histosol).

Biodiversity in terms of tree species of herbs, shrubs (Figure 2.9), and epiphytes can be relatively high (considering the small areal extent). Endemism is often very high.

Figure 2.9. Summit vegetation in the cloud forest on Mt. Lata (left) with typical conditions (right), Tau Island.

TMCF occurs on a global scale within a wide range of annual and seasonal rainfall regimes (i.e., 500-10,000 mm/year). There is also significant variation in the altitudinal position of the mountain belt. For large, inland mountain systems, TMCF may typically be found between 2,000-3,500 m (Andes, Ruwenzoris), whereas in coastal and insular mountains this zone may descend below 800 m (Stadtmueller 1987).

Montane cloud forests are often refuges for plant and animal species whose lower elevation habitat has been lost. Hawaiian cloud forest is dominated by *M. polymorpha*, with about 240 other flowering plant species (ca. 90% endemic), 100 ferns (ca. 50% endemic), 600-1000 invertebrates (ca. 65% endemic), one endemic mammal (the Hawaiian hoary bat, *Lasiurus cinereus semotus*), and nine endemic forest bird species (Hawaiian honeycreepers: family Fringillidae, subfamily Drepanidinae). Dominant canopy species in Samoan cloud forests are *Dysoxylum huntii* (maotamea) and *Syzygium samoense* (fena vao), and *Crossostylus biflora* (saitamu). A rich variety of epiphytic ferns and orchids is characteristic of Samoan cloud forests (Whistler 1994).

Montane Bog and Pond

Montane bogs and wetlands are found in HALE and HAVO. HALE also has several bog-associated ponds (Figure 2.10). Mid- and high-elevation wetlands and bogs generally form in places where there is high rainfall, soils are poorly drained, or the volcanic geology has created aquitards or slope wetlands influenced by groundwater. Bogs occur on montane plateaus or depressions and consist of a variety of sedges, grasses, ferns, mosses, small trees and shrubs that form irregular hummocks. These wetlands often are home to rare or endangered plants, insects, other invertebrates, and birds.

Figure 2.10. Characteristic pond and bog, found in HALE.

Smaller freshwater features in PACN parks include springs and seeps. These may be present at any elevation, and may be formed by aquitards in upland areas or intersections of land surface with the groundwater table in coastal areas. Due to the dynamics of groundwater lenses, freshwater springs are common in coastal areas just under sea level. Upland springs and seeps serve as important breeding grounds for endemic insects and snails. They are often important cultural resources, especially in arid regions.

Hawaiian Mesic Forest

Mesic forests or forest remnants are found in KALA, HALE, and HAVO. The climatic moisture pattern in Hawaiian mesic forests is seasonal but not drought-prone. Most mesic forest has been eliminated, but several native forest types are recognized: mixed mesophytic lowland forest, open early-successional *Metrosideros polymorpha* forest on young lava fields, and *Acacia koa* forest. Mixed mesophytic forest included three canopy endemics (*M. polymorpha*, *A. koa*, and *Syzygium sandwicense*), several sub-canopy native species (including the genera *Myrsine*, *Psychotria*, *Antidesma*, and *Diospyros*), and several woody vines and ferns.

Early-successional *M. polymorpha* forest occurs on <1,000 year-old lava flows at 400-1,200 m elevation on Kilauea Volcano. This open forest originally contained native shrubs (*Styphelia tameiameiae* and *Dodonea viscosa*) and a bunchgrass (*Andropogon virginicus*) in canopy openings, but has now been heavily invaded by the nitrogen-fixing tree *Myrica faya* and the fire-promoting grass *Schizachyrium condensatum*.

Acacia koa mesic forests (Figure 2.11) extend from 300-2,300 m elevation, although this species is also found in the dry *Acacia koa* and wet *M. polymorpha* forest types. On the older islands, this forest type generally occurs below the montane rain forest belt, usually on drier slopes or on deeply weathered lavas. Associated tree species include the native sandalwood and species in the genera *Myrsine*, *Psychotria*, *Nestegis*, *Bobea*, *Charpentiera*, *Pisonia*, *Sapindus*, and *Psydrax*. Many shrubs are found, but few ferns, vines, and bryophytes. Lichens, particularly *Usnea* spp., are abundant in cloudier upper-elevation areas. On Hawaii Island, this forest type is most prominent above the montane rain forest band, and there are fewer associated tree species.

Figure 2.11. Example of a mesic forest ecosystem in HAVO, with native *Metrosideros polymorpha* and *Acacia koa* on weathered lava.

Marianas Limestone Forest

These forests occur on exposed limestone with a typical mosaic of intergraded communities resulting from local dominance of one or two typical species (Raulerson 1979). Limestone forest on Saipan consists of up to 27 canopy tree species (Craig 1992), with *Pisonia grandis* dominant. Several types of limestone forest have been distinguished on Guam: *Artocarpus-Ficus*, *Mammea*, *Cordia*, *Merrilliodendron-Ficus*, and *Pandanus.* Forest species are adapted to frequent tropical cyclones (Mueller-Dombois and Fosberg 1998).

Figure 2.12. Limestone cliffs of Ritidian Point, Guam.

It is believed that much of Guam and Saipan were originally occupied by limestone forest. Northern Guam is primarily limestone (Figure 2.12), with karstic terrain in the central part of the island. Southern Guam has a mixed volcanic-limestone composition. Most of Saipan is limestone, though some ridges and slopes are volcanic. Guam is covered by a mosaic of small vegetation patches of extremely varied composition (Figure 2.13). There is very little undisturbed primary forest remaining on Guam, and the southern half of the island contains grasslands of primarily alien composition. Within WAPA, limestone forest can be found in the beach area, river valleys, and Fonte Plateau slopes of the Asan Unit as well as the slopes of the Mt. Chachao Unit and the coastal islands and slopes of the Agat Unit. AMME, located on the coast, does not contain this forest type.

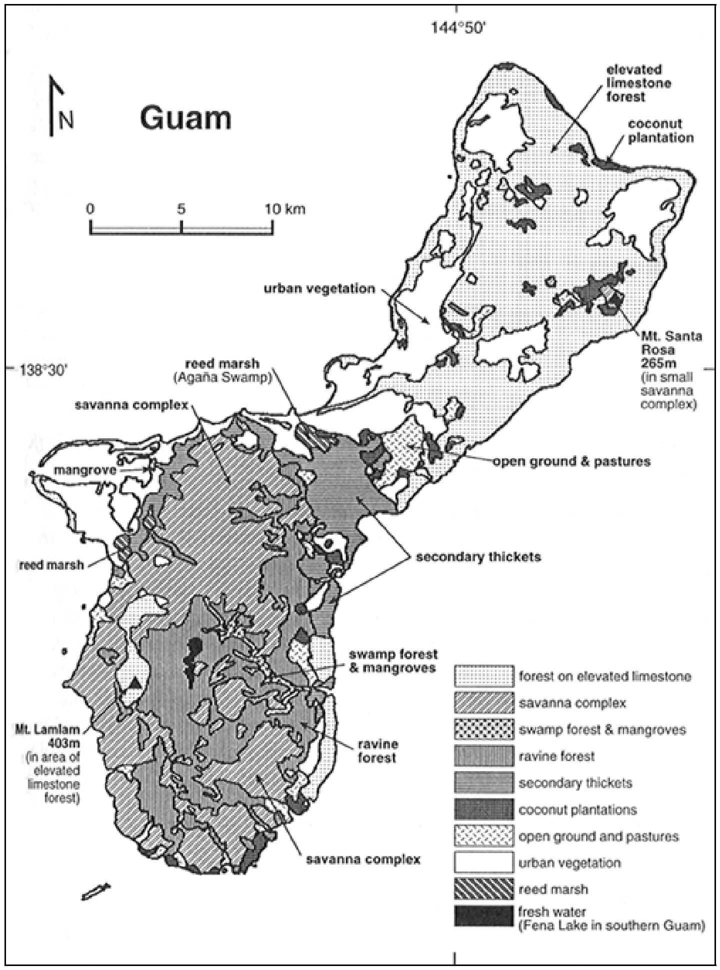

Figure 2.13. Vegetation map of Guam (from Mueller-Dombois and Fosberg 1998).

Hawaiian Dry Forest and Grassland

Various types of dry forest and mixed grassland communities are found in KALA, HALE, ALKA, PUHE, KAHO, PUHO, and HAVO.

Vegetation in Hawaiian coastal and lowland dry shrublands includes grasslands of *Eragrostis*, *Fimbristylis*, *Sporobolus*, and *Lepturus*, and mixed shrublands dominated by one or more of *Sida*, *Dodonaea*, *Scaevola*, *Heliotropium*, *Gossypium*, *Chamaesyce*, *Chenopodium*, *Myoporum*, *Vitex*, and *Anthium*. Non-tree plant diversity of this ecoregion is high (more than 200 species) and highly endemic (greater than 90%).

Hawaiian dry forests vary from closed to open canopied forests, can exceed 20 m in height in montane habitats, and are dominated by the tree genera *Acacia*, *Chamaesyce*, *Metrosideros*, *Sapindus*, *Sophora*, *Canthium*, *Diospyros*, *Nestegis*, *Erythrina*, and *Santalum* (Gagne and Cuddihy 1990). Dry forests harbor a number of specialist species, including native hibiscus trees of the genus *Hibiscadelphus*, *Kokia cookei*, *Caesalpinia kauaiense*, and *Santalum paniculatum*, and several rare endemics such as *Gouania*, now represented by only a few individuals (Sohmer and Gustafson 1987, Cuddihy and Stone 1990). Around 22 percent of native Hawaiian plant species occur within this ecoregion, with lower habitat type endemism than tropical moist forests (Sohmer and Gustafson 1987). The palila (*Loxioides bailleui*), an endangered finchlike bird, specializes on mamane trees that occur in dry forest habitats (Noss and Peters 1996). Several shrubland, grassland, and herbaceous formations occur within this ecoregion (Gagne and Cuddihy 1990). Lower Hawaiian dry forest was habitat for several forest birds, such as honeycreepers, fly catchers, flightless rails, other flightless birds (now extinct), and the Hawaiian owl (*Asio flammeus sandwicensis*).

Mariana Islands Savanna

(Partly modified from Minton 2005)

Mariana Islands savanna is found only in WAPA. Savanna communities comprise approximately one third of Guam's vegetated area (Donnagan et al. 2002). Prior to human arrival, savanna grasslands are believed to have been rare on the island (Raulerson 1979), but the application of human derive fire starting approximately 4,000 years ago (Athens and Ward 2004). Guam's savannas are a xeric ecosystem characterized by a relatively continuous grass layer intermixed with solitary trees and bushes and bare patches of exposed saprolite clay (Raulerson 1979).

Commonly observed native savanna plants include *Dicranopteris linearis*, *Dimeria chloridiformis*, *Fimbristylis tristachya*, *Miscanthus floridulus*, *Phragmites karka*, *Premna obtusifolia*, *Scaevola sericea*, and *Timonius nitidus* (Yoshioka 2005). Commonly present non-native plants include *Hyptis capitata*, *Pennisetum polystachyon*, and *Waltheria indica*; and isolated trees of *Leucaena leucocephala* and *Casuarina equisetifolia* (Yoshioka 2005). Less common shrub species observed in Mount Alifan Unit include the Mariana Island endemic *Phyllanthus saffordii* and the indigenous species, *Melastoma malabathricum* var. *mariannum* and *Myrtella bennigseniana* (Yoshioka 2005) (Figure 2.14).

Stone (1970) recognized four subtype savanna communities: *Miscanthus*, *Dimeria*, erosion scar, and *Phragmites*. *Miscanthus* ("swordgrass") is dominated by the native bunchgrass *Miscanthus floridulus*, which often grows in dense monotypic stands on steeper slopes in burned areas. *Dimeria* ("mixed"), the native savanna community climax (Fosberg 1960) is fire intolerant (Raulerson 1979). The native grass, *Dimeria chloridiformis*, dominates *Dimeria* communities (Figure 2.14, Right). Erosion scar ("fern") is found in patches of nutrient poor bauxite clays with *Dicranopteris linearis* dominating other pioneering species of grasses and shrubs. *Phragmites* is often found in marshy valleys, and contains *Phragmites karka* and other sedges, also present in riverine forested areas.

Figure 2.14. Native grassland in Guam, Mount Chachao (left) and Endemic shrubs *Myrtella bennigseniana* and endemic grass *Dimeria chloridiformis* found in the Mount Chachao-Mount Tenjo Unit, War in the Pacific National Historical Park, Guam.

Forest and Shrubland Ecosystem Stressors

Many of the stressors on forest and grassland ecosystems are similar in nature. Significant stressors identified for PACN vegetation include: drought and severe weather events, wildfire, management activities, adjacent land use, forest fragmentation, visitor use and human harvest, alien invertebrates (insects, slugs and snails), alien vertebrates (herpetofauna, birds, rodents, and feral ungulates), plant disease, invasive alien plants, volcanic activity, and nutrient cycling. The following descriptions provide details on ecosystem stressors specific to the distinctive systems found in the Forest and Grassland Ecosystem.

Rain Forest: An important part of vegetation dynamics in Hawaiian forests is stand-level canopy dieback, particularly of *M. polymorpha*, the dominant species. Within a mature stand, the canopy component of this species appears to belong to a single generation. Saplings of *M. polymorpha* are rare, but numerous seedlings are found in the undergrowth or on decaying logs (Figure 2.15-A). During dieback, sequential cohort crashes open up the canopy, leading to a wave of sapling growth (Figure 2.15-B).

Dieback events appear to be triggered by climatic conditions as well as the demographic predisposition of *M. polymorpha* for such events. Before this phenomenon was understood, it was commonly believed that native forests were “doomed”, and many non-native species were imported to replace the native species. This practice led to the deliberate establishment of non-native vegetation over large areas that had been devegetated by feral ungulates, as well as the introduction of non-native species into intact forest reserves.

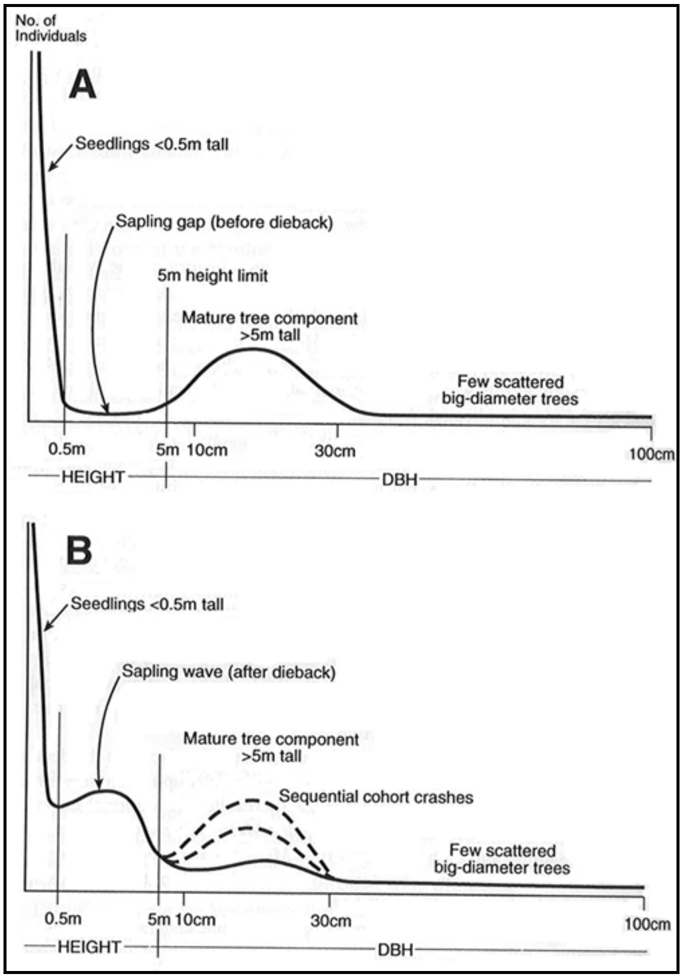

Figure 2.15. Population size structure models of *Metrosideros polymorpha* stands. A= in mature Hawaiian montane rainforests; B=in same forests after dieback (from Mueller-Dombois and Fosberg 1998).

Montane Bog and Pond: Lowland and foothill moist forests have been largely eliminated in the Pacific Islands. Some relatively large blocks of montane forest still exist on larger islands, but even here there is much degradation from feral ungulates, introduced weed species, development, and recreational activities. For example, it is estimated that there has been 61% loss of mesic forest and shrubland and 42% loss of wet forest, shrubland, and bog in the Hawaiian Islands (State of Hawaii 1992, Hawaii Heritage Program 1992). Global climate change is considered to be a significant threat to montane cloud forest (Loope and Giambelluca 1998). The World Wildlife Fund classifies Hawaiian moist forests (including mesic, rain, and cloud forests, wet shrublands, and bogs) as having globally outstanding biological distinctiveness and an endangered conservation status (Ricketts et al. 1999, World Wildlife Fund 2001). The World Wildlife Fund classifies Samoan tropical moist forests (including lowland, montane, and cloud forests) as having a critical conservation status (World Wildlife Fund 2001).

Marianas Limestone: Humans have had a major influence on the ecosystems of the Mariana Islands for at least 3,500 years. Over time, a general clearing and burning of forests on volcanic soils has created either secondary forest or savanna. This succession has caused soil erosion and loss of nutrients after frequent heavy rains. In areas of limestone soils, which are more fertile than volcanic soils, the forests have largely been cleared for coconut plantations, fields, and gardens. A major forest species, *Intsia bijuga*, has been mostly logged out. Much habitat was destroyed or altered during World War II. Abandoned cleared land reverts to a tangled secondary growth, dominated by introduced woody plants such as *Triphasia trifolia*, *Jatropha gossypifolia*, *Pithecellobium dulce*, *Muntingia calabura*, *Cananga odorata*, and especially *Leucaena leucocephala* (Mueller-Dombois and Fosberg 1998). A major threat to birds is the potential spread of the introduced brown tree snake (*Boiga irregularis*), an Australasian native which is responsible for the extinction of much of Guam's avifauna. The World Wildlife Fund classifies Marianas tropical dry forests (including limestone forest) as having a critical conservation status (World Wildlife Fund 2001).

Dry Forest and Grassland: Over 90 percent of the Hawaiian low shrublands have been lost to development or displacement by alien vegetation. Small, degraded examples of the natural communities of the ecoregion remain. Fire, weed invasions, feral animals (especially goats and deer), and continued development threaten this ecoregion. The World Wildlife Fund classifies Hawaiian lowland shrublands as having bioregionally outstanding biological distinctiveness and a critical conservation status (Ricketts et al. 1999, World Wildlife Fund 2001).

Tropical dry forests are globally threatened, and Hawaiian dry forests have been reduced by 90 percent (State of Hawaii 1992, Hawaii Heritage Program 1992, Noss and Peters 1996). Clearing and burning of lowland dry forests began with the arrival of Polynesians and the last remnants are being destroyed today through development, expansion of agriculture and pasture, and burning. Larger fragments of relatively intact dry forests are in montane areas. Introduced plant species are widespread and dense growth and competition for resources prevents the establishment of native plant seedlings. The African fountain grass (*Pennisetum setaceum*), the shrub *Lantana camara*, and molasses grass (*Melinis minutiflora*) are among the major problem species. Introduced rats, plants, and seed-boring insects, grazing by domestic livestock and introduced deer, goats, and pigs, as well as recurring fires inhibit almost any regeneration of native species in most altered habitats. The World Wildlife Fund classifies Hawaiian tropical dry forests as having globally outstanding biological distinctiveness and a critical conservation status (Ricketts et al. 1999, World Wildlife Fund 2001).

Prior to the arrival of humans, Guam was heavily forested, and grasslands, while present, were relatively rare. The introduction of fire to the island by people has caused much of Guam's native forest to be replaced with grasslands, in which many of the species are non-native and well adapted to repeated burning (Figure 2.16). In WAPA, native savannah grasslands are found on the slopes of the Agat and Asan units. They typically consist of native swordgrass (*Miscanthus floridulus*), native and non-native scattered trees, and non-native grasses. Non-limestone forest on Guam contains many of the same tree species as limestone forest, with the addition of betel nut palm (*Areca catechu*). Saipan also has areas of grass (primarily *M. floridulus*) and fern savanna on volcanic soil.

Figure 2.16. Tropical savanna grassland with fire in the foreground. Fire, usually started by arson, routinely burn acres of the park's grassland. Fire poses a significant threat to Guam's terrestrial and marine ecosystems.

Forest and Shrubland Ecosystem Model

Figure 2.17 is the conceptual model for the wet and dry forest and shrubland ecosystems. Rectangles indicate prominent agents of change and circles represent major components of the ecosystem. Large pink arrows link agents of change to the entire ecosystem, including biotic, physical, and chemical components. The dark green area indicates those agents of change or resources that are actively managed by the National Park Service.

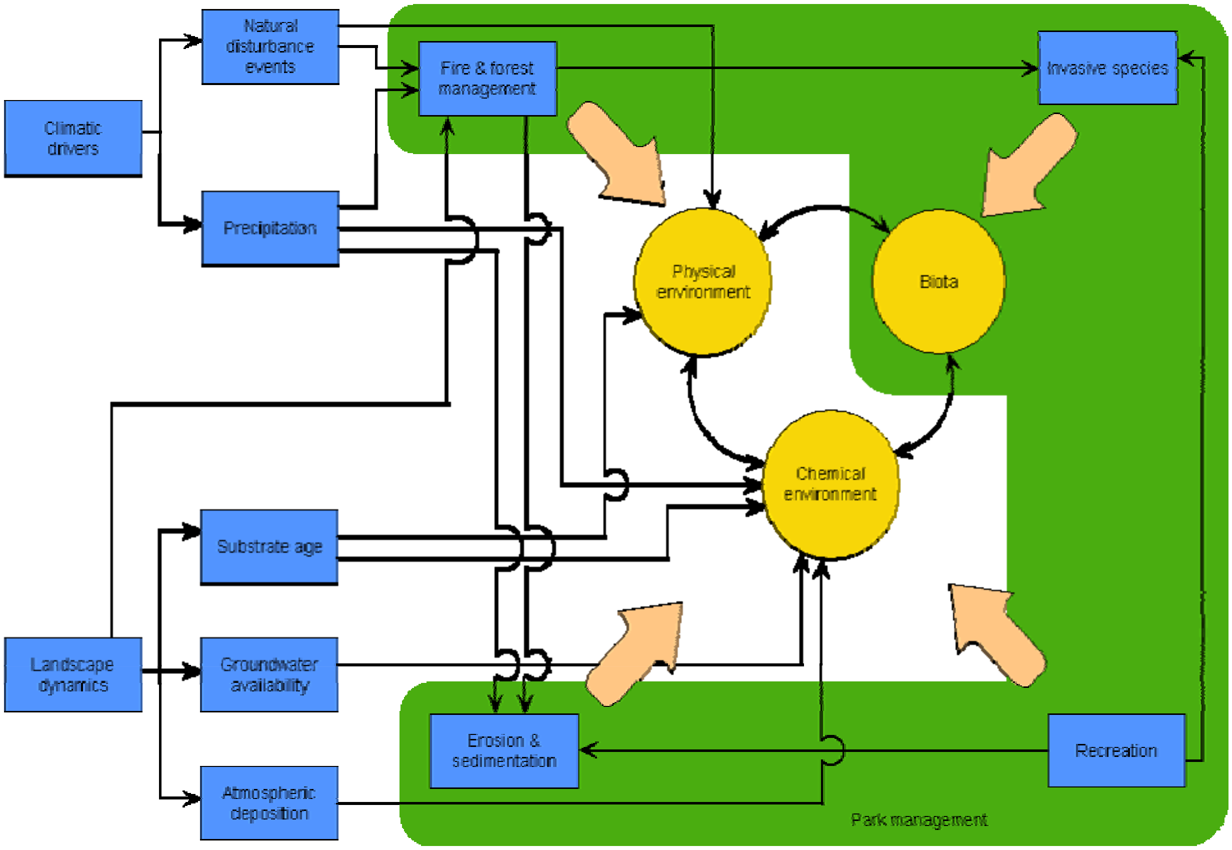

Figure 2.17. Conceptual model of ecosystem dynamics in wet and dry forest ecosystems of PACN parks.

SUBTERRANEAN ECOSYSTEM

(Partly modified from Giffin 2003.)

Subterranean ecosystems are found in WAPA, NPSA, KALA, HALE, ALKA, PUHE, KAHO, PUHO, and HAVO. Two types of subterranean ecosystem are found on Pacific Islands: terrestrial caves and lava tubes and mixohaline aquatic systems, also called anchialine systems. Anchialine systems are described in the *Coastal Ecosystems* section of this appendix.

Guam's karst caves are primarily formed by the action of water on limestone, in contrast to most caves in other PACN parks, which are volcanic in origin (though small caves may be formed in uplifted ancient limestone deposits). Karst features on Guam include sinkholes, caves, springs, and heavily weathered surface rocks (Taborosi 2004). An undescribed goby species has been observed in these caves (Myers and Donaldson 2003).

Hawaiian lava tube communities are the most well-characterized of these ecosystems. Older islands contain fewer lava tubes, as they tend to collapse over time. Unlike soil, which acts as a filter trapping nutrients and water, the voids in cavernous rock strata act as conduits that transport organic resources deep underground. Young basaltic flows, like cavernous areas generally, contain a vast anastomosing system of medium to large sized voids. Figure 2.18 shows the five recognized habitat zones of a lava tube ecosystem.

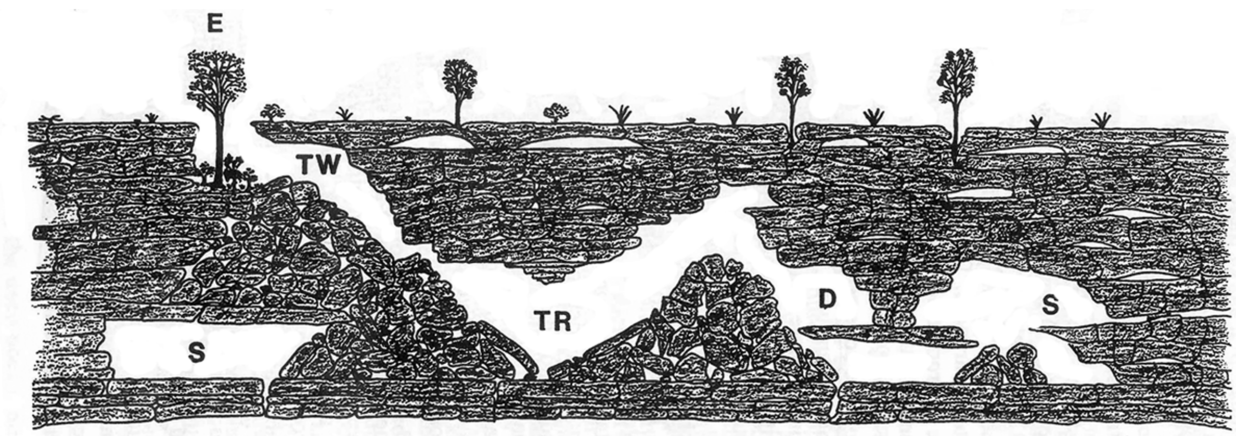

Figure 2.18. Profile view of a lava tube showing the five habitat zones. Scale for length is greatly condensed relative to height. E=entrance zone, TW=twilight zone, TR=transition zone, D=dark zone, S=stagnant zone (from Howarth 1993).

The ecosystem of the dark zone is largely dependent on roots of *Metrosideros polymorpha* and other trees that extend through the soil and bedrock into the lava tubes as its primary energy supply (Figure 2.19). Additional food energy comes from organic material washing or falling into crevices, surface animals wandering underground, and probably chemoautotrophic bacteria. Caves are high-stress environments for animals. Obligate cave species are adapted to perpetual darkness, high humidity, lack of important environmental cues, complex mazelike living space, stressful or even lethal gas mixtures, patchy food resources, barren rocky substrates, wet and slippery vertical surfaces, and occasional flooding (Howarth 1993).

Figure 2.19. Characteristics of lava tubes. Roots growing into a lava tube (left). Vegetation growing in and around entrance to a lava tube (right).

Lava tubes (Figure 2.19) harbor unique cave-adapted species, usually independently evolved from surface-dwelling ancestors at each cave complex (Hoch and Howarth 1999). These include crickets, planthoppers, spiders, moths, crane flies, earwigs, assassin bugs, and others. More than 70 species of cave arthropods have been discovered to date in the Hawaiian Islands, with 26 species known from Hawaii Island (Howarth 1991).

Biologists generally classify cave animals into four ecological categories: troglobites, troglophiles, trogloxenes, and accidentals. Troglobites have the highest degree of specialization for subterranean life. They are so highly modified that they cannot survive above ground. This group of arthropods is characterized by reduced pigment, small eyes (or none) elongate antennae and legs, and flightlessness (Howarth 1993). They live in the dark zone of lava tubes, feeding on bacteria, fungi, cave debris, plant roots, slimes and dead animals. Troglophiles are able to live in subterranean habitats, but are not especially modified for cave life. Members of the same species may also occur above-ground in damp habitats. Trogloxene species often occur in caves, but cannot complete their entire life cycle there. Accidentals are surface species that occasionally fall, wander or are washed into caves. These temporary visitors only survive underground for a short period of time and often serve as food sources for other cave inhabitants.

Subterranean Ecosystem Stressors

Cave systems are fragile and easily disturbed, either by human activity within caves or by above-ground activities such as clearing vegetation, diverting streams, or dumping. Caves and lava tubes are legally protected in Hawaii. These systems frequently contain sensitive cultural sites, including burial sites, former shelters, and locations modified for water collection and food storage. Some passages have man-made structures such as rock platforms, trails paved with smooth stones, fire pits, calabash cradles for catching water and rock walls. Midden deposits in some shelter caves contain bird bones and marine invertebrate shells. Traditional beliefs hold that cultural sites, particularly burial sites containing human remains, should not be disturbed.

Subterranean Ecosystem Model

Figure 2.20 is our conceptual model of ecosystem dynamics in subterranean ecosystems of PACN parks. Rectangles indicate prominent agents of change and circles represent major components of the ecosystem. Large pink arrows link agents of change to the entire ecosystem, including biotic, physical, and chemical components. The dark green area indicates those agents of change or resources that are actively managed by the National Park Service.

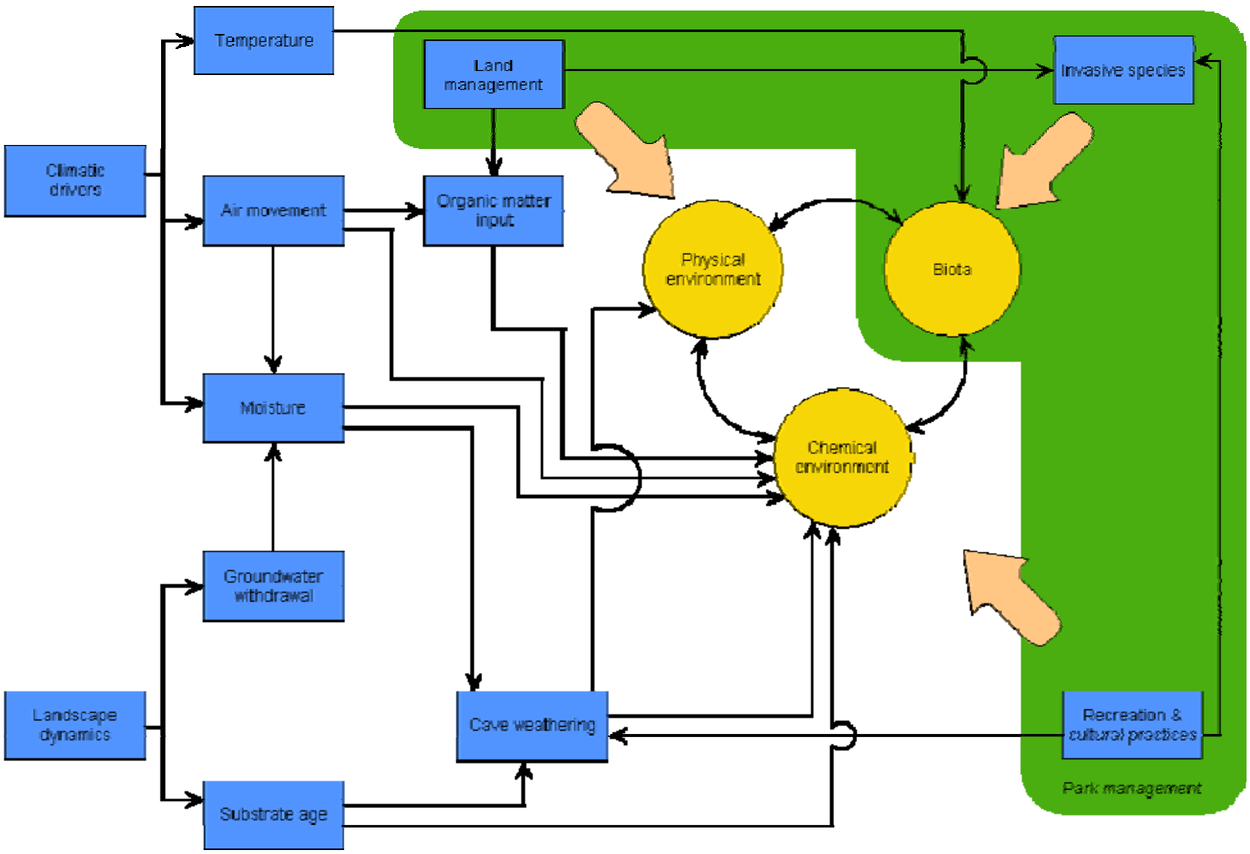

Figure 2.20. Conceptual model of ecosystem dynamics in subterranean ecosystems of PACN parks.

Stream Ecosystem

The extreme isolation of Pacific island stream systems has resulted in a limited diversity of native species, but a high degree of endemism (Ford and Kinzie 1991). The native stream fauna of Pacific Island streams includes fish (primarily gobies, sleepers, and eels), shrimp and prawns, water-breeding insects and other arthropods, and snails. Freshwater native species richness generally declines and the degree of endemism increases with distance from Southeast Asia (Haynes 1988, Ford and Kinzie 1991, Font 2003).

Perennial streams (Figure 2.21) provide habitat to completely aquatic species, while intermittent streams (Figure 2.21), springs, and seeps are important as breeding habitat for insects and snails and feeding areas for other fauna (Polhemus et al. 1992). Estuarine regions tend to be fairly small, as compared to continental estuaries. However, they are important biologically as both a breeding ground and nursery for marine fishes and serve as a link between freshwater and marine environments for migratory species. Several streams in the PACN also have associated riparian wetlands (Scott 1993). Perennial streams are found in AMME, WAPA, NPSA, KALA, HALE, ALKA, and PUHE; NPSA, KALA, ALKA, PUHO, PUHE, HALE and HAVO have intermittent streams.

Figure 2.21. Perennial stream habitat, Waikolu Stream on Molokai (left). Intermittent stream at NSPA (right).

Because of the vast ocean distances separating freshwater habitats on different islands, freshwater Pacific Island fauna have in many cases evolved from marine ancestors. Marine stages in their life cycles allow these organisms to travel great distances across the ocean. Many native stream fish and some macroinvertebrate species have an amphidromous life history (Figure 2.22), in which an adult lays eggs in a stream. Larvae hatch and are washed downstream, and spend several months maturing as part of the marine plankton community (Radtke and Kinzie 1991). Juveniles then recruit back to a stream and mature. Other fish species have a catadromous life cycle, which only differs from amphidromy in that adults migrate to estuarine or marine habitats to breed. These species can reproduce several times over the course of their lives, and do not necessarily return to the stream from which they were spawned (Fitzsimons et al. 1990, Chubb et al. 1998, Hodges and Allendorf 1998, Way et al. 1998). 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.

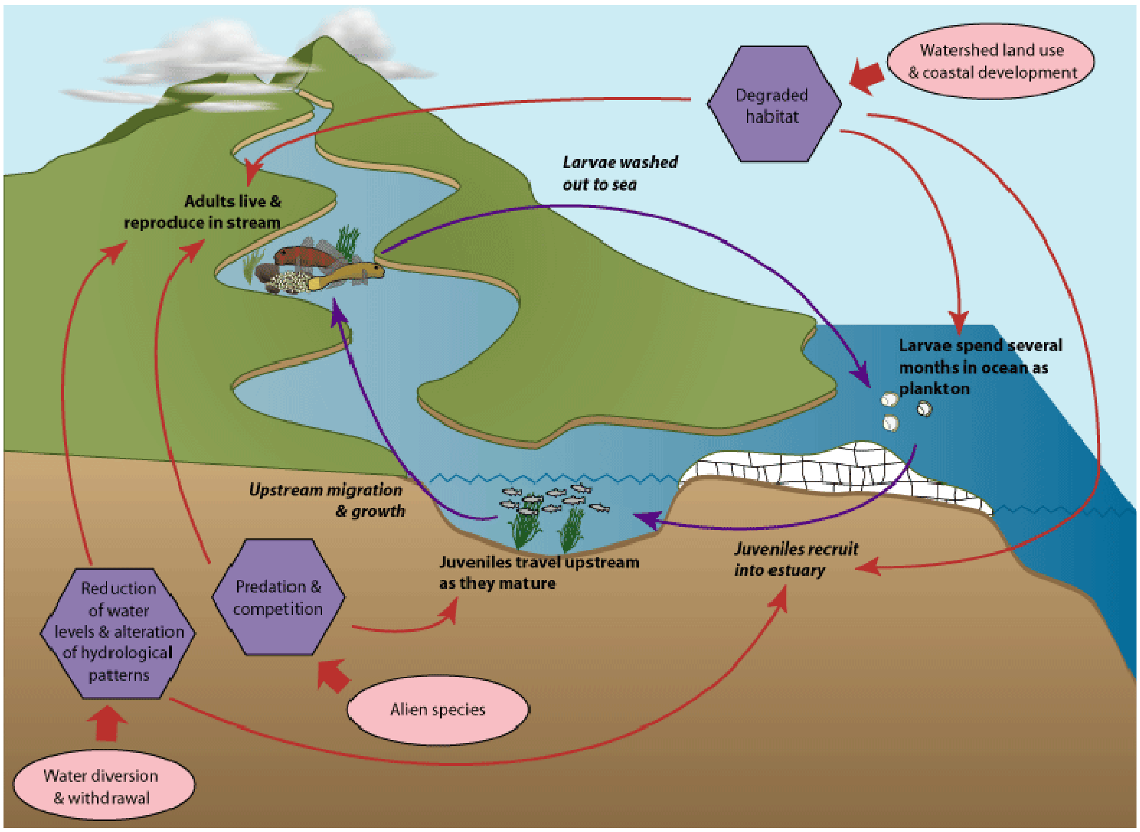

Figure 2.22. Amphidromy life history model, illustrating locations in which life history stages occur, potential anthropogenic disturbances (ovals), and effects of stressors upon organisms in each life history stage (hexagons).

Stream Ecosystem Stressors

Changing land use practices on most Pacific islands, especially in low-lying areas, are rapidly altering instream habitats. These changes include increasing urbanization, groundwater and surface water withdrawal, stream channelization and hardening for flood control, dam construction, increased frequency of forest or grassland fires, and clearing of riparian areas for agriculture and urban growth. Riparian land use also affects water quality, resulting in changes in nutrient levels, contaminant detections and concentrations, water flow, turbidity, sediment levels, and water temperature (Gregory et al. 1991). These changes make freshwater resources less suitable as habitat for native species (Nishimoto and Kuamoo 1997, Brown et al. 1999, Brasher 2003, March et al. 2003, Laws and Roth 2004), and may facilitate the spread of alien species that are able to out-compete native species in changed environmental conditions (Vitousek et al. 1996, Brown et al. 1999, Brasher 2003).

Pacific Island streams are typically fed by a combination of groundwater and precipitation, and are characterized by frequent and unpredictable periods of high flow associated with rainfall

(Oki and Brasher 2003, Oki 2004). Water withdrawal reduces base flow and dampens both the frequency and magnitude of periodic flooding events (Brasher 1997, Oki 2004). While natural disturbance events such as floods cause local or system-wide changes to physical, chemical, or biotic components, these variations are considered part of the natural state.

The degree of stream alteration by human activity varies from island to island and park to park. Most PACN streams are highly modified physically and/or chemically, but several streams are among the few remaining slightly-modified stream systems region-wide. No PACN streams are entirely unaffected by invasive aquatic or riparian species, whose wide range of effects on stream systems include predation, parasitism, or competition for food with native species, alteration of the food source of native predators, habitat alteration, and changes in nutrient input and cycling (Kido et al. 1993, Eldredge 1994, Englund 1999, Yamamoto and Tagawa 2000, Font 2003). Key processes that drive stream ecosystems to modified states are changes in flow regime, channel alteration, erosion, contaminant inputs and introduction of invasive species (Figure 2.23).

Stream Ecosystem Model

Figure 2.23 is our conceptual model of ecosystem dynamics in stream ecosystems of PACN parks. Rectangles indicate prominent agents of change and circles represent major components of the ecosystem. Large pink arrows link agents of change to the entire ecosystem, including biotic, physical, and chemical components. The dark green area indicates those agents of change or resources that are actively managed by the National Park Service.

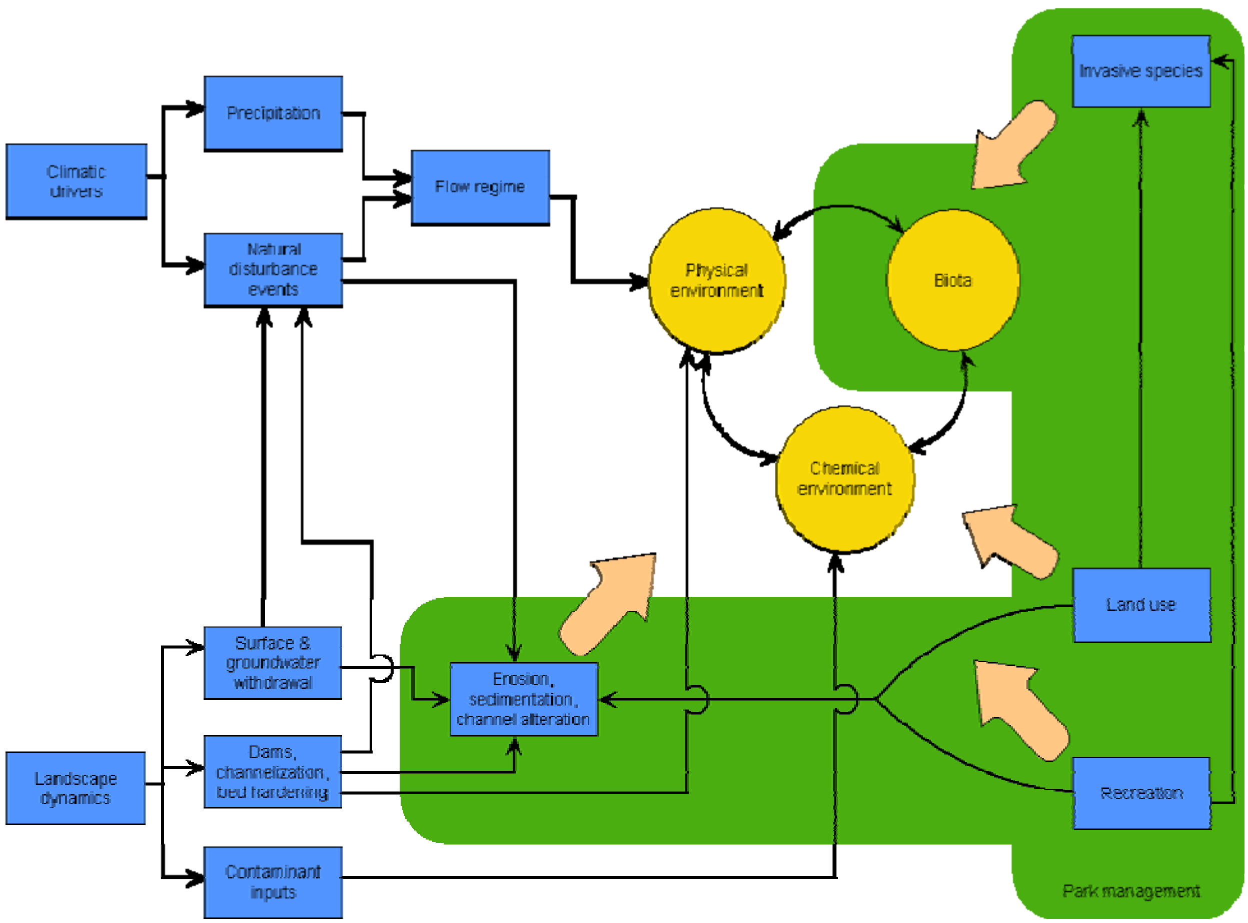

Figure 2.23. Conceptual model of ecosystem dynamics in stream ecosystems of PACN parks.

COASTAL ECOSYSTEM

The coastal ecosystems vary across the PACN and are influenced and characterized by large scale oceanographic features and processes and smaller scale geologic and biological processes with time. As volcanic islands are formed, animals and plants colonize shallow nearshore waters and reefs develop over long periods of time (Figure 2.24).

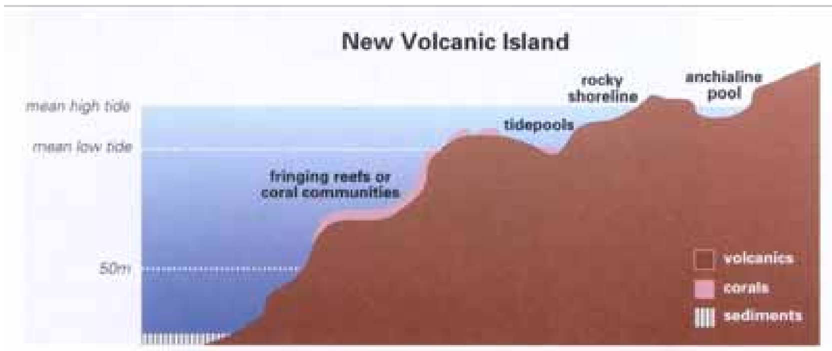

Figure 2.24. Conceptual diagram of a new volcanic island, illustrating the location and development of important nearshore (fringing reefs) and onshore (tidepools and anchialine pools) habitats (from Juvik and Juvik 1998)

New volcanic islands support few living structural reefs and communities of algae, corals and sand-dwelling species inhabit underwater slopes (Juvik and Juvik 1998). The accumulation of skeletons from algae, corals, and other calcareous organisms accrete together into a solid framework with the assistance of encrusting coralline algae and over time these accretions form a fringing reef close or adjoined near the shoreline. Most of the reefs in the main Hawaiian islands are fringing reefs. In younger islands, such as the island of Hawaii, tidepools and anchialine pools are common along the rocky coastline. Beaches are not as common and are usually found in and around bays and coves (Juvik and Juvik 1998).

As time progresses and an island moves off the volcanic hot-spot, it begins to erode and subside. During this slow process, reefs grow outward, away from shore, to form a barrier reef such as present in southern Guam and eastern Saipan (Figure 2.25).

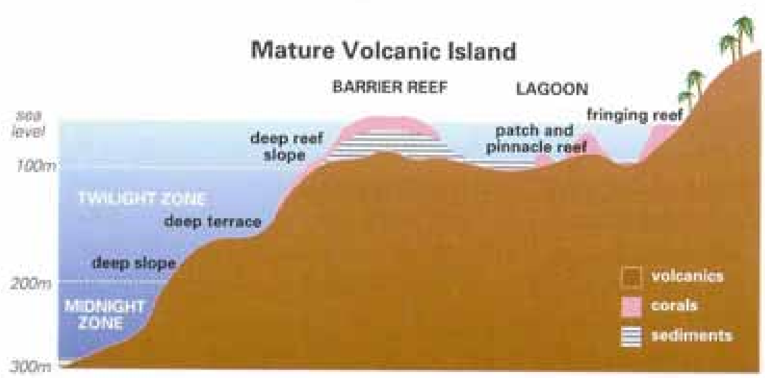

Figure 2.25. Conceptual diagram of a mature volcanic island illustrating the development of barrier reefs and lagoons resulting from subsidence (from Juvik and Juvik 1998)

With time, erosion and weather alter the rugged shoreline with gently sloping coastal plains dotted with streams, estuaries, sandy beaches, many fringing reefs, and barrier reefs (Juvik and Juvik 1998). Lagoons behind barrier reefs provide protected environments where patch reefs can develop. Additionally, these sheltered waters promote the growth of marine plant communities and ecosystems such as seagrasses and mangroves adjoining the shoreline. Eventually, as islands erode and subside they disappear below the ocean and all that remains above the surface is a ring of living reef and its accumulated sediment, an atoll.

Coastal ecosystems across the PACN contain diverse habitats with abundant resources. Distinctive systems found within the coastal ecosystem could be classified accordingly: anchialine pool (Figure 2.26), coastal marsh, mangrove swamp, fish pond, coastal strand and nearshore marine ecosystems which include coral reef (Figure 2.26), lagoon, seagrass, and nearshore intertidal. The common theme that unites them is the interaction of fresh and saline ground and surface water, which forms highly dynamic ecosystems (another term for ecosystems formed by this type of interaction is mixohaline). Their location at the interface of the terrestrial and marine environments makes them very important culturally, economically, and ecologically.

Figure 2.26. Example of distinctive features in the coastal ecosystem. Anchialine pool, KAHO (left). Coastal ecosystem at NPSA, Ofu Island (right).

Anchialine Pool

Anchialine pools are found in ALKA, PUHE, KAHO, PUHO, and HAVO. Anchialine pools are surface expressions of complex, subterranean brackish water systems formed by the interaction of fresh and saline groundwater and lacking surface connections to the sea. They are rare worldwide, and within the United States are only present on the younger Hawaiian Islands (Maciolek 1987). The majority of pools are found on the west coast of Hawaii Island (Brock 1985). The surface pools function as “windows” into brackish groundwater systems that may extend for long distances. They are tidally influenced: water levels rise as the tide comes in and fall as it goes out, though there is a time delay depending on the distance to the ocean and directness of the subsurface connection to the ocean (Figure 2.27). Some pools are only visible on the surface during high tide.

Characteristic pool biota includes algal mats, the aquatic wigeongrass (*Ruppia maritima*), several different types of shrimp and snails, isopods, amphipods, and polychaetes (Maciolek 1983). Marine or amphidromous fish species, shorebirds, and other waterbirds are also found in the pools. Several rare, threatened, or candidate endangered species are found, including several shrimp, a snail, and several insects (particularly damselflies). Organisms that live in these systems may either require light for survival and be restricted to open pools (epigeal species), or not require light and live within the system crevices in the water table below the pools (hypogeal species) (Bailey-Brock and Brock 1993).

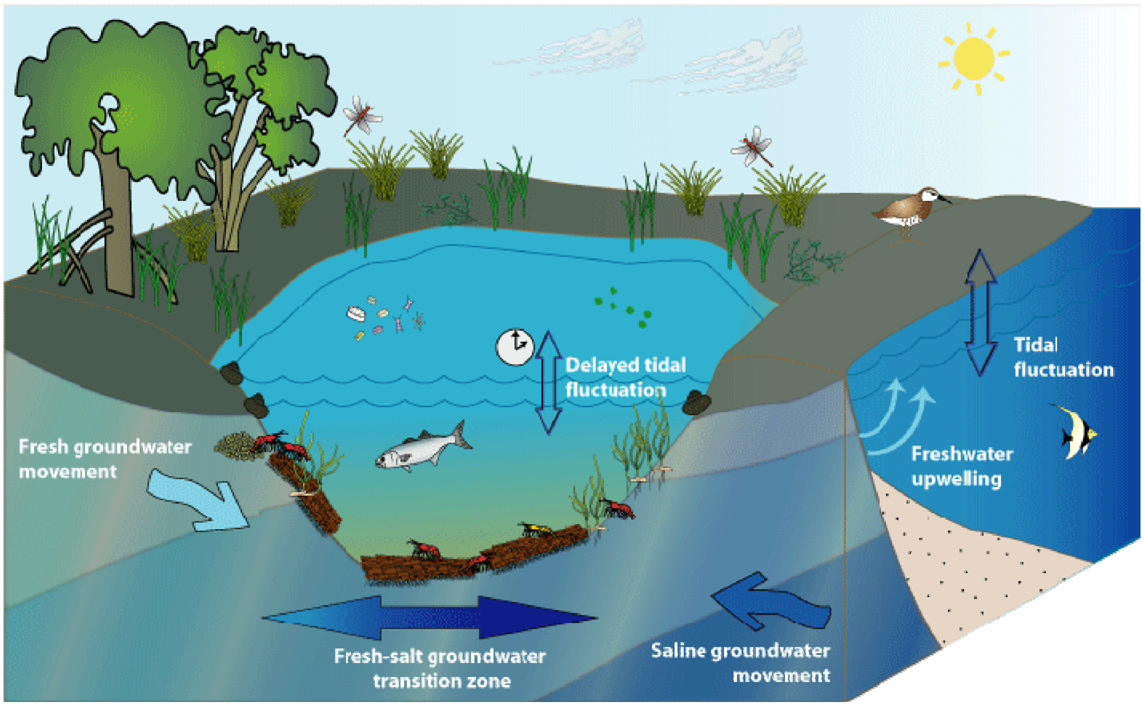

Figure 2.27. Diagram of an anchialine pool system, illustrating interaction of fresh and saline groundwater and typical pool biota.

Lake Kauhako: There are few natural lakes on Pacific Islands. One of these, Lake Kauhako, is believed to be the fourth-deepest in the United States (Maciolek 1982), with the highest ratio of depth to surface area of any lake in the world (Donachie et al. 1999). Lake Kauhako, located in Kalaupapa N.H.P., is found in a 248 meter deep pit crater near sea level. It is morphologically and hydrogically unusual. The top four meters are brackish and support an array of algae, anchialine shrimp, and other invertebrates, while waters below are saline and anoxic and support an unusual bacterial community. The forest on the upper slopes of the crater is a special management area, and human impacts to the lake appear to be minimal.

Coastal Marsh

Coastal marshes are found in AMME, WAPA, NPSA, ALKA, PUHE, KAHO, and PUHO. They may be associated with streams, lakes, or anchialine pools, or be fed by groundwater. Vegetation includes grasses, sedges, ferns, and other flowering plants. Native species such as damselflies, fish, coots, moorhens, ducks, and other waterbirds, utilize coastal marshes. Like other lowland ecosystems, coastal marsh ecosystems have been substantially altered by invasive species of plants and animals.

Coastal Swamp

Coastal swamps, including mangrove, *Pandanus* spp., and *Hibiscus tiliaceus* swamps, are found in AMME, NPSA, ALKA, and KAHO. Mangroves are native to Saipan, Guam, and Samoa, but all species of mangrove are recent introductions to the Hawaiian Islands and considered invasive. These forests are recognized for their high biodiversity and associated ecological functions, including sediment retention, processing of organic matter and nutrients, and protection from storms and tsunami (Ewel et al. 1998). The AMME mangrove wetland (Figure 2.28), for example, contains approximately 200 species of plants and animals, including two endangered species of birds, the nightingale reed-warbler (*Acrocephalus luscinia*) and the Mariana common moorhen (*Gallinula chloropus guami*), as well as the humped tree snail (*Partula gibba*), a species of concern.

Figure 2.28. Mangrove swamp in AMME (left) contains the entire range of Bruguiera gymnorrhiza for Saipan and it is home to many species (unique to the NPS system) such as the Micronesian honeyeater (*Myzomela rebratra*, right).

Fishpond

Fishponds are brackish-water Hawaiian man-made coastal structures, used in the past for farming of marine and estuarine fish species (Figure 2.29). They are an excellent example of a resource with shared natural and cultural value. Most fishponds in Hawaii have fallen into disuse or been filled in for shoreline development, and there is a high level of interest in restoring several of the remaining ponds in PACN parks. The two major categories of fishponds are shore ponds and inland ponds, though there are several pond types within each of these categories. Inland fishponds are found at KALA, ALKA, and PUHO, and shore ponds are found at ALKA and KAHO.

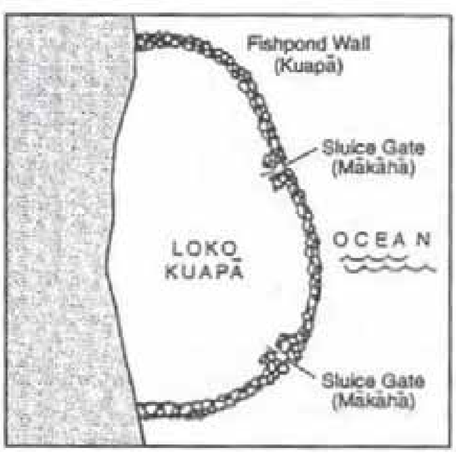

Figure 2.29. Diagram of a loko kuapa (left, from Dieudonne 2002). Kaloko Pond at KAHO, a representative fishpond (right).

The fishponds remaining in PACN parks vary in size, type, and condition, and are utilized by a variety of birds, fish, and invertebrates. For example, the 11-acre Kaloko Pond at KAHO is a loko kuapa, a shore fishpond distinguished by its arc-shaped seawall and sluice gates (Figure 2.29). Its seawall is currently being repaired, and the park plans to restore it to use as a managed fishpond. The 15-acre, sand-bermed Aimakapa Pond, also at KAHO, is more brackish than saline, and is largely being managed as endangered waterbird habitat. In contrast, the inland Royal Fishpond at PUHO is only approximately ten square feet, and is currently inhabited almost exclusively by high densities of the invasive fish tilapia (*Oreochromis* spp.).

Coastal Strand

Coastal strand communities are found at all PACN parks except USAR. Coastal strand communities are located on strips of coral or volcanic sand or limestone or volcanic rock adjacent to the shoreline. They contain species adapted to salt spray, storm surge and shifting substrate, such as the coconut (*Cocos nucifera*), and various vines, grasses, and shrubs. Coastal strand communities, in contrast to the other habitats found in coastal ecosystems, are typically limited by nutrients and water. Strand vegetation is typically widespread throughout the Pacific (e.g., *Scaevola sericea, Ipomoea pes-caprae, Pandanus tectorius*), though the Hawaiian Islands have several endemic species. Endangered sea turtles use beaches for nesting and Hawaiian monk seals (*Monachus schauinslandi*) frequently haul out on them to rest and give birth to and nurse pups (Figure 2.30). Distinctive features within the coastal strand community found in the PACN are the black and green sand beaches found at HAVO and ALKA.

Figure 2.30. Example of coastal strand community at Kalaupapa N.H.P. Monk seals (*Monachus schauinslandi*) haul out onto beaches to give birth and nurse pups.

Coastal Ecosystem Stressors

Coastal habitat of many Pacific islands has been significantly modified in the last century. The loss of coastal ecosystems has occurred for various reasons, including reclamation of land for harbor, residential, and resort construction, dumping and filling for insect control, modification of habitat by invasive species, agriculture and aquaculture, and water withdrawal (Scott 1993). Low-lying costal freshwater resources such as wetlands, pools, and fishponds are heavily impacted by sea level rise. Even small levels of sea level rise may cause enough upward infiltration of saline water into groundwater to significantly increase salinity in anchialine pools and coastal wetlands, rendering these habitats unsuitable for freshwater biota. Excessive withdrawal of groundwater can lower the water table, causing brackish wetlands to become more salty and freshwater wetlands to shrink in size or dry up. Specific stressors affecting distinctive systems within the coastal ecosystem follow.

Anchialine Pool: Anchialine pools are considered "special aquatic sites" under the Clean Water Act and are offered the same kind of regulatory protections as wetlands. Threats to these systems include establishment of invasive species, habitat destruction for development, collection of shrimp for the aquarium trade, decreased water quality, groundwater withdrawal, and sea level rise.

Coastal Marsh: Direct human modification of wetland vegetation, especially in lowland areas, has been occurring on Pacific Islands since initial settlement. In the Hawaiian Islands, for example, most of the large, saline lowland marshes have been highly modified or destroyed (Mueller-Dombois and Fosberg 1998). Wetlands have traditionally been modified for growing taro and rice, for grazing, and for aquaculture. More recently, they have been filled or dredged for housing, urban and resort development, and dumping.

Coastal Swamp: Coastal swamps on Pacific Islands face the same impacts from human activity and invasive species as coastal marshes do. The AMME wetland is one of the few remaining swamps on Saipan. Coastal swamps in the Hawaiian Islands differ from those in the west and south Pacific, in that the dominant woody species are introduced. Hau (*Hibiscus tiliaceus*) is a Polynesian introduction, and mangroves (most commonly *Rhizophora* mangle) (Figure 2.31) are modern introductions. While mangrove swamps in Hawaii retain sediment and process nutrients, they also damage archaeological structures, promote infilling of estuaries, fishponds, and anchialine pools, and eliminate marsh habitat utilized by native waterbirds (Allen 1998). Thus, in Hawaii parks, mangroves are a management concern, while in NPSA and AMME they are considered an important resource.

Figure 2.31. Coastal swamp community with red mangrove, *Rhizophora mangle*.

Coastal Strand: Coastal strand communities have been significantly altered by human activity. Coastal development and the introduction of invasive species have severely restricted the ranges of some endemic strand species, though more cosmopolitan strand species have not been as affected.

Coastal Ecosystem Model

Figure 2.32 is our conceptual model of ecosystem dynamics in coastal ecosystems of PACN parks. Rectangles indicate prominent agents of change and circles represent major components of the ecosystem. Large pink arrows link agents of change to the entire ecosystem, including biotic, physical, and chemical components. The dark green area indicates those agents of change or resources that are actively managed by the National Park Service.

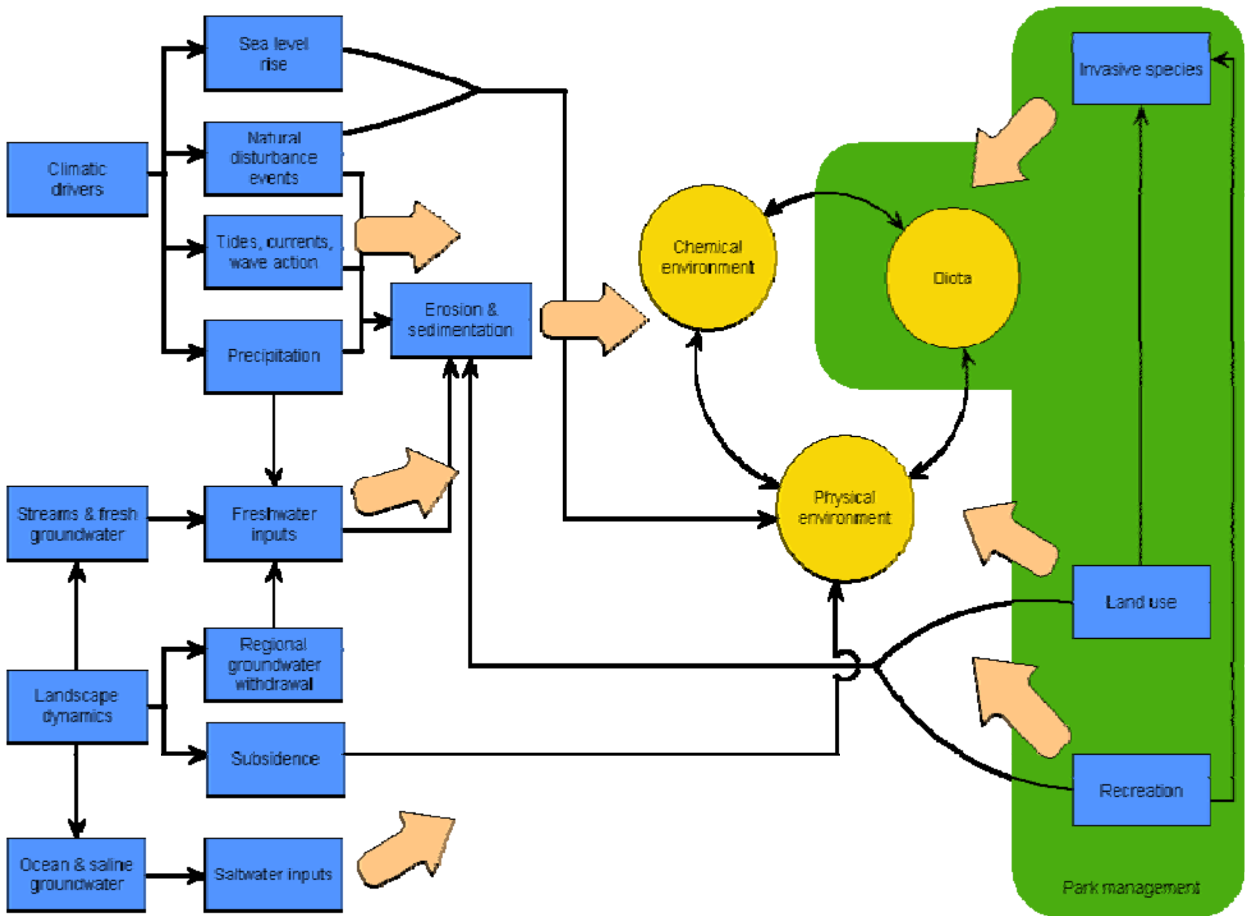

Figure 2.32. Conceptual model of ecosystem dynamics in coastal ecosystems of PACN parks.

NEARSHORE MARINE ECOSYSTEM

Nearshore marine ecosystems are diverse and varied across PACN parks. Distinctive systems found within the PACN nearshore marine ecosystem include coral reefs, fringing reefs, lagoons, seagrasses, and shoreline intertidal systems. All parks either contain (WAPA, NPSA, KALA and KAHO) or adjoin (all others) the nearshore marine environment.

Coral Reef

Coral reefs are found in shallow tropical salt waters and are constructed primarily by hermatypic or reef-building corals. Coral reefs are diverse and complex marine ecosystems, often drawing comparisons to tropical rainforests in terms of species numbers and complexity of interactions (Connell 1978, Birkeland 1997). Coral reef ecosystems are centers of biodiversity because of the habitat complexity available to different organisms created by the combination of several factors including structure, nutrients, water quality and light (Figure 2.33). The reef provides substrate for sessile organisms to attach and an increased surface area for motile organisms to live or feed. Coral reefs are important components in shallow benthic, fringing and barrier reef ecosystems in PACN parks.

Figure 2.33. Coral reef community at Ofu lagoon, where a diverse community of coral species, algae and fish reside.

A prominent aspect of the coral reefs is the presence of distinct physiographic and biologic zones. The example of reef zonation by Randall and Myers (1983), while specific for Guam, exemplifies a generalized reef profile (Figure 2.34).

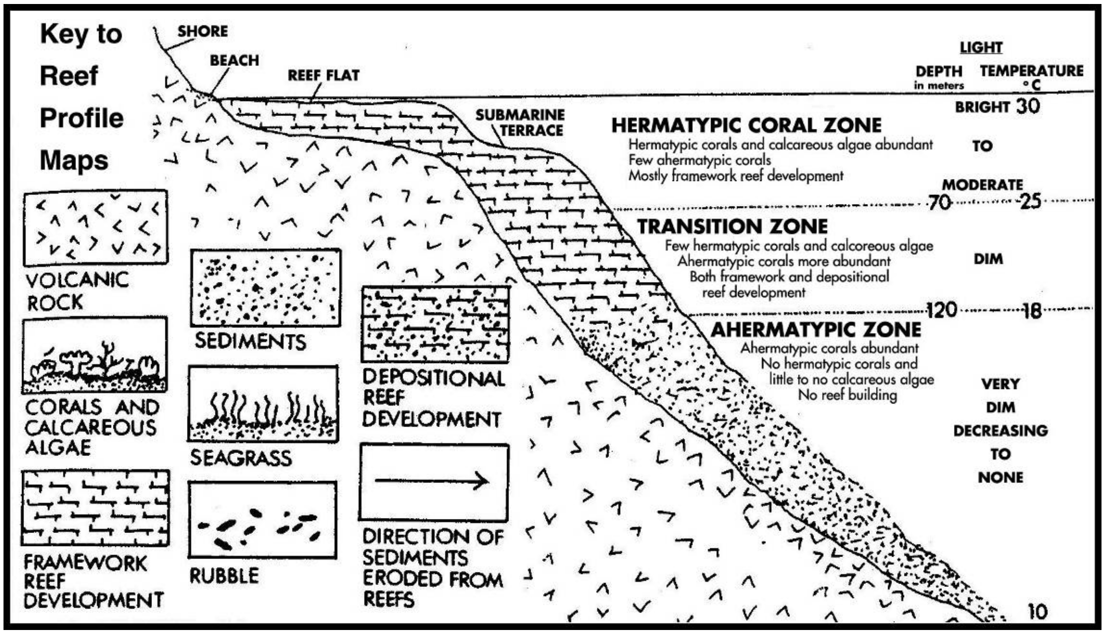

Figure 2.34. Generalized reef profile showing hermatypic and ahermatypic coral distribution (modified from Randall and Myers 1983).

Patterns of zonation arise and are maintained primarily by the interaction of physical, chemical, and biological processes – mainly those of accretion of reef deposits by corals, calcareous algae, and other calcium carbonate metabolizers, erosion, and sedimentation (Randall and Myers 1983). Reef zones are most distinct in parallel bands that follow the long axis of a fringing or barrier reef platform. Regardless of the type of reef, limestone bench, volcanic platform, or sea cliff present, most of their subtidal regions have a variety of corals, algae, and other reef-associated organisms growing on their surface.

The proximity of coral communities to coastal areas makes them susceptible to sources of anthropogenic stress (Jokiel and Cox 1996, Wilkinson 2000, 2002, 2004). Globally, coral reefs are at-risk and imperiled by many stressors, including both anthropogenic (e.g., pollution, sewage discharge) and naturally occurring (e.g., heavy weather and mass wasting) sources. In part, due to their biological complexity and because they are sessile, corals are very sensitive to changes in their environment. Changes in surrounding water quality, turbidity, or the presence of contaminants or pollutants have an impact on corals and ultimately the associated community.

Shallow benthic communities are found to depths of 160 feet (50 m) or more (Juvik and Juvik 1998). The substrate consists of basalt, consolidated limestone and sediments. Community composition depends upon light penetration, temperature, wave action and type of substrate. Common community biota includes macroalgae, coralline algae, coral communities and sand-dwelling communities such as cone shells (*Conus*) and tritons (*Charonia*). Other biota commonly associated with shallow benthic communities includes reef fish, sea urchins, sea cucumbers, and endangered Hawaiian monk seals (in the Hawaiian Islands). All parks in the PACN either contain or adjoin marine waters with shallow benthic communities.

Fringing Reef

(Modified from Juvik and Juvik 1998)

Fringing reefs grow offshore such as in Figure 2.35 (in Hawaii, for example, to a depth of around 165 feet (50 m)). They are comprised primarily of calcium carbonate skeletons and sediments produced by corals and coralline algae. Sand deposits and seaweeds are common on low inner reef flats; living coral and coralline algae predominate at the reef's outer edge; deeper slopes are mostly dominated by live corals or old reef rock. Beneath the living outer layer of reef organisms, the remains of reef builders are compacted and cemented into a hard limestone wave resistant structure, which in places may be cut through by channels. Biota is similar to those found in shallow benthic communities, with the frequent observation of sea turtles that forage on reef flats.

Figure 2.35. Example of fringing reef at Ofu, American Samoa. For perspective, the shoreline lies at the top of photograph.

Barrier Reef and Lagoon

(Modified from Juvik and Juvik 1998)

Between barrier reefs and shore line lie deep lagoons with relatively calm waters. Lagoon and ocean waters are connected by passes cut through the reefs. Barrier reefs consist of consolidated carbonate rock, with the bottom between shore and barrier reef covered with sediments consisting of gravel or mud. Pinnacle and patch reefs can occur within lagoons and fringing reefs line the shoreline. Biota consists of similar community members as benthic and fringing reef communities. True barrier reefs and lagoonal systems are not present in any of the parks but can be found offshore adjacent to AMME on Saipan.

Seagrass

Seagrass communities are found within PACN national parks only at WAPA and adjacent to AMME. They can be found close to shore below the tidal zone and off inner reef flats, typically completely submerged in areas with low wave action (Juvik and Juvik 1998). Seagrasses root in soft sand and mud that are either terrigenous or carbonate. They are comprised of marine flowering plants that occur in predominately shallow, soft-bottom coastal waters and estuaries (Kirkman 1990). Seagrasses are important in stabilizing sediments, reducing suspended material within the water column, and improving coastal water quality, but are susceptible to smothering by heavy sedimentation. They often serve as nursery grounds for ecologically or economically important coral reef species and are critical to the long-term health of the coral reef ecosystem. Globally, seagrass ecosystems are 'at risk' and imperiled, primarily from anthropogenic sources (e.g., sedimentation) and natural stressors (e.g., tropical cyclones).

Shoreline Intertidal

The shoreline intertidal region overlaps with the coastal strand vegetation described above, but describes and emphasizes the area periodically and cyclically covered by water. The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) benthic mapping of the Main Hawaiian Islands defined the shoreline intertidal region as the "area between the mean high water line (landward edge of emergent vegetation when present) and lowest spring tide level (excluding emergent segments of barrier reefs). Typically this zone is narrow due to the small tidal range in the main Hawaiian Islands" (Coyne et al. 2003). Typical habitats found in this region include mangroves, seagrass, sand, hau trees (*Hibiscus tiliaceus*) and uncolonized volcanic/carbonate rock.

Shorelines consist of sandy or muddy slopes and rocky beaches where sand and other sediments are absent due to constant wave action, currents, steep submarine slopes, or lack of offshore sand reservoirs. Rocky beaches consist of mostly consolidated basalts, but sometimes consolidated limestone such as cemented beach rock or raised coral reefs. Sandy beaches are more common on older islands and their longevity is determined by wave action, biological and chemical erosion, and seasonal cycles of erosion and accretion of offshore sand reservoirs (Juvik and Juvik 1998).

Most PACN parks contain an intertidal zone, either adjacent to or within their boundary. Tropical intertidal zones in the PACN are relatively harsh environments, with nutrient poor waters, and are exposed to rough water and warm air temperatures during low tides resulting in fewer organisms than in temperate locations (Connell 1961, Paine 1974, Zabin 2003). Relatively little scientific work has been conducted in tropical intertidal regions within the PACN but some information will be forthcoming in the next several years for Hawaiian intertidal zones (Zabin et al. in prep.). Characteristic rocky intertidal species include algal and invertebrate assemblages that are adapted to desiccation or are highly mobile and can easily move with changing tide levels (Figure 2.36). Tidepools serve as nurseries for some coral reef species.

Figure 2.36. Example of shoreline intertidal habitat found within the PACN. Intertidal region at KAHO with basking green sea turtle (*Chelonia mydas*) and intertidal region along the Kau shoreline near HAVO.

Algal assemblages commonly seen on Hawaiian rocky intertidal can include green algae (*Ulva* spp.), coralline red algae (*Hydrolithum* spp.), red fleshy algae (e.g., Melanamansia, Pterocladiella, Jania), brown algae (Padina, Turbinaria, Dictyota), and fleshy green algae (e.g., Neomeris, Halimeda, Caulerpa) (Maragos 1998). Invertebrate assemblages commonly observed within the Hawaiian intertidal zone can include limpet, or opihi (*Cellana* spp.), littorine snails (*Littorina*, *Nerita*), rock crabs (*Metapograpsus*), gastropods (*Drupa*, *Morula*, *Cyraea*), and rock urchin (*Colobocentrotus astratus*) (Maragos 1998).

Intertidal organisms are easily accessible from shore and constitute an important role in the cultural significance of Pacific Islanders. Intertidal assemblages also because of their proximity to the coast are affected by nearshore coastal development. They are also susceptible to impact and trampling from nearshore recreational use.

Nearshore Marine Ecosystem Stressors

Nearly all stressors affecting the marine environment have a terrestrial origin, and most are associated with human activity. In the past several decades, there has been a well-documented demographic shift toward higher concentrations of human settlement in the coastal zones of many countries, including the U.S. (Culliton et al. 1990). More than half of the U.S. population now lives in coastal communities, a trend that is expected to continue to increase (Pew Oceans Commission 2003). This trend has increased the frequency and magnitude of impacts from activities such as the construction of residential developments, hotels and resorts (Figure 2.37), recreational facilities, and infrastructure such as roads and wastewater treatment plants (WWTPs).

Figure 2.37. Development of human settlement along coastline, Guam.

Marine stressors across the Pacific islands are prevalent, documented, and well identified. Nearly all areas have land management issues that result in terrestrial runoff. Runoff-associated issues (e.g., sedimentation, eutrophication, contaminants, and freshwater inputs) have been identified as one of the most significant threats to Pacific marine habitats. Harvesting of marine resources is another significant stressor, and few areas in the Pacific have not been subject to intense fishing pressure that has already altered, and in several cases already potentially impaired, marine resources. Climatic stressors are also significant for marine resources. These include El Niño/Southern Oscillation (ENSO) events, global climate change, and “heavy weather” (e.g., seasonal sea conditions, tropical cyclones). Atmospheric conditions alter the physical and chemical properties of ocean water, including surge, currents, temperature, nutrient availability, light availability, and salinity. The importance of invasive species as a significant marine stressor is currently unknown in most Pacific Island ecosystems, but the seriousness of this threat is well demonstrated by several highly visible and very costly cases in Hawaii (Smith et al. 2002).

Nearshore Marine Ecosystem Model

Major components of the PACN marine ecosystem include the biotic, physical, and chemical components of the previously described ecosystems. These components are represented in the PACN conceptual model of ecosystem dynamics in Figure 2.38 as yellow circles. Key processes acting as agents of change within PACN marine nearshore ecosystems include shoreline change and sediment transport, freshwater input from fresh and groundwater sources, climatic drivers including disturbance events and changes in water quality, recreational use such as boating and jet skis, mooring, harbor effects, diving, snorkeling, fish feeding, beach use, and fisheries. The impact and pathway of change of invasive species and disease on the PACN marine environments are less known and poorly understood; however, research is underway to better understand mechanisms and pathways. Rectangles indicate prominent agents of change and circles represent major components of the ecosystem. Large pink arrows link agents of change to the entire ecosystem, including biotic, physical, and chemical components. The dark green area indicates those agents of change or resources that are actively managed by the National Park Service.

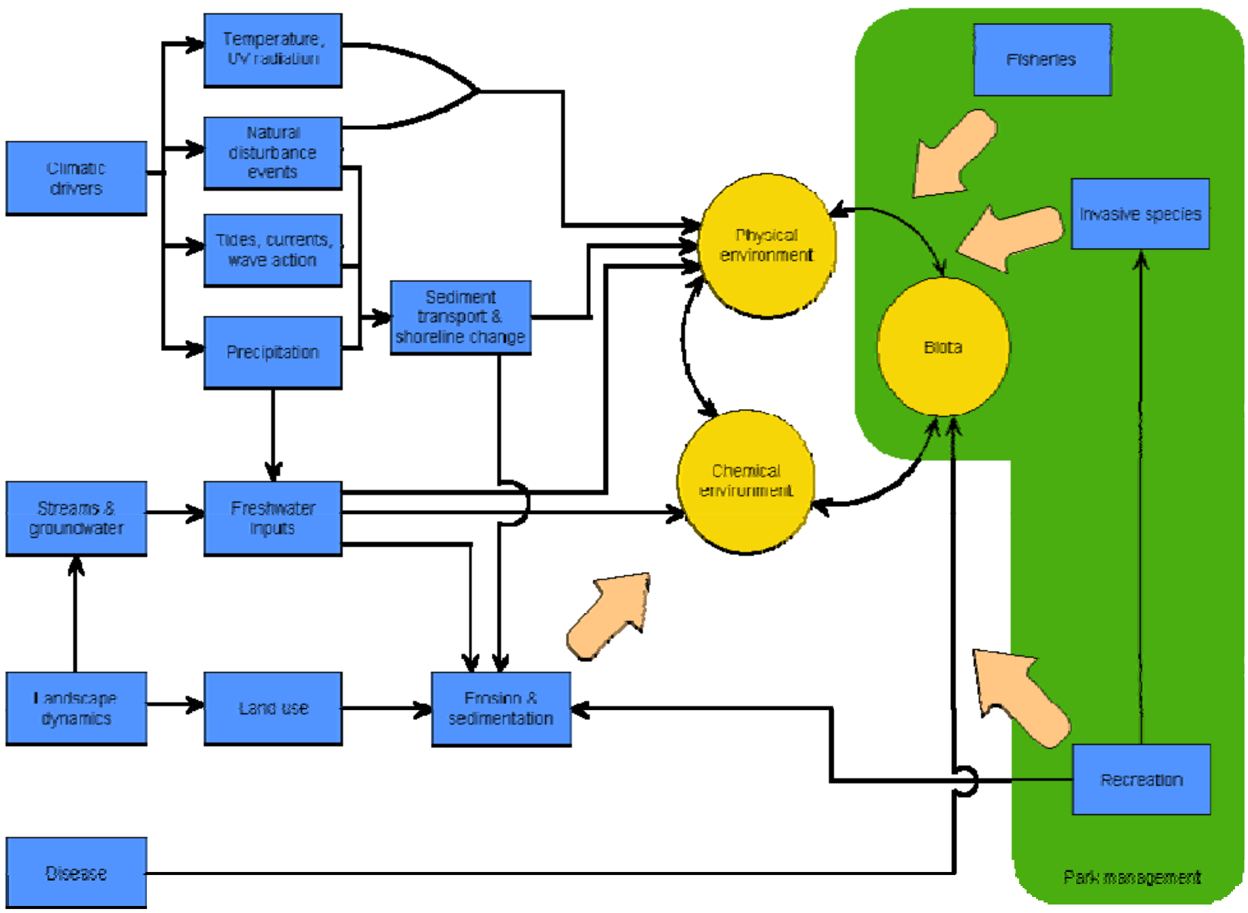

Figure 2.38. Conceptual model of ecosystem dynamics in nearshore marine ecosystems of PACN parks.

CHAPTER THREE: AGENTS OF CHANGE

In this following third section we describe major stressors affecting the network integrated on a landscape level and particularly how they affect sustainability of unique ecosystems in the network.

The PACN region has several features which make it distinctive within the National Park Service, and present both challenges and opportunities for a long-term monitoring program. These features include processes which tightly link the atmosphere, land, and ocean; shared stressors and resource concerns such as invasive species and increasing demand for limited water resources; a wide variety of ecosystems (often spatially small); high levels of species endemism, specialization, and endangered status, and strong cultural traditions.

Areas for monitoring identified as significant based upon legal mandate include water quality, air quality, and endangered species. Other significant resources include ecosystems or communities recognized for their regional or global distinctiveness or imperiled status, endemic groups of species, and geological features (Table 3.1). The Vital Signs the PACN has identified and prioritized are focused to help us better understand and manage these resources, as well as ecosystem drivers, stressors, and threats.

Table 3.1. Distinctive and threatened PACN ecosystems, communities, and groups.

Resource	Significance
Ecological Distinctiveness	
tropical alpine bogs and cloud forests	Tropical alpine bogs and cloud forests are rare throughout the Pacific Islands, and imperiled worldwide by human activity and climate change.
anchialine pools	Rare worldwide, they are only nationally represented in Hawaii, and are imperiled by development and invasive species.
tropical alpine deserts	Insular tropical alpine deserts are rare, found on islands with high elevations.
lakes and ponds	Kauhako Lake is geologically unique worldwide, having the largest depth to surface area ratio of any lake in the world.
offshore islets	A small number of islets offshore of the main Pacific islands provide predator-free refugia for native plants and animals.
Imperiled Ecosystems	
coastal wetlands (including mangrove wetlands)	Coastal wetlands, especially mangrove forests, are rare throughout the ecoregion and globally imperiled by development.
streams	Most streams on Pacific Islands are affected by water diversion, habitat alteration, and alien species invasions.
coral reefs	These highly productive habitats are globally imperiled by climate change and human activity.
seagrass meadows	Rare across the region, seagrass meadows are globally imperiled by human activity and climate change.
tropical rainforest	Tropical rainforests worldwide are affected by logging and development.
tropical dry forests	Originally rich in endemic plants, this vegetation zone just above the coastal zone has been heavily affected by development.
Endemic Groups	
endemic species	Multiple terrestrial, freshwater, and marine endemic species and species complexes are found within the PACN. Many of these species are at risk from biological invasions and development. Their genetic significance to evolutionary species pools in the face of climate change is unknown.
Geological Features	
volcanoes	Mauna Loa and Kilauea are distinctive as two of the most active and well-studied volcanoes in the world.
coastal zone	PACN parks contain several globally and regionally recognized beaches, as well as areas of dynamic shoreline change due to geologic uplift and settling.

An example integrating a variety of ecosystem stressors to assess general ecosystem health was evaluated for various sites within the Hawaiian Islands in 1992 for marine, aquatic, lowland, and upland ecosystems (Juvik and Juvik 1998). Astoundingly, for four of the islands, over 50% of the ecosystems were classified as highly stressed (Figure 3.1). For the other two islands, the proportion of stressed ecosystems was just below 50%. Many of the agents of change affecting these ecosystems are outlined in this section.

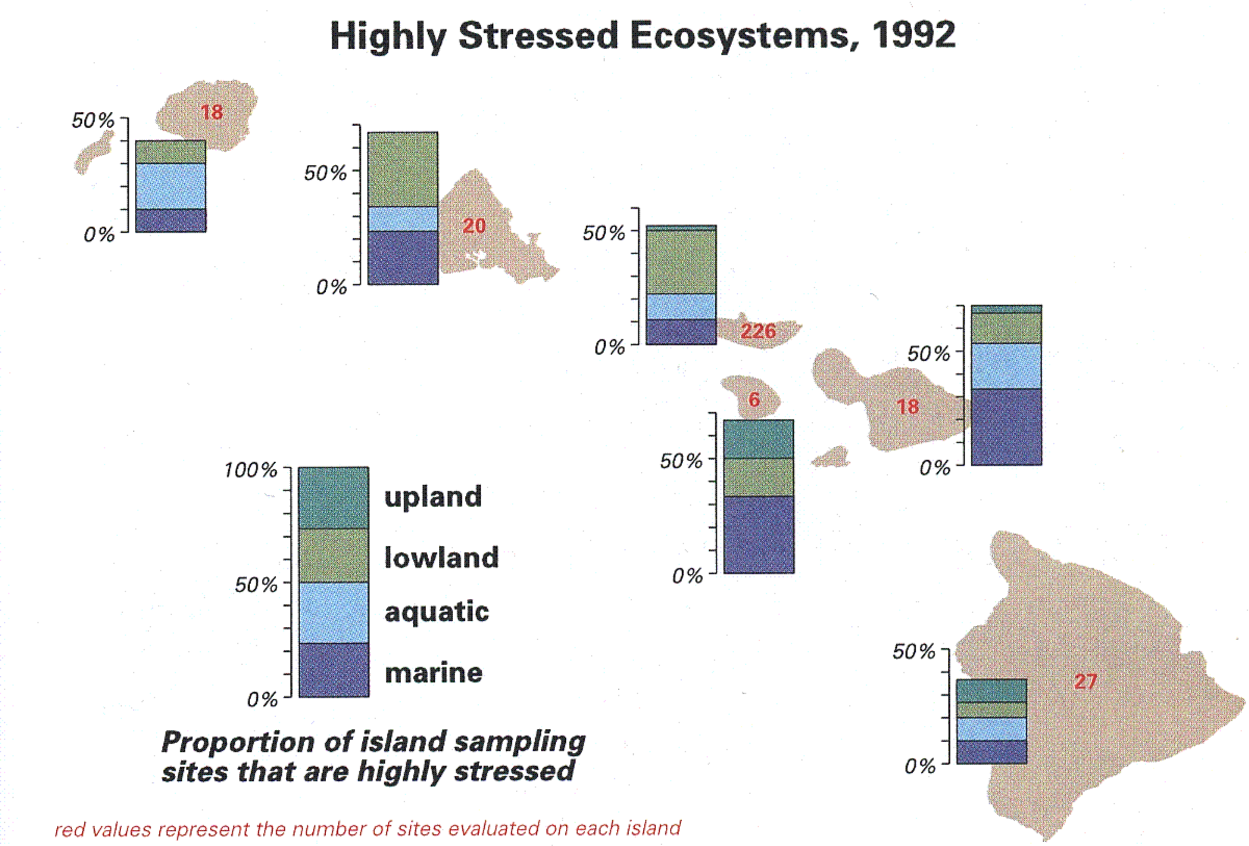

Figure 3.1. Pictorial representation of island sampling sites with high proportion of 'highly stressed' ecosystems across the Hawaiian Islands (from Juvik and Juvik 1998).

An important consideration for recognizing and monitoring unique and distinctive monitoring is the idea of shifting baselines. The concept of a "shifting baseline" is that each individual considers what they first observed (e.g., as a child) in a natural environment to be in 'good' condition (Pauly 1995). Then, in subsequent human generations the baseline of what is considered natural in the ocean shifts further and further from the truly unimpaired natural state that occurred prior to human influence. This concept can be illustrated in the example of marine fish in the Hawaiian Islands. Friedlander and De Martini (2002) compared fish assemblages in the Main Hawaiian Islands (MHI) to those in the Northwestern Hawaiian Islands (NWHI) and found considerable differences. Apex predators (sharks and jacks) in the NWHI comprise more than 54% of the total fish biomass, whereas in the MHI they consist of less than three percent of the total fish biomass. Results of this study surprised many in the public, who had considered the condition of the MHI to be in fair condition. The study results demonstrate 'fishing down the food web,' and illustrate the effect of high fishing pressure on fish assemblages whereby the next trophic level is targeted after the highly prized larger fish are removed (Pauly et al. 1998). If management action is not undertaken, removal of fish may follow the globally observed pattern (Figure 3.2).

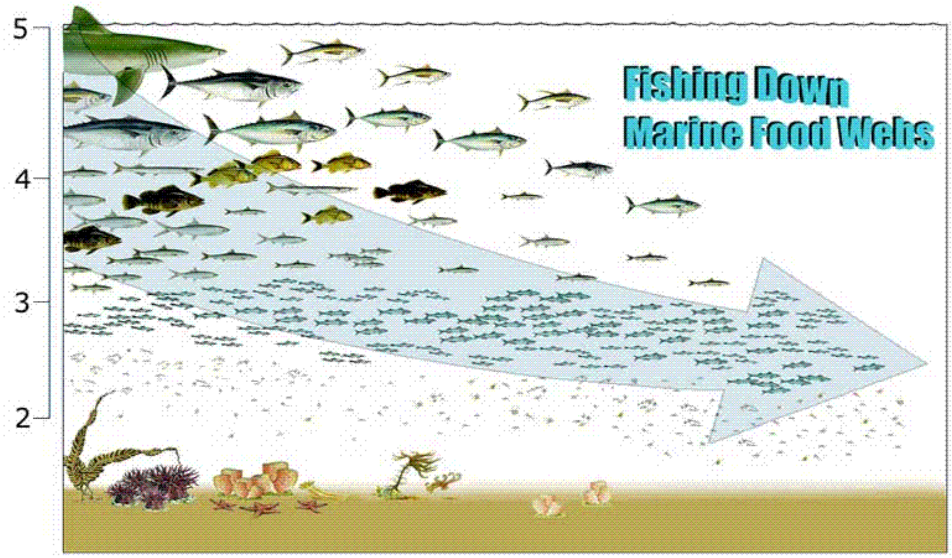

Figure 3.2. Illustration of 'fishing down the marine food web.' After the large, more prized fish at the top of the food web disappear, fisheries then target the smaller fish and invertebrates, working down the trophic levels (numbers on left), In time (blue arrow moving right), the apparent size of fish becomes smaller (from Pauly 2003).

Sustainable ecosystems, as defined by Chapin and colleagues (1996), are persistent. Inherent in the notions of ecosystem sustainability and persistence is the hypothesis that ecosystems can be caused to cross thresholds and switch from one state (or dynamic) to an alternative state (or dynamic). Of greatest concern from a conservation perspective are alternative states characterized by irreversibly degraded ecosystem structure and function. Ecosystems that have been driven across thresholds of degradation cannot be restored to previous conditions simply by removing the stressor. Costly, manipulative restoration efforts are usually required (Hobbs and Norton 1996, Whisenant 1999). The success of such restoration efforts usually is uncertain. Given the recent large-scale changes in ecosystems in the Pacific Island region, questions of stability in ecosystem state are increasingly important, and in particular the effect of major stressors on Pacific island ecosystems.

Ecosystem stressors operating in PACN parks on Pacific Islands may be grouped into several categories. These include air quality, water quality, land use, fire, erosion-sedimentation, invasive species, disease, fishing, terrestrial hunting and gathering, visitor activity, natural hazards, and effects of global climate change. These stressors currently affect multiple parks within the network and are key management concerns. The following descriptions provide more detailed descriptions of these stressors

WATER QUALITY

Aquatic systems on Pacific Islands are often impacted by sedimentation, organic enrichment, and chemical run-off. These problems are accelerated with urban development and agricultural land-uses. Chemical and microbial contaminants from terrestrial sources leach into the groundwater and eventually into coastal resources such as anchialine pools and wetlands. Atmospheric deposition of chemicals and particulates may cause problems in sub-alpine lakes and anchialine pools. Since many water bodies may be unique to their park and have water quality issues due to specific stresses, research and monitoring requirements will need to be addressed individually. The PACN Vital Sign "Water chemistry" addresses these concerns.

All PACN parks have nearshore reef communities that may be impacted by situations inside or outside of park boundaries. Adjacent land uses have impacts on the marine environment (Figure 3.2) (Houk 2001, Sutherland et al. 2004). Moreover, the Hawaii parks do not have jurisdiction over the submerged lands containing reef resources that they are mandated to protect.

Figure 3.2. Industrial complex, Apra Harbor, Guam.

Alteration of watersheds and associated changes in vegetative cover often decrease the ability of the land to absorb rainfall, which flows through streams and channels, carrying sediments and pollutants into nearshore areas. Generally, runoff from developed watersheds carries higher sediment loads than from undeveloped areas, and this effect is more pronounced in areas where the topography is characterized by steep slopes. Removal of mangrove forests that normally trap sediments may allow a greater proportion of terriginous sediments to reach reef areas. Runoff from developed watersheds tends to have higher concentrations of waste products. Increased freshwater inputs to marine waters are considered pollutants, as they can decrease salinity levels in some nearshore areas.

Development of adjacent lands and watersheds is a concern at all PACN parks. Harbor operations, such as boat maintenance and fueling facilities, contribute to chemical pollution in these areas by increasing the presence of paints, solvents, diesel, oils, and heavy metals. The operation of cruise ships, commercial fishing, and diving charters raises the likelihood of illegal dumping of chemicals, sewage and debris. Three West Hawaii parks, PUHE, KAHO, and ALKA, are adjacent to State Harbors that are in the planning stages for expansion. Harbor expansion will escalate these and other threats to the marine community such as fishing pressure, introduction of alien algae and invertebrates, boat groundings and other physical damage to reef resources from increased recreational activities. Other contaminants derived from human use of nearshore areas include oil leaking from vehicles, pesticides and lawn fertilizers applied to yards, parks and golf courses, chemicals in asphalt that wash off roads, excrement from livestock and domesticated animals, and litter. Figure 3.3 illustrates groundwater and surface water movement on volcanic islands, as well as sources and pathways of pollutant movement.

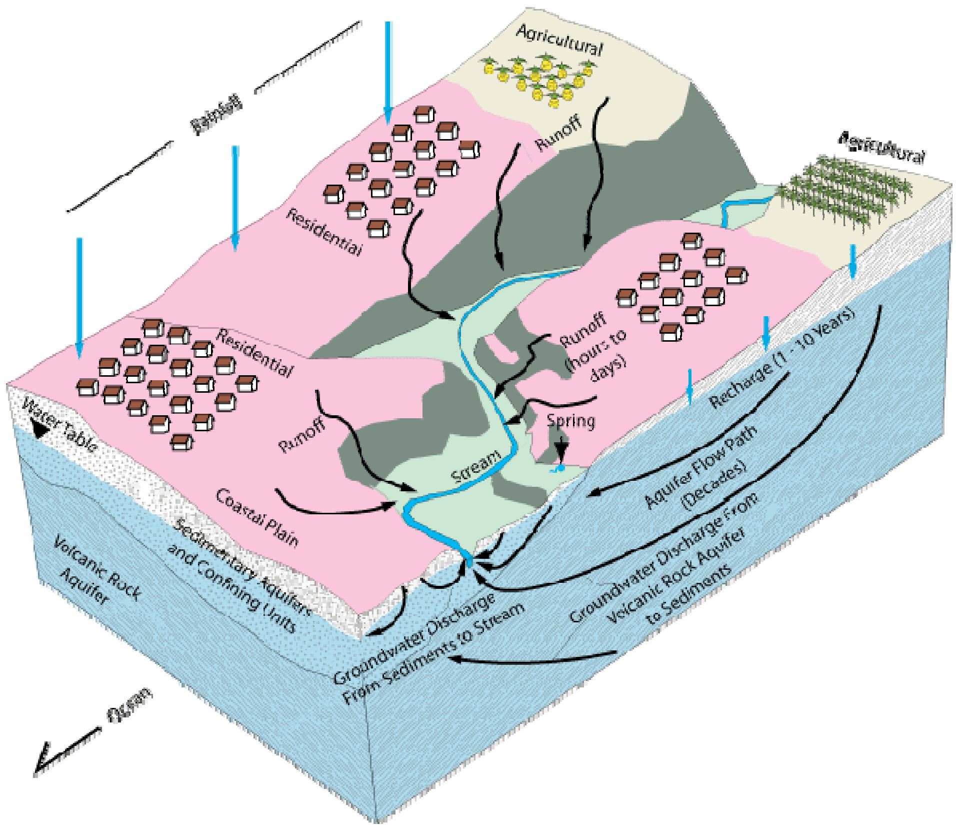

Figure 3.3. Schematic of groundwater and surface water movement on volcanic islands, illustrating pollution pathways (modified from Anthony et al. 2004).

Human population growth contributes to loss of habitat buffers and subsequent degradation of water quality. Almost all PACN parks are susceptible to the effects of invasive feral animals that degrade native vegetation, increasing fire hazards and accelerating erosion. Island subsidence, rising sea levels, and storm surge will ultimately accelerate shoreline erosion, resulting in increased sedimentation of reefs and changes in coastal habitat. Coral bleaching, mortality, and disease also are occurring, and are thought to be due to warming sea surface temperatures, sedimentation, and water pollution (Hoegh-Guldberg 1999, Craig and Basch 2001, Houk 2001, Sutherland et al. 2004).

Water Withdrawal

Both surface water diversion and groundwater withdrawal occur in watersheds and aquifers of PACN parks. Diversion of surface water for agriculture and industry and withdrawal of groundwater for human consumption is one of the most significant stressors to freshwater biota on Pacific Islands. Water withdrawal affects aquatic resources by lowering the water table and changing wetland and stream hydrology and habitat characteristics. Water diversion reduces base flow in streams, thereby decreasing habitat availability, flow velocity, and channel size. Another issue in coastal areas for groundwater wells is saltwater intrusion into wells with increased pumping pressure (Figure 3.4).

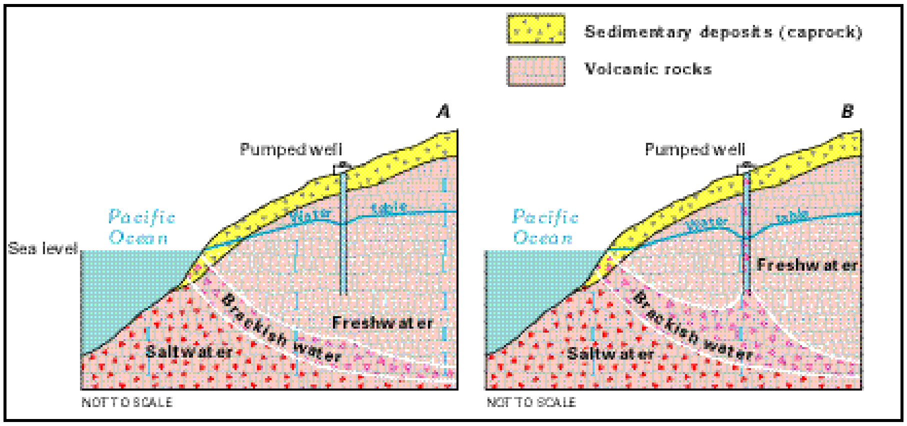

Figure 3.4. Diagram of well completed near the coast. A) Where well is completed in a volcanic-rock aquifer in which withdrawal is much less than recharge. B) Where well has large groundwater withdrawls, and saltwater has intruded the aquifer and brackish water reached the well (from Oki et al.1999)

Other effects of stream diversion include dampening of both the frequency and magnitude of periodic flooding events (Brasher 1997, 2003, Oki and Brasher 2003). Fresh water supply on Pacific Islands is limited, and population growth and development are placing increasing pressure on these resources. In the Hawaiian Islands, long term downward trends in base flow of streams have been observed, suggesting that groundwater withdrawal is having a deleterious effect on surface water resources (Oki 2004). In PACN parks, stream diversion generally is associated with agriculture, whereas groundwater withdrawal is associated with irrigation, drinking, and other uses.

LANDSCAPE-RELATED STRESSORS

Land Use

External land use, including encroaching subsistence agriculture, impacts the size of natural areas around parks. Several PACN parks, including WAPA (Figure 3.5-A), AMME, ALKA, and KAHO, are adjacent to or being affected by rapid urban, industrial, or resort development. Figure 3.5-B illustrates changes in zoning near KAHO since its 1978 authorization. The remaining Conservation land around the park is owned by entities that are planning to seek land zoning change to Urban in the future.

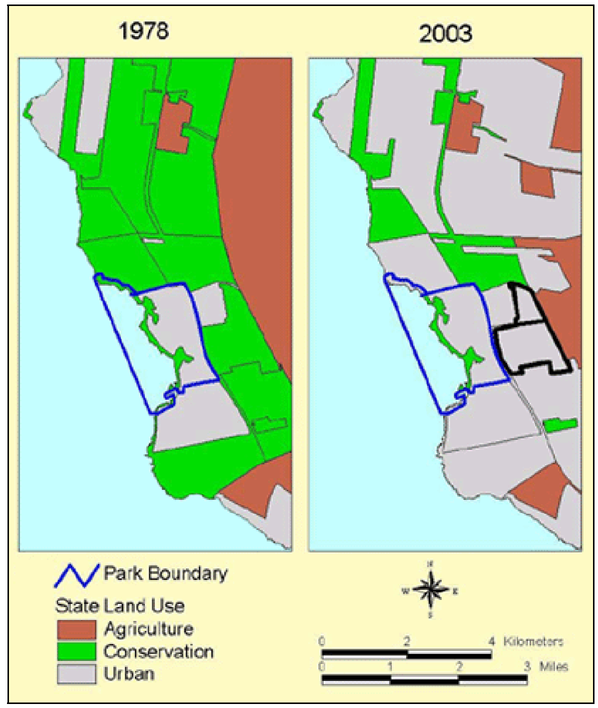

Figure 3.5. Grading a hill in Guam for future development (left). Change in land use zoning surrounding KAHO since its 1978 authorization. The black outline indicates the location of Kaloko Light Industrial Park (right).

The development of adjacent infrastructure is a major concern for water quality in the PACN. In many areas, coastal development often occurs without a commensurate improvement in the wastewater infrastructure, and existing systems cannot adequately accommodate the added burden. As a result, untreated or partially-treated sewage overflows into nearshore areas. Outside of urban areas, many homeowners are not able to access wastewater treatment plants (WWTPs) and often must rely on septic tanks, which are subject to corrosion and leakage. The hard-to-detect leaks often allow untreated sewage to seep into groundwater and nearshore waters. A recent report (Carter and Burgess, Inc. 2002) assessing the sustainability of tourism in Hawaii noted that many of the islands' municipal wastewater systems are nearing capacity. While most new developments have private WWTPs to satisfy permit conditions, many residents still rely on private systems, such as septic tanks, which are in various stages of disrepair. Though they considered myriad aspects of tourism, the authors of the study contend that such nonpoint source pollution is "one of Hawaii's greatest environmental threats" (Carter and Burgess, Inc. 2002).

Adjacent land use changes also contribute to ecosystem fragmentation, introduction of new invasive species, degradation of air quality, and light and sound pollution. Loss of contiguous natural areas leads to reduction of habitat for native plant species, loss of corridors for native species, increased invasions of alien plants along the park edges and roads, and increased alien animal invasions. Monitoring and management of land use will require a cooperative effort. Figure 3.6 illustrates the complex nature of land management on the west and south sides of Hawaii Island, on which five PACN parks are located.

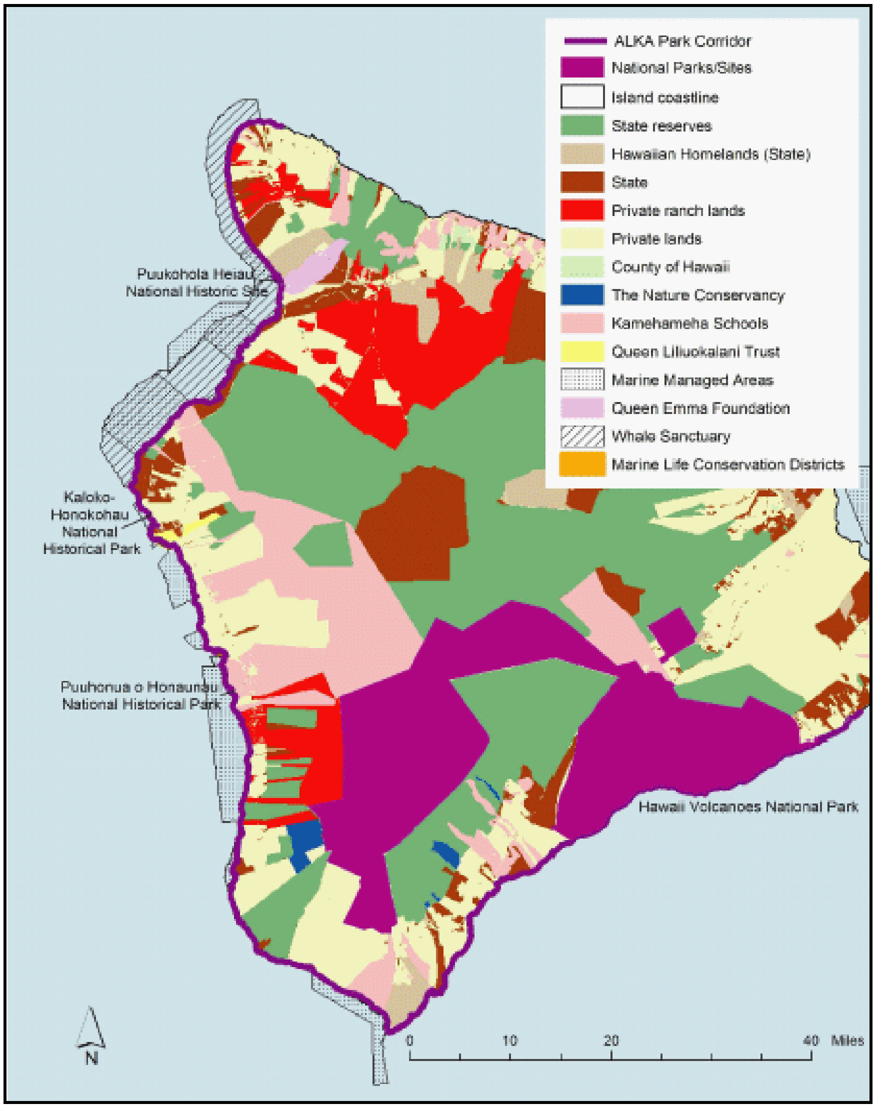

Figure 3.6. Land and marine management surrounding Hawaii Island parks.

Subsistence Agriculture

Encroaching subsistence agriculture (such as at NPSA) can lead to a loss of integrity of protected rainforest vegetation and, sometimes, direct clearing within the park. Subsistence agriculture is not uncommon in the PACN, as the Park Service often explicitly allows traditional land use practices in these parks (Figure 3.7). For example, the community group Kipahulu Ohana is responsible for the revival and cultivation of 14 kalo (or taro, *Colocasia esculenta*) patches within the Kipahulu Valley at HALE. NPSA is another park where subsistence farming is occurring, and there has been resurgence in the use of fallow areas within the park on the island of Tutuila since park establishment. Monitoring in these areas is essential for early detection of degraded ecosystems, where farming practices facilitate erosion. Increased agricultural activities may lead to decline of overall forest health and the appearance of crop species or weeds within parks.

Figure 3.7. Subsistence agriculture, taro field in American Samoa.

Fire

(partly modified from Minton n.d. and Minton 2005)

Before human colonization, fire was very rare on most Pacific Islands, as lightning is uncommon (Mueller-Dombois 1981). However, fires were associated with volcanic activity. Pacific Island species and ecosystems evolving under these conditions are extremely sensitive to fire. Many Pacific Island ecosystems have been extensively modified or destroyed by fire since the time of first colonization (Kirch 1982, 1997). Fire destroys vegetation, facilitates invasion by alien species, and contributes to erosion.

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. The new ecological state is then maintained by ecological feedbacks promoting the continuance of frequent fires (D`Antonio and 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 (Figure 3.8).

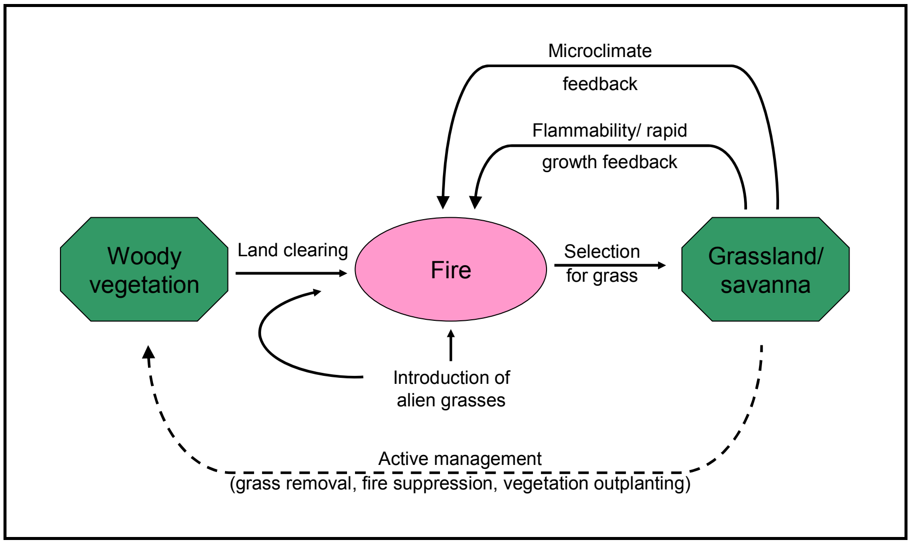

Figure 3.8. Conceptual model of alien grass invasion and fire frequency (modified from D`Antonio and Vitousek 1992).

Savanna grassland fires are serious problem in War in the Pacific N.H.P. Estimates suggest that an average of 20% of the park’s land burns every year (Minton 2005). While this percentage appears to be an overestimate, hard data are lacking. Once a biological community enters a cycle of repeated burning, it is difficult to break out of it. Grasslands, particularly ones with non-native fire-adapted grasses, promote more fire, as dry grass is an excellent fuel source. Repeated burnings expand the spatial extent of grasslands by burning back the forest edge. Grasses quickly invade the burned ground and increase the size of the grassland. Fire maintains Guam's savannas, and without it, it is likely that forests would encroach upon and eventually replace grasslands.

Erosion and Sedimentation

Erosion is a particular problem on Guam, but is also a concern in other PACN parks. On Guam, fires remove vegetation, leaving bare ground that is susceptible to erosion when it rains. The eroding topsoil is transported to the ocean where it settles on corals, potentially killing them.

Guam’s topsoil is thin, forming a layer about five inches thick in many places that can be entirely lost with as few as 15-20 burn events (Minton 2005). Once the topsoil has eroded, the underlying clays, which are alkaline and nutrient poor, cannot support vegetation, leading to “badland” areas, patches of bare red dirt that are a common sight on southern Guam (Figure 3.9). Badlands are incapable of naturally re-vegetating, and continue to erode and transport sediment into streams, altering water quality (Neubauer 1981, Townsend and Douglas 2004), and impact coastal marine ecosystems (Minton 2005, Fabricius 2005). Preliminary work by WAPA biologists has shown that badlands may be eroding at a rate that is ten times higher than surrounding grasslands (Minton 2005).

Figure 3.9. Sediment plume offshore from Guam . Sediment in this case was a result of erosion (red) from upland grassland (forefront).

Sediments are believed to be responsible for the coral die-off on southwestern Guam, and poor erosion control during road construction is the most likely cause of this mortality. Sedimentation has been identified by several international conservation agencies as one of Guam's primary threats to its coral reefs. Physical smothering may be the most obvious effect of sedimentation. Although most corals have some ability to rid themselves of foreign particles, the removal of sediments requires the diversion of energy from vital activities such as reproduction and feeding. The negative effects of the accumulation of sediments on corals can be exacerbated by wave action repeatedly suspending sediments into the water column (Rogers 1990). Increased turbidity in the water column reduces light availability for photosynthesis and growth, and may be party responsible for low recruitment rates for reefs off WAPA (Minton and Lundgren 2006). Increases in nearshore sediment loads have been shown to affect morphology of corals and gorgonians as well as inhibit the development and recruitment of coral larvae (Rogers 1990). Consistently low recruitment rates, whether a result of increased sediments or low light levels, are a concern for long-term health of coral reefs.

Dredging of nearshore sediments for marina facilities, ship access and navigation, beach nourishment, and building materials can introduce significant quantities of particulate matter into the water column. While strong currents tend to dissipate some of the added sediments, nearshore areas with gentle slopes and low flushing rates tend to accumulate sediments, which can have detrimental effects on sessile invertebrates like corals (Rogers 1990). Because marine communities within parks are directly connected with communities outside park boundaries by water motion and movement of species, the condition of marine resources within parks is often identical to that outside the park, despite park management activities.

INVASIVE SPECIES

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 (Figure 3.10) (e.g., Cuddihy and Stone 1990, Vitousek et al. 1996, Brasher 2003).

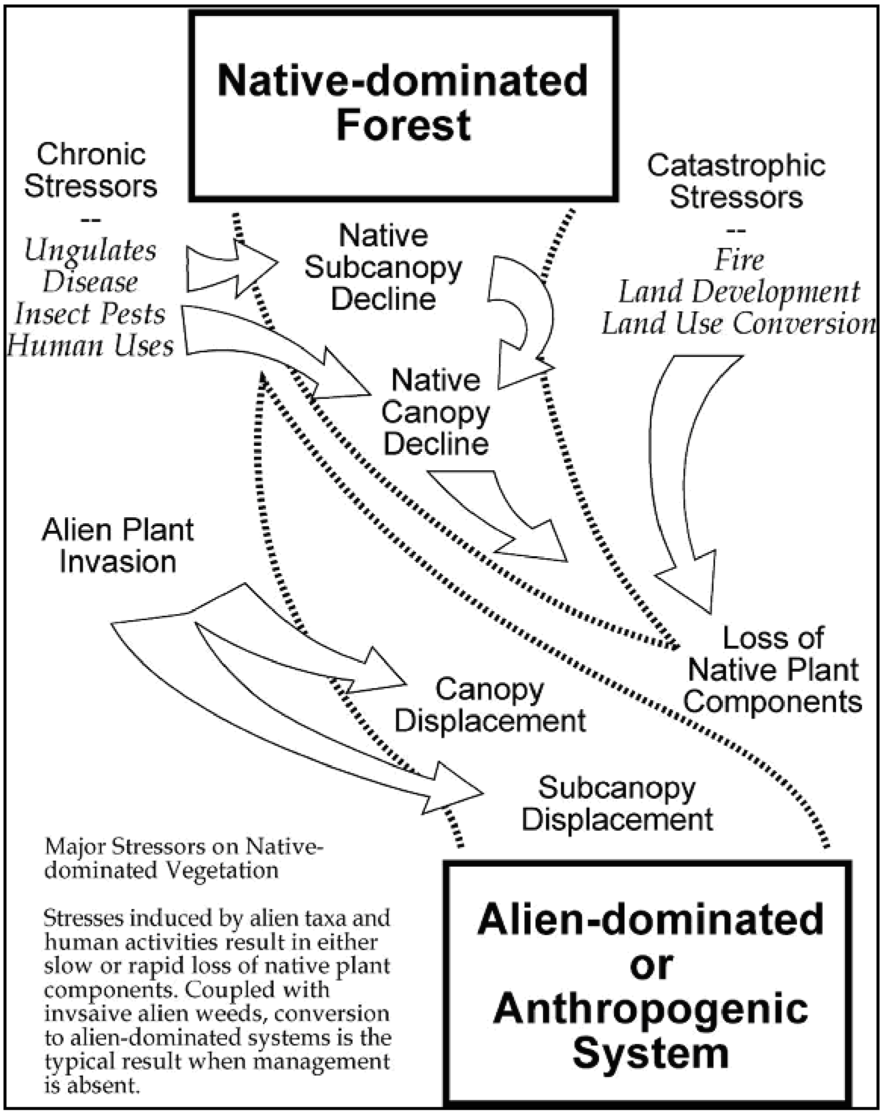

Figure 3.10. Transition between a native-dominated forest and an alien-dominated or anthropogenic system (from Sam Goll, TNC).

For example, the trophic structure of Guam's terrestrial vertebrate fauna has been significantly altered by the introduction of invasive species and extinction of native species (Figure 3.11). In several Pacific Island ecosystems, alien species now form the dominant biological components (Figure 3.12), and restoration of native systems will require a large effort. In cases of extinction (e.g., of lowland birds and tree snails, Burney et al. 2001) complete system restoration will not be possible.

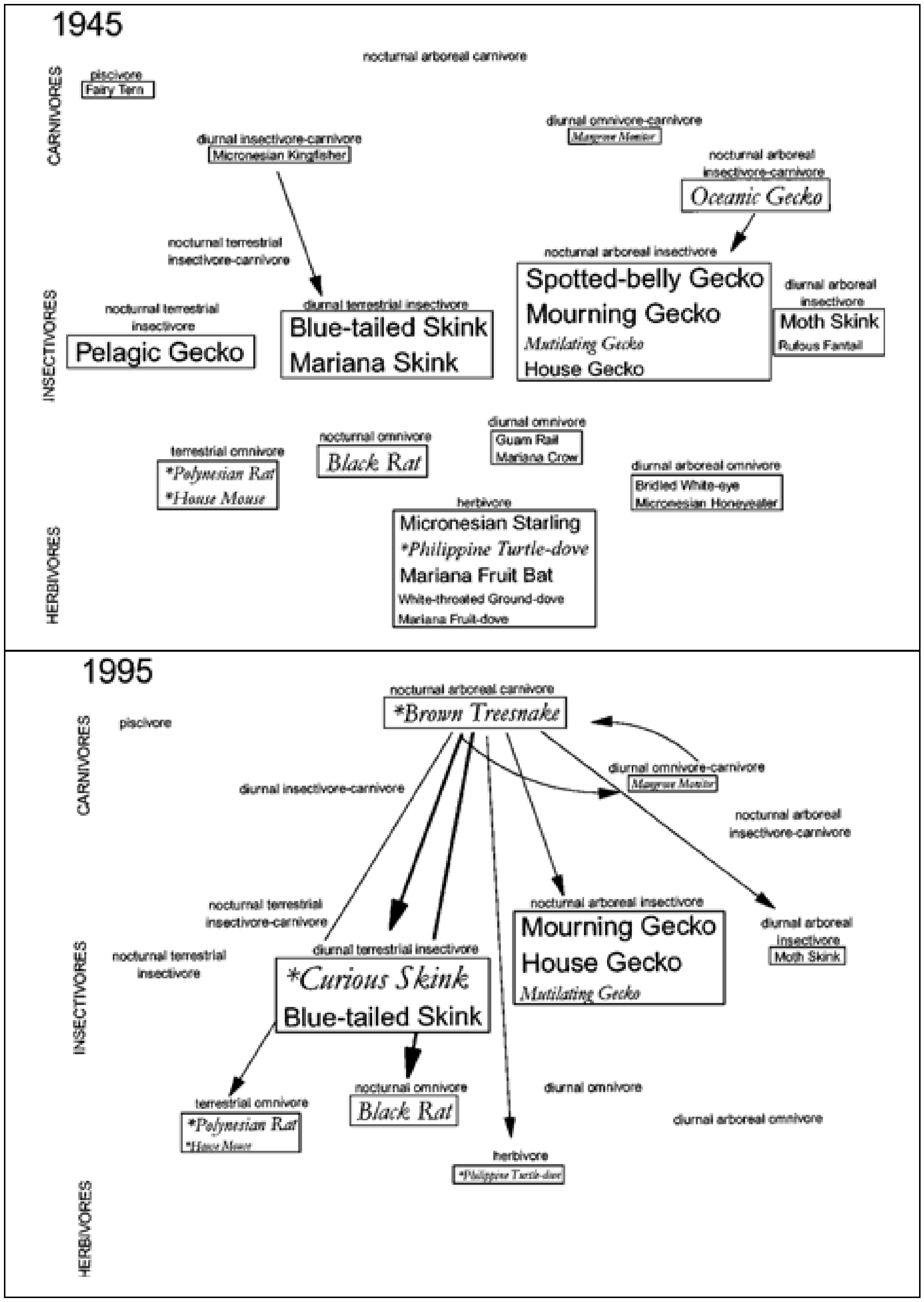

Figure 3.11. Typical vertebrate food webs for Guam in 1945 and 1995, showing the effects of invasive species establishments on ecosystem structure and function. Italics indicate introduced species, asterisks indicate historic introductions, and type size indicates relative biomass abundance (from Fritts and Rodda 1998).

It is important to distinguish between islands or island groups when categorizing a species as native or alien within the PACN. For example, red mangrove (*Rhizophora mangle*) and the Tahitian prawn (*Macrobrachium lar*) are invasive alien species in the Hawaiian Islands, but indigenous to Samoa and the Marianas Islands. Other species have been identified as potentially serious threats network-wide. Assessing the threat posed by incipient invasive species and detecting their presence are important monitoring functions for Pacific Island parks to ensure timely, proactive, and cost-effective management.

Figure 3.12. Native species Pandanus tectorius and Scaevola sericea surrounded by invasive species, *Leucaena leucocepha*, which can also be seen invading the lower ridge, Guam.

Many threatening species have become established recently in the parks or on the home islands of the parks. Others are likely to be introduced to the islands, including some that are present on other islands of an archipelago. For example, the carnivorous snail *Euglandina rosea* has been introduced to the islands of Tutuila and Tau, but not Ofu and Olosega, where it would have a serious impact on rare native snails (Cowie and Cook 1999). Although a large number of invasive ants are already established in the PACN, there are other known invasive species (such as the red imported fire ant, *Solenopsis invicta*) that could still cause serious problems. The "Early Detection of Invasive Plants and Invertebrates" Vital Sign will monitor the progress of potentially invasive species.

As in terrestrial environments, alien and invasive species can have profound effects on the structure and function of marine ecosystems. The type and extent of marine alien or invasive species distribution and abundance are only just beginning to be determined. Alien and invasive species can be transported in ballast water, as fouling organisms on hulls (Godwin 2003), or can be accidentally or intentionally released by humans. Park areas closer to harbors or areas of vessel traffic are generally more susceptible to introductions. In contrast, areas on exposed outer coasts or areas with limited contact with vessels or harbors have less vulnerability to introductions of these aquatic nuisance species.

Invasive and alien algae are a well-documented, severe ecological and economical threat on several Pacific Island reefs. Several algal species have been implicated in problems and damage to coral reefs (Smith et al. 2002, Smith 2003, Smith et al. 2004). Numerous species of fish have been intentionally introduced to develop fisheries and are believed or known to compete with ecologically similar native species. Examples in Hawaii include snappers (*Lutjanus kasmira*, *L. fulvus*) and a grouper (*Cephalopholis argus*) (State of Hawaii DLNR 2003). Little is known about invasive marine invertebrates other than their presently known distributions. A recent study by the Bishop Museum (Coles et al. 2004) investigated the impact of invasive species on coral reefs in Hawaii and results were similar to other studies on Guam (Paulay et al. 2002) and American Samoa (Coles et al. 2003) in that there was a low frequency of occurrence of invasive alien species on the coral reefs. These studies recommend that efforts should focus on preventing initial introductions, particularly in embayments, which had the greatest frequency of occurrence.

DISEASE

Avian Malaria and Pox:

(extensively modified from Benning et al. 2002 and Jacobi and Atkinson 1995)

Avian diseases, especially avian malaria and avian pox, are one of the greatest factors leading to the decline of native Hawaiian birds (van Riper and van Riper 1985, Banko et al. 2001, van Riper and Scott 2001). According to Jacobi and Atkinson (1995), a major avian malaria and avian pox epidemic in mid-elevation forest birds was documented during a National Biological Service study in 1992. Avian malaria is probably the most important factor preventing endemic bird populations from recovering in low elevations (Jarvi et al. 2001). Many introduced birds develop nonfatal infections that can be transmitted to other birds by introduced mosquitoes (Figure 3.13).

Figure 3.13. Apapane, *Himatione sanguinea*, with mosquito near left eye. Photo: Jack Jeffrey.

Many native Hawaiian birds are extremely susceptible to malaria and pox because they did not evolve in an environment with strong selective pressure for resistance to these diseases. The iiwi (*Vestiaria coccinea*) is so susceptible to malaria that in a study where juveniles were infected with a dose equivalent to the bite from a single infected mosquito, 90% died (Jacobi and Atkinson 1995). Introduced birds are found in all forests, but most native birds have been found to be restricted to forests with few or no mosquitoes (Shehata et al. 2001).

The accidental introduction of *Culex* mosquitoes in the early 19th century, and the importation and widespread release of domestic fowl, gamebirds, and cage birds with their accompanying diseases, are believed responsible for the establishment of avian pox virus and malaria (*Plasmodium relictum*) in Hawaiian forest bird populations (Warner 1968, van Riper et al. 1986). The concurrent fragmentation of native forests probably hastened the spread of mosquitoes and exotic birds into forest habitats, exposing native birds to avian pox (Perkins 1893, Henshaw 1902) and malaria.

Strategies for breaking the cycle of vector-transmitted diseases include intensive environmental management to reduce mosquito breeding sites, chemical and biological control agents, genetic manipulation of the vector population, and release of sterile male mosquitoes. In addition, removal of feral ungulates from critical forest habitats may reduce available breeding sites and mosquito densities to levels too low to support disease transmission. Efforts by land mangers in Hawaii to fence and control feral ungulates will provide an opportunity to coordinate disease research with management.

Field research in Hawaiian forests shows that native bird abundances, malarial parasite prevalence, and mosquito vector levels vary predictably along elevational gradients (van Riper and van Riper 1985) (Figure 3.14). The introduced mosquito (*Culex quinquefasciatus*) is present in high numbers at lower elevations where many introduced birds and almost no native birds are found. Because the introduced birds are resistant to malaria, the prevalence of *Plasmodium* in avian populations from those elevations is low. Malaria prevalence increases significantly in mid-elevation forest, corresponding to the lowest elevations at which native birds are found currently, and here transmission of malaria to native birds is significant (LaPoint 2000). At higher elevations, both *Culex* populations and prevalence of *Plasmodium* decline while native birds reach their peak abundance and diversity.

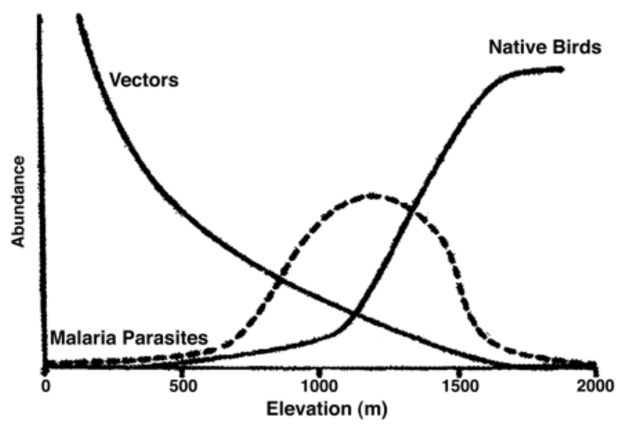

Figure 3.14. A generalized model of native bird abundances, malarial parasite incidence, and mosquito vector levels along an elevation gradient in Hawaii [(reproduced with permission from van Riper and van Riper 1985), in Benning et al. 2002].

West Nile Virus:

(modified from Burgett n.d.)

The invading West Nile virus (WNV) is having severe impacts on birds and other wildlife as it moves westward from its point of introduction to the United States in New York. Birds in many taxonomic groups suffer fatal infections, including corvids, other passerines, and raptors, with some groups having nearly 100 percent mortality rates. Because WNV is apparently carried by migrating birds, wildlife managers in North America have few options but to watch and wait for its arrival, and hope that stricken bird populations can recover with time. The Pacific islands cannot, and need not, watch and wait. There is a good chance that pathways that could introduce WNV to Hawaii and other Pacific islands can be controlled, and WNV can be kept out of the islands.

The introduction of WNV into Hawaii would have catastrophic consequences for the native avifauna and would likely produce losses similar to or greater than other previously introduced pathogens. We would expect that most endangered passerines, with populations ranging from three to a few thousand, eventually would be either rendered extinct or have their recovery precluded. The vulnerability of other endangered bird taxa, as well as non-listed endemics, is unknown but probably high due to their insular evolutionary history. In total, 41 of the 92 listed species of birds in the U.S. could face extinction if WNV were to become established in Hawaii and the Marianas Islands.

The mosquito vectors are widespread in Hawaii and there is no disease-free winter. Once established in competent host populations of alien birds, WNV could not be eradicated and would spread to other islands by the same pathways by which it reached Hawaii. Mitigation strategies, while important for public health, would not prevent the spread of the disease to native birds. Therefore, efforts must be focused on preventing the introduction and establishment of WNV in Hawaii and other Pacific islands. Three main potential routes of entry exist. Importation of infected birds has been prevented for the present by a postal embargo and state and territorial quarantines. Migratory birds are thought to be low-risk due to the stress of migrating over 2500 miles nonstop, which could be fatal to birds ill with the virus. Accidental importation of infected mosquitoes is a little-researched pathway that may be a significant threat. Research is needed to determine these risks, and if necessary resources will be needed to devise and carry out a strategy to close out this pathway.

Highly Pathogenic Avian Influenza

Avian influenza (AI), or 'bird flu' is a disease caused by a virus that infects birds. There are two strains of AI, low (LPAI) and high (HPAI) pathogenicity. HPAI is fatal to birds and easily transmissible between susceptible species, and it is the strain to which the currently spreading strain, H5N1 HPAI, belongs. Avian influenza has been found in many species, but frequently occurs in migratory waterfowl and shorebirds and common in gulls and terns (Friend and Franson 1999). Many shorebirds in the PACN migrate to and from Pacific islands to breeding grounds. Influenza A viruses also cause illness in humans and other animals (e.g., pigs, horses, sea mammals, and mustelids) (Center for Infectious Disease Research and Policy 2006). The U.S. Department of the Interior and the U.S. Department of Agriculture are currently monitoring wild migratory birds for early detection of this virus on major migratory pathways. As new information becomes available this section will need updating.

Diseases of Marine Organisms:

Diseases of marine organisms in the Pacific and their ecological consequences are poorly understood. Recently, diseases of corals and turtles have received considerable scientific attention, as the occurrence appears to be increasing worldwide. Coral disease, currently more prevalent in the Atlantic Ocean and Caribbean Sea than the Pacific regions, has lead to significant coral mortality on some reefs. Some areas experienced just under 40% mortality during the later half of the 90s (Richardson et al. 1998). There are 18 known coral diseases with pathogens resulting from bacteria, cyanobacteria, fungi and protists (Richardson 1998, Sutherland et al. 2004).

Little is known about mechanisms that trigger and execute disease as well as its transmission. In many cases, it is very difficult to establish direct causal relationships, but progress has been made. For instance, the occurrence of fibropapilloma tumors in Hawaiian sea turtles (Figure 3.15) has been correlated with the presence of a marine leech acting as a transmission vector for the virus (*Ozobranchus* spp.; Greenblatt 2004, Greenblatt et al. 2004). Some disease is suggested to originate from anthropogenic activity (Sutherland et al. 2004). Abiotic stressors that have been linked with disease in coral reefs include elevated temperature, eutrophication, sedimentation, pollution, fecal contamination, solar ultraviolet radiation, poor water quality, and precipitation (Bruckner et al. 1997, Richardson 1998, Sutherland et al. 2004).

Fiture 3.15. Fibropapilloma tumors on green sea turtle, *Chelonia mydas*.

Coral diseases prevalent in the Indo-Pacific include black band disease, white plague-like disease, skeletal anomalies (including tumors), skeletal eroding band, and yellow-blotch band disease (Sutherland et al. 2004). American Samoa, the Main Hawaiian Islands and the Mariana Islands have all documented some of these or other diseases.

HUMAN USE AND CONSUMPTION

Fishing

Fishing is increasingly documented as being the principal threat to Pacific coral reefs and other marine ecosystems worldwide (Wilkinson 2000, 2002, 2004, Dayton et al. 2002, Tupper and Donaldson 2005). Fishing refers to the catching or harvesting of any marine biological organisms, and may be conducted for recreational, traditional or subsistence, or commercial use, including take for aquarium trade. A diversity of marine species, in addition to fish, are harvested for consumptive uses in the Pacific (Figure 3.16).

Figure 3.16. Many species are harvested from Pacific island marine waters. Examples include giant clams (left, *Tridacna* spp.) and palolo worms (right, *Eunice viridis*) in American Samoa.

All PACN parks include a coastal zone where fishing occurs. Several parks also include marine areas within their boundaries, although other agencies than the NPS may have jurisdiction over them. Fishing and the collection of shellfish and other invertebrates has increased in the parks concomitantly with the increase in fishing pressures throughout the Pacific Islands, and often threatens remaining marine communities (Langlas 2003, Tupper and Donaldson 2005). For example, ethnographic studies conducted at HAVO have found that the populations of opihi (*Cellana* spp., a limpet) along the coast of the Kalapana extension have decreased, as the species declines in both abundance and average size across the state (Langlas 2003). The park's attempt to regulate such activities has helped to reduce gathering and maintain the stock, but area residents continue to enter the park and gather opihi that are below the legal size limit.

Removal of species from the assemblage, such as by fishing, can lead to tremendous changes in community structure and function as fished species become absent from an area and negatively affect biodiversity (Vecchione et al. 2000, Rice 2000, Murawski 2000). Ample data exist documenting coral reef phase shifts linked to overharvest of herbivorous fishes (e.g., McManus et al. 2000). Fishing has significant, well documented impacts on ecosystem structure, function, and on the condition of resources (Friedlander and DeMartini 2002). Predator removal can lead to increases in herbivorous species that could affect primary producers, the abundance of other herbivores, and community structure. The increasing trend of overfishing is a global phenomenon for all marine ecosystems regardless of location, depth or habitat type (Pauly 1995, Dayton et al. 1998). In the Main Hawaiian Islands the total commercial catch has been gradually declining (Friedlander et al. 2005). These declines are not a product of market or consumer demands, but a sign of overfishing (Figure 3.17).

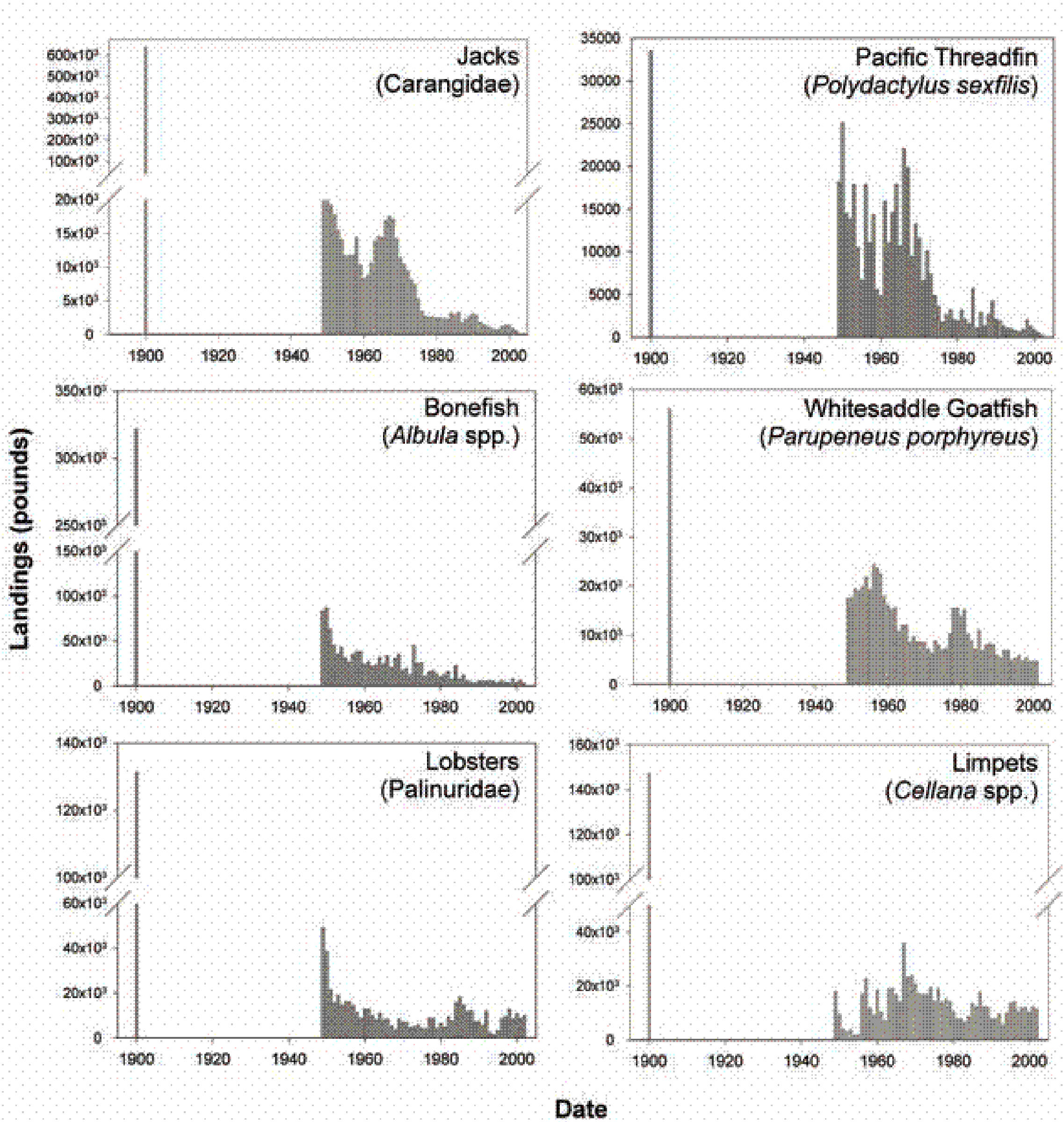

Figure 3.17. Commercial catch data from Hawaii Division of Aquatic Resources from 1949 to present. (from Friedlander et al. 2005)

Aquarium Fishing

Aquarium fishing is a subset of fishing addressed above, but receives special attention here because of its increased probability for ecological damage. Aquarium fishing tends to focus on small individuals, which are often juveniles, potentially removing individuals that should be entering the breeding population. Aquarium fish collecting is significant in Hawaii, particularly along the west (Kona) coast of Hawaii Island (Tissot and Hallacher 2003). Approximately fifty permits have been issued and just over 100 target species are sought (Figure 3.18) on the Kona coast. Aquarium fishermen are required to report monthly catch. However, it is believed that the majority of these reports are not filed, and actual catch statistics are underestimated (Tissot and Hallacher 2003). At present, aquarium fisheries are not significant sources of catch in the Mariana Islands or American Samoa.

Figure 3.18. Goldring surgeonfish (*Ctenochaetus strigosus,* left) and four-spot butterflyfish (*Chaetodon quadrimaculatus*, right), two of the targeted aquarium fish on the Kona coast. Other species targeted include the yellow tang, *Zebrasoma flavescens*; achilles tang, *Acanthurus Achilles;* naso tang, *Naso lituratus;* longnose butterflyfish, *Forcipiger flavissimus;* pebbled butterflyfish,*Chaetodon multicinctus;* and moorish idol, *Zanclus canescens*.

Terrestrial Hunting and Gathering

Hunting has impacted the populations of several terrestrial species in the parks in historic times, and poaching continues in some areas. One example is the Pacific pigeon (*Ducula pacifica*), Samoa's royal bird, which is responsible for transporting large seeds of the natural rainforest trees. A ban on hunting is in effect to preserve the remaining populations. While the gathering of plants is permitted in parks for traditional cultural or religious purposes, these activities can greatly reduce the amount of resources and create regeneration problems caused by invasive understory species.

Visitor Activity

National Parks in the Pacific continue to experience an increase in visitation due to spectacular scenic vistas, wilderness areas, historical resources (both natural and cultural), and numerous other features (Figure 3.19). Providing the public with a venue to experience natural and cultural resources, while preserving resources "unimpaired for enjoyment of future generations", is the primary mission the park service is tasked with. PACN parks are used by the public in a variety of ways, some of which significantly impact natural resources.

Direct physical impacts to natural resources from visitors include trampling of native vegetation and coral reefs as foot traffic increases, soil and cinder compaction along trails, use of motorized vehicles, litter and waste degrading natural value and supporting rodent populations, removal of objects, trespassing onto sacred places, and obstructing wildlife movement and foraging. These impacts are generally localized to particular areas of parks.

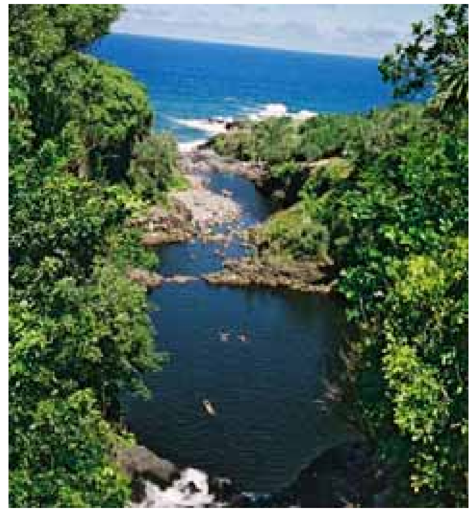

Figure 3.19. Scenic beaches and recreation opportunities attract visitors, such as at PUHO (left) and at HALE (right).

NATURAL HAZARDS

Pacific Island ecosystems may experience a variety of natural hazards due to their geographic setting and geologically active setting. Such hazards include volcanic activity, earthquakes, landslides, tsunami, and tropical cyclones. Natural hazard risks to parks vary by region and park geography. While Pacific Island ecosystems have evolved in concert with such natural events, large-scale disturbances often interact with anthropogenic stressors, and are considered a threat to at-risk ecosystems. For example, tropical cyclones have been shown to facilitate the invasion of invasive plant species into formerly native-dominated areas (Horvitz et al. 1998), and volcanic activity poses a serious threat to small, localized populations of threatened species.

Volcanic Activity

Volcanic activity is a hazard in several PACN parks to varying degrees. On Hawaii Island, Kilauea (affecting ALKA and HAVO), Mauna Loa (affecting ALKA, PUHE, PUHO, and HAVO) and Hualalai (affecting ALKA and KAHO) have erupted in the past 200 years and are therefore considered active, while on the island of Maui, Haleakala last erupted 400-500 years ago and is considered dormant. Kilauea and Mauna Loa are two of the most active volcanoes in the world. In the Mariana Islands, active volcanism is concentrated on the islands north of Saipan, and there is the possibility of ash fall on Saipan (AMME) and Guam (WAPA). In American Samoa, Olosega Volcano is dormant. Geologic and tectonic events such as earthquakes and volcanic eruption may affect coral reefs and have had a recorded impact in the Northern Mariana Islands.

Tropical Cyclones

(Partly modified from United National Environment Programme/World Conservation Union 1988.)

Tropical cyclones have affected all the islands in the PACN within the past 25 years. However, they are more frequent in the Western Pacific (Guam and Saipan). Tropical storm activity in this region frequently affects China, Japan, the Philippines, and Taiwan. This region is by far the most active basin worldwide, accounting for one third of all tropical cyclone activity in the world. The destructive forces of tropical cyclones include storm surge, winds, salt stress, and heavy rainfall/flooding. The forces of the initial tropical cyclone and the loss of protection from further storms may also lead to long-term problems with erosion and sedimentation, with further damage to the shoreline and coral reefs (Figure 3.20). Stoddart (1985) summarized the impact of storm damage with most research of hurricane impact occurring in the Caribbean.

Figure 3.20. Once forested landscape in NPSA, Tau Island, hit by cyclone Olaf in February 2005.

Extreme weather events (including tropical cyclones) reduce the three-dimensional structure (rugosity) of reefs by breaking branching and other "delicate" corals (Rogers 1993, Dollar and Tribble 1993). Rugosity, one of the measures of the "Benthic marine community" Vital Sign, is strongly correlated with density of individuals and species diversity on coral reefs. Reducing rugosity has been shown to lower fish diversity on coral reefs (Jokiel et al. 2004, Friedlander et al. 2003). Figure 3.21 shows worldwide regions of tropical cyclone formation and typical storm tracks and indicates the various names used for these storms in different geographical regions.

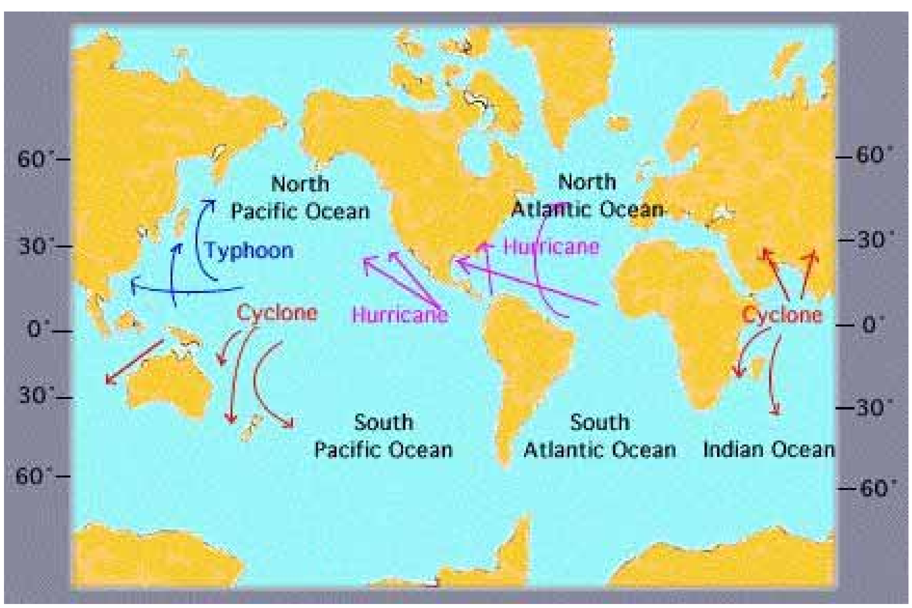

Figure 3.21. Regions of tropical cyclone formation and typical storm tracks.

CLIMATE

El Niño-Southern Oscillation (ENSO)/ Pacific Decadal Oscillation (PDO)

ENSO and PDO are characterized by patterns of sea surface temperature (SST) and atmospheric pressures in the Pacific. Climatic consequences of ENSO are much more pronounced in the Pacific region than on the North American continent and the rest of the world, while the climatic fingerprint of PDO affects primarily the North American continent and has only secondary effects in the Pacific. Climatic changes resulting from ENSO are dependent on the pattern of SST and thus vary throughout the Pacific. However, the following effects of El Niño are common to the PACN region (La Niña events affect these parameters in the opposite way.):

- Changes to wind patterns: The trade winds weaken, die down entirely and the wind may even completely change direction blowing towards the east.
- Increased sea surface temperature: Change in wind strength and direction allows the western Pacific warm pool to expand eastward. The larger the warm pool the stronger the El Niño tends to be.
- Rise in sea level: Due to the increased volume of water and thermal expansion sea level tends to rise.
- Increased tropical cyclone frequency and intensity: Warm waters are one of the prerequisites for the formation of tropical cyclones. In the Pacific El Niño events increase the area of origin and expand the season for tropical cyclones.
- Increased flood frequency and intensity: The increase in tropical cyclone frequency and intensity also affects flooding.
- Extended drought conditions: Although flood events increase as a result of storm events overall precipitation is decreased to the point of causing serious drought damage.

Flooding can occur as a result of storm waves or excessive rain associated with a tropical cyclone or other storm systems. It must be noted that periods of strong rainfall are a characteristic of this region and a certain amount of flooding is needed to recharge the freshwater lens. Tropical cyclones that pass by the islands without causing extensive wind and wave damage, but deliver strong rain serve the important purpose of recharging the freshwater lenses. Reduced groundwater levels have been noted during La Niña years, when tropical cyclone activity in the PACN region is reduced.

Pacific Islands, particularly the low-lying islands, are very vulnerable to drought conditions as the only freshwater resources are the freshwater lenses and rainwater collection in tanks or reservoirs. The size of the freshwater lenses is directly proportional to the size of the island, thus small islands are less buffered from drought conditions during which the lens is not recharged (Meehl 1996, Carter et al. 2001). Under drought conditions ground water use increases leading to even more rapid depletion of aquifers and salt water intrusion.

Global Climate Change

Global climate change may be an on-going natural phenomenon recorded throughout the planet's geologic history. However, the rate of climate change, including increasing atmospheric greenhouse gases (e.g., carbon dioxide) with ozone depletion and concomitant increases in air and sea surface temperatures is unprecedented (Hughes et al. 2003, Board on Atmospheric Sciences and Climate 2006). Human-induced global climate change is expected to cause much more rapid rates of change in climate parameters than have been experienced for millennia

(Kennedy et al. 2002). Marine and coastal, and in particular small island ecosystems are considered to be especially vulnerable to rapid climate change (Carter et al. 2001, Hay et al. 2001). Throughout the Pacific, changes in climate related parameters (e.g. temperature, precipitation, sea surface temperature, and sea level) over the last few decades are attributed to anthropogenic climate change. Global climate change is expected to interact with other agents of change, such as land use, disease occurrence, and alien species introductions, and severely restrict or eliminate the occurrence of native species.

Temperatures have been recorded since 1861 for land and sea surface recordings. Over the past century, mean near surface air temperature over land and over sea have increased 0.6 +/- 0.2 degrees Celsius (Intergovernmental Panel on Climate Change 2001). Although in some years the global surface mean anomaly was negative, it is evident that the general trend over the last 20 years is upward (Figure 3.22).

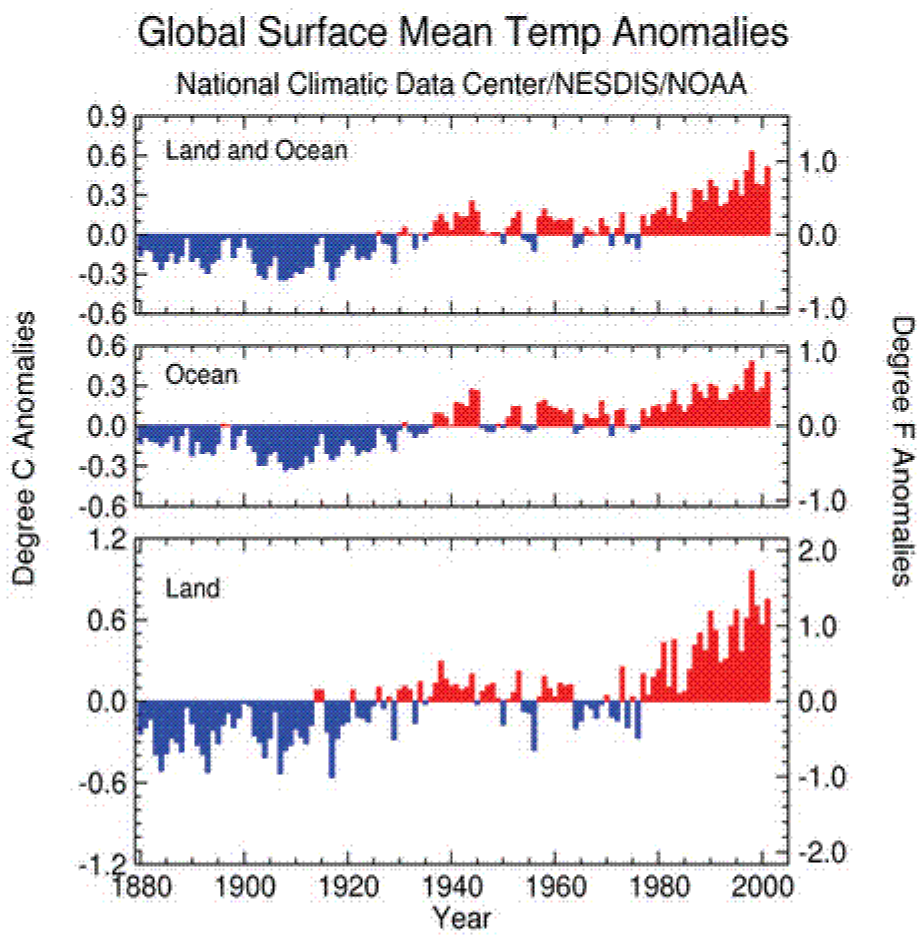

Figure 3.22. Mean global temperature anomalies recorded from 1880 to 2001. Zero line represents long term mean temperature throughout the period, while red and blue bars indicate annual departures from that mean. Data from NOAA's National Climactic Data Center (figure from Bruckner et al. 2005)

Rising Levels of Atmospheric CO_2: Atmospheric CO_2 concentrations have increased globally (Figure 3.23), making resulting climate change and CO_2 sequestration important issues for all PACN parks. Increased marine sequestration of CO_2 lowers oceanic pH, affecting surface ocean carbonate chemistry and, in turn, planktonic organisms with carbonate skeletons (Kennedy et al.

2002, Andersson et al. 2003). Many of these organisms are involved in air-sea exchange processes, and diminished populations of these organisms would affect these processes, as well. Changes in carbonate chemistry would also affect the growth of coral reefs, exacerbating existing stresses for coral reefs due to other climate change factors and pollution.

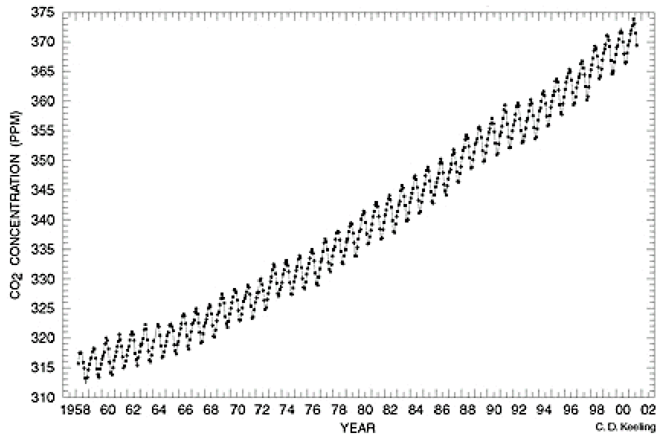

Figure 3.23. The "Keeling Curve" illustrates rising levels of atmospheric CO_2 at Mauna Loa Observatory, Hawaii (Source NOAA).

Growth of many plants is limited by CO_2. Mueller-Dombois (1992), conducting research on native Hawaiian trees, concluded that increased CO_2 will lead to increased primary production and leafier canopies. However, it may also mean shorter life-spans and hastened senescence, which may be an additional stress factor in forest decline. Increased CO_2 levels have also been correlated with an increase in belowground biomass and resulting changes to microbial and microarthropod populations (Rillig et al. 1999, Schortemeyer et al. 1996). There is also evidence that increased carbon sequestration affects the cycling of other nutrients, for instance it has been linked to increased nitrogen mineralization (Ebersberger et al. 2003).

Changes in Rainfall Patterns: The Intergovernmental Panel on Climate Change (2001) reports that "mean rainfall intensity is projected to increase by approximately 20–30% over the tropical oceans at the time of doubling of CO_2". The pattern of increase is not uniform across the Pacific since it is dependent on the pattern of sea surface temperature. However, all the islands in the PACN are predicted to experience an increase of several mm/day as shown in map projections of the Hadley model and the Canadian model presented in the Pacific Assessment (Shea et al. 2001). Across the Pacific, surface temperatures have increased in excess of global rates of warming over the last 90 years: between 0.3 to 0.8 ºC across much of the South Pacific (Shea et al. 2001) and over 2 ºC in Honolulu (U.S. Environmental Protection Agency 1998).

There is no consensus among scientists on whether frequency of cyclones in the tropical Pacific will increase in a warmer world even during non-El Niño years. Both increases and decreases in frequency have been suggested in a number of studies reviewed by the Intergovernmental Panel on Climate Change (2001). However, there seems to be agreement that an increase in global CO_2 levels and associated rise in temperatures would lead to an increase in the intensity of storms.

Certain species or ecosystems are predicted to be particularly vulnerable to changes in rainfall pattern. For example, cloud forests, which support high levels of endemism, are particularly vulnerable to effects of global climate change (Loope and Giambelluca 1998). Even small changes to the lifting condensation level, which determines the height of the cloud base, and the trade wind inversion, which determines the cloud ceiling, can dramatically change the environmental conditions for this special ecosystem.

Sea Surface Temperature: Invertebrate communities, particularly coral reefs, can be intolerant to even small temperature changes. A prolonged exposure to an increase in temperature leads to decreased photosynthetic rates and protein denaturing leading to bleaching (Porter et al. 1999). Coral bleaching (Figure 3.24) refers to the loss of the zooxanthellae from the coral polyp. Large scale coral bleaching has been correlated with elevated water temperature (Jokiel and Coles 1990, Glynn 1993, Brown 1997, Berkelmans and Oliver 1999). Biological response of corals to bleaching result in both increased mortality and decreased fecundity with potential effects of changing community structure (Hoegh-Guldberg 1999). In the PACN, one of the greatest threats identified for NPSA is increased coral mortality due, in part to bleaching and increased sea surface temperatures (Craig and Basch 2001). Bleaching events have recently been observed to coincide with increased sea surface temperatures in the Northwestern Hawaiian Islands (Aeby et al. 2003).

Figure 3.24. Coral bleaching in Ofu Lagoon, National Park of American Samoa.

Some studies suggest that coral disease outbreaks are also enforced by elevated sea surface temperature (SST) and are in part responsible for coral mortality (Harvell et al. 2001) (Figure 3.25). Increased SST and associated changes to water quality such as a decrease in oxygen levels have been linked to more intense and frequent disease outbreaks in coastal areas (The Intergovernmental Panel on Climate Change 2001). SST is also an important regulator of fish behavior. El Niño related increases in SST have been linked to changes in the distribution pattern of skipjack tuna in the Pacific (Lehodey and Bertignac 1997).

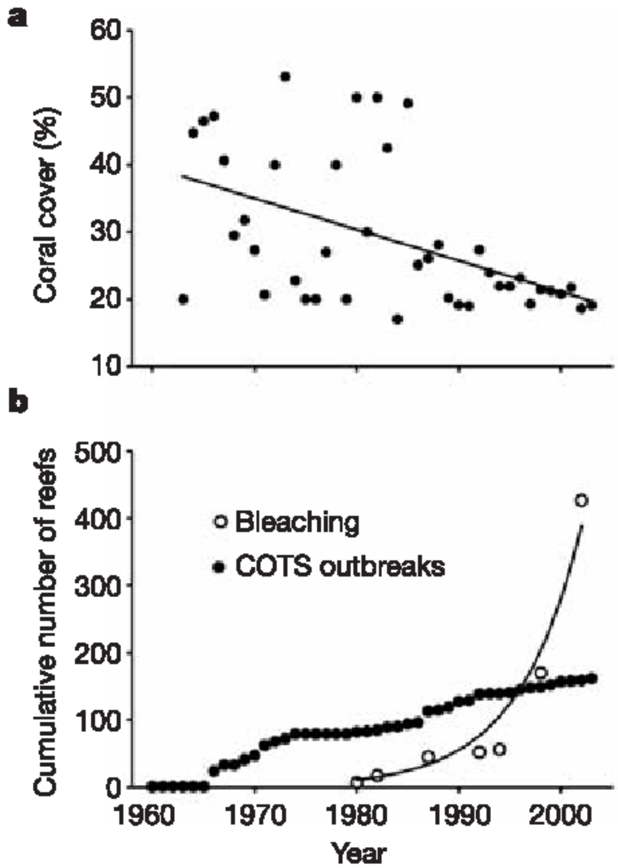

Figure 3.25. Model for degradation of coral reefs at Great Barrier Reef, Australia (GBR). A) Results of meta-analysis of published datasets showing decline in coral cover on GBR. Each point represents the mean cover of up to 241 reefs sampled in each year. B) The recorded number of reefs on GBR damaged by outbreaks of crown-of-thorns (COTS) and episodes of coral bleaching (from Bellwood et al. 2004).

Coral Bleaching Index: (*Adapted from Bruckner et al. 2005*) Coral reef ecosystem managers and stakeholders consistently use one particular satellite-derived index – the Degree Heating Week (DHW) – to gauge accumulated thermal stress on reef ecosystems. The DHW, which was developed by scientists in the National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Watch (CRW) Program, represents the accumulated temperature stress for each 50 x 50 km^2 pixel during the preceding 12-week period as compared to the baseline value calculated for that pixel. The unique baseline value, roughly equal to the expected annual maximum temperature, was empirically determined for each of the 250 km^2 pixels shown in Figure 2.26. To calculate the DHW, temperature deviations (in degrees Celsius) above this baseline are multiplied by the duration of the elevated temperature event (in weeks). For example, if there is a sustained SST of 1°C above the threshold for one week, during a 12-week period, the DHW value will be one. If SST is 2°C above the threshold for three weeks, the DHW value will be six. Figure 67 illustrates the distribution of the maximum DHW values for each pixel for 2002.

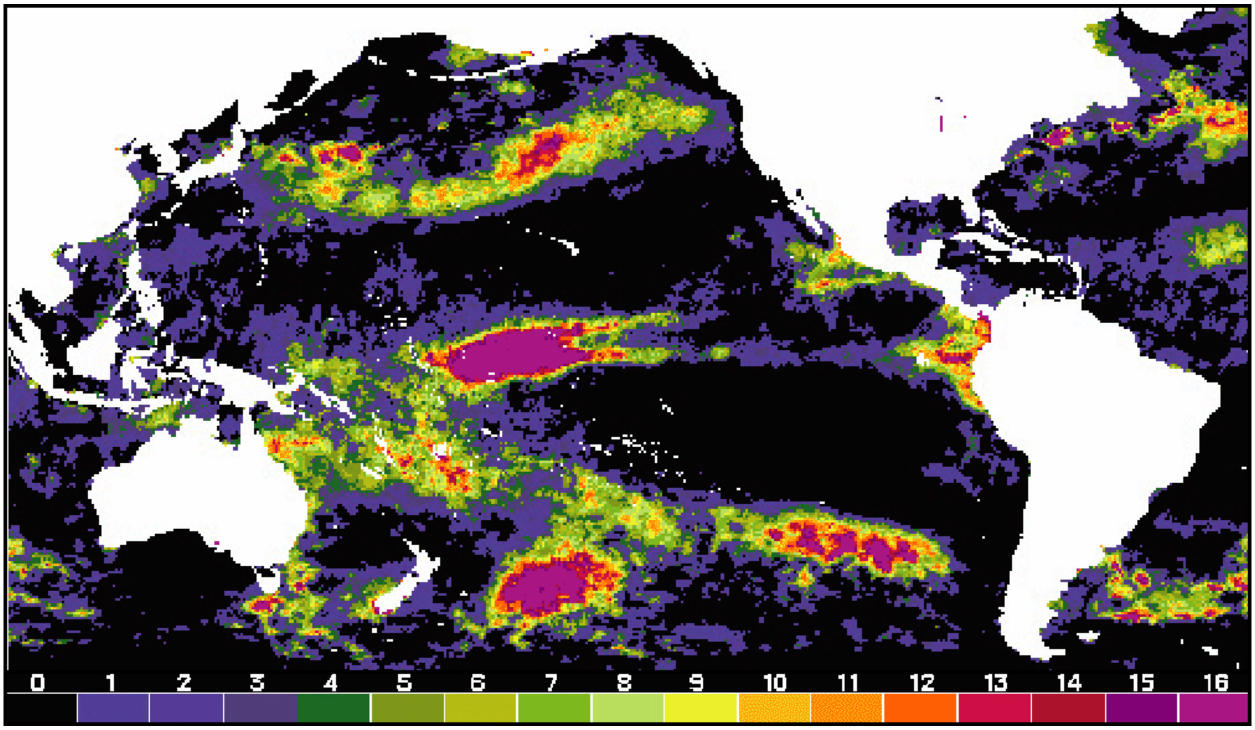

Figure 2.26. 2002 Maximum annual DHW values indicate locations that experienced significant thermal stress, which has been shown to be correlated with coral bleaching. Values above four represent areas that are likely to experience bleaching, while values above eight represent areas that are likely to experience significant bleaching with widespread mortality (from Bruckner et al. 2005).

Ultraviolet Radiation (UV): Ultraviolet (UV) light is present in all shallow and coastal waters, but can be particularly damaging to cells at lower latitudes. Biological organisms either produce chemical compounds (e.g., microsporine amino acids) or otherwise counter UV effects by seeking shelter from UV radiation (Kuffner 1999). Many marine animals are capable of sensing light in UV wavelengths and some have UV coloration, suggesting that UV may play an important role in animal behavior and species interactions. Photosynthetic zooxanthallae in corals have UV absorbing compounds with concentrations that are generally inversely proportional with water depth. Many invertebrates, including corals, are sensitive to high levels of UV radiation, which can cause bleaching and mortality in corals (Lesser et al. 1990, Gleason and Wellington 1995). Invertebrate community structure is also partially determined or controlled by UV radiation as corals show mass mortality for some UV wavelengths (Jokiel 1980).

Air Temperature: (*Modified from Benning et al. 2002*) There is substantial evidence from studies of human as well as avian malaria that the development of *Plasmodium* parasites within mosquitoes is temperature-dependent and that there is a threshold temperature below which *Plasmodium* cannot develop to its infective stage (Lindsay and Martens 1998, Patz and Reisen 2001). In Hawaii, the threshold temperature for transmission of *Plasmodium relictum* has been estimated to be 13°C, whereas peak *Plasmodium* prevalence in wild mosquitoes occurs in mid-elevation forests where the mean ambient summer temperature is 17°C (Lapointe 2000). Benning et al. (2002) evaluated the probable effects of climate change on the extent of forests with low risk for avian malaria on three Hawaiian islands with intact forests and the highest abundance of native birds (the Hanawi Forest on Maui, the Hakalau National Wildlife Refuge on the island of Hawaii, and the Alakai Swamp region on Kauai).

Their analyses entailed spatially projecting the isotherms for the critical temperatures for Plasmodium development under both current conditions and a 2°C warming scenario. The change in forest reserve area under the warmer climate scenario for the following three temperature zones was calculated: above 17°C (high-risk zone for malaria infection), between 17 and 13°C (a transition zone where some transmission is possible but limited), and below 13°C (a low-risk zone where high-elevation forest is at or below 13°C). Some malarial infections are present in these low-risk zones, but they may reflect mobility of the birds. Transmission, if it occurs at all in the uppermost temperature zone, is likely brief, episodic, and limited to periods of warm weather (Feldman et al. 1995). Results for the three areas are shown in Table 3.1 and Figure 3.27.

Table 3.1. Total forest area in hectares for each zone under current (before) and after 2°C warming scenario for each island refuge.

Zones	Hanawi (3,166 ha)		Hakalau (12,999 ha)		Alakai region (15,326 ha)	
	Before	After	Before	After	Before	After
Above 17°C	1,266	1,995	650	5,200	0	12,937
Between 17 and 13°C	1,235	886	9,229	7,669	15,236	2,299
Below 13°C	665	285	3,120	130	0	0

Hanawi Forest yields the most straightforward and hopeful result in response to the climate-change scenario. For this preserve, the area of forest with a low risk of malarial infection (below 13°C) is cut in half with 2°C of warming. Although a reduction of this magnitude is likely to affect endemic forest bird populations substantially, Hanawi represents the best-case example, because past land use practices did not include the clearing of high-elevation forests for pasture. In contrast, 2°C of warming nearly eliminates low-risk forest in Hakalau. The predominant land use about Hakalau Refuge is pasture land, which constrains the mount of forest available at higher elevations and could prevent migration of forests upslope. Restoration of high-elevation forests above the refuge is crucial to improving the changes for survival of the honeycreeper species, particularly the Hawaii Akepa, a cavity nester that requires large trees (Freed et al 1987).

Finally, the island of Kauai offers the least hope for maintaining endemic honeycreepers in the face of malaria and climate change. The Alakai Swamp region occupies the top of a plateau that has been eroding for millions of years as the island itself has been subsiding. It presently supports no forest above the 13°C isotherm, and no area is free from malaria. The area above the 17°C isotherm is indicative of transition forest, where transmission is limited and the prevalence of Plasmodium in mosquitoes is tied to episodic warming events (Feldman et al. 1995). Under the warming scenario, this isotherm shifts upward about 300 m in elevation, corresponding to an 85% reduction in transition forest area. On this island, prevention of the disease in the remaining populations must become the main conservation focus.

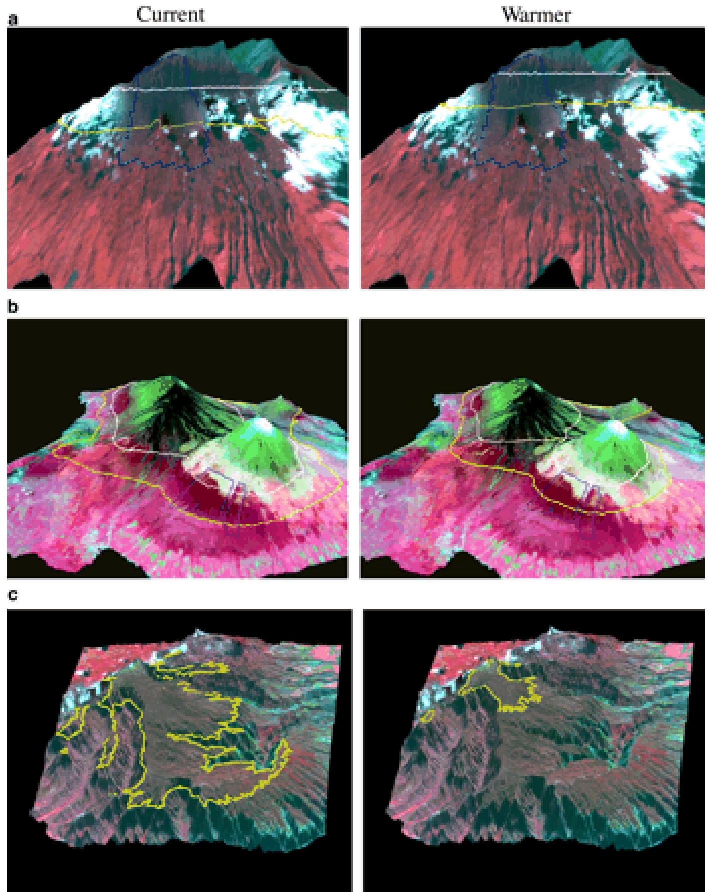

Figure 3.27. Projected changes in forest cover in relation to 17°C (yellow) and 13°C (white) isotherms under current and 2°C warming conditions. Changes are shown for (a) Hanawi Reserve (blue boundary) on the island of Maui, (b) Hakalau Refuge (blue boundary) on Hawaii, and (c) the Alakai swamp region on the island of Kauai (from Benning et al. 2002).

Sea Level Rise: Pacific islands are particularly vulnerable to sea level rise. Changes in sea level occur as both periodic changes associated with ENSO events and long term rise in sea level as a result of anthropogenic climate change. According to reports from the Intergovernmental Panel on Climate Change (The Intergovernmental Panel on Climate Change), an average between one and two millimeters per year rise of sea level has been recorded globally over the last century (The Intergovernmental Panel on Climate Change 2001, Burkett et al. 2001). In the Pacific there is no consistent trend for sea level (Table 3.2). In some areas sea level has increased, which is attributed to global climate change, while in others it has decreased as a result of geologic uplift (Shea et al. 2001).

Table 3.2. Mean sea level trends at selected Pacific Island stations, modified from the Pacific Assessment (Shea et al. 2001); original based on data from the University of Hawaii Sea Level Center.

Location	Rate of change (cm/decade)	Record duration	Total change (cm)
Hawaii			
Honolulu	± 0.2	1950-2000	14.2 ± 1.9
Kahului	± 0.5	1950-2000	10.8 ± 2.6
Hilo	3.2 ± 0.5	1927-2000	23.9 ± 3.7
Guam	0.4 ± 0.6	1948-2000	2.0 ± 3.2
American Samoa	1.6 ± 0.5	1948-2000	8.5 ± 2.7

In the PACN, the largest rise in sea level has occurred in the Hawaiian Islands. Within Hawaii, the change in mean sea level rise varies, and the highest rate of change has been experienced on the island of Hawaii. The change is a result of subsidence of the island due to active volcanism. The IPCC lists seven key impacts of sea level rise on coastal systems:

- Lowland inundation and wetland displacement
- Shoreline erosion
- More severe storm-surge flooding
- Saltwater intrusion into estuaries and freshwater aquifers
- Altered tidal range in rivers and bays
- Changes in sedimentation patterns
- Decreased light penetration to benthic organisms

If the trends identified in the table continue, park ecosystems in the PACN could be severely affected. All PACN parks will be affected by increased storm damage due to higher reach of breaking waves, which together with salt stress will lead to the destruction of coastal habitat which harbors native species. The growth of coral could potentially be inhibited due to decreased light availability in increased water depth (Kennedy et al. 2002). The added stress of increased water depth will add to other stress factors experienced by corals, such as excessive erosion at WAPA and stress from increases in sea surface temperature and storm damage for coral reefs in the entire PACN region.

CHAPTER FOUR: VITAL SIGN CONCEPTUAL MODELS

This fourth, and final section of Appendix H, provides an overview of the actual subset of selected Vital Signs and the specific variables to be measured. Each of the models presented here is intended as an "overview" of the Vital Sign being monitored, and provide 1) justification for their selection as Vital Signs to be monitored, and 2) provide a cohesive communication tool for selected Vital Signs and associated measures.

The Principal Investigators for each of the PACN protocols have created an initial "large-scale" conceptual model for each Vital Sign selected for monitoring. These Vital Sign conceptual models serve as a tool for communication between the PIs, network staff, park staff, and other interested parties. For the 'phase one' vital signs, these models are designed to communicate important information about the system (or species) of interest with an emphasis on key drivers, stressors, ecological linkages and specific monitoring objectives. The 'phase two' models are more general at this time, but will be revised during protocol development to include similar information. Principal Investigators, with assistance from PACN staff, are being encouraged to create additional models to clarify important aspects of the ecology of their particular Vital Sign. These models will serve as a baseline for future monitoring efforts, in the sense that they will give an indication of the knowledge of the systems at the time monitoring was initiated.

The Vital Signs selected for monitoring include and are presented in the following order (with Vital Sign names in parenthetical): Landscape-level Vital Signs that carry across all ecosystems as presented earlier (Climate, Water Quality, Groundwater Dynamics, Erosion and Deposition, Landscape Dynamics); Forest and Grassland Ecosystem Vital Signs (Focal Terrestrial Plant Communities, Early Detection of Invasive Plants, Status and Trends of Established Invasive Plant Species, Landbirds, Bats, Terrestrial Invertebrate Communities); Subterranean Ecosystems (Cave Community); Stream Ecosystems (Freshwater Animal Communities); Coastal Ecosystem (Seabirds); and Nearshore Marine Ecosystems (Benthic Marine Community, Marine Fish, and Fish Harvest).

LANDSCAPE-LEVEL VITAL SIGNS

The PACN has five landscape level Vital Signs: (1) Climate, (2) Water Quality, (3) Groundwater Dynamics, (4) Erosion and Deposition, and (5) Landscape Dynamics. These five Vital Signs span all geographic regions within all PACN parks and within virtually all habitats of any single PACN park.

Climate Vital Sign

Analyses of ecosystem development and processes are based on the ideas of Jenny (1941, 1980) who identified five 'state factors' that determine how systems evolve, differ from each other and vary from one landscape to another. Climate is one of these state factors, and a major ecosystem driver (Figure 4.1). Climate, in fact, is influencing ecosystem processes, but is also affecting other control factors directly, such as water resources and biota. Many of the PACN Vital Signs are directly or indirectly affected by changes in climatic conditions. The overall goal for monitoring climate in the network is to provide researchers and park managers with information about climate conditions and trends such that possible effects on other ecosystem characteristics can be discerned; while also being able to characterize status and trends in climate in its' own right.

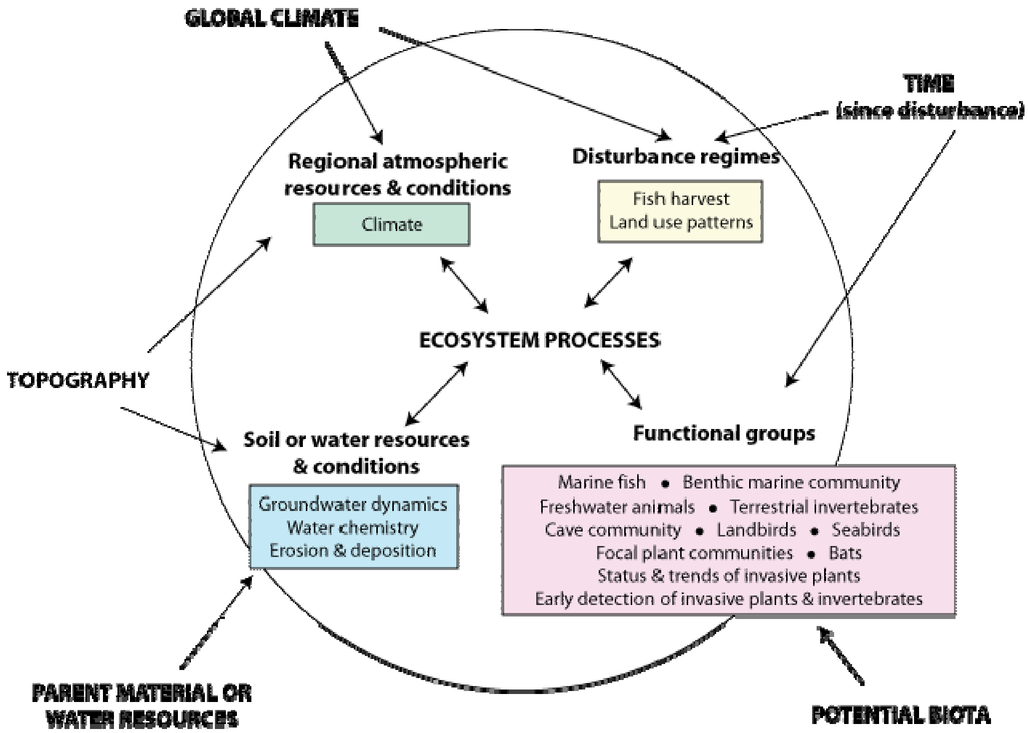

Figure 4.1. Relationship of the Vital Signs selected for monitoring by the PACN to the network's modified interactive-control model.

The climate in the PACN region is often described as mild, referring to relatively warm temperatures and minimal daily and seasonal temperature fluctuations. Moderate wet and dry seasons exist throughout the region, yet these seasons are not synchronous. For example, in American Samoa the wet season lasts from October to May, in the Marianas from July to November, in most of Hawaii from October to April, while in some portions of leeward Hawaii (i.e., North Kona) it lasts from April to September. The dominant factor shaping the climate is the tropical marine setting. The vast Pacific Ocean dampens the temperature fluctuations and leads to a constant high relative humidity. Located between 15°S and 21°N the climate is influenced by Hadley cell circulation, which describes the global circulation pattern in these latitudes. Warm, moist tropical air rises near the equator (the doldrums), moves poleward and, as it cools, sinks back to the surface at around 30° north and south. At the surface the air moves from the subtropical high pressure center back toward the equatorial trough. As a result of the Coriolis force these air masses are deflected, such that the northern and southern hemispheres experience persistent notheast and southeast trade winds respectively.

Climate Variability: Climate variability for the region is often described in terms of the Pacific Decadal Oscillation (PDO) and the El Niño/Southern Oscillation (ENSO). These are naturally occurring phenomena that are defined by atmospheric and oceanic conditions in the Pacific Ocean but affect climatic and oceanic conditions around the globe. An El Niño phase is characterized by unusually warm waters over the eastern and central tropical Pacific. The opposite is true during La Niña, which is characterized by sea surface temperatures in the region that are cooler than normal (Figure 4.2). El Niño and La Niña events often but not always follow each other and each typically lasts for a year to 18 months. El Niño events recur every 3-7 years.

Extreme Events: Extreme events or disturbances both affect and are indicative of climate conditions in the PACN. Examples of such events range from tropical cyclones, storm waves, flash flooding, extended drought conditions to extended wind or cloud free conditions. Extreme weather events are part of the natural conditions of the area. For instance, storm waves and flooding resulting from extreme rainfall during tropical cyclones are recurring events due to the climatic setting. However, many scientists expect that anthropogenic climate change will affect the frequency and/or intensity of extreme weather events in the Pacific (Carter et al. 2001, Hay et al. 2001). Extreme events have severe, wide ranging and often long lasting effects on ecosystems.

Climate Change: Global climate change is a natural phenomenon as paleontological records show. However, human-induced global climate change is expected to include much more rapid rates of change in climate parameters than have been experienced for millennia (Kennedy et al. 2002). Marine and coastal, and in particular small island ecosystems, are considered to be especially vulnerable to rapid climate change (Carter et al. 2001, Hay et al. 2001). Throughout the Pacific, changes in several climate and climate related parameters over the last few decades are attributed to anthropogenic climate change. These include temperature, precipitation, sea-surface temperature, and sea-level. Some of these changes have already negatively impacted ecosystems. For instance, increases in sea surface temperatures have been linked to coral bleaching.

Ecosystem Responses: The effects of climate change are wide ranging, affecting ecosystems on all levels. Specific effects that are of concern within the PACN include coral bleaching, due to increased levels of UV radiation and increased sea temperatures, as well as habitat changes affecting sensitive cloud forest due to increased drought.

Extreme events have severe impacts on ecosystems and recovery time is long. Sometimes the destruction is so severe that a return to original conditions will not occur unless restoration efforts are implemented.

Both abiotic and biotic characteristics of ecosystems are directly affected by the stressors. Additionally, there are indirect effects through the interaction between the ecosystem attributes. For example, for cloud and rain forest habitat, long-term changes in cloudiness and precipitation will directly affect the hydrological cycle which will then affect community structure and biodiversity. There are numerous interactions between the drivers/stressors, such as increasing CO_2 (anthropogenic emissions) leading to climate change, which in turn affects the occurrence of extreme events. The Air Quality and Climate Ecological Conceptual Model (Figure 4.2) illustrates the relationships between the drivers, stressors and the affected ecosystem attributes.

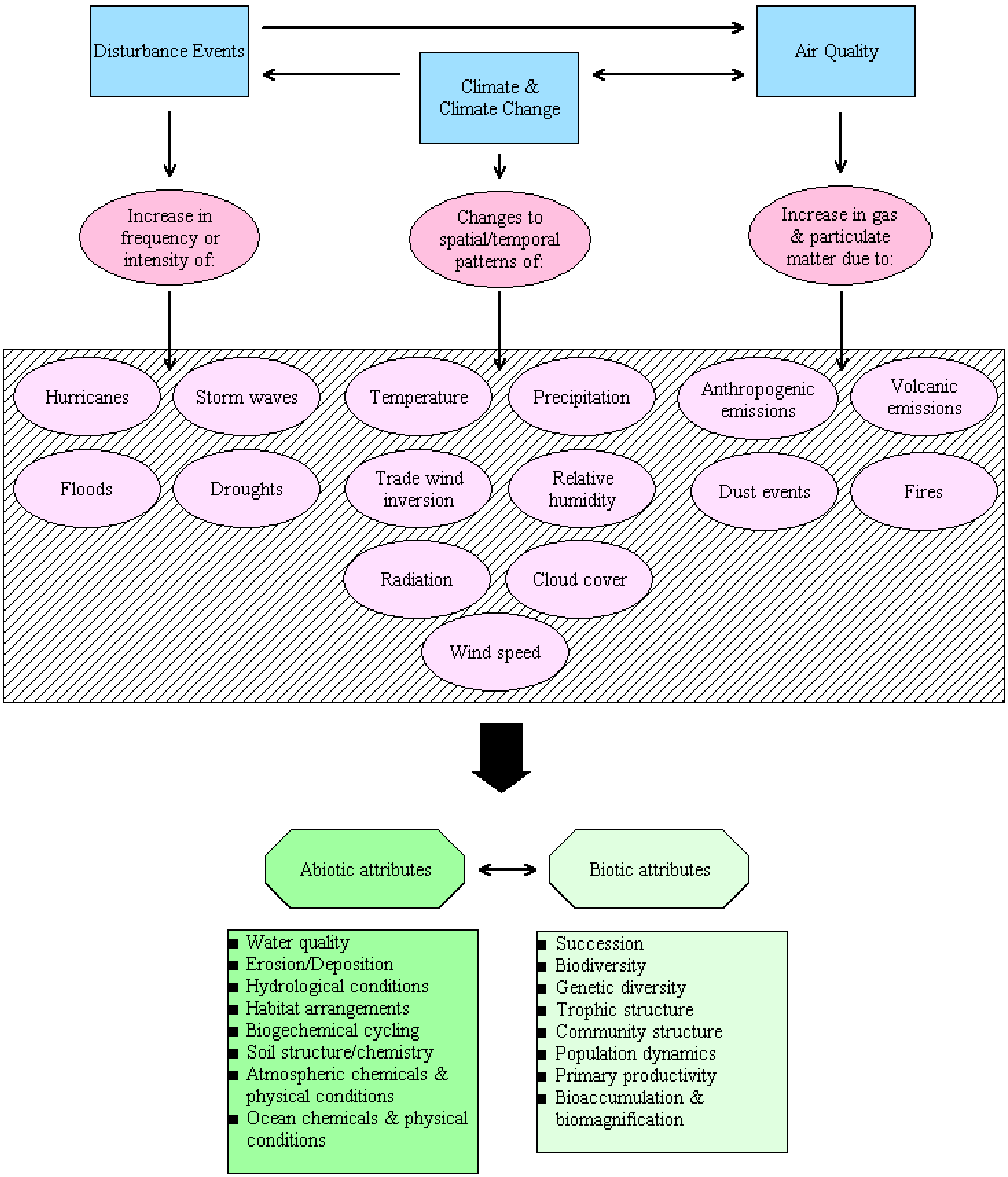

Figure 4.2. Air Quality and Climate Ecological Conceptual Model. In this model, blue rectangles represent drivers, pink ovals are stressors, and green octagons are affected ecosystem attributes. This climate model indicates that the monitored variables are stressors, unlike most other Vital Sign conceptual models which monitor attribute variables.

Water Quality Vital Sign

The quality of surface waters, marine waters, and groundwater is critical to the functioning of aquatic and terrestrial ecosystems across the PACN. Water resources in all National Parks span a range of conditions from pristine to highly impaired water bodies. Both point and nonpoint sources impact the waters at various locations. National Park Service (NPS) management policies mandate that parks will determine the quality of their water resources, strive to avoid anthropogenic pollution occurring within and outside of park boundaries, and "perpetuate surface waters and groundwaters as integral components of park aquatic and terrestrial systems" (U.S. Department of the Interior, National Park Service 2001). The PACN parks each contain or adjoin marine, stream, mixohaline, bog and groundwater resources (Figure 4.3). Examples of water body types in the PACN are subalpine lakes, wetlands, coastal and submerged springs, coastal marine waters, shoreline fishponds, anchialine pools, and a saline lake.

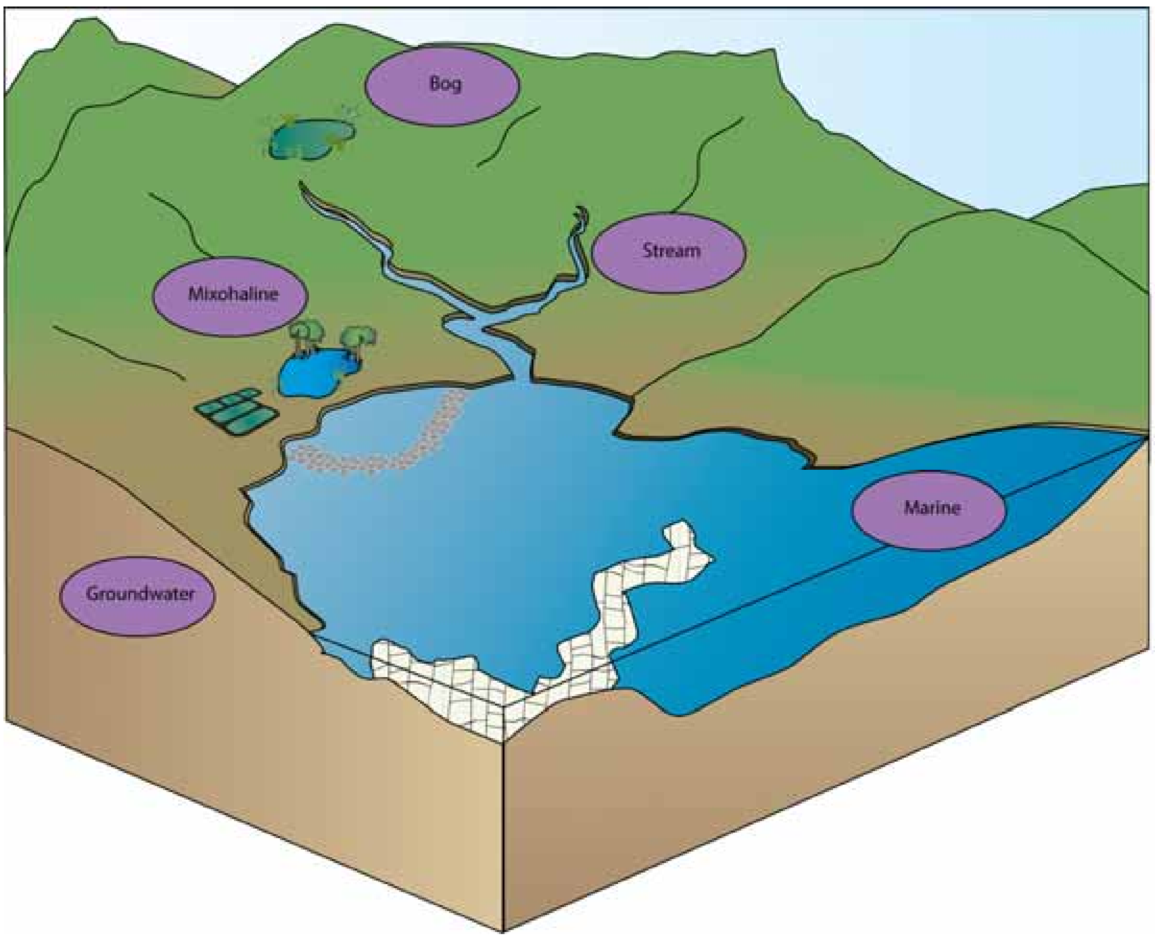

Figure 4.3. Water body types contained within the PACN.

All PACN parks are concerned about effects of adjacent land uses and increasing development of watersheds outside park boundaries on park water resources. The PACN Water Quality conceptual model encompasses all resource types (fresh, marine, and ground water) and is intended to help distinguish causal relationships between natural and anthropogenic factors on water quality. At local spatial scales, drivers can occur independently of one another, synergistically magnifying the effect of associated stressors on the ecosystem, indicated in

Figure 4.4, by enclosure of the stressors into one box relating to ecosystem responses. Parameters for this Vital Sign include temperature, salinity/conductivity, dissolved oxygen, pH, turbidity, PAR, chlorophyll a, flow/level/stage, total nitrogen, and total phosphorus.

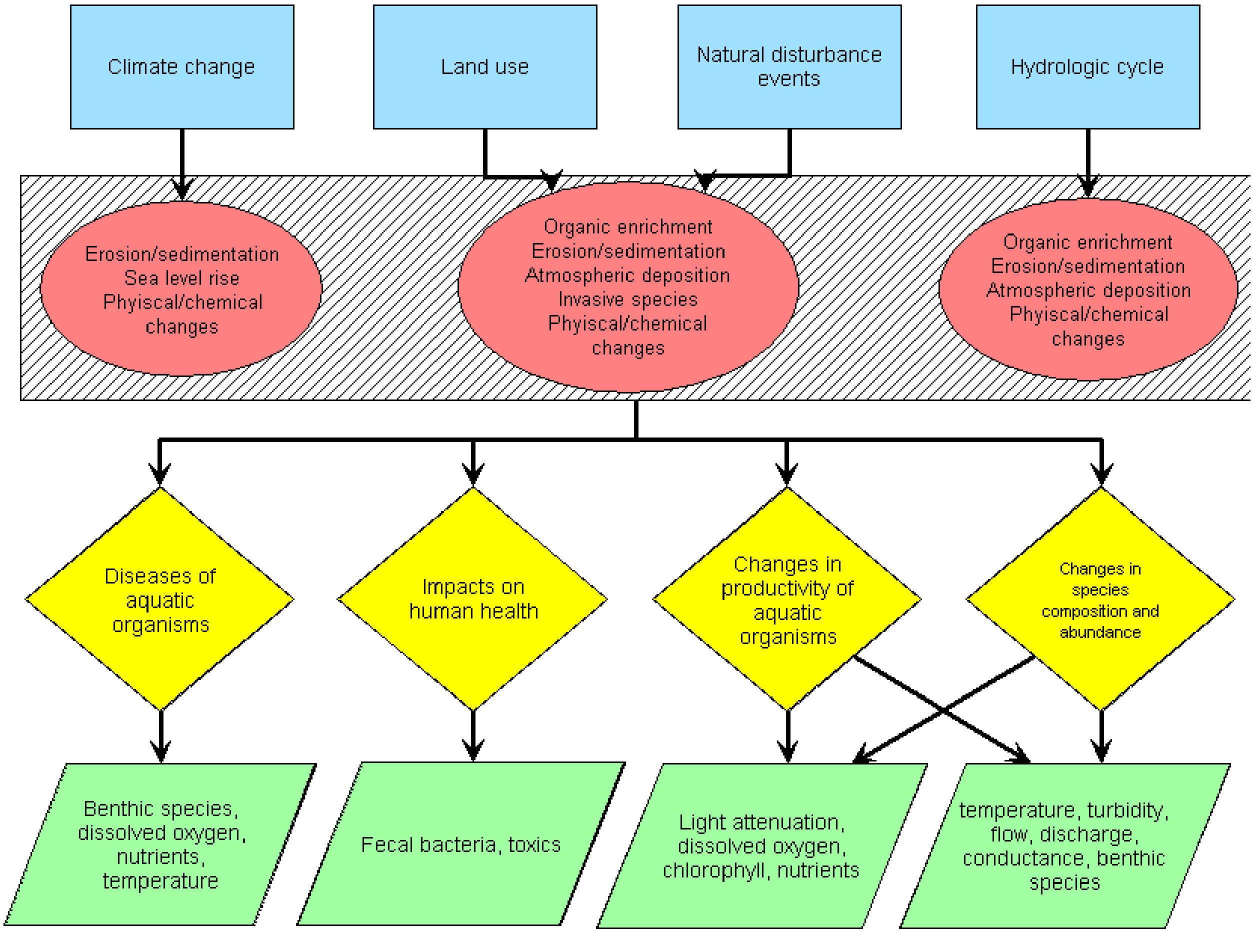

Figure 4.4. Water Quality Conceptual Model. Drivers are symbolized using blue rectangles, stressors are indicated with pink ovals, ecosystem responses are contained in the yellow diamonds, and the measurable attributes are listed in the green parallelograms.

Climate Change: Parks in the PACN are coastal parks susceptible to rising sea level, due to global warming and the thermal expansion of seawater (Wetherald 1991). Changes in sea level affect shoreline dynamics and hydrological factors leading to inundation and erosion of coastlines (Leatherman 1991) and sedimentation of nearshore areas.

Land Use: Human activity negatively influences water quality (Valiela et al. 1990, Cosser 1997, Hoegh-Guldberg 1999, Houk 2001, U.S. Department of the Interior, Geological Survey 2003a). Organic enrichment and other chemical changes in water quality may occur due to the presence of farms, human waste, waste water systems, solid waste, and landscaped areas. Land use, such as agriculture, construction of roads, piers, and barriers in coastal areas, and stream channelization, contributes to erosion and subsequent sedimentation, with concurrent physical and chemical changes in aquatic environments (De Carlo et al. 2000). Large scale removal of vegetation can influence precipitation patterns (Salati and Nobre 1991, Betts 2004) increasing the likelihood that drought, fire, and erosion contribute to the degradation of streams, wetlands, anchialine pools, fishponds, and reefs.

Natural Disturbance Events: Atmospheric deposition, earthquakes, and tsunamis can have unpredictable effects on water resources. Sewers, storm drains, and wastewater treatment plants may overflow into streams causing physical and chemical changes that eventually affect groundwater and/or nearshore receiving waters (De Carlo et al. 2000). Erosion and sedimentation are accelerated during hurricanes and typhoons either directly or through loss of vegetation.

Hydrologic Cycle: Moving water carries physical and chemical constituents to the receiving body (Figure 4.5) (De Carlo et al. 2000). Furthermore, both the character and the impacts of these constituents are affected by water quantity and flow rate (Li 1988, Lapointe et al. 1990). When a system is operating within natural ranges of water movement, potential stressors are balanced over time by ecosystem processes. Changes in the hydrologic cycle may offset the capacity of a system to restore itself, resulting in degraded water quality. Carbon dioxide emissions by industrialized populations and destruction of tropical forests are contributing to global climate change (Ehrlich 1991) which will alter the hydrology of the earth (Wetherald 1991, Hayes 1991, Valiela 1995).

Figure 4.5. Stream in WAPA, flowing into the Philippine Sea from Guam.

In order to evaluate water resource issues, an understanding of the effects of stressors on the ecosystem is important. In Figure 4.4, aquatic ecosystem responses are divided into generalized categories represented by diamonds. Several possible measures of ecological change resulting from altered water quality are indicated for each category of ecosystem response.

Health of Aquatic Organisms: Variations in ambient water quality can result in physical stress, poor health, disease, and increased mortality of aquatic organisms (Valiela et al. 1990, Cosser 1997). Examples of diseases in aquatic organisms include avian botulism in waterbirds, fibropapillomatosis tumors on turtles, and coral diseases. Bioaccumulation of and exposure to toxins and heavy metals can have adverse effects in many types of aquatic life (Long et al. 1995, Brown 2003, Obert et al. n.d.). Considering their sedentary nature and influential position in the trophic web, benthic invertebrates and algal communities are a logical choice as indicators of ambient water quality conditions (Jameson et al. *in press*).

Impact on Human Health: When aquatic ecosystems become contaminated, communities reliant on potable water, subsistence fishing, and tourism are impacted. Toxins, microbial contamination, and sewage pollution such as ciguatera, "red tide" algal blooms, *Escherichia coli,* and *Enteroccoci* are already affecting fishing areas and recreational opportunities throughout the Pacific (Cosser 1997). Experts on tropical marine microbiology are currently developing alternatives to microbial water quality criteria for this region due to low confidence in the current U.S. Environmental Protection Agency sewage pollution indicators, *E. coli* and *Enteroccoci*, for predicting illness rates in coastal recreation areas (Fujioka et al. 1998, Fujioka 2004a, 2004b).

Change in Primary Productivity: Changes in productivity affect ecosystem processes such as nutrient cycling and the rate of succession, compounding the effect of the stressors themselves. Benthic species abundance and composition is often used to characterize an ecosystem in terms of general water quality parameters (Jameson et al. *in press*). Certain benthic and plankton species need specific conditions of water clarity, nutrient availability (Hodgkiss and Ho 1997), temperature, pH, primary productivity, dissolved oxygen, and salinity. Changes in these parameters may act as drivers in the impact of related variables in ecosystem processes.

Change in Biological Species and Abundance: As with primary producers, the composition of other trophic level species and their abundance is a factor of reproduction, growth, and survival that is influenced by environmental stressors (Valiela et al. 1990, Beyers et al. 1999). Changes in ambient water quality can affect community structure in coral reefs (Matson 1986, Brown 1997). In areas where herbivores are depleted and nutrients are added, algal growth can increase to the point of smothering coral, causing mortality and regime shift (Hughes 1994). The close relationship of change in productivity to change in species composition and abundance is reflected by the same array of parameters used to describe them.

Because water quality is intimately associated with several other vital signs, co-visitation and co-location will be necessary during monitoring activities to address these correlations and increase the effectiveness and value of monitoring efforts for all associated vital signs.

Groundwater Dynamics Vital Sign

The source of fresh groundwater in Pacific island aquifers is rainfall that infiltrates the ground surface and recharges the groundwater system. In general, wetter areas are expected to have greater volumes of fresh groundwater than drier areas, all other factors being equal. Near coastal areas on larger islands, and throughout smaller islands and atolls, fresh groundwater generally occurs as a lens-shaped body of freshwater underlain by saltwater derived from the surrounding ocean (Figure 4.6). A transition zone of brackish water separates the freshwater from saltwater and is formed by the mixing of freshwater with saltwater. In some coastal areas, extensive mixing may cause brackish water to extend to the water table and a freshwater lens does not form. Freshwater generally flows from inland recharge areas to coastal discharge areas. Freshwater may discharge into stream channels from onshore springs near the coast, or from submarine springs and seeps. Features of locally lower permeability, including dikes, alluvium, and fault planes, may impede the general offshore flow of groundwater resulting in localized vertical changes in the water table from a few to hundreds of feet.

The parameters (measures) for this vital sign include level and salinity.

Precipitation and groundwater recharge: Precipitation, principally rainfall, is the primary source of the freshwater that recharges aquifers. Precipitation varies considerably. Most tropical Pacific islands have distinct wet and dry seasons. Interannual rainfall variation is commonly associated with the El Niño – Southern Oscillation cycle, corresponding to lowered rainfall and droughts. Precipitation can evaporate, run off to the ocean, or infiltrate the soil. Soil water is subject to further evaporation and transpiration by plants back to the atmosphere. Water not removed by these processes becomes groundwater recharge. The amount of recharge is typically calculated by estimating the amount of total precipitation and then subtracting the estimated amounts of evapotranspiration and direct runoff. Accurate estimates of recharge are extremely important to assess the availability and sustainability of groundwater resources.

Groundwater quality: On most tropical Pacific islands, the availability of drinking groundwater from freshwater-lens systems is limited primarily by salinity. The salt in groundwater comes from the seawater that surrounds and underlies the islands. Natural processes and pumping mix this saltwater with freshwater. Seawater contains many dissolved salts, and the concentration of dissolved chloride (Cl) is typically used to indicate the presence of salt from seawater, which has a dissolved Cl concentration of about 19,500 mg/L.

Island aquifers are susceptible to contamination from various human activities (Anthony et al. 2004). Land uses such as agriculture or urban and suburban development can alter both the quantity and quality of water recharging an aquifer. Leaks and inappropriate disposal of industrial solvents and hydrocarbons have contaminated ground water in many areas. Similarly, pesticides and nutrients introduced by agricultural practices have contaminated groundwater in some areas.

Improperly handled human sewage can result in potentially serious microbial contamination of groundwater, particularly where the groundwater is close to the surface, or where the soil and aquifer permit fast vertical movement (U.S. Environmental Protection Agency 2004c). Sewage contamination of groundwater may come from leaking, poorly constructed, or failing cesspools, pit latrines, or septic systems, as well as from leaking sewer pipes, or failing and overflowing sewage-pump stations.

Effects of pumping: Withdrawal of groundwater by pumping from a well reduces the water level and removes water from storage in the aquifer, causing a decrease in the amount of groundwater discharge equal to the amount of pumping (Heath 1989). In settings where groundwater discharges to streams, the lowering of water levels by pumping can result in reduced streamflows (Winter et al. 1999). In a freshwater-lens system, pumping also shrinks the freshwater lens, resulting in upward movement of the transition zone. These effects are greatest near the source of water withdrawal. Over time, the water table and transition zone reach a new equilibrium.

If too much water is pumped, the freshwater lens may shrink enough that brackish water from the transition zone is drawn into the well. This process, known as saltwater intrusion, can either affect individual wells or degrade an entire aquifer. Because of the delay between the onset of pumping and the rise in the transition zone, it may take several years before it becomes apparent that a well is being over-pumped, or that a well is recovering from the effects of over-pumping. The timelag for a particular well to reach a new equilibrium is determined by, among other things, the location and depth of the well, the rate of pumping from that well and others in the aquifer, the physical properties of the aquifer, and the volume of groundwater flowing through the aquifer.

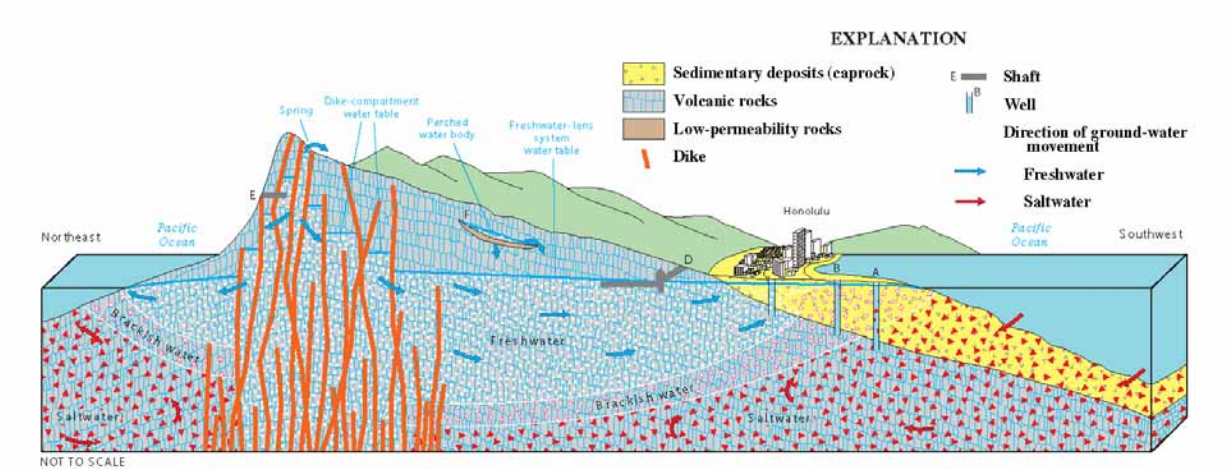

Figure 4.6. Conceptual diagram of groundwater sources on a volcanic Pacific island. (From Oki et al. 1999)

Erosion & Deposition Vital Sign (Phase Two)

Erosion and sedimentation are directly indicative of soil disturbance and movement, and therefore, represent a significant threat to terrestrial, aquatic and marine resources. Soils in the PACN tend to occur in limited quantities (e.g., very thin or no soil in many locations) and have variable quality. Loss of soil through erosion can directly result in the wholesale conversion or entire loss of vegetation communities (Figure 4.7). Any activity that reduces vegetation cover, disturbs the ground, or increases overland water flow will increase erosion and sedimentation rates to streams and the ocean. When suspended in water, fine sediments increase turbidity, decrease light penetration, and alter primary productivity in aquatic systems (Fabricius 2005, Minton 2005, Minton and Lundgren 2006). Sediments also settle on the bottom and smother benthic organisms such as corals (Rogers 1990).

Figure 4.7. Erosion on the hills of Guam, resulting in loss of vegetation.

This Vital Sign proposes to annually assess soil depth, quality (e.g., organic matter, pH, infiltration, aggregate stability, soil crusts), and loss/accretion at sites stratified across rainfall and slope gradients in PACN parks. Slope and rainfall are important covariates to consider when selecting sampling sites for this objective (Renard et al. 1997). Soils in PACN parks generally occur as a thin layer overlying inhospitable clays or volcanics. Plant communities are intimately linked to soil quality and quantity, and processes (e.g., volcanism, erosion, wildland fire, and introduced species) that alter these factors can cause significant community-level changes (Figure 4.8). These can include anthropogenic land uses such as agriculture, poorly managed development and urbanization, and fire and human-induced climate change. For example, badlands are incapable of naturally re-vegetating, and continue to erode at a rate ten times higher than surrounding grasslands (Minton 2005).

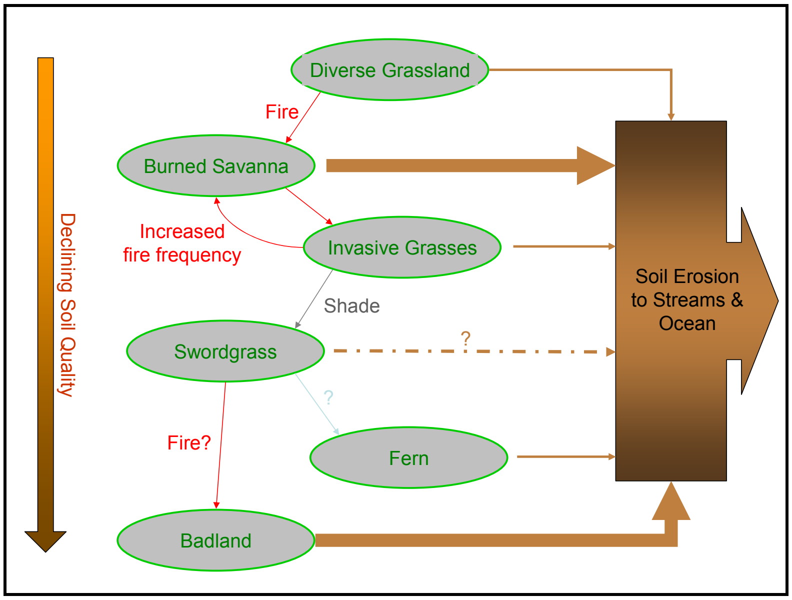

Figure 4.8. Conceptual diagram for erosion dynamics. Soil quality (left arrow) and fire (red arrows) are drivers of erosion. Thickness of horizontal arrows represent relative contribution to overall soil loss.

Furthermore, this Vital Sign proposes to seasonally (wet versus dry season) measure water column turbidity at marine or freshwater monitoring sites. Where applicable, monitoring sites should be stratified to monitor point sources (e.g., river mouths, outfall pipes) and areas away from point sources. Suspended sediments can indirectly impact primary producers by reducing light penetration to sessile benthic organisms (Rogers 1990, Minton and Lundgren 2006). Turbidity reduces the penetration of light, harming plants and animals that require light to survive (Figure 4.9).

This Vital Sign also proposes to seasonally (wet versus dry season) measure the sediment collection rate and determine the percent contribution and total load of the terrestrial soils in marine or freshwater locations. Where applicable, monitoring sites will be stratified to monitor point sources (e.g., river mouths, outfall pipes) and areas away from point sources. Sedimentation rate is a direct measure of the suspended matter (excluding re-suspension) settling from the water column onto the benthos. Marine and freshwater sediments are comprised of materials originating from land, freshwater or marine sources. Determining the contribution of terrestrial sources to marine sediments is necessary to assess and manage terrestrial activities.

Figure 4.8 is our conceptual model for the erosion part of this Vital Sign. Soil quality (left arrow) and fire (red arrows) are important drivers for erosion, contributing to increased erosion by changing plant communities (ovals). Figure 4.9 is a conceptual diagram representing the deposition portion of this Vital Sign. Once sediments are transported to the nearshore environment they can smother seagrass habitat, and reduce light availability to corals, which gain energy through photosynthesis. This Vital Sign is closely linked to the Landscape Dynamics (land use), Benthic Marine Community (coral recruitment), and Water Quality (turbidity) Vital Signs.

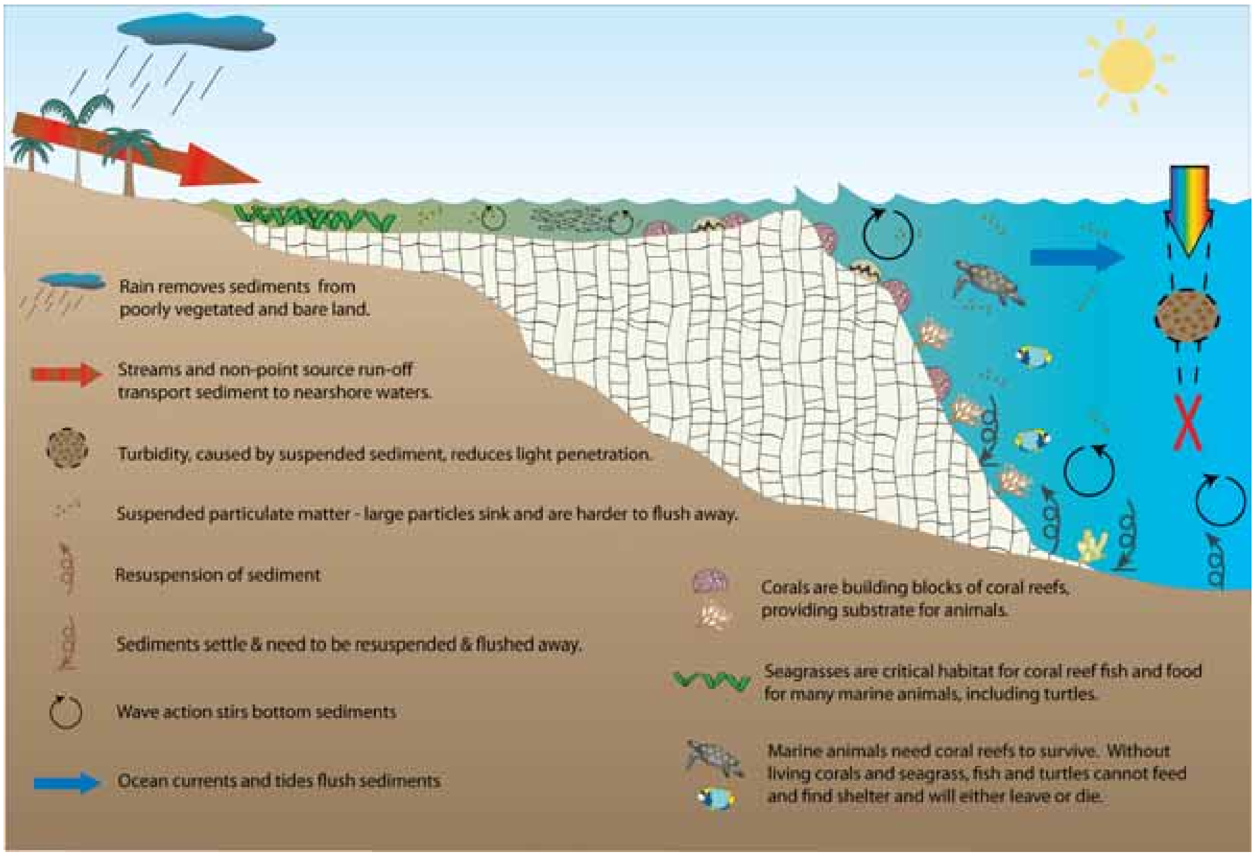

Figure 4.9. Conceptual diagram for deposition and effects of sedimentation on nearshore environment in the PACN.

Landscape Dynamics Vital Sign

Landscape change brought about by the Polynesians was significant, but far less in scope than that brought about after European contact (Cuddihy and Stone 1990). Traditionally, Native Hawaiians used an integrated approach to land management. The population was clustered within ahupuaa, a land division usually triangular in shape stretching from the mountaintops to the sea, ruled by chiefs. Each tribal group thus had access to all the resources of the uplands as well as the coastal resources. The health of the ahupuaa was maintained through strict adherence to protocols for using and caring for the natural resources within that land division (The Kohala Center 2006). For instance, the amount of water given to a kalo farmer within the ahupuaa depended upon his cooperation in building and maintaining the auwai, the irrigation channel (Moanalua Gardens Foundation 2003). In American Samoa and the Marianas Islands, traditional land management systems were somewhat different, but still had a communal village approach.

As Westerners settled Hawaii, this integration was lost. Upland forests were destroyed in the search for sandalwood and lands converted to grazing. Populations became less rural and more urban. Plantations began mono-crops for sugar or pineapple. Much of the productive lowlands were converted from their native vegetation. Today, the National Park lands within Hawaii and the PACN protect some of the last remaining natural landscapes.

There are several ecological mechanisms linking landscape change to park resource impacts (Hanson and Jones 2005). Effects commonly include habitat fragmentation and edge effects, spread of exotics, changes in the effective size of natural areas, degraded water quality, changes in flow of energy, nutrient cycling, and overall ecological functioning (Bolstead and Galvert 2005). As well as ecological and biodiversity impacts, development can negatively affect aesthetic values such as viewsheds or the experience of nature and quiet, and recreational values.

Parks usually contain undeveloped natural lands which are reserves for wildlife and native vegetation. However, parks are generally not large enough to contain all important resources of an ecosystem. Changes in zones of the ecosystem can lead to changes elsewhere, such as lower watershed impacts from disturbance higher in the watershed. Development in areas outside of the parks changes the effective size of reserves, resulting in a species area/populations effect, such as species being forced into smaller areas with consequent habitat lost, or losing areas that may have been important for breeding or seasonal feeding, ultimately impacting populations. Unique habitats necessary for certain life cycles may be lost to development if not owned by the park. Trophic changes can also occur. Often higher trophic levels are the first to succumb to changed conditions, finding the habitat no longer suitable. Then the system can become dominated by lower levels, without the natural checks and balances on populations. Herbivore populations may soar in the absence of predators, resulting in over-grazing of vegetation. Migration or dispersal routes may become blocked, switching habitats that were once population sources into sinks. Edge effects from development at the edge of reserves can extend some distance into the reserves (Hanson and Jones 2005).

The identification of behavior as a link between process and pattern in landscape ecology can be termed functional connectivity, the degree to which the landscape facilitates or impedes movement among resource patches. Another way of describing this link would be through the use of travel costs (Belisle 2005).

New patterns of land use are occurring with the modern society's information age. The agricultural phase of economic development had most impact on those components of biodiversity that depend on high-productivity environments, while preserving those components that can survive on marginal lands. However, the transition from an industrial to an information-driven economy breaks the linkage between productivity and land-use intensity, and remaining reservoirs of biodiversity on marginal lands are now being threatened as formerly remote rural areas are being developed for recreational and residential use (Huston 2005). The wildland-urban interface (WUI) is the area where houses meet or intermingle with undeveloped wildland vegetation (Figure 4.10), and is thus a focal area for human-environment conflicts, such as building loss due to fire, habitat fragmentation, invasive species spread, and loss of biodiversity. The WUI in the conterminous U.S. covers 9% of the land area but contains 39% of all houses (Radeloff et al. 2005).

Figure 4.10. Pago Pago, American Samoa, encroaching on the undeveloped landscape.

The objectives of this protocol are to describe landscape dynamics at a scale useful to park managers' response, and to identify areas of change so that appropriate studies or actions can then take place to preserve biodiversity and park resources. Comparing modern patterns of landuse and cover to traditional patterns allows us to see impacts on cultural resources. Figure 4.11 is the conceptual model explaining some of the linkages between the drivers (blue), stressors (pink), and the measures (green) of this Vital Sign.

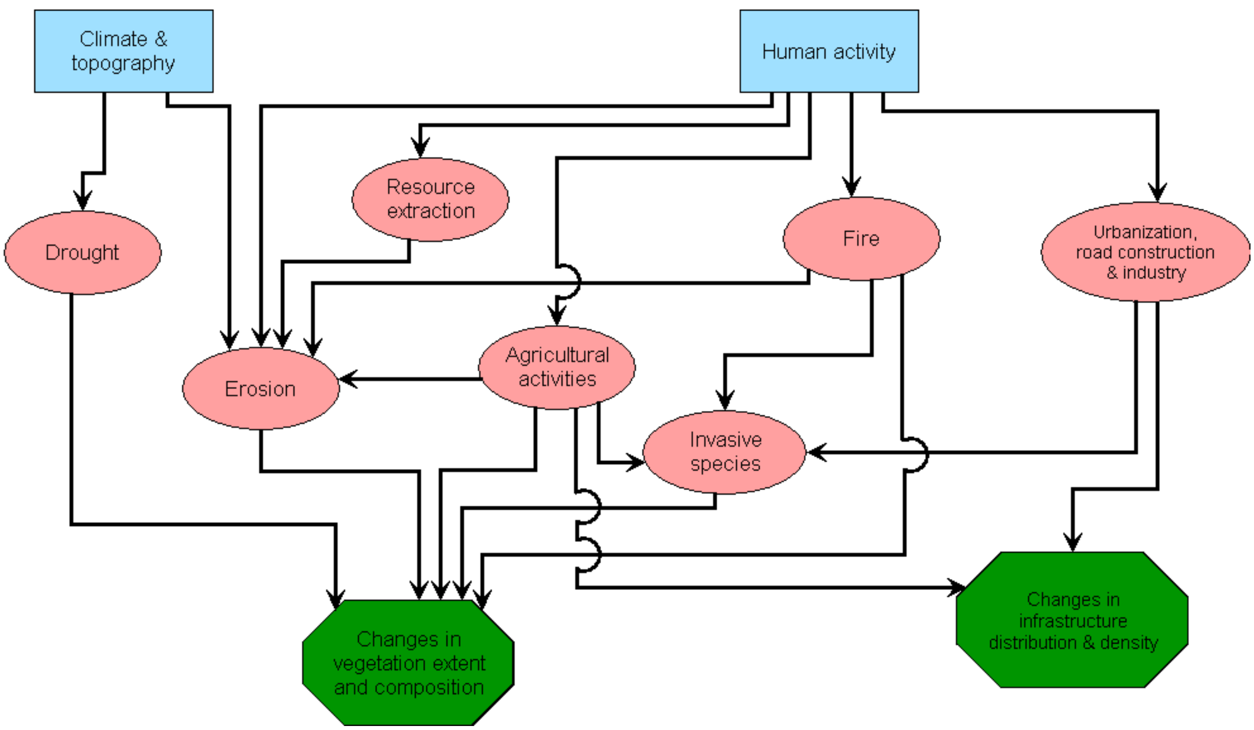

Figure 4.11. Conceptual model for Landscape Dynamics Vital Sign illustrating linkages between the major drivers (blue), stressors (red), and the measurable attributes (green).

FOREST AND GRASSLAND ECOSYSTEMS VITAL SIGNS

Terrestrial Plant Communities and Invasive Species Vital Signs

Terrestrial plant communities are the cornerstone of an ecosystem. They are comprised of a complex assemblage of plant species that interact with each other, as well as with other elements of their environment. The distribution, composition, and structure of terrestrial plant communities are continually influenced by natural and anthropogenic drivers. Drivers are defined as external forces that have large-scale influences on terrestrial plant communities. Examples of drivers that shape terrestrial plant communities include: regional atmospheric resources and conditions, soil or water resources, disturbance regimes, and biotic community (i.e., the types of species present, their relative abundance, and the nature of their interactions) (Figure 4.12, blue rectangles). Stressors are physical, chemical, or biological perturbations to the ecosystem and are agents of ecological change (pink ovals) in community and ecosystem processes. Figure 4.12 shows the relationships among the three terrestrial plant Vital Signs selected for monitoring: Focal Terrestrial Plant Communities, Early Detection of Invasive Plants, and Status and Trends of Invasive Plant Species.

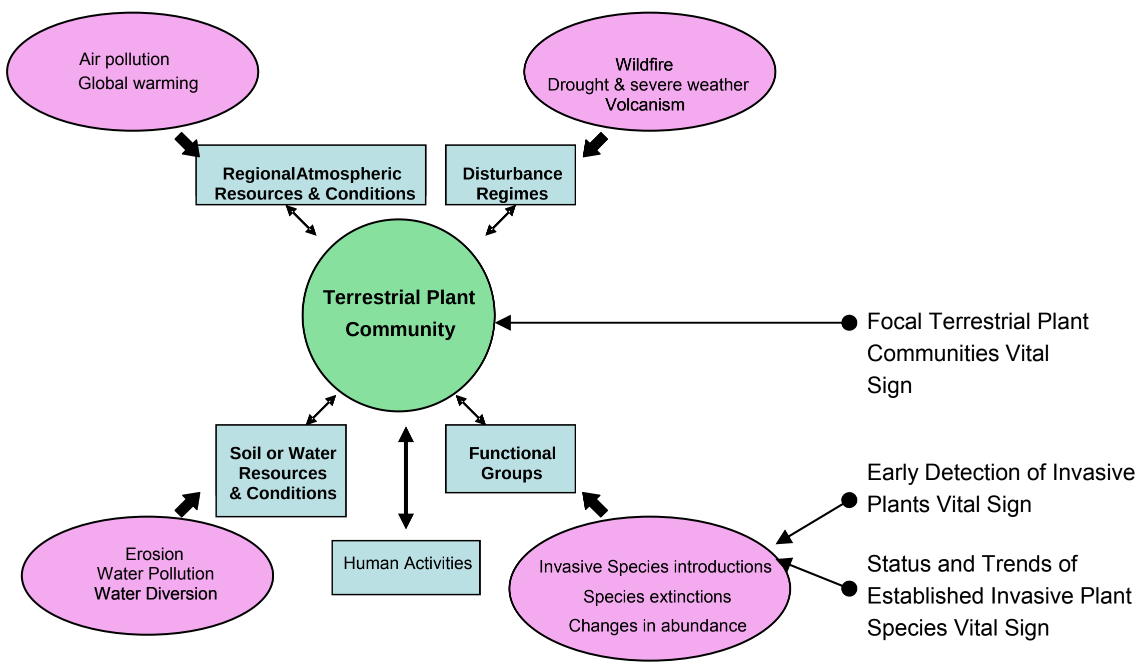

Figure 4.12. Stressors (pink ovals) that affect terrestrial plant communities and their relationship to three terrestrial plant Vital Signs (modified from Chapter 2, HaySmith et al. 2006).

Focal Terrestrial Plant Communities Vital Sign

Ecosystem changes can be quantified by monitoring vegetation attributes such as distribution, structure, and composition over time. Changes in these parameters can impact terrestrial vegetation communities, potentially leading to declines in ecosystem integrity. Linkages among key drivers, stressors, vegetation attributes, monitoring objectives, and their products or measures are identified in Figure 4.13.

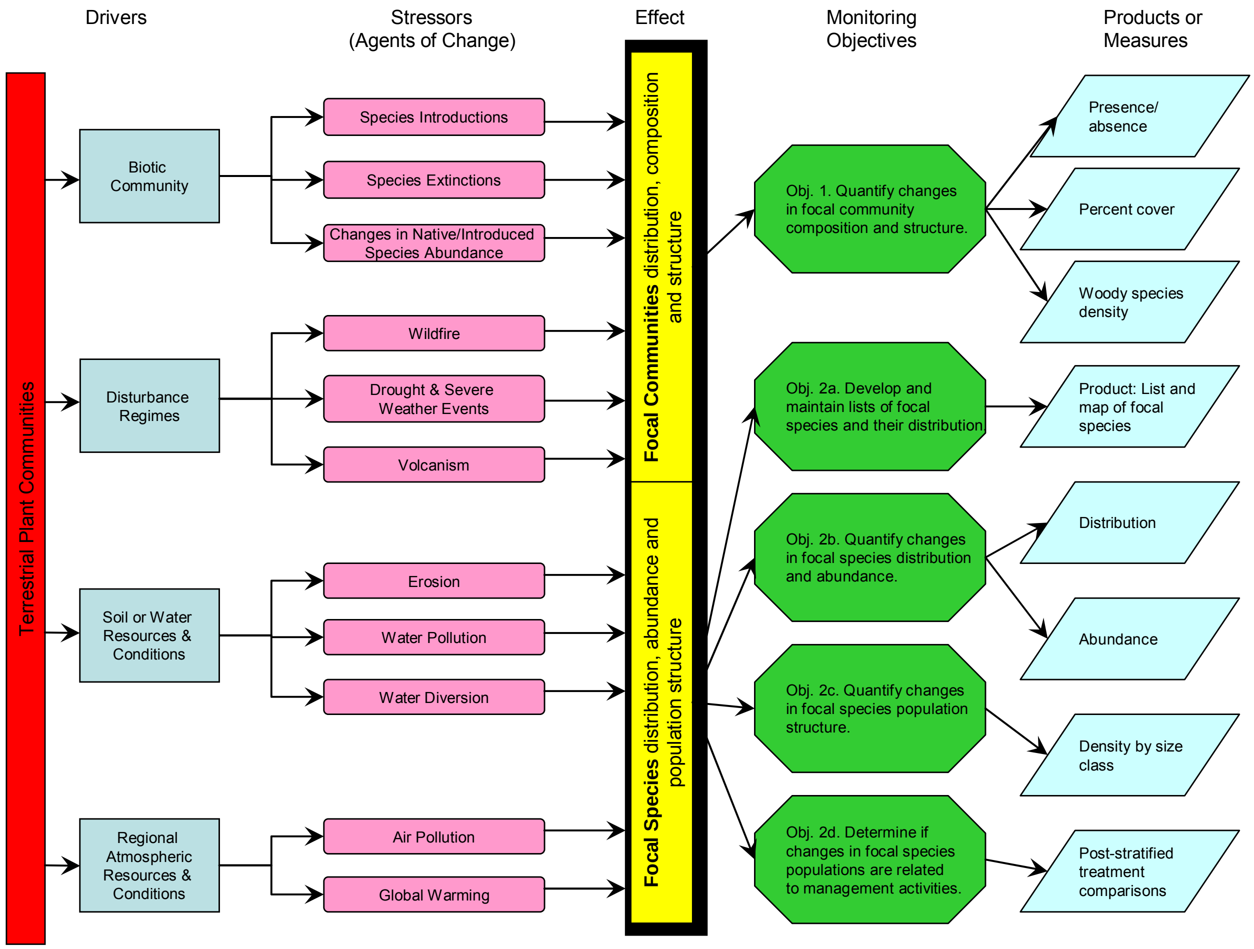

Figure 4.13. Conceptual model of the PACN Focal Terrestrial Plant Communities Vital Sign illustrating the linkages among drivers, stressors, vegetation attributes effected, monitoring objectives and products or measures.

In the PACN network, changes in the biotic community are considered one of the greatest threats to terrestrial ecosystem integrity. These changes can occur through species introductions such as the intentional introduction of kahili ginger (*Hedychium gardnerianum*) at HAVO (Figure 4.14), or changes in native and introduced species abundance, as well as extinctions. This high level of threat exists because invasive species are likely to alter ecosystem function and succession. Although many ecosystems in the PACN parks evolved with landscape-level disturbance events, anthropogenic changes may alter their magnitude and subsequent effects on the vegetation. Soil erosion, water pollution, and diversion are stressors that can affect nutrient and hydrologic cycles, thereby altering available resources for vegetation growth and maintenance. Global and regional atmospheric changes, such as global climate change and air pollution, may result in higher sea levels, increased ambient temperatures, and increases in carbon dioxide concentrations. To determine if these current stressors are altering the integrity of vegetation communities in PACN parks, we have identified monitoring objectives and specific parameters to be measured for the community, population, and species levels (Figure 4.13).

Figure 4.14. Invasive kahili ginger, *Hedychium gardnerianum*, in HAVO.

Invasive Plant Species Monitoring

One of the major stressors to plant communities is invasive species introductions, which includes invasive plants, animals, and pathogens (Figure 4.15). Invasive plant species have significant potential to compromise the integrity of terrestrial plant communities (Figure 4.16) and associated biological diversity through competition and displacement (Vitousek et al. 1997). Oceanic islands are extremely vulnerable to invasion by alien plant species from continents (Loope and Mueller-Dombois 1989, Denslow 2003) due to their evolution in relative isolation and in the absence of forces shaping continental organisms. The catastrophic impacts of plant invaders on native biodiversity and ecosystem processes in island ecosystems, particularly Pacific Islands, are well-documented (Huenneke and Vitousek 1989, Vitousek and Walker 1991, Meyer and Florence 1996, Lavergne et al. 1999, Buddenhagen et al. 2004, Hughes and Denslow 2005, Asner and Vitousek 2005, Bellingham et al. 2005).

The impact of invasive alien species on native natural communities in island ecosystems is costly, both ecologically and economically (OTA 1993, Leung et al. 2002). Figure 4.15 suggests that preventing new introductions are the most economical solution to preventing an invasion. After an invasion, early detection of invaders through effective active or passive monitoring of pathways and other priority areas results in greater return on the investment of scarce resources. When combined with rapid response, total eradication of the invasive species from an area can be achieved if addressed quickly and before it is firmly established in natural communities. After the establishment and naturalization of the invasive species, eradication may be cost prohibitive and no longer considered a viable solution. In these cases, containment or long-term control is often the more feasible option (Hobbs and Humphries 1995, Leung et al. 2002). Monitoring the status and trends of established invasive plant species over time and space is an important part of a comprehensive long-term monitoring program because of the rapid loss of biological diversity that can occur as invasive species invade focal communities.

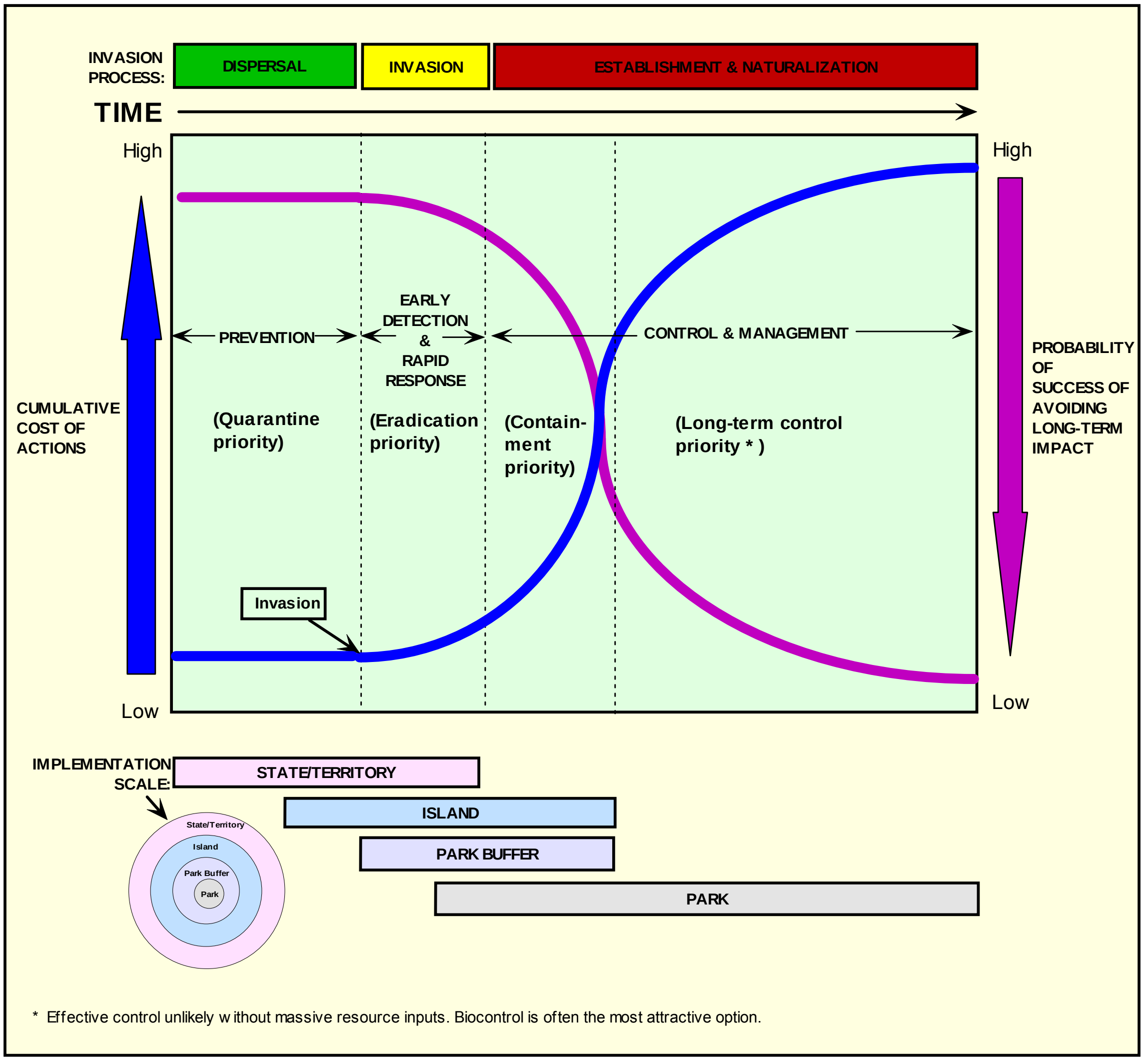

Figure 4.15. Relative societal cost and probability of success for actions designed to avoid negative impacts of invasive plant species in the PACN at four scales (modified from Hobbs and Humphries 1995).

Figure 4.16. Invasive mile-a-minute vine, *Polygonum perfoliatum*, covering native vegetation in American Samoa.

The severe threat of invasive species to national park ecosystems requires a multi-scale approach to early detection with a three level monitoring strategy: (a) within park boundaries, (b) extending through buffer areas outside of the park, and (c) extending to invasion sources and pathways across entire islands (Figure 4.17). As part of a comprehensive monitoring strategy, the PACN Inventory and Monitoring program will work synergistically with park resource managers, volunteers, and local island partnerships to detect, eradicate, and manage the most threatening invasive species. The protocol developed for this Vital Sign will eventually include Federal, State or Territorial, and local agencies, traditional governments, and private entities. At the largest scale, the system's eventual success will depend in part on public participation in efforts to report and respond to invasions (NISC n.d.).

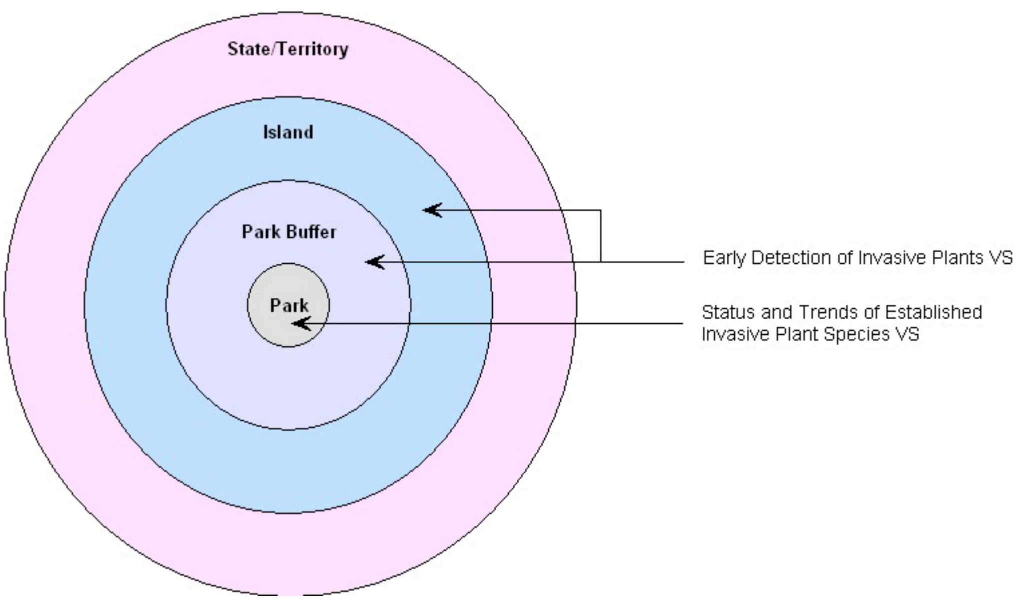

Figure 4.17. Relative spatial scope of two invasive species Vital Signs.

Early Detection of Invasive Plants Vital Sign

The Early Detection of Invasive Plants Vital Sign monitoring program is an innovative approach to address the severe threat of invasive species to national park ecosystems that involves monitoring buffer areas around parks. It also includes a plan for NPS and partners to extend IS monitoring to other areas and sites across the islands in which they occur. Early detection programs offer a stop-gap response in the absence of strict prevention programs. They can show high effectiveness when used in conjunction with an optimal prevention program to which various agencies and organizations contribute. Long-term monitoring for early detection in buffer areas outside park boundaries provides an increased opportunity to protect park ecosystems. Likewise, the PACN network can contribute to collaborative interagency action to address the huge problem of proliferation of invasive plant establishment and spread. To accomplish this, protocol design will include options for collaborative monitoring with other local and State entities.

Invasive species are a stressor on terrestrial plant communities. Several drivers impact invasive species such as the legal and institutional framework, economic policies and tools, and research capacity (blue rectangles) (Figure 4.18). Various management inadequacies, insufficiency of funds, inadequate collaboration and institutional framework for preventing invasive species introductions (pink oval) result in the introduction of a new species to an island.

The primary mode of dispersal of incipient invasive plants is recognized as humans (Reichard and White 2001, Sullivan et al. 2005). Therefore, PACN early detection monitoring efforts will focus on the pathways of human habitation and movement (i.e., island road networks) in buffer areas and other areas outside parks, as well as roads and trails (avenues of human dispersal) within parks (the latter is a component of the Status and Trends of Established Invasive Plant Species Vital Sign). This pathway is complex and involves botanical gardens, arboreta, nurseries, seed trade among garden clubs and horticultural societies, seed trade industry, and aquaria (Reichard and White 2001). Intentional introductions by professional and non-professional collectors have been cited as dominantly responsible for large-scale plant introductions in Hawaii (Yee and Gagne 1992). The ED of Invasive Plants monitoring program will focus on developing a list of target species and standards of operations for monitoring these high risk corridors and plant distribution centers. Each step of monitoring will be linked to a rapid response program headed by agency partners that have the responsibility and authority to ensure quick eradication and control of the target species.

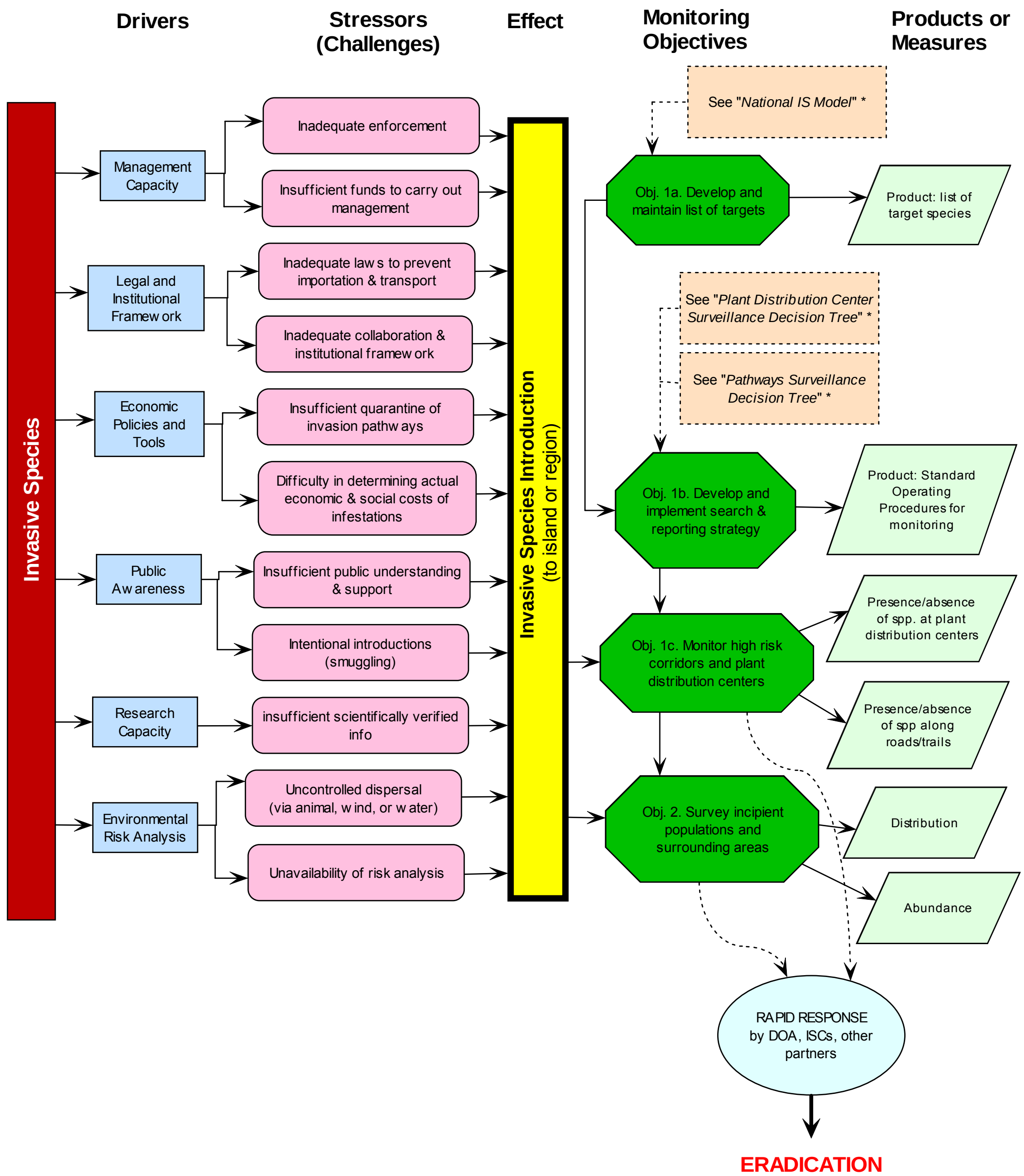

Figure 4.18. Conceptual model of the PACN Early Detection of Invasive Plants Vital Sign for an island-level early detection of invasive species monitoring program (drivers from McKneely et al. 2001).

Status and Trends of Established Invasive Plant Species Vital Sign

The Status and Trends of Established Invasive Plant Species Vital Sign monitoring protocol is designed to identify new populations of invasive species within Park boundaries. The focus is on pathway corridors of human habitation and within focal terrestrial vegetation communities (Figure 4.19). Similar to the Early Detection of Invasive Plants Vital Sign, new arrivals in Parks and/or focal communities may be targeted for eradication. In addition, the population dynamics or status and trends of select established invasive species within park boundaries will be monitored so that invasions into new areas of concern can be identified and possibly controlled. Many plant species strongly influence ecosystem processes through their utilization of resources, effects on microclimate and disturbance regimes (Chapin et al. 2002). In many parks, species diversity is changing rapidly due to (a) an increase in species introductions, (b) changes in abundance, and (c) species extinctions. The community and ecosystem consequences of changing species diversity are largely unknown.

Figure 4.19. Invasive, agricultural and native plant species at Afono Pass, Amalau Valley, NPSA.

In the PACN parks, nonnative floral and faunal species invasions, native species extinctions, and changes in species abundance present a serious threat to ecosystem integrity, represented in a generalized conceptual model (Figure 4.20). At their very worst, ecologically disruptive species (e.g., exotic grasses, *Morella faya, Miconia calvescens, Psidium cattleianum* in Hawaii) are able to completely displace the native vegetation and alter ecosystem processes (Vitousek and Walker 1989, D'Antonio and Vitousek 1992). Nonnative plant invasions can also lead to significant economic and cultural costs. For example, exotic grasses are responsible for increased fire frequency and spread in wildland urban interfaces, and the loss or alteration of culturally significant species and landscapes. Likewise, the loss of canopy species such as tree ferns can change light regimes, impact vegetation structure, and may lead to a loss of the plant community. Other possible indicators or impacts from changing biotic communities include decreased resource availability, decreased reproduction, decreased population size, herbivory, and decreases in native pollinators and native seed dispersers. Because individual species have the potential to greatly influence ecosystem processes, changes in species composition are likely to alter ecosystem function and succession.

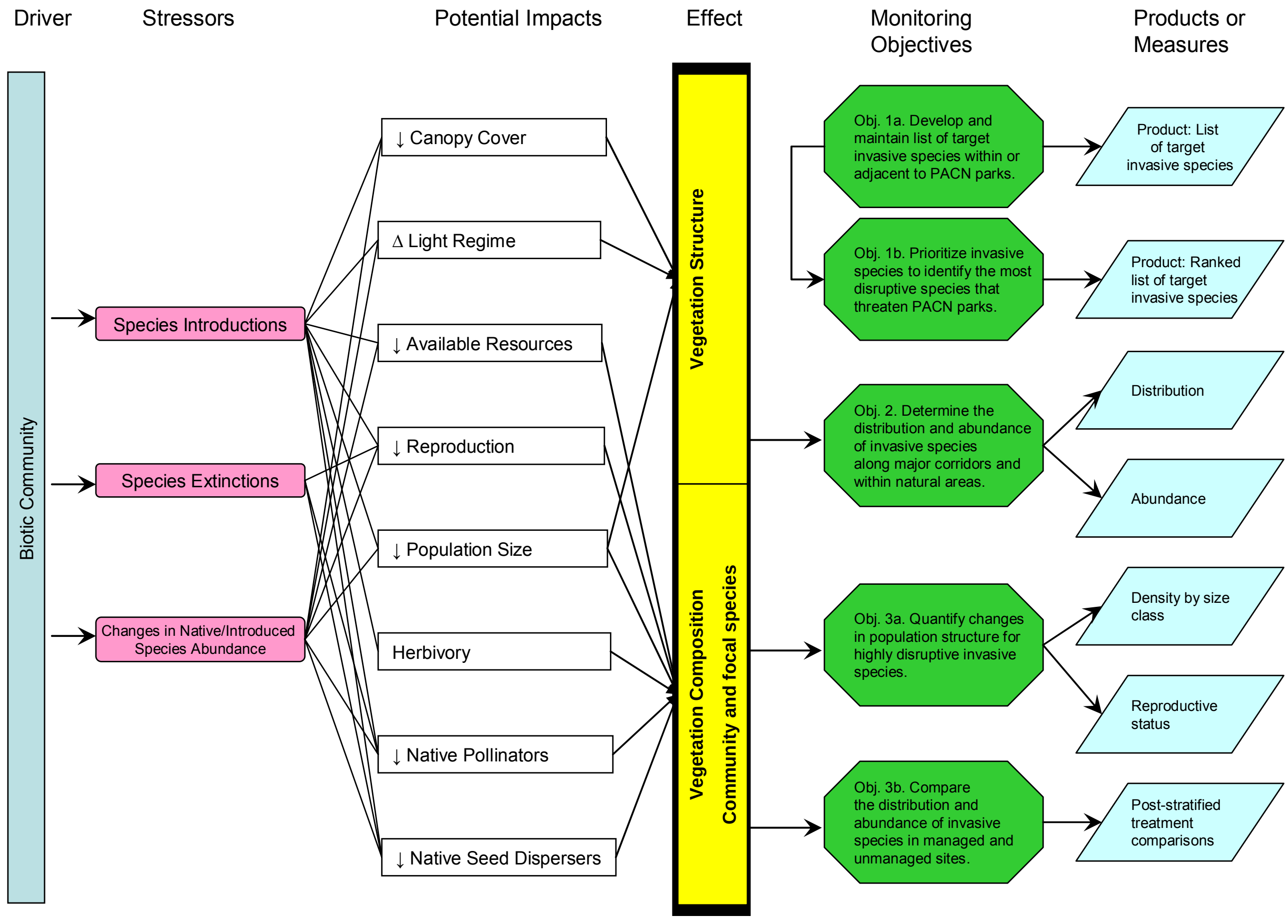

Figure 4.20. Conceptual model of the PACN Status and Trends of Established Invasive Plant Species Vital Sign illustrating the linkages among the biotic community driver, stressors, potential impacts of stress, vegetation attributes effected, monitoring objectives and products or measures.

Landbirds Vital Sign

Birds are the principal, and sometimes only, terrestrial vertebrates on oceanic islands. From their position at the top of the terrestrial food chain, birds strongly influence ecological processes in the Pacific islands as consumers, pollinators, and seed vectors. Long-term monitoring of landbirds is, therefore, critical in the PACN, and can be accomplished through the following two objectives: (1) monitor long-term trends in landbird community composition, and species-specific distribution and density, and (2) monitor landbird community composition, and species-specific distribution and density changes relative to management actions.

We have identified 8 key processes, or ecosystem drivers, that influence the community indicators. In some cases, the indicators act as agents of change to the drivers (Figure 4.21). The response of landbird indicators is based on either observed or expected drivers. In some cases these relationships are hypotheses which could be evaluated through research studies (which are outside the scope of a monitoring program).

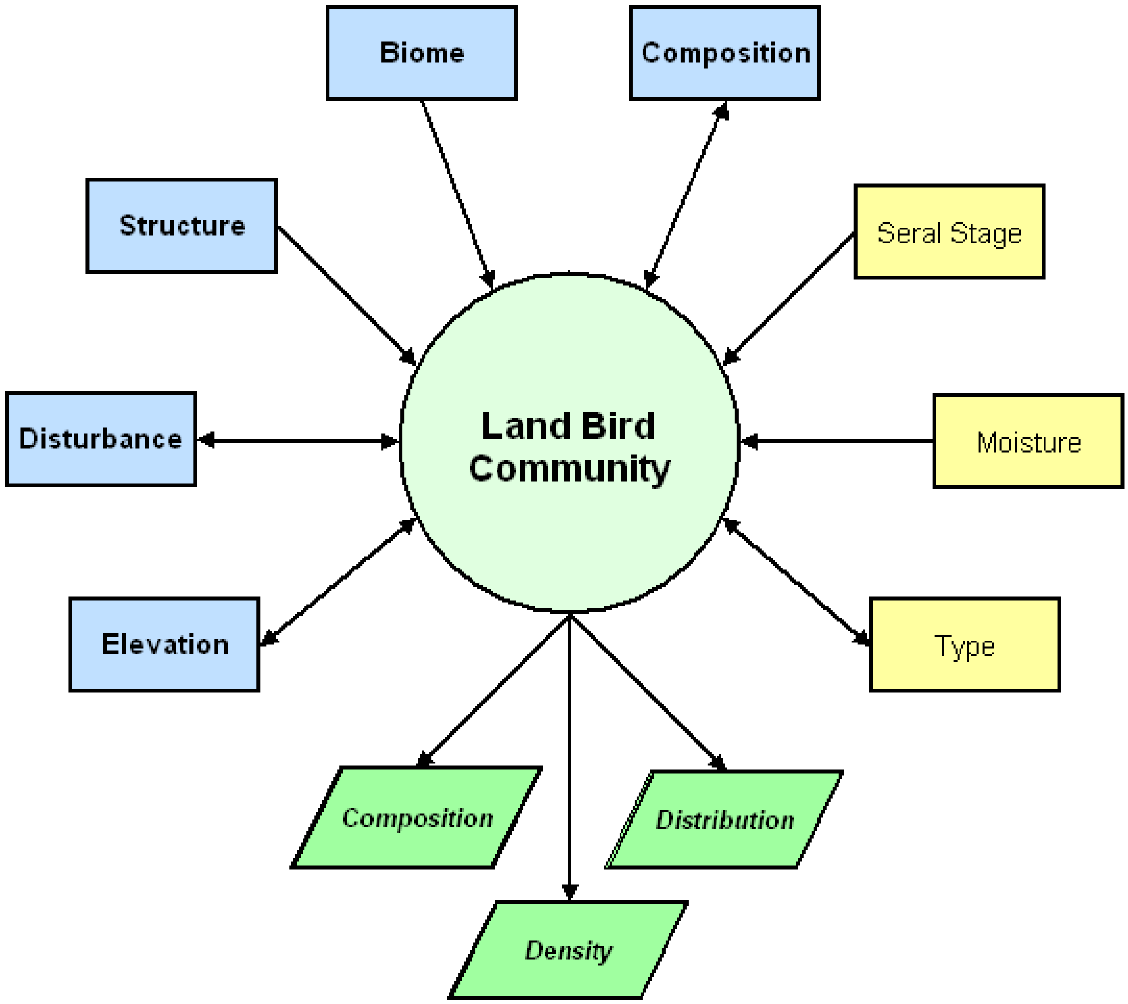

Figure 4.21. Conceptual model of the PACN Landbirds Vital Sign illustrating the linkages among primary drivers (rectangles, indicators (circle) and measures to be monitored (parallelograms) within a park unit. Drivers that influence the landbird community are indicated (strong influence in blue rectangle, less influential in yellow rectangle).

The response of the indicators is based on either observed or expected patterns to the drivers. In many cases the relationship can be thought of as hypotheses and evaluated through research studies (although this research question is outside the scope of a monitoring program).

Biome, Structure, and Type: In general, species abundance and composition increases as habitat changes from barren to forest, as canopy and understory cover changes from very sparse to closed, and as the vegetation changes from alien to native dominated types. In Hawaii, native birds typically are less abundant and there are fewer species compared to aliens. In addition, few native birds usually occur in barren and grassland/shrubland habitats, as well as sparse or low stature structures, or alien dominated vegetation types. Scott et al. (1986) and Steadman and Freifeld (1998) provide information on the relationships between the landbirds community and these ecosystem drivers.

Elevation: In the Hawaiian Islands, the abundance of native birds increases with elevation, where elevation is a proxy for release from avian diseases (pox and malaria). The largest increase occurs between 1,200 and 1,500 m. This elevation is the region where mosquito abundance and the efficacy of avian diseases (e.g., pox) are minimal (van Riper et al. 2002). However, both mosquitoes and avian diseases occur at all elevations, and these factors are stressors on native Hawaiian landbirds (Figure 4.23). This pattern is observed in landbirds in the South and West Pacific islands. However, the elevation/disturbance interaction may be the driving factor (not disease).

Figure 4.22. Forest in the Kahuku unit, HAVO (left), home to the endangered Hawaiian creeper, *Oreomystis mana* (right).

Moisture: A substantial rainfall gradient occurs in Hawaii (250 – 11,300 mm annual rainfall, Juvik and Juvik 1998), and the landbird community responds to this moisture driver. Moisture influences species assemblages and distribution. For example, Hawaii Amakihi are strongly negatively associated with rainfall (correlation = -0.48) (Camp et al. 2003) and are absent from the wettest portions of the Hamakua region on Hawaii Island. In addition, the abundance of native landbirds is greater in xeric than in mesic habitats, accounting for elevation (van Riper et al. 1986). This relationship between moisture and the landbird community is not expected to be as prevalent on the South and West Pacific islands, and may not occur at all on low elevation islands.

Disturbance: Disturbance to the environment from a verity of stressors can affect landbird communities. These sources can be either natural or human induced (e.g., habitat disturbance, development and conversion), and may negatively or positively affect the indicators. Alien species are probably the most influential stressor to the native landbird community (Pratt et al. in prep.). Fragmentation can also be a major stressor. However, its effect on the landbirds community in PACN park units is nominal because these environments were historically fragmented through fire, lava flows and other disturbances.

Seral Stage: In temperate ecosystems, the general pattern is that bird composition increases with the progression of seral stages. However, it is important to note that the relationship between and seral stage does not follow the normal pattern in many Pacific Island ecosystems. For example, the complete extant assemblage of Hawaiian honeycreepers is present in both middle and late seral stages. Also noteworthy is that the honeycreeper composition in the disturbance stage may be some component of the extant generalists, foragers among leaves, and bark-pickers. Disturbance is undefined for this illustrative purpose, but examples include dieback, hurricanes, fires, and other natural or human induced factors.

Composition: The range of biomes that landbirds occupy is influenced by the biome composition (dominant vegetation / tree species) (Wiens 1989). Scott et al. (1986) conducted species-habitat association analyses of Hawaiian landbirds and found several species that were composition specialists. For example, palila occur only within mamane and mamane-naio dominated woodland and forest biomes. Three additional endangered and threatened species that are restricted to specific biome compositions are the akiapolaau (ohia, koa-ohia and mamane), Hawaii creeper (ohia, koa-ohia and koa-mamane), and Hawaii akepa (ohia and koa-ohia). Similarly, the many-colored fruit-dove (*Ptilinopus perousii*) is a fig specialist and occurs mostly in mature forest biomes (Steadman and Freifeld 1998, Watling 2001).

Bats Vital Sign

Frugivorous Bats

The Bats Vital Sign was selected as one of the indicators for long-term monitoring within the PACN. A protocol will be developed for monitoring populations of frugivorous bats, also known as flying foxes or fruit bats, in American Samoa and Guam. We will measure distribution and relative abundance of fruit bat populations, as well as determine habitat requirements and preferences for roosting and foraging.

Fruit bat populations are strongly influenced by forest ecosystem dynamics (Figure 4.23), which are in constant flux due to natural and anthropogenic disturbances. These disturbances, in turn, affect when and where forest fragmentation occurs. Gaps in the forest community are created when disturbance events (i.e., treefall or storm) create a gap in the vegetation and new colonizing plant species begin early successional growth. Plant species which can occur in gaps and dominate are often invasive introduced plants which may or may not have nutritive or roost value. Phenological events of fruiting and flowering vegetation, and the quality and availability of roost sites, are responses to the changing ecosystem. This can directly affect distribution, abundance and habitat utilization by fruit bat species, parameters that will be measured in and near PACN park units.

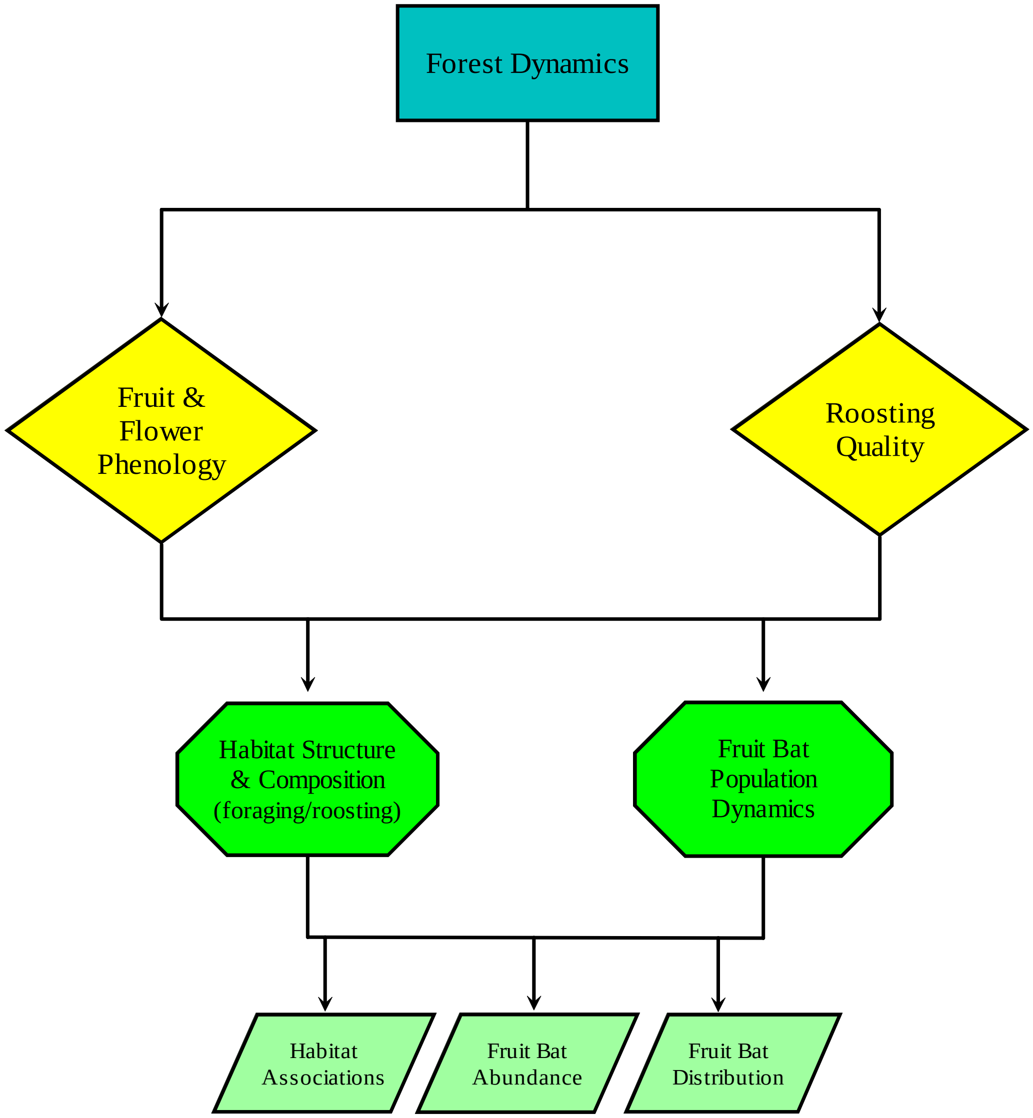

Figure 4.23. Conceptual model of the PACN Frugivorous Bats Vital Sign illustrating forest dynamics as a primary driver (rectangle), ecological effects (diamonds), and indicators (octagons) and their relationships with the measurable population and habitat parameters (parallelograms) that will be monitored in the PACN parks.

Two species of fruit bats are found in American Samoa: the white-naped fruit bat (*Pteropus tonganus*), and the Samoan fruit bat (*P. samoensis*), Figure 4.24. The authorizing legislation for NPSA notes the importance of flying foxes in maintaining the biodiversity of the national park's tropical forests, as they play an important role as pollinators and seed dispersers of tropical forest plants (U.S. Department of the Interior1997). These fruit bats have been found to consume flowers, fruit or leaves from 60 percent of the tree species in the Amalau Valley, located within NPSA's Tutuila unit (Banack 1996).

Figure 4.24. White-naped fruit bat, *Pteropus tonganus*, a colonial species (left), and the solitary Samoan fruit bat, *Pteropus samoensis* (right).

Flying foxes are also an important part of Samoa's culture and are the source of many traditional stories, myths and legends. They have long been a source of food and are still occasionally hunted for consumption in American Samoa (Epi Suafoa, pers comm.). Hurricanes and habitat destruction have also attributed to a decline in bat populations. The Samoan flying fox was listed as a candidate of concern by the U.S. Fish and Wildlife Service, although formal listing for this species is not yet warranted. In 1996, biologists estimated there were about 1000 left on Tutuila, and the white-naped flying fox was found to number about 5,500 (Utzurrum 1997).

Two species of fruit bat, the Marianas fruit bat (*P. mariannus*) and the Little Marianas fruit bat (*P. tokudae*), are native to Guam. Bat populations have dramatically declined since the 1920s due to overhunting by Chamorro residents (Wiles 1987b). Fruit bats continue to be hunted illegally today despite being fully protected by local laws since 1973 and federal law since 1984 (Wiles 1987a). Predation on young *P. mariannus* by brown tree snakes (*Boiga irregularis*) has emerged as a second, equally serious threat to bats since the early 1980s. *P. tokudae* has long been considered rare on Guam. No confirmed sightings of this bat have been made since 1968 and the species is likely extinct (Wiles 1987a, 1987b).

Insectivorous Bats

Long-term monitoring of the Hawaiian hoary bat (Figure 4.25) in national parks of Hawaii will require an assessment of: (1) the distribution of Hawaiian hoary bats in park units, (2) changes in seasonal occurrence and relative activity levels of Hawaiian hoary bats at various elevations, and (3) habitat associations and use by Hawaiian hoary bats in national parks of the Hawaiian Islands.

Physical and biotic factors essential to bat survival include temperature, precipitation, loss or expansion of available habitats, and insect availability (Bogan 2003). In the Hawaiian Islands, these factors are driven by elevation, climate, and land use changes.

Figure 4.25. The insectivorous Hawaiian hoary bat, HAVO.

Elevation: Observations of seasonal and altitudinal movements by hoary bats in Hawaii are both conflicting and poorly documented. Menard (2001) reported that Hawaiian hoary bats were more common at lowland sites between April and August, while Tomich (1986) commonly observed them from April to November in upland areas. Jacobs (1994), however, found no evidence of altitudinal or regional migrations. Nevertheless, altitudinal and seasonal migrations have been demonstrated by hoary bats in other parts of North and South America. For example, Sanborn and Crespo (1957) suggested that hoary bats (*Lasiurus cinereus villosissimus*) in Argentina demonstrated a north/south migration and an altitudinal migration in Chile, and perhaps in Colombia and Venezuela. In the Galapagos Islands, McCracken et al. (1997) observed movements of hoary bats into lowland habitats during the cool season and less activity in these areas during the hot season. Such movements may be linked to factors including age, gender, prey availability, and reproductive success. Cryan et al. (2000) found that reproductive female bats were less common than males at high elevations during warm months in the Black Hills, South Dakota. Distribution of these female bats may be dependent on altitudinal conditions, since lower, warmer elevations may provide higher insect densities and foraging success and allow more efficient thermoregulatory functions and fetal development (Cryan et al. 2000).

Climate: The climatic stability of a region is important to roosting and foraging bats. Disturbances may interrupt or alter plant communities and, therefore, insect occurrence and distributions. Bats rely on insects as sources of food and energy and, as a result, the feeding habits of insectivorous bats play an important role in maintaining a balance among insect populations (Bogan 2003). In addition, foliage roosting bat species, such as the Hawaiian hoary bat, may be more exposed to environmental conditions than bat species that roost in more stable, buffered shelters, such as caves or tree cavities.

Land Use Change: In addition to climate and elevation, land use change also affects local plant, insect, and thus bat populations through urbanization, agriculture, and other land use practices and modifications (Bogan 2003). Land use changes that dramatically alter the natural flora and fauna of an area inevitably lead to changes in forest dynamics and may cause fragmentation and habitat patchiness, as well as promote introduction of exotic species (Figure 4.26).

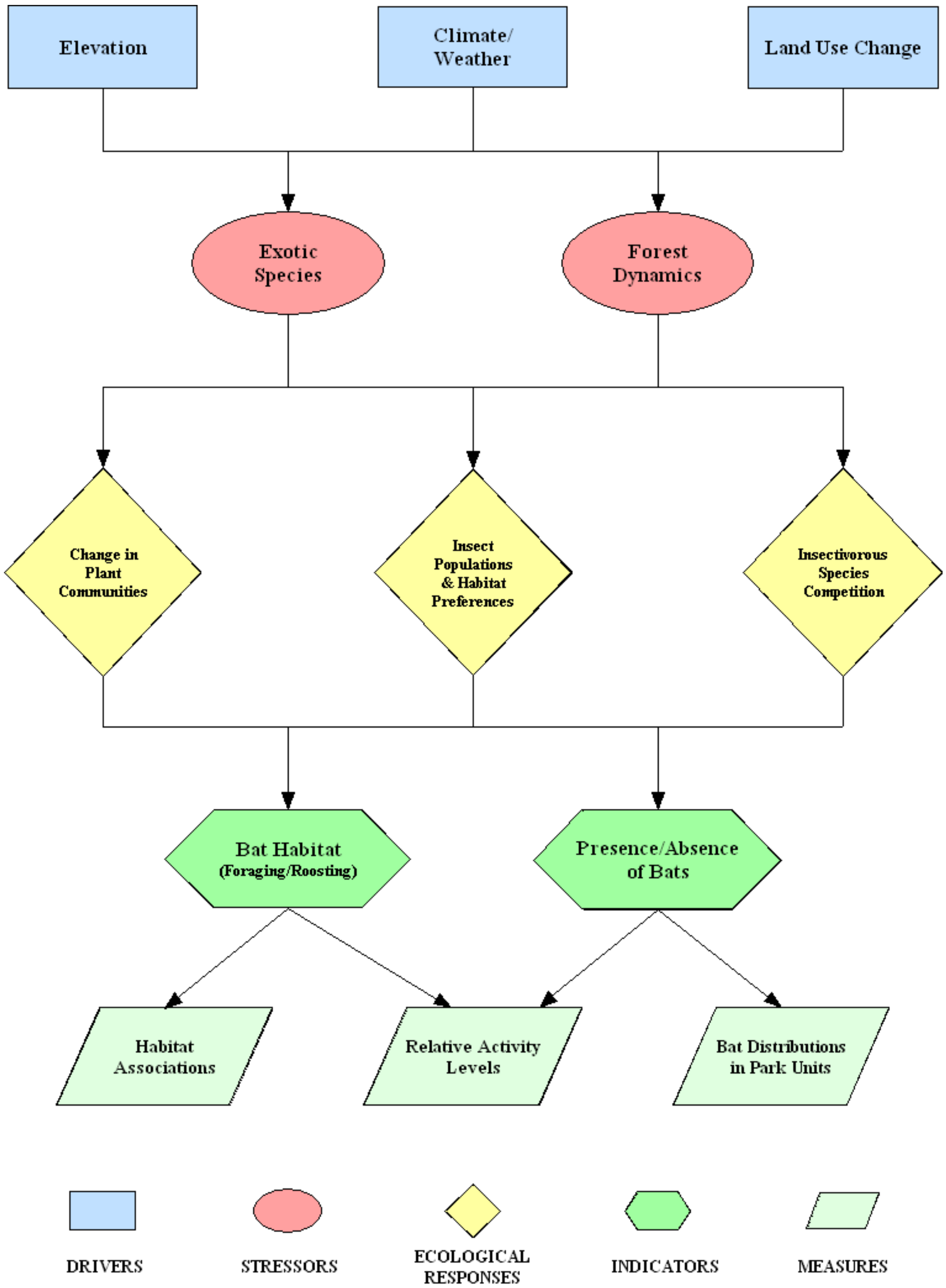

Figure 4.26. Conceptual model of the PACN Insectivorous bats Vital Sign, illustrating the linkages among primary drivers (blue), stressors (pink), ecological responses (yellow), indicators (dark green), and the associated measures (light green) to be monitored within park units.

Terrestrial Invertebrate Vital Sign (Phase Two)

Long-term ecological monitoring of invertebrate communities and species is relatively new, compared to monitoring that has been done for plants and birds. However, invertebrates are now being widely recognized as an important component of monitoring programs. Monitoring is especially critical in areas such as Hawaii where the endemic insect fauna (Figure 4.27) is diverse and unique, and the direct and indirect threats to them are great. In addition to monitoring diversity and abundance of invertebrates, they can be used as indicators for other ecological conditions (Foote and Carson 1995), such as water quality and invasive species impacts. Because invertebrate generation times are faster than those of vertebrates and plants, invertebrate monitoring programs can serve as important early warning systems for detecting habitat degradation on a timescale where intervention and recovery can occur more rapidly.

Figure 4.27. Rare endemic orange-black damselflies (*Megalagrion xanthomelas*) at PUHO. Photo: Jesse Czekanski-Moir, USGS.

Monitoring of invertebrates can be used for three purposes: (a) to track changes in the populations of native, alien, and rare or sensitive species, (b) detect incipient or encroaching invasive species, and (c) pick up early warning signs of environmental change by using indicator species. Like vegetation monitoring, native and alien invertebrate surveys are an important part of long term monitoring for tracking the health of native ecosystems, such as documenting recovery after feral ungulate removal. A monitoring system will provide resource managers with information essential to track invertebrate biodiversity (Howarth and Nishida 1995). Monitoring programs for established alien invertebrates also serve as the basis of integrated pest management programs that can be readily combined with other alien species detection and control efforts.

The invertebrate monitoring program will operate within an adaptive management framework to help establish and evaluate alien species control, ecological restoration, and rare species recovery programs. Integration with research organizations, such as invasive species where rapid response is needed, is also a critical component of monitoring. A conceptual model illustrates potential interactions between drivers and the invertebrate community (Figure 4.28).

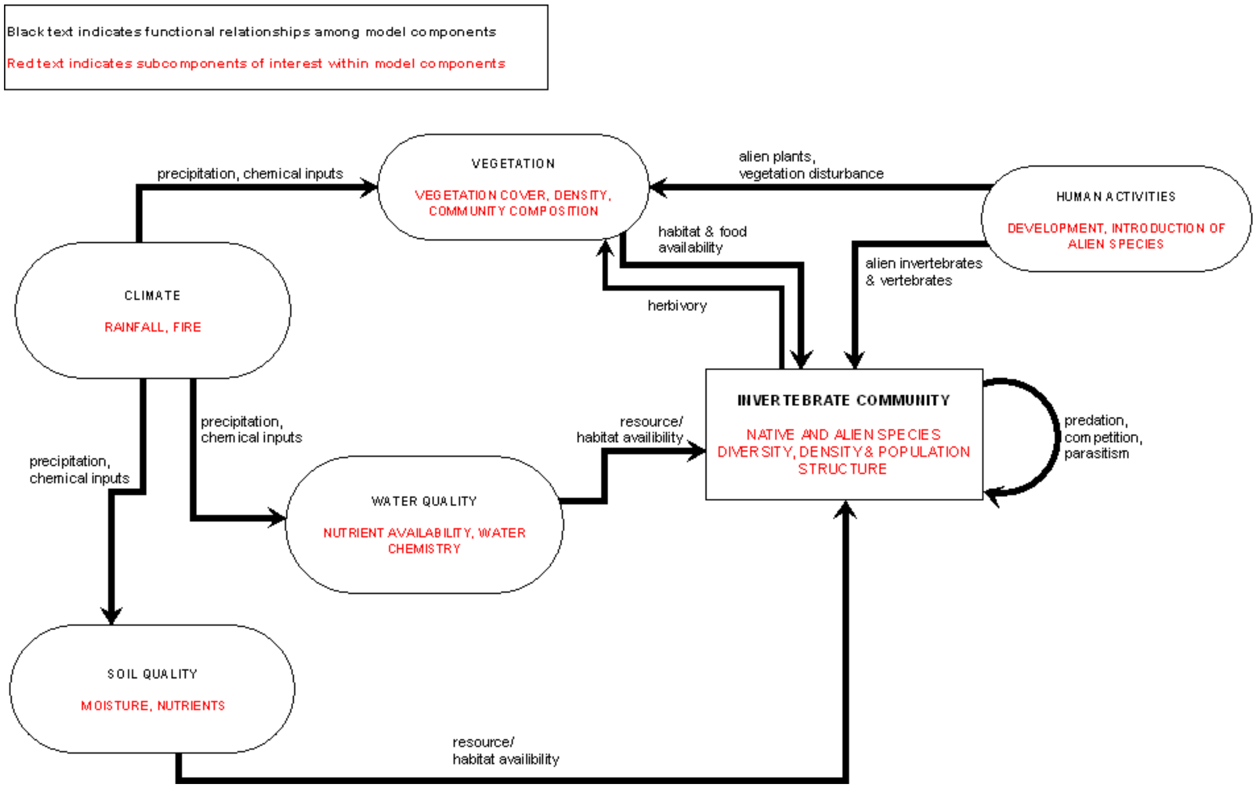

Figure 4.28. Conceptual diagram for Terrestrial Invertebrate Vital Sign. Drivers are indicated by the ovals. Black text indicates functional relationships among model components. Red text indicates subcomponents of interest within model components and potential attributes.

SUBTERRANEAN ECOSYSTEM VITAL SIGNS

Cave Community Vital Sign (Phase Two)

The most common caves in the PACN are lava tubes (Figure 4.29), which characteristically form in fluid basaltic lava called pahoehoe and which are a common land form on younger volcanoes on Hawaii, Maui, and Molokai. Remnant lava tubes occur on older volcanoes such as in American Samoa, Guam, and Oahu. Limestone caves formed by dissolution of elevated reefs and lithified sand dunes are found on the older islands of Oahu and Guam. Piping (or suffosion) caves formed when water erosion plucked softer material out from under a layer of harder material. In Hawaii, they are best developed beneath montane rainforests on Molokai where a lava flow covers an ash layer. Sea (littoral) caves and talus caves occur on all high islands.

Figure 4.29. Representative lava tubes in Hawaii.

Cave habitats are strongly zonal, and five terrestrial zones are recognized: entrance, twilight, transition, deep, and stagnant air (Figure 2.18) (Howarth 1993). The surface and underground environments meet in the entrance zone. The twilight zone extends from the boundary of plant life to the limit of light. The transition zone is in total darkness but is subjected to nocturnal desiccating winds caused by cold air sinking into the cave. The deep zone is characterized by total darkness and long-term presence of moisture and saturated atmosphere. The stagnant air zone lies beyond the deep zone and only slowly exchanges air with the surface, and therefore decomposition gases, especially carbon dioxide, can accumulate. The stagnant air zone occurs not only in deep caves that trap air masses, but also it is considered to be the characteristic environment of intermediate-sized voids (mesocaverns) in cavernous rock.

Plant roots were not considered an important food resource in cave ecosystems until the discovery of a planthopper and other cave adapted animals on tree roots in a lava tube in Hawaii Volcanoes National Park in 1971 (Howarth 1973). Furthermore, very few troglobites (obligate cave dwellers) had been reported from lava tubes or from tropical caves. In the subsequent three decades, cave adapted species have been discovered in many areas of the tropics in lava tubes as well as in other suitable subterranean habitats. Advances in knowledge of tropical cave communities and of the Adaptive Shift hypothesis for cave species evolution have been previously described (Hoch and Howarth 1993, 1999). The potential for discovery of new cave species in the tropics is great, since only a tiny part of the potential underground habitat has been studied to date.

Tree root communities gain their energy from photosynthesis on the ground surface, and therefore have the same trophic structure as surface communities with primary producers, herbivores, carnivores, detritivores, decomposers, and fungivores (Figure 4.30). Sugar produced in the tree leaves is transported downward through the trunk and into the roots, where it becomes the energy source for root growth and for the species that feed on the roots.

In areas with low, dead-end passages, virtually no air motion, and an energy source for respiration, carbon dioxide can increase and oxygen decrease. Carbon dioxide readily mixes with the air, so there is no build-up where there is air exchange with other zones. However, where air is stagnant, carbon dioxide, being heavier than air, settles into low areas. If these areas also have high humidity and energy sources, they are home to the most highly cave adapted species. Bayliss Cave is a lava tube in Australia with a large bad air zone, high humidity, and abundant tree roots penetrating the cave ceiling and growing through the soil on the floor. It is home to 24 highly cave-adapted species, among the highest diversity of any cave community.

Not explicitly included in these models are abundant cultural and archaeological resources. These models may be adapted to include these features during protocol preparation. Also not included in these models are impacts or stressors associated with human activities and land use. As a PACN Phase 2 Vital Sign, these additions may be added as appropriate if/when funding is received to prepare a monitoring protocol.

Caves and their fauna are threatened by land use practices such as mining activities, deforestation, urbanization, alterations of ground water flow patterns, waste disposal, and pollution. The extirpation of cave-roosting species that bring in food and the introduction of non-native species also pose significant threats to the specialized fauna (Howarth 1983). Determination of the conservation status of invertebrate cave species and the development of management recommendations is hampered by the lack of good ecological data concerning the requirements of the species. Many cave species are exceedingly vulnerable to direct human disturbance, include the brief visit of an investigator (Howarth 1983)

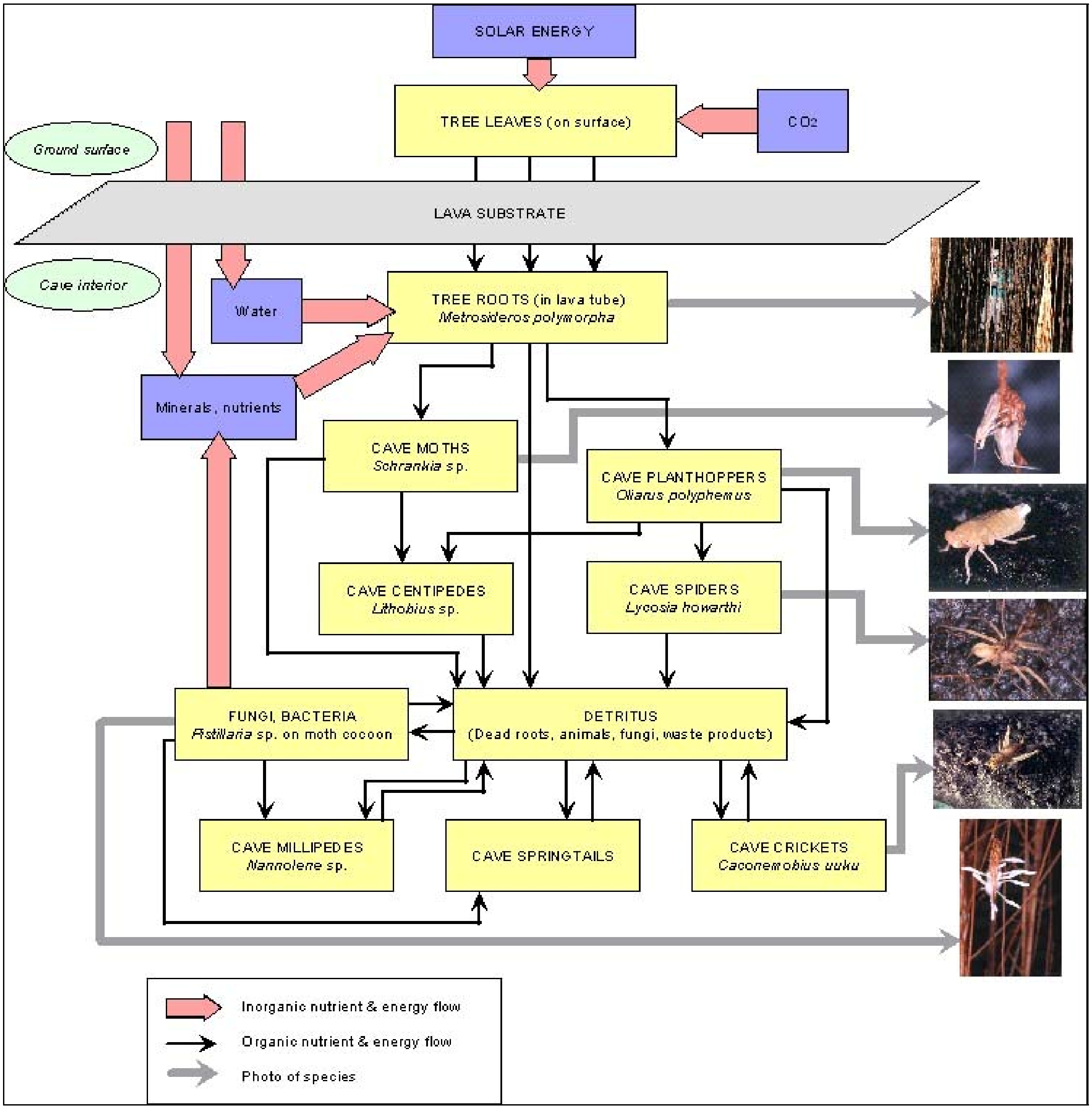

Figure 4.30. Conceptual model and food web for Cave Community Vital Sign with drivers in blue and potential attributes in yellow boxes.

<u>STREAM VITAL SIGNS</u>

Freshwater Animal Communities Vital Sign

Freshwater animal communities represent a biological link between changes in water quality and the biotic component of an ecosystem. Their high susceptibility to shifts in community structure resulting from habitat alteration and changes in water quality makes them useful as ecological indicators (Karr et al. 1986). Furthermore, the scientific merit of utilizing changes in freshwater animal community structure as indicators of ecological health has been clearly demonstrated through the development and implementation of the Index of Biotic Integrity (IBI) (Karr 1981, Fausch et al. 1984, Lyons 1992). Almost all States currently use a modified version of the IBI for fish, benthic macroinvertebrates, or algae (Simon and Lyons 1995). Because of their well established scientific merit and easily identifiable links between vital signs and ecosystem health, the PACN has chosen freshwater animal communities as a monitoring vital sign.

Freshwater resources on Pacific Islands that may be monitored for faunal community structure variations exist in the form of perennial streams (flowing to the sea all year), intermittent streams (seasonally flowing), interrupted streams (with lower reaches seasonally dry, but always having water in their upper reaches) (Polhemus et al. 1992), and anchialine pools (a land locked body of water with a subterranean connection to the ocean). Perennial and interrupted streams provide habitat to completely aquatic species, such as fish, algae, snails, and shrimp, in addition to being important breeding and feeding habitats for insects (Figure 4.31). Intermittent streams and anchialine pools may be important as breeding habitat for snails, crustaceans, and insects as well as feeding areas for other fauna. Estuarine regions of Pacific Island streams tend to be fairly small compared to continental estuaries. However, they are important biologically as both a breeding ground and nursery for marine fishes and serve as a link between freshwater and marine environments for amphidromous species.

Figure 4.31. Dragonfly (left), and breeding habitat for this and other insects (right).

Freshwater and brackish systems in the PACN are particularly vulnerable to invasions by alien species, especially when natural environmental conditions have been modified by human activity. The extreme isolation of Pacific islands has resulted in a limited diversity of native species and a high degree of endemism. As in many terrestrial plant and animal groups, freshwater native species richness generally declines and the degree of endemism increases with distance from a continent (Haynes 1988, Ford and Kinzie 1991, Font 2003). Species to be monitored in this protocol include native and exotic fish, aquatic and semiaquatic snails, and crustaceans. A relatively small number of native and exotic freshwater fish and macroinvertebrate species are present in any one habitat type in the PACN, though species present will vary in different island groups. Figure 4.32 illustrates the conceptual model of the freshwater communities ecosystem and the connections between model components.

Monitoring objectives of this Vital Sign are to:

- Determine long-term trends in the composition and diversity of fish and invertebrates in selected freshwater and mixohaline communities.
- Determine trends in the distribution and abundance of fish and invertebrate populations in selected stream and lentic habitats.
- Improve understanding of relationships between freshwater and brackish water animal communities and their habitat by correlating physical and chemical habitat measures with changes in distribution and abundance of fish and invertebrates.

This information is critical in determining the effects of habitat change on aquatic animal communities. Monitoring will also be coordinated with Water Quality Vital Sign monitoring to link water quality monitoring data to physical habitat data. Understanding the relationship between habitat and animal communities is crucial to providing information about the effects of management activities on physical habitat.

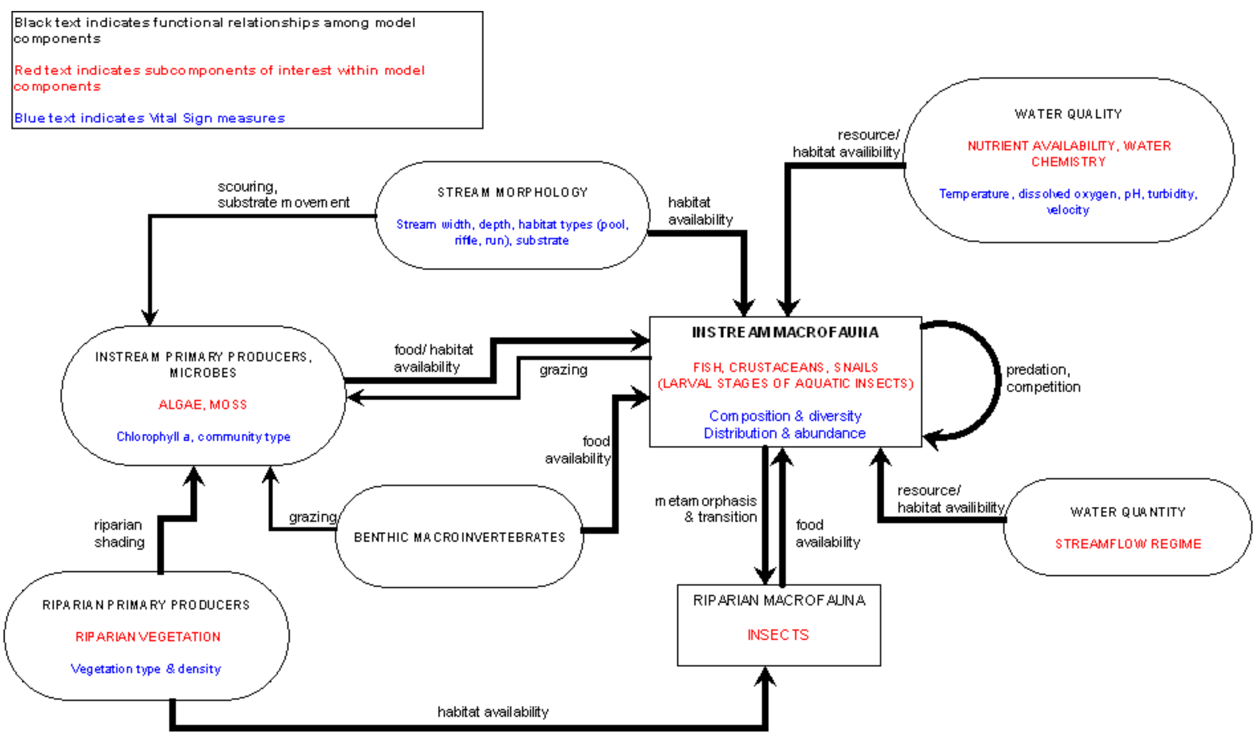

Figure 4.32. Conceptual model for Freshwater Animal Communities Drivers are indicated by the ovals. Black text indicates functional relationships among model components. Red text indicates subcomponents of interest within model components. Blue text indicates potential Vital Sign measurable attributes.

COASTAL ECOSYSTEM VITAL SIGNS

Seabirds Vital Sign

Seabirds in the Hawaiian Archipelago are a significant wildlife resource and therefore, the "Seabirds" Vital Sign was selected as one of the indicators to be developed for long-term monitoring within the PACN. Seabird monitoring will focus on land-based populations, to include colonies, roosts, and relative counts of birds near or over land. Specifically, vital sign monitoring will measure composition of communities (species diversity), distribution of birds and colonies in a variety of nesting habitats (Figure 4.33), and abundance-relative abundance for some species and colony density for others.

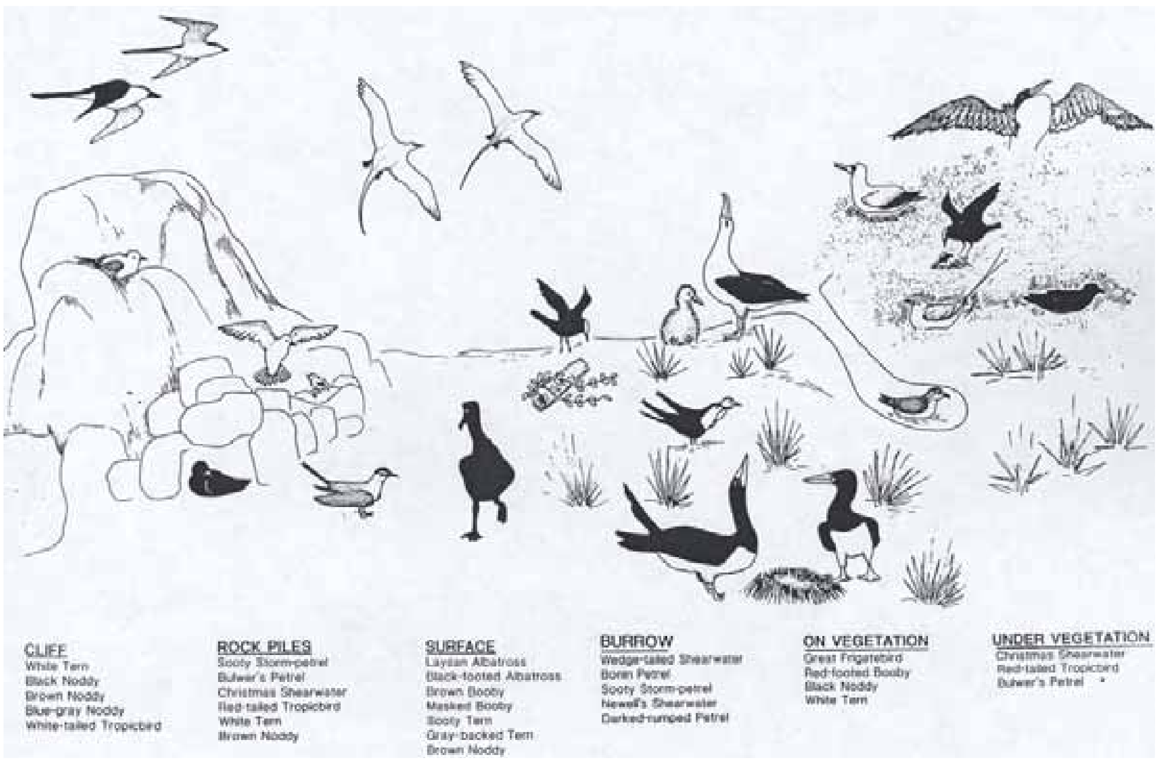

Figure 4.33. Seabird nesting habitats (from Harrison 1990).

In pre-contact Hawaii, seabirds were formerly a prominent component of the avifauna. Both paleontological and archeological evidence (Olson and James 1982, Allen et al. 1995, Moniz 1999) suggests seabirds were abundant prior to human arrival and served as a food source for Hawaiians after colonization. As a rule, the arrival of humans and their commensal pests on oceanic islands antedates and predicts the decline of oceanic birds (Steadman 1995). This pattern undoubtedly also occurred on Guam, Saipan, and the islands of American Samoa. Specious and abundant seabird colonies served to circulate nutrients, particularly nitrogen and phosphorus, from the ocean to these relatively low productivity islands (Loope 1998), illustrated in Figure 4.34. They also were top predators in oceanic food webs. Today, colonies are much reduced in size, distribution, and diversity, concomitantly changing the role this group plays in island ecology. Nonetheless, they remain important to native vertebrate biodiversity and have promising potential for restoration.

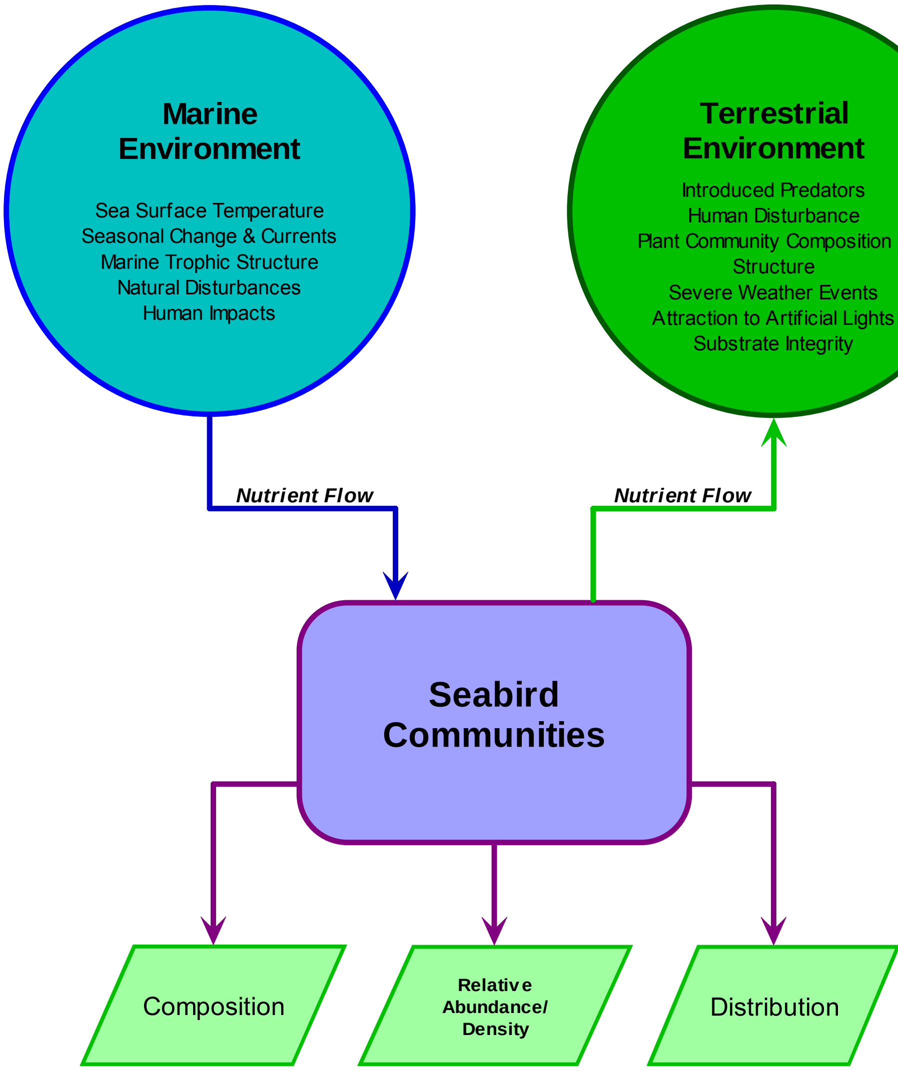

Figure 4.34. Conceptual model illustrating ocean and land-based ecosystems and their associated natural and anthropogenic stressors, the nutrient flow between seabirds and these ecosystems, and the population measures that will be monitored in PACN parks.

Many of the species in Hawaii are abundant, with wide distribution throughout the archipelago. Others are restricted in number and distribution. Three seabird species are endemic to Hawaii: the endangered dark-rumped petrel (*Pterodrama phaeopygia sandwichensis*), the threatened Newell's shearwater (*Puffinus* newelii) (Figure left, 4.35), and the Hawaiian noddy (*Anous minutus melanogenys*). The first two relatively rare species nest in upland forest or sub-alpine and alpine sites (right, Figure 4.35), and as with all of the ground-dwelling or nesting birds, they are extremely susceptible to predation during their long nesting period. A successful predator-control program in nesting areas in Haleakala National Park on Maui has resulted in a significant increase in petrel productivity. Recently discovered nesting areas for these petrel and shearwater species on the island of Hawaii offer similar opportunities to use predator control to reestablish significant breeding colonies for these species in upland habitats.

 

Figure 4.35. Newell's shearwater, *Puffinus newelii* (left) and Searching for eggs and chicks of a subalpine petrel nest, HAVO (right).

Because of their ecological importance, the offshore islands dotting the main islands are part of the Hawaiian State Seabird Sanctuary. Shearwaters, noddies and petrels are among the birds that use the island for roosting and nesting. Many seabirds build their nests under dense vegetation or in shallow, sandy burrows which cannot be seen, and are easily crushed or disturbed (Figure 4.33).

Many areas within the National Park of American Samoa provide important habitat for native seabirds. The steep and rugged Pola Island and Polauta Ridge are the most important nesting and roosting areas for several species of seabirds in all of American Samoa. These include the red-footed (*Sula sula*) and brown (*S. leucogaster*) boobies (Figure 4.36), Greater (*Fregata minor*) and lesser (*F. ariel*) frigate birds, brown (*Anous stolidus*), black (*A. minutus*) and blue-gray (*Drocelsterna cerulean*) noddies, the gray-backed tern (*Sterna lunata*) and possibly others. The cloud forest and montane scrub portions of the national park on Tau are used by several ground-nesting seabirds, including the Audubon's shearwater (*Puffinus lherminieri*).

 

Figure 4.36. Red footed booby (*Sula sula)* (left) and brown booby (*S. leucoga*ster) (right) nesting in American Samoa.

Significant populations of boobies, noddies, terns, and white-tailed (*Phaethon lepturus*) and red-tailed (*P. rubricausa*) tropic birds are primarily restricted to the uninhabited islands north of Saipan in the Mariana Islands. Small populations of boobies and brown noddies occur on some of the small offshore islets around Guam and Saipan. The Seabird Sanctuary on the eastern coast of Rota, an island northeast of Guam, supports the largest breeding populations of red-footed and brown boobies in the southern Mariana Islands.

NEARSHORE MARINE ECOSYSTEM VITAL SIGNS

Ideal conditions for marine ecosystems across the PACN vary from park to park. Benthic cover or biodiversity alone are only partial indicators of reef health because many healthy reef ecosystems have low coral cover (e.g., many Hawaii reefs) relative to reefs in other areas such as the Indo-Pacific (e.g., Guam). Healthy reefs (Figure 4.37) are better characterized by the presence of no invasive species, a full complement of ecological guilds (e.g., no lack of herbivores due to overfishing), stable population dynamics (e.g., adequate recruitment) among native species, and low stress on individuals resulting from good environmental conditions (Waddell 2005). Determining the health of the marine environment will benefit from co-located monitoring of water quality, the marine benthic community, and the marine fish community vital signs.

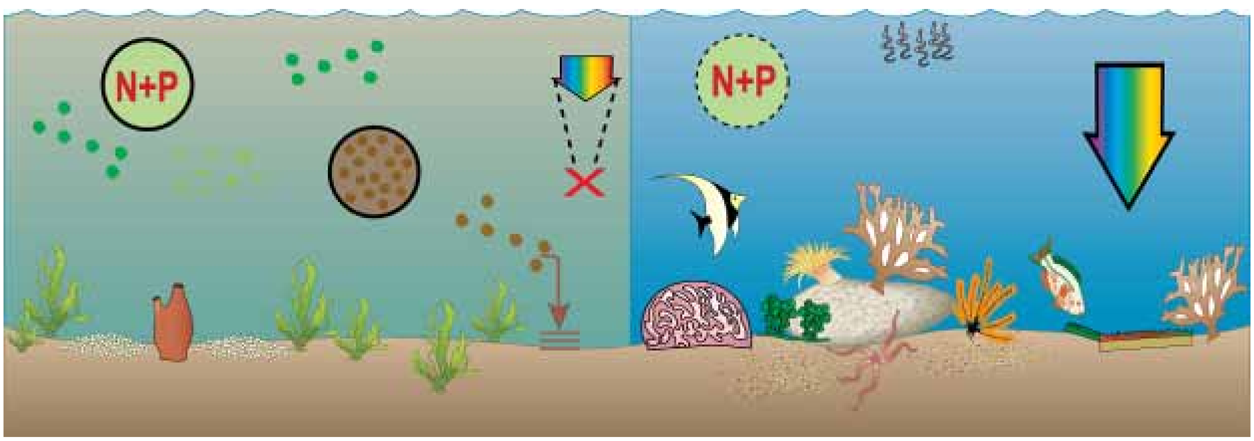

Figure 4.37. Simplified conceptual depiction of desired or "healthy" conditions (right frame) with oligotrophic conditions, no suspended sediment, high light penetration, and great biological diversity contrasted to the left frame where water quality is poor, with increased levels of nitrogen (N) and phosphorus (P) with sediment loading and burial of live coral; conditions that may promote algal growth and potentially decrease species diversity

Marine Benthic Community Vital Sign

The indicators selected for the Marine Benthic Community Vital Sign provide information on the state (healthy or degraded) of the system and include benthic substrate percent cover, reef rugosity, coral recruitment, growth, and presence and prevalence of disease and bleaching.

Long-term change in the abundance of invertebrate and algal taxa or assemblages (Figure 4.38) can often be correlated with variation in certain environmental stressors or drivers. Increased nutrient levels in the marine environment result in conditions that facilitate an increase in growth and reproduction by phytoplankton and some macroalgae species; increasing the ability of macroalgae to compete with corals for space on the benthos (Smith et al. 1981, Done 1992, McCook et al. 2001, Smith et al. 2004). Eventually macroalgae exclude and reduce coral abundance and diversity. A change in species dominance may cause a cascade of ecological change throughout the benthic community, resulting in an ecological phase shift (Figure 4.37) (Smith et al. 1981, Hughes et al. 1987, Jokiel et al. 1993, Lapointe 1997, McClanahan et al. 1999, Smith 2003).

Figure 4.38. Example of benthic marine community in NPSA.

Both top-down and bottom-up influences are hypothesized to influence the outcome or benthic space occupation at given reef location (Hughes et al. 1987, Hughes et al. 1999, Lapointe 1999, Smith 2003, Rogers and Miller 2006). Low nutrient levels (bottom-up forcing) are predicted to promote a state of coral or algal turf dominance. Concomitantly, grazing activity (top-down forcing) influences the state of benthic cover by limiting turf and frondose macroalgal growth. Human activity may reduce grazer levels and increase nutrient availability, thus shifting reefs from coral to macroalgal dominance.

Disturbances, naturally occurring events within ecosystems, can vary by nature, degree, and scale. A loss of coral cover often follows a disturbance event, but given time, the ecosystem may regenerate to some former state (Figure 4.39). However, increasingly, the ability of many coral reef ecosystems to regenerate and recover has been hindered by other factors that are anthropogenic in origin, such as eutrophication and sedimentation (Bruckner et al. 2005). Moreover, the increasing frequency of various disturbance events in time and space can lower community resiliency and prevent recovery to a former state, facilitating phase shifts (Figure 4.39). Consequently, supplementary data on natural (e.g., storm events – Climate Vital Sign) and anthropogenic (e.g., land use changes – Land Use Vital Sign) factors will be utilized to help explain phase shifts or other ecosystem changes that might occur.

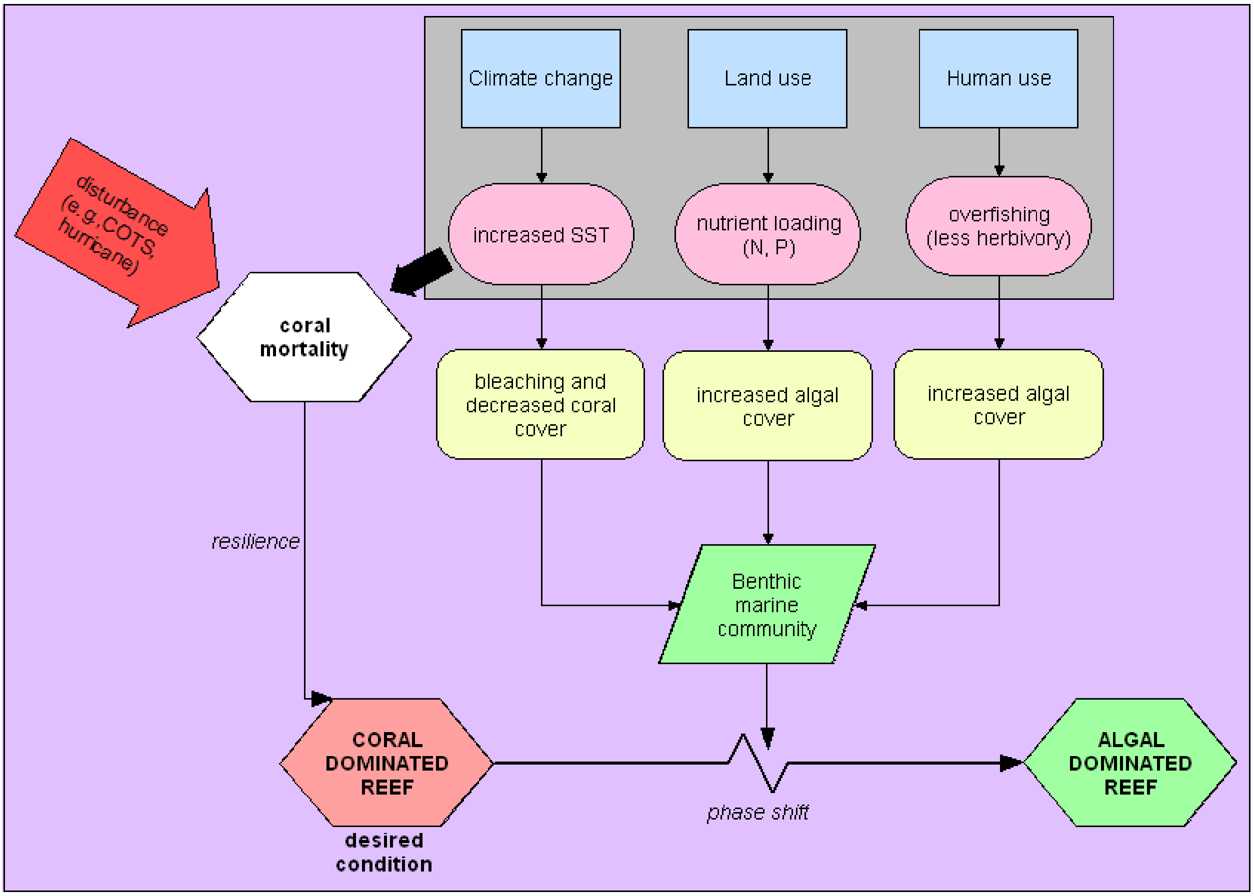

Figure 4.39. Alternate states conceptual model, where disturbance (red arrow) acts to decrease coral cover which over time, returns to a former state (desired condition); however, multiple stressors (drivers=blue, stressors=pink in gray area) may act to decrease resilience of the ecosystem, with ecological effects (in yellow) on the benthic marine community (Vital Sign indicator) promoting phase shift between, a coral or algal dominated community, (hexagons = Vital Sign measures of percent coral cover).

Marine Fish and Fisheries Harvest Vital Sign

Fish, a major component of the coral reef ecosystem, are a highly diverse assemblage of carnivores, planktivores, herbivores and detritovores that serve a variety of ecological functions affecting ecosystem structure, processes, productivity, and sustainability (Sale 1991, Hixon 1997). Fish assemblages or selected species (Figure 4.40) can also act as indicators of general reef health and provide a warning of environmental stress and potential ecosystem change (Friedlander and DeMartini 2002). The indicators for the Marine Fish Vital Sign will be abundance and biomass of key reef slope species (of ecological, cultural or harvest significance) and the indicators for the Fisheries Harvest Vital Sign are the quantity, composition, and size of fish and invertebrates extracted from park waters.

Figure 4.40. Example of fish assemblage in an Ofu coral reef community in American Samoa (left). Species include convict tangs (manini), *Acanthurus triostegus*, and saddled butterflyfish, (tifitifi-tuauli), *Chaetodon ephippium*. Traditional fish harvesting, American Samoa (right).

Long-term changes in the abundance and biomass of fish assemblages can often be correlated with specific stressors or drivers, such as declines in size and abundance of harvested species due to overfishing (Figure 4.41). Reef fish diversity and biomass also correlate with the structural complexity of reef habitats (i.e., function of rugosity and percent cover, both measures in the Marine Benthic Vital Sign). A declining trend in habitat complexity is known to be associated with declines in the fish community. Moreover, many reef fishes are either large apex predators or major herbivores whose trends in abundance can have ecologically and statistically significant impacts on coral reef ecosystems and the dynamics of major system components. For example, declines in herbivorous fishes could result in increased growth and benthic cover of native or invasive algae which can out-compete and overgrow corals, leading to associated declines in coral health, reef structure and ecosystem resiliency (Figures 4.39 and 4.41). To assess the Marine Fish Vital Sign, the monitoring objective is to annually determine the density and biomass of the defined component of the reef fish habitat along an isobath of 10-20 m.

Additionally, fish within the parks are harvested in traditional, subsistence, artisanal, and recreational fisheries (Craig et al. 2005) which may affect the species composition, abundance and size of targeted species, as depicted in the Fisheries Harvest Vital Sign conceptual model in Figure 4.41. Fishing is increasingly recognized as the principal threat to Pacific coral reefs and other marine ecosystems worldwide (Dayton 1998, Friedlander and DeMartini 2002, Birkeland 2004, Hutchings and Reynolds 2004). To fully assess the status of marine fish populations in park waters, it is important to monitor both their direct mortality due to harvest as well as their in-water abundance (i.e., the fisheries-independent monitoring described above). To assess Fisheries Harvest Vital Sign, the monitoring objectives will be to assess fishing effort by gear type, catch per unit effort, and composition and size of species harvested.

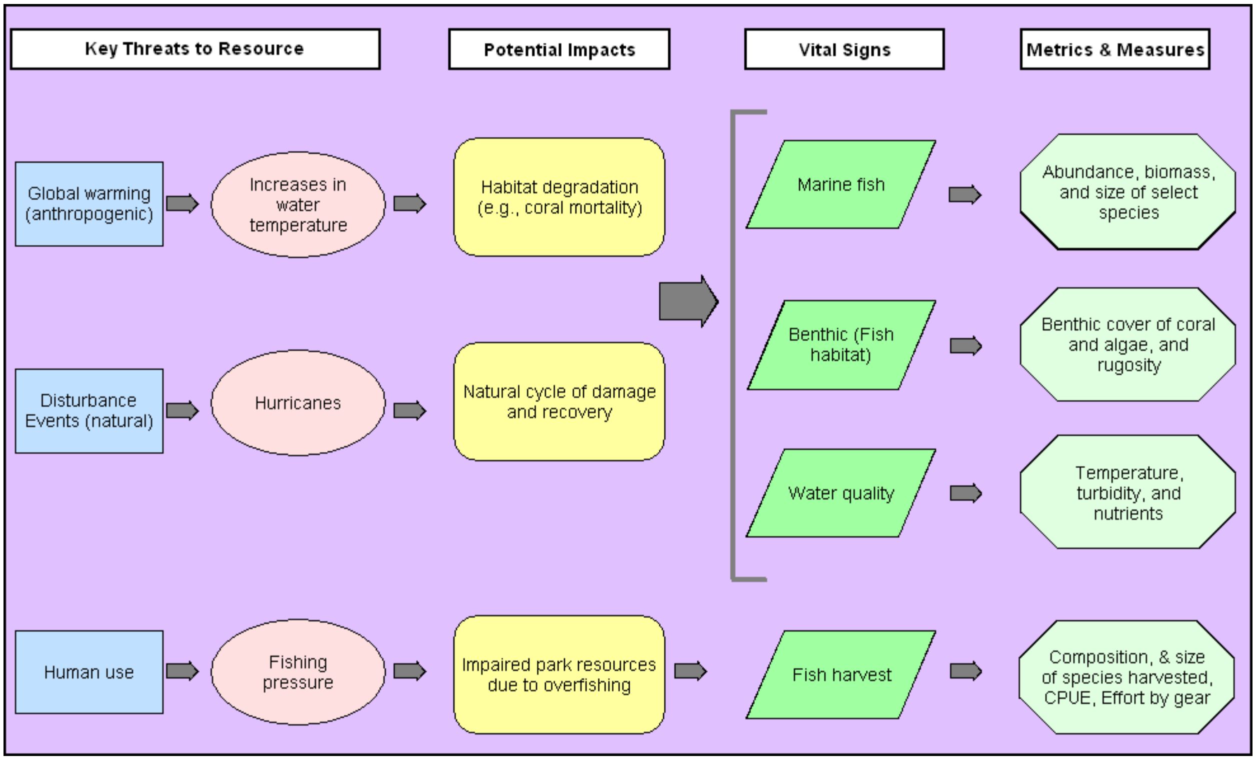

Figure 4.41. Conceptual diagram showing the integration of the Marine Fish and Fisheries Harvest Vital Signs with the Marine Benthic Community and Water Quality Vital Signs. Drivers=blue, Stressors=pink, ecological effects=yellow, Vital Signs=dark green, and measurable attributes=light green.

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