Prepared in Cooperation with Olympic National Park

A Framework for Long-term Ecological Monitoring in Olympic National Park: Prototype for the Coniferous Forest Biome

USGS/BRD/ITR—2003-0006
Information and Technology Report

U.S. Department of the Interior
U.S. Geological Survey

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A Framework for Long-term Ecological Monitoring in Olympic National Park: Prototype for the Coniferous Forest Biome

By Kurt Jenkins, Andrea Woodward, and Ed Schreiner
U.S. Geological Survey

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U.S. Department of the Interior
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Suggested citation:
Jenkins, Kurt, Woodward, Andrea, and Schreiner, Ed, 2003, A Framework for Long-term Ecological Monitoring in Olympic National Park: Prototype for the Coniferous Forest Biome: U.S. Geological Survey, Biological Resources Discipline, Information and Technology Report, USGS/BRD/ITR-2003-0006, 150 p.

Key words:
1. U.S. Geological Survey. 2. Status and trends program. 3. National Park Service. 4. Inventory and monitoring program. 5. Long-term ecological monitoring. 6. Vital signs monitoring. 7. Conceptual ecosystem models. 8. Olympic National Park. 9. Coniferous forests. 10. Ecological indicators. 11. Environmental sampling. 12. Conceptual monitoring plan.

Executive Summary

This report is the result of a five-year collaboration between scientists of the U.S. Geological Survey Forest and Rangeland Ecosystem Science Center, Olympic Field Station, and the natural resources staff of Olympic National Park to develop a comprehensive strategy for monitoring natural resources of Olympic National Park. Olympic National Park is the National Park Service's prototype monitoring park, representing parks in the coniferous forest biome. Under the umbrella of the National Park Service's prototype parks program, U.S. Geological Survey and Olympic National Park staffs are obligated to:

- develop strategies and designs for monitoring the long-term health and integrity of national park ecosystems with a significant coniferous forest component.
- design exportable monitoring protocols that can be used by other parks within the coniferous forest biome (i.e., parks having similar environments), and
- create a demonstration area and 'center of excellence' for assisting other parks in developing ecological monitoring programs.

Olympic National Park is part of the North Coast and Cascades Network, a network of seven Pacific Northwestern park units created recently by the National Park Service's Inventory and Monitoring Program to extend the monitoring of 'vital signs' of park health to all National Park Service units. It is our intent and hope that the monitoring strategies and conceptual models described here will meet the overall purpose of the prototype parks monitoring program in proving useful not only to Olympic National Park, but also to parks within the North Coast and Cascades Network and elsewhere.

Part I contains the conceptual design and sampling framework for the prototype long-term monitoring program in Olympic National Park. In this section, we explore key elements of monitoring design that help to ensure the spatial, ecological, and temporal integration of monitoring program elements and discuss approaches used to design an ecosystem-based monitoring program. Basic monitoring components include ecosystem drivers, (e.g., climate, atmospheric inputs, human pressures), indicators of ecosystem integrity (e.g., biogeochemical indicators), known threats (e.g., impacts of introduced mountain goats), and focal or 'key' species (e.g., rare or listed species, Roosevelt elk). Monitoring system drivers and key indicators of ecosystem integrity provide the long-term baseline needed to judge what constitutes 'unnatural' variation in park resources and provide the earliest possible warning of unacceptable change. Monitoring effects of known threats and the status of focal species will provide information useful to park managers for dealing with current park issues.

In Part I we describe the process of identifying potential indicators of ecological condition and present conceptual models of park ecosystems. In addition we report results from several workshops held in conjunction with Olympic National Park aimed at identifying potential indicators of change in the park's ecosystem. First, we describe the responses of Olympic National Park staff to the generic question, "What is the most important resource to monitor in Olympic National Park and why?" followed by the responses from resource and land managers from areas adjoining the park. We also catalogue the responses of various expert groups that we asked to help identify the most appropriate system drivers and indicators of change in the Olympic National Park ecosystems. Results of the workshops provided the justification for selecting basic indicators of ecosystem integrity, effects of current threats to park resources, and focal resources of parks to detect both the currently evident and unforeseeable changes in park resources.

We conclude Part I by exploring several generic statistical issues relevant to monitoring natural resources in Olympic National Park. Specifically we discuss trade-offs associated with sampling extensively versus sampling intensively in smaller geographic regions and describe a conceptual framework to guide development of a generic sampling frame for monitoring. We recommend partitioning Olympic National Park into three zones of decreasing accessibility to maximize monitoring efficiency. We present examples of how the generic sampling frame could be used to help ensure spatial integration of individual monitoring projects.

Part II of the report is a record of the potential monitoring questions and indicators identified to date in our workshops. The presentation is organized according to the major system drivers, components, and processes identified in the intermediate-level working model of the Olympic National Park ecosystem. For each component of the park system, we develop the need and justification for monitoring, articulate park management issues, and describe key resources and ecosystem functions. We also present a pictorial conceptual model of each ecological subsystem, identify monitoring questions, and list potential indicators for each monitoring question. We conclude each section by identifying linkages of indicators to other ecological subsystems in our general ecosystem model, spatial and temporal contexts for monitoring (where and how often to monitor), and research and development needs. Part II represents the most current detailed listing of potential indicators—the material for subsequent discussions of monitoring priorities and selection of indicators for protocol development.

Collectively, the sections of this report contain a comprehensive list of the important monitoring questions and potential indicators as well as recommendations for designing an integrated monitoring program. In Part I, Chapter 6 we provide recommendations on how to proceed with the important next steps in the design process: establishing priorities among the many possible monitoring questions and indicators, and beginning to research and design effective long-term monitoring protocols.

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PART II: INDICATORS OF ECOLOGICAL CONDITION IN OLYMPIC NATIONAL PARK

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Acknowledgments

We extend our sincere thanks and appreciation to the entire staff at Olympic National Park for their commitment and work towards developing an effective long-term monitoring program. We especially thank Cat Hawkins Hoffman, Chief of Natural Resources, for dedicating so much of her time and self in furthering this program and assisting us in our work, Roger Hoffman and Katherine Beirne for preparing the map-based graphics in this report; Doug Houston and D. Erran Seaman at the U.S. Geological Survey (USGS)-Olympic Field Station; Patti Happe, Cat Hawkins Hoffman, Roger Hoffman, and John Meyer at Olympic National Park for participating in our planning discussions from the beginning and contributing freely with their ideas. We also thank Sam Brenkman, Steve Fradkin, and John Meyer for their written contributions summarizing monitoring indicators for aquatic and marine resources (see Part II).

Most of the ideas contained in this report were generated from a series of workshops (see Appendix A for a list of all participants) hosted by USGS-Olympic Field Station and Olympic National Park. We are particularly grateful to Gary Davis, Cat Hawkins Hoffman, Barry Noon, D. E. Seaman, Ed Starkey, and Kathy Tonnessen for their help in organizing and facilitating workshops. We thank Steve Acker, Mike Adams, Steve Fancy, Bruce Freet, Paul Geissler, Darryll Johnson, Kathy Jope, Gary Larson, Lyman McDonald, Karen Oakley, Dave Peterson, Steve Ralph, and Ed Starkey for numerous helpful discussions about long-term monitoring philosophy, objectives, and practice. We are indebted to Paul Geissler for his many contributions to Chapter 6, including allowing us to use his tabular summaries of sampling methods. Literally dozens of others have wittingly or otherwise contributed many ideas—we thank you all.

We would like to thank the many individuals who have reviewed parts of this report at various stages during its preparation including: Steve Acker, Katherine Beirne, Tamara Blett, Dave Conca, Carrie Donnellan, Paul Gleeson, Patti Happe, Shelley Hall, Cat Hawkins Hoffman, Roger Hoffman, Martin Hutten, Darryll Johnson, Rob Norheim, Rich Olson, Dave Peterson, Ruth Scott, Mark Vande Kamp, and Brian Winter. Finally, we extend our thanks to Gary Davis, John Emlen, Steven Fancy, Paul Geissler, Cat Hawkins Hoffman, David Peterson, Reg Reisenbichler, Charles Roman, Lyman Thorsteinson, and David Woodson for providing peer review comments on the final draft. Their thoughtful and constructive comments very much improved this document.

This work was funded by the USGS with thanks to Drs. Norita Chaney and Paul Geissler (USGS) for providing guidance, support and funding. We extend a special thanks to Dr. Michael Collopy, former Center Director of the USGS Forest and Rangeland Ecosystem Science Center, for his unyielding support of our research and monitoring activities and his extraordinary efforts in soliciting funding for this project.

A Framework for Long-term Ecological Monitoring in Olympic National Park: Prototype for the Coniferous Forest Biome

By Kurt Jenkins, Andrea Woodward, and Ed Schreiner[1]

Introduction

Importance of Monitoring:

Maintaining a current understanding of ecological conditions is fundamental to the National Park Service in meeting its overarching mission—to preserve park resources "unimpaired for the enjoyment of future generations" (U.S. Congress 1916). Initially, the implementation of an ecological monitoring program establishes reference conditions for natural resources from which future changes can be detected. Over the long term, these "benchmarks" help define the normal limits of natural variation, may become standards with which to compare future changes, provide a basis for judging what constitutes impairment, and help identify the need for corrective management actions. Issue-specific monitoring programs (as opposed to general ecological monitoring) are also important because they provide the basis for evaluating effectiveness of specific management actions and provide information on how management practices may be adapted to achieve desired objectives.

National Park Service Monitoring 'Strategy':

The National Park Service began developing a comprehensive long-term ecological monitoring program in 1993 by soliciting proposals for 'prototype' parks. The goal of the 'prototype' parks monitoring program is to "…develop a better understanding of national park ecosystem dynamics and ecological integration" (National Park Service 1995). Prototypes were to be phased in over time and the U.S. Geological Survey assumed primary responsibility for developing and testing monitoring protocols for prototype programs.

Prototype monitoring programs are established in several national park units or in clusters of parks throughout the nation, each representing one of the major biogeographic associations (e.g., biomes) within the National Park System. The prototype monitoring programs provide a forum to evaluate monitoring strategies appropriate in national parks and, importantly, serve as demonstration areas and 'centers of excellence' for assisting other parks in monitoring. This includes the development of exportable monitoring protocols for use by any park with similar resources throughout the system.

Before all prototype monitoring programs were established, Congress directed the National Park Service to "undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources" (National Park Service Omnibus Management Act 1998). The National Park Service subsequently developed a

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"Natural Resources Challenge," an action plan and budgetary strategy for improved resource stewardship in the National Park System (National Park Service 1999). The Challenge included a specific call to action to expand monitoring efforts beyond the currently funded prototype monitoring parks to all National Park Service units. The National Park Service's Inventory and Monitoring strategy currently recognizes three major components of Inventory and Monitoring:

1. Completion of basic resource inventories as a basis for subsequent monitoring.
2. Sustaining eleven experimental prototype monitoring programs to evaluate alternative monitoring designs and strategies for selected biomes.
3. Monitoring indicators of ecosystem status or health ('Vital Signs') at all natural resource parks (S. Fancy, Monitoring Natural Resources in our National Parks, http://www.nature.nps.gov/im/monitor/).

'Vital signs' monitoring, the last element, is intended to extend monitoring of key ecosystem health indicators to all units of the National Park Service. The purpose is to "assess the basic health or integrity of park ecosystems, and to be able to formulate management prescriptions wherever necessary to maintain the integrity of those ecosystems" (S. Fancy, Monitoring Natural Resources in our National Parks, www.nature.nps.gov/im/monitor/). The National Park Service organized 270 park units into 32 networks of parks in similar geographic areas of the country to achieve this goal. 'Networks' form the framework for designing, implementing, and analyzing vital signs of the National Parks.

Olympic National Park staff is intensely involved in both the prototype parks and vital-signs monitoring programs. In 1993, Olympic National Park was selected to develop a prototype monitoring program representing parks in the coniferous forest biome. Recently, Olympic National Park was also included in the North Coast and Cascades Network of parks for vital signs monitoring. Other parks in the North Coast and Cascades Network include Ebey's Landing, Fort Clatsop, Fort Vancouver, Mount Rainier, North Cascades, and San Juan Islands. A significant aspect of the National Park Service Inventory and Monitoring Program is the integration of the prototype-park program with the monitoring requirements of other parks in the network. Accordingly, parks with prototype programs are encouraged to develop protocols that are applicable at the network level. The prototype-park program in Olympic National Park is an integral part of the North Coast and Cascades Network vital signs monitoring program. The park plays a key role in the network, by providing technical assistance to the other parks in the Network, and developing protocols needed by other parks

Scope and Content:

A rather critical first-step in designing a monitoring program is figuring out just what attributes should be monitored, and deciding how to integrate the individual monitoring projects into a comprehensive program. This is easily the most difficult task facing national park managers because the list of possibilities is literally endless. Scientists with the USGS Forest and Rangeland Ecosystem Science Center, Olympic Field Station, obtained funding in 1996 from the USGS Inventory and Monitoring program to initiate development of a long-term ecological monitoring program for Olympic National Park. This involved developing the design process itself, creating conceptual models of park ecosystems, identifying potential monitoring indicators, and developing the conceptual framework for monitoring. This necessitated setting up several workshops with park staff and subject-matter experts to explore the conceptual underpinnings of monitoring, as well as the important park issues, key attributes of park ecosystems, monitoring indicators, and general sampling questions. From the outset, field station scientists have worked closely with Olympic National Park resource management staff to create a comprehensive monitoring framework for the park.

This report synthesizes results of these workshops and many discussions into what we hope is a workable conceptual framework for developing long-term monitoring in Olympic National Park. Our scope includes all the major ecosystem components in Olympic National Park, although we hope that the conceptual materials may prove useful to other parks within the North Coast and Cascades

Network and elsewhere. The focus of our work is on coniferous forest ecosystems, but it is not our intent that this be a limiting factor. At the beginning of this study in 1996, we proposed to develop a conceptual plan for monitoring coniferous forest ecosystems of Olympic National Park, in keeping with the 1993 Olympic National Park monitoring proposal and the selection of Olympic National Park as a prototype for the coniferous forest biome. The scope and content of our planning exercise expanded over the years as we began to embrace the broader scope of 'vital-signs' monitoring programs, park-wide monitoring needs, and Network monitoring goals. Hence, many of our conceptual models and examples emphasize the coniferous forest subsystems within Olympic National Park, but the concepts apply also to monitoring aquatic or coastal subsystems.

This report consists of two sections:

Part I contains the conceptual design and a sampling framework for the prototype monitoring program in Olympic National Park. In this section, we elaborate on monitoring goals and approaches used to design an ecosystem-based monitoring program. We describe the environmental setting of Olympic National Park as context for selecting potential indicators and developing conceptual models and sampling plans. We describe the process of identifying potential indicators of ecological condition and change. We present conceptual models of park ecosystems, and describe a conceptual framework for monitoring in the coniferous forest subsystem. Because we focused initially on terrestrial ecosystems, many of the examples provided contain greater emphasis on those systems.

Part II contains a complete record of potential indicators identified to date for Olympic National Park. In this section we focus discussion on the system drivers, components, and processes identified in the current working model of the Olympic National Park ecosystem (see Part I, Chapter 4). For each individual component of the park system, we develop the need and justification for monitoring in a word model of park management issues, key resources and ecosystem functions. We present a pictorial conceptual model of each ecological subsystem, identify monitoring questions, and list potential monitoring indicators for each monitoring question. We conclude each section by identifying linkages of monitoring indicators to other ecological subsystems in our general ecosystem model, identify spatial and temporal contexts for monitoring (where and how often to monitor), and research and development needs. Part II represents the current most detailed listing of potential indicators—the material for subsequent discussions of monitoring priorities and selection of indicators for protocol development

This report IS a living document. The ideas described here evolved in response to a continuous input of ideas and changing organization within the National Park Service monitoring community. Olympic National Park and the North Coast and Cascades Monitoring Network continue to prepare to implement ecological monitoring at the park and network levels with the hiring of new monitoring coordinators, data management specialists, and biological and physical scientists. As these monitoring programs develop, this report will need to be updated to keep pace with the evolution of new ideas, park resource-management issues, and logistic constraints. We expect that additional monitoring components and protocols will be required and that current thinking on monitoring issues will be modified.

PART I: DESIGN FOR LONG-TERM ECOLOGICAL MONITORING IN CONIFEROUS FOREST ECOSYSTEMS IN OLYMPIC NATIONAL PARK

Chapter 1. Monitoring Goals, Strategies, and Tactics

1.1 The Role of Monitoring

Monitoring is critically important to the scientific management of national parks and other protected areas (Fig. 1.1.1). Monitoring identifies the "normal" range of variation in park resources, establishing a temporal baseline from which changes may be detected and the need for management intervention recognized. If a management action is prescribed, monitoring again plays a pivotal role in assessing the effectiveness of implemented actions, identifying necessary adaptations for management, and determining when management objectives are achieved. Monitoring in this context is a critical component of adaptive ecosystem management (Holling 1978, Walters 1986). Monitoring also may identify the need for scientific research to explain the causes of temporal change.

Because resource inventory, monitoring, and research are so integrally a part of management, monitoring is easily confused with related activities involving measurement of natural systems and resources. Ecological ***monitoring*** is the sequential measurement of ecological systems over *time* with the primary purpose of detecting *trends* in the components, processes or functions. By contrast, an ***inventory*** is a point-in-time effort to quantify presence, abundance, or distribution of resources in *space*. Often inventories are more extensive than the subsequent monitoring, and are designed to document species occurring in the park and to determine their distribution. Inventories may be used as the foundation for monitoring if the inventory is repeated over time. For example, monitoring long-term changes in species distribution patterns may require sequential measurements of a species presence/absence using broadly accepted inventory methods. Ecological ***research*** entails measuring ecological systems for the purpose of explaining the causes and effects of spatial or temporal patterns in resource condition. While it is often hoped that ecological monitoring can help to explain complex relationships in ecological systems, such understanding generally requires a more focused research investment. In general, monitoring is the tool used to identify whether or not a change occurred and research is the tool to determine what caused the change. However, it seems likely that in many cases evidence of causes may be perishable; thus, establishing cause after the fact may be unlikely. Hence, we should keep in mind the possibility of monitoring based on hypotheses, with concurrent collection of ancillary, potentially explanatory data. This ancillary data may be exceptionally valuable because quick action may be needed after a decline is detected and there may not be time to collect these data in subsequent years.

1.2 Monitoring Goals and Objectives: The Desired Endpoints

Monitoring goals and objectives define the expectations from monitoring, and are critical elements of the conceptual design. All subsequent decisions stem from the initial statement of monitoring goals and objectives. Here we define the broad goals of the overall monitoring program at Olympic National Park. Specific objectives of individual monitoring projects are described in Part II.

Ultimately the goal of ecological monitoring in Olympic National Park, as in all parks, is to promote knowledge about and understanding of ecological dynamics, processes, and functions of the park ecosystem. Such understanding is needed to help park managers identify problems, make ecologically-based decisions, formulate management plans, undertake appropriate management actions, and assess effectiveness of adaptive management

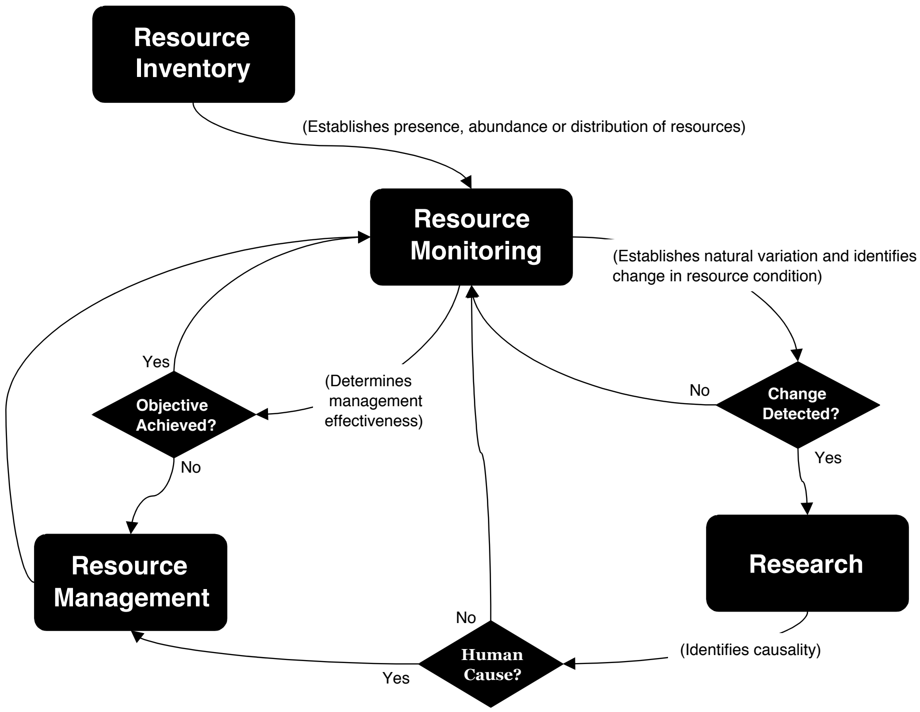

Figure 1.1.1. Relationships between resource inventories, monitoring, research, and resource management activities in national parks.

actions, while also promoting public understanding of these unique protected resources. All such uses of monitoring data are critical for the National Park Service to fulfill its mission of preserving park resources unimpaired in perpetuity. Increasingly, monitoring in protected ecosystems of national parks also plays an important societal role in defining conditions of 'naturalness' for comparison with and management of exploited ecosystems beyond park boundaries. The National Park Service Inventory and Monitoring program has established specific goals of monitoring to assist the park service in meeting its overarching mission. We adopt these service wide goals as guidance for developing the prototype monitoring program in Olympic National Park. They are:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals (S. Fancy, Monitoring Natural Resources in our National Parks, www.nature.nps.gov/im/monitor/).

These goals recognize that ecosystems are fundamentally dynamic and that the challenge of monitoring is to separate 'natural' variation from undesirable anthropogenic sources of change to park resources. Although the distinction between natural and anthropogenic change is somewhat artificial, and sometimes difficult to distinguish, we define "natural" change as the normal consequence of often cyclical ecosystem processes that are in a state of dynamic equilibrium in the absence of modern human pressures. By comparison, "anthropogenic" changes result mainly from industrial activities of humans. Because they are, by definition, caused by humans, they should be responsive to local, regional, or global changes in human activities. Anthropogenic changes tend to be directional, rather than cyclical, and may be accompanied by losses in biodiversity or functional integrity. Primary intents of monitoring in Olympic National Park, therefore, are to document natural variation in key components of forest ecosystems as context for recognizing unacceptable impairment to park resources, to identify the goals of resource restoration projects, and to compare to more altered landscapes outside parks.

1.3 Monitoring Strategies: Approaches to Monitoring

How best to meet these goals—whether to focus monitoring on effects of known threats to park resources or on general properties of ecosystem status--was the topic of considerable discussion at a recent workshop (Woodward et al. 1999). We and others have described many considerations inherent in choosing among a strictly threats-based monitoring program, or alternate taxonomic, integrative, or reductionist monitoring designs (Woodley et al. 1993, Woodward et al. 1999). We assert that the best way to meet the challenges of monitoring in national parks and other protected areas is to achieve a balance among different monitoring approaches, while recognizing that the program will not succeed without also considering political issues (Woodward et al. 1999). To meet those needs, we recommend a multi-faceted approach for monitoring park resources, building upon concepts presented originally for the Canadian national parks (Woodley 1993, Figure 1.3.1). Specifically, we recommend choosing indicators in each of the following broad categories:

(1) **ecosystem drivers** that fundamentally affect park ecosystems,
(2) **effects of currently known** threats to the condition of park ecosystems
(3) **basic indicators of ecosystem integrity**, and
(4) **focal resources** of parks.

Ecosystem drivers, both natural and anthropogenic, are the primary factors influencing change in park ecosystems. These may be related to global or regional changes in climate, nutrient inputs, or human pressures. At some point it is possible (even likely) that these drivers will exceed their range of natural variation (natural drivers, e.g., climate) or that the ecosystem will loose the capacity to absorb their effects (anthropogenic drivers, e.g., pollutants). Trends in ecosystem drivers will suggest what kind of changes to expect and may provide an early warning of presently unforeseen changes to the ecosystem.

Monitoring the **effects of known threats** will provide information useful to management on current issues. Monitoring effects of current threats will ensure short-term relevance of monitoring.

Indicators of ecosystem integrity will provide the long-term baseline needed to judge what constitutes unnatural variation in park resources and provide the earliest possible warning of unacceptable change. For our purposes, we've embraced Karr and Dudley's (1981) definition of biological integrity as the capability of supporting and maintaining a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region. Ecological integrity implies the summation of chemical, physical, and ecological integrity, and it implies that ecosystem structures and functions are unimpaired by human-caused stresses. Indicators of basic ecosystem integrity are aimed at early-warning detection of presently unforeseeable detriments to the sustainability or resilience of ecosystems.

Focal resources are flagship resources of parks. By virtue of their special protection, public appeal, or other management significance, these resources have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity.

Collectively, these basic strategies for choosing monitoring indicators achieve the diverse monitoring goals of the National Park Service. They include many of the criteria that have been suggested previously for selection of monitoring attributes (Davis 1989, Silsbee and Peterson 1991).

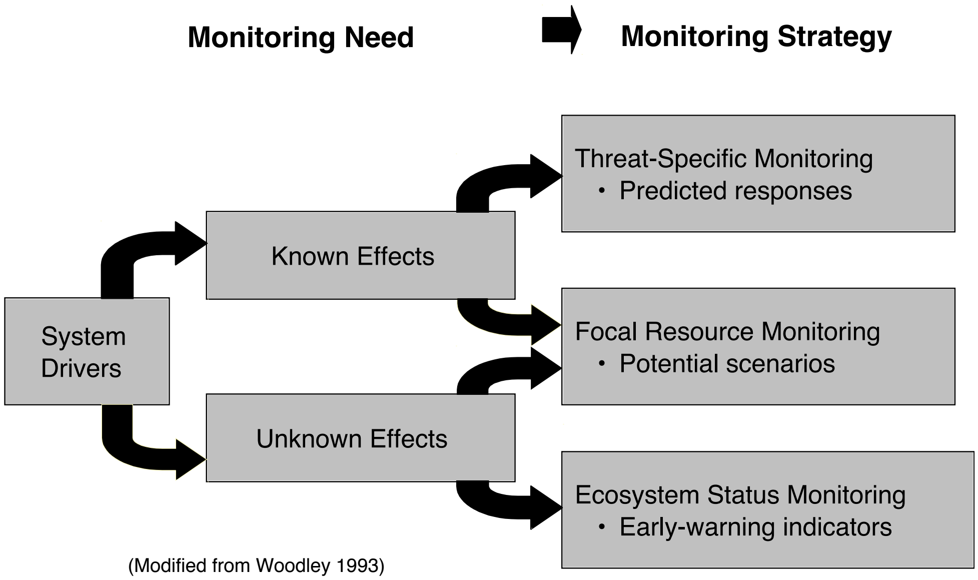

Figure 1.3.1. A multi-faceted approach for monitoring known and unknown effects of system drivers on ecosystem integrity and health in national parks.

1.4 Monitoring Strategies: Integration of Monitoring Projects

One of the most difficult aspects of designing a comprehensive monitoring program is integration of monitoring projects so that the interpretation of the whole monitoring program yields information more useful than that of individual parts. The National Park Service strongly encourages integration within and among monitoring programs so as to avoid a "stovepipe" approach to monitoring. The analogy of the stovepipe refers to the tendency for elements of monitoring programs to be conceived, developed, and implemented independently such that information flows from individual stovepipes with minimal interaction. One of the strategic goals identified in the 1993 prototype monitoring proposal submitted by Olympic National Park is to develop an integrated monitoring program for coniferous forest ecosystems.

Although integration is admittedly a subjective goal for which it is difficult to identify benchmarks of progress, we recognize several characteristics of integrated monitoring programs that serve as strategic goals for program design and implementation. Our perspectives on integrative monitoring are influenced by proceedings of a workshop on "Integrating Environmental Monitoring and Research in the Mid-Atlantic Region," sponsored by the Committee on Environment and Natural Resources (1997), as well as our own workshops (see Woodward et al. 1999).

We consider the following as strategic goals for the design of integrated monitoring:

Ecological Integration involves considering the ecological linkages among system drivers and the components, processes, and functions of ecosystems when selecting monitoring indicators. The most effective ecosystem monitoring strategy will employ a suite of individual measurements that collectively monitor the integrity of the entire ecosystem. One strategy for effective ecological integration is to select indicators at various hierarchical levels of ecological organization (Noss 1990).

Spatial Integration involves establishing linkages of measurements made at different spatial scales, including nested spatial scales within a park-specific prototype monitoring program, or between individual park programs and broader regional programs (i.e., National Park Service or other national and regional programs). It requires understanding of scalar ecological processes, the co-location of measurements of comparably scaled monitoring attributes, and the design of monitoring frameworks that permit the extrapolation and interpolation of scalar data.

Temporal Integration involves establishing linkages between measurements made at various temporal scales. It will be necessary to determine a meaningful time line for sampling different ecological attributes while considering characteristics of temporal variation in such attributes. For example, sampling changes in forest overstory structures (e.g., size class distribution) may require much less frequent sampling than that required to detect changes in composition, phenology or biomass of herbaceous understories. Temporal integration requires nesting the more frequent and, therefore, more intensive sampling within the context of less frequent sampling.

Methodological Integration involves choosing sampling methods that promote sharing of data among neighboring land management agencies or other national parks in the region, while also providing context for interpreting the data. For example, the use of a common monitoring methodology across jurisdictional boundaries on the Olympic Peninsula (e.g. spotted owl monitoring), would provide context for interpreting trends in park resources relative to other land ownerships on the Peninsula while also enhancing the usefulness of monitoring data from Olympic National Park as an environmental benchmark for the region.

Programmatic Integration involves the coordination and communication of monitoring activities at the park and regional levels to promote broad participation in monitoring and use of the resulting data. For example, involving National Park Service resource protection and education divisions in routine monitoring activities at the park level results in a well-informed park staff, improved potential for informing the public, wider support for monitoring, and greater acceptance of monitoring results in the decision-making process. Coordination and integration of monitoring activities between the prototype and network monitoring programs is also essential to ensure maximum usefulness of protocols developed at the prototype parks.

1.5 Design Tactics: How to Get There?

We identify three stages in the maturation of any monitoring program: a design phase, a protocol development phase, and an implementation phase (Figure 1.5.1). The design phase boils down to deciding what, when and where to monitor, and articulating why. The individual design steps—scoping (Chapter 3), conceptual modeling (Chapter 4), sampling framework (Chapter 5)—are all important elements of achieving ecological and spatial integration in monitoring. The subsequent chapters of Part I summarize steps we have taken in designing the prototype monitoring program in Olympic National Park and our efforts to build an integrated monitoring program.

The protocol development phase, which follows the design phase, includes the critically important research and development that results in specific study plans, sampling methodologies, data management systems, and written monitoring protocols (Figure 1.5.1). Implementation of a mature monitoring program involves routine collection, analysis, interpretation and reporting of data following approved protocols over the long term. Peer review is a critical component of each stage providing suggestions for revisions in design, protocols, or implementation (Figure 1.5.1). Although the three stages of program development are largely implemented sequentially, the feedback arrows between them recognize the iterative characteristics of a dynamic monitoring program.

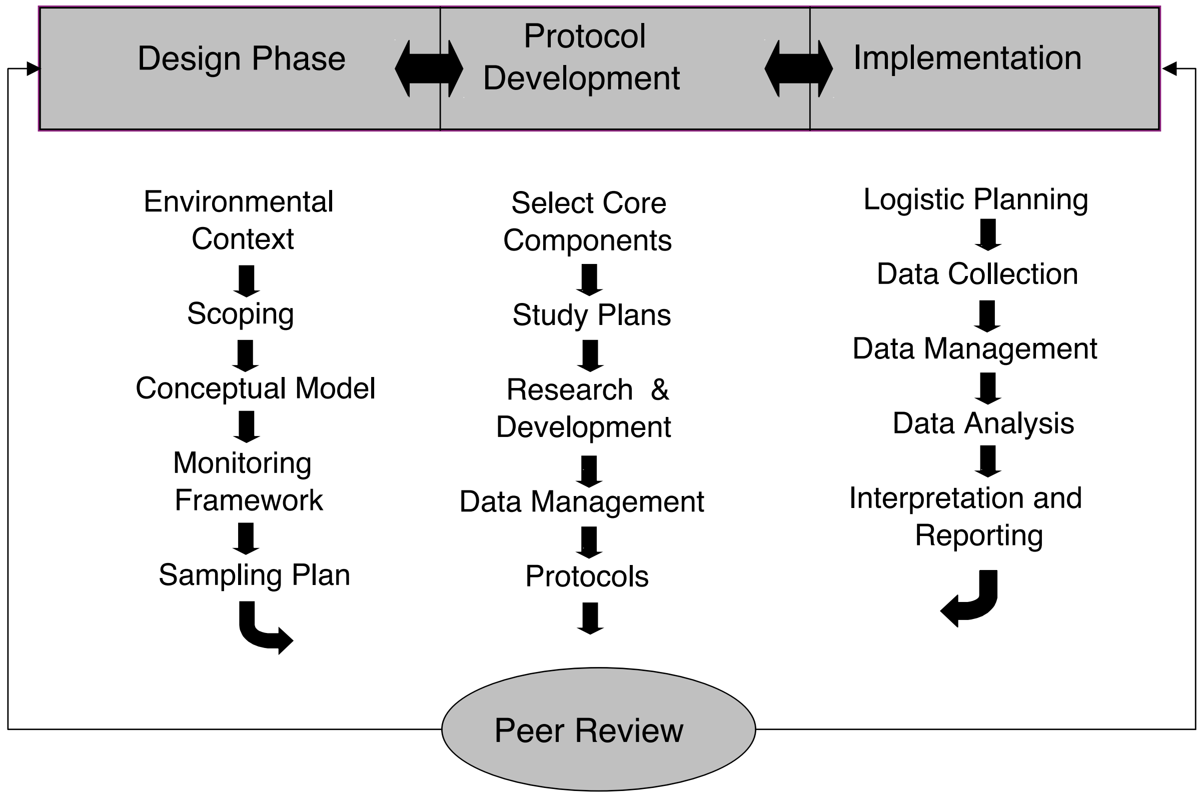

Figure 1.5.1. Sequence of steps taken in designing long-term ecological monitoring in Olympic National Park and relationships among 'design', 'protocol development' and 'implementation' phases of program development.

Chapter 2. Environmental Context: Ecological Resources, History, and Threats

The natural resources of Olympic National Park are the raw materials for developing a long-term ecological monitoring program. Here, we briefly present the background material with which we work to formulate a monitoring program for Olympic National Park. The information for this chapter is synthesized from Henderson et al. (1989), Houston et al. (1994), Buckingham et al. (1995), and the Resource Management Plan of Olympic National Park (Olympic National Park 1999).

2.1 Setting

Olympic National Park is the centerpiece of the Olympic Peninsula, a 13,800 km^2 landmass in the extreme northwest corner of the conterminous United States. The Peninsula resembles an island because it is surrounded on three sides by water: the Pacific Ocean to the west, the Strait of Juan de Fuca to the north, and Hood Canal to the east. The southern boundary is usually considered to be the Chehalis River Valley (Figure 2.1.1). The Olympic Mountains rise from sea level at the coast to culminate on Mt. Olympus at 2430 m. Geologic uplift, heavy precipitation and a dynamic glacial history have created a radial pattern of 11 major river valleys centered in the mountains.

Olympic National Park covers 3700 km^2 in two units: 3530 km^2 in the central mountainous core, and a narrow 170 km^2 strip extending 84 km along the coast. Ninety-six percent of the park is designated wilderness; roads, campgrounds, and structures occupy less than 1% of the area and are located around the periphery of the park. The center of the park is accessible only by the 984 km of maintained trails (Figure 2.1.2). The park shares 474 km of boundary with land managed primarily for timber by the Washington State Department of Natural Resources (1600 km^2), the USDA Forest Service (2800 km^2) and private timber companies. However, 350 km^2 of Olympic National Forest is included in six units of Wilderness Areas, all abutting the park (Olympic National Park 1999).

2.2 Climate

Mountainous areas are often distinguished by steep moisture and temperature gradients resulting in substantially different environments over short distances. In addition to being influenced by the mountains, the Olympic Peninsula environment also reflects its maritime climate, which is characterized by exceptionally high levels of precipitation along the western slope. Most storms pick up moisture over the Pacific Ocean and move across the Peninsula from the southwest depositing over 600 cm of precipitation annually on Mount Olympus. The northeast corner of the Peninsula is in a striking rain shadow with Sequim, only 55 km from Mount Olympus, receiving an average of 45 cm of precipitation annually (Figure 2.2.1). Hence, the area experiences one of the steepest precipitation gradients in the world. Most precipitation (80%) falls from October through March while only 5% falls in July and August, creating summer drought conditions especially in the northeast. Winter precipitation falls primarily as rain below 300 m elevation, rain and snow from 300 to 750 m, and snow at higher elevations. Long-term data from lowland areas around the Peninsula show the average January temperature to be 0^{o}C with average August maxima averaging 21^{o}C (Phillips and Donaldson 1972, National Oceanic and Atmospheric Administration 1978).

The steep climatic and elevation gradients of the Peninsula create a diversity of conditions within the park. Climate ranges from mild, maritime conditions on the coast to harsh, cold alpine areas at high elevations to dry, near-continental climate in the northeast. Consequently, cold-stressed alpine vegetation exists within 15 km of intertidal communities and an urban area that would naturally be an oak savanna, and even closer to lush temperate coniferous rainforest with some of the world's largest trees.

2.3 Geology and Soils

The major formative geologic process for the Olympic Mountains is plate tectonics, specifically the subduction of the oceanic Juan de Fuca plate as it travels eastward and collides with the westward-moving continental North American plate. During the Miocene this oceanic plate slid under the continental plate at the subduction zone, folding and raising the edge of the continent. Basaltic sea mounts, probably originally located on the ocean floor near the shore, became the Crescent Formation forming the northern, eastern and southern edges of the mountains. Later, sedimentary rock from the ocean floor located west of the basalts but east of the subduction zone, folded to create the central core and western side of the Peninsula. Eventually the subduction zone moved further west, relieving the downward pressure on the Peninsula and allowing the mountains to rise. As the mountains uplifted, erosion from precipitation and sculpting by glaciers produced the radial river drainage pattern and precipitous mountain slopes (Tabor 1987).

The geologic and glacial histories of the Peninsula and western Washington provide a diversity of parent materials for soil formation. The ocean floor contributed sedimentary and marine-deposited basaltic bedrock. The continental glaciers deposited a variety of soil materials including granitic rocks from the Cascade Range along the east and north sides of the Peninsula. Mass wasting and glaciers mixed, washed, and eroded all three material, creating a complex of mountainous and riverine soil materials (Tabor 1987).

Olympic soils are considered to be young and, in general, they are relatively infertile except in the lower Dungeness River Valley. Local soil characteristics, (e.g., soil moisture, subsurface flow, soil temperature, and chemical properties) are highly variable, being influenced by the parent material, climate, and biotic communities of the area. Common soil orders include spodosols, inceptisols, entisols, histosols, and andisols (Henderson et al. 1989).

2.4 Glacial History

Although more than 20 ice ages occurred during the Pleistocene epoch (Mix 1987), little is known about any except the most recent one, known as the Wisconsin Ice Age. During the Wisconsin Ice Age, there were several glaciations of which at least four left records in the Puget Sound region. The most recent of these was the Fraser glaciation with two major periods of glacial advance (stades). The first, known as the Evans Creek Stade, occurred 21,000-18,000 BP (years before present), and was characterized by the expansion of alpine glaciers (Booth 1987). During this stade, glaciers filled valleys and some adjacent lowlands, especially on the west side of the Peninsula. Sea level was lower, exposing perhaps an additional 50 km wide strip of coast (Long 1975). Eventually the valley glaciers retreated, but ice returned to the area during the Vashon Stade, this time due to the southern advance of the Cordilleran ice sheet from Canada. This stade was at its maximum about 15,000 BP when the Puget trough and the Strait of Juan de Fuca were filled with ice, reaching a thickness of approximately 1100 m near Port Angeles (Armstrong et al. 1965, Tabor 1987). Ice was thickest in the northeast corner of the Peninsula but the continental sheet never contacted the remaining valley glaciers (Booth 1987, Tabor 1987). The Vashon Stade ended about 12,500 BP and was followed by a minor re-advance of the ice sheet about 11,500 BP (Sumas Stade).

During the Holocene, the period since the last ice age, the area experienced the Hypsithermal Period or “early Holocene warming” (10,000-7,000 BP) and then the Neoglacial Period (5,000-4,000 BP) characterized by renewed glacial advances (Hammond 1976). The latest advance, known as the Little Ice Age, occurred 1350-1850 AD (Porter and Denton 1967).

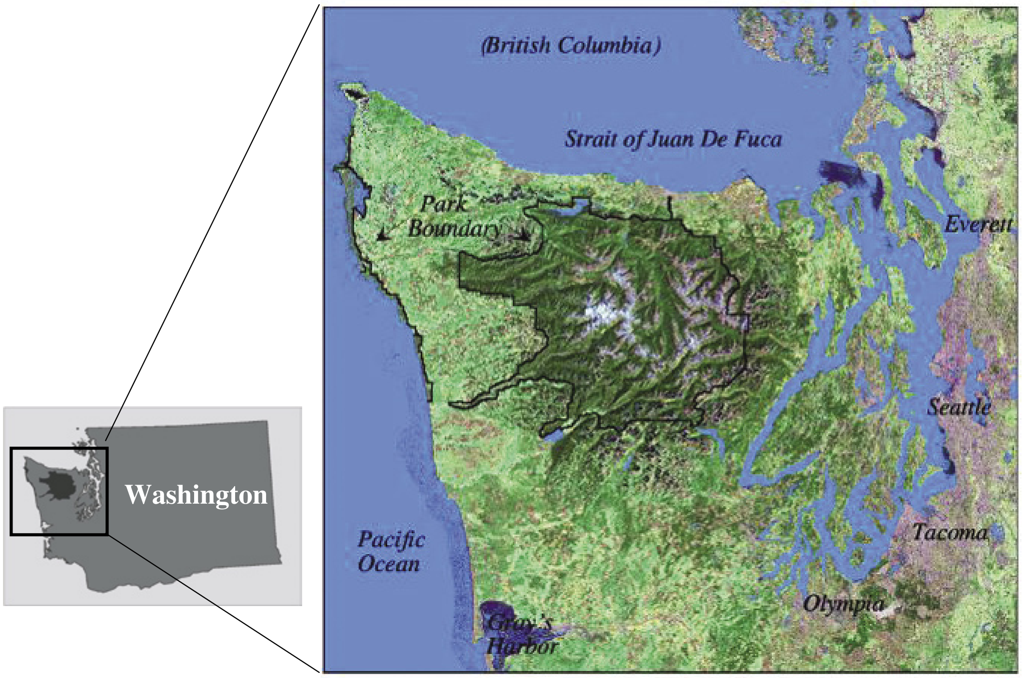

Figure 2.1.1. Location of coastal and interior units of Olympic National Park on Washington's Olympic Peninsula.

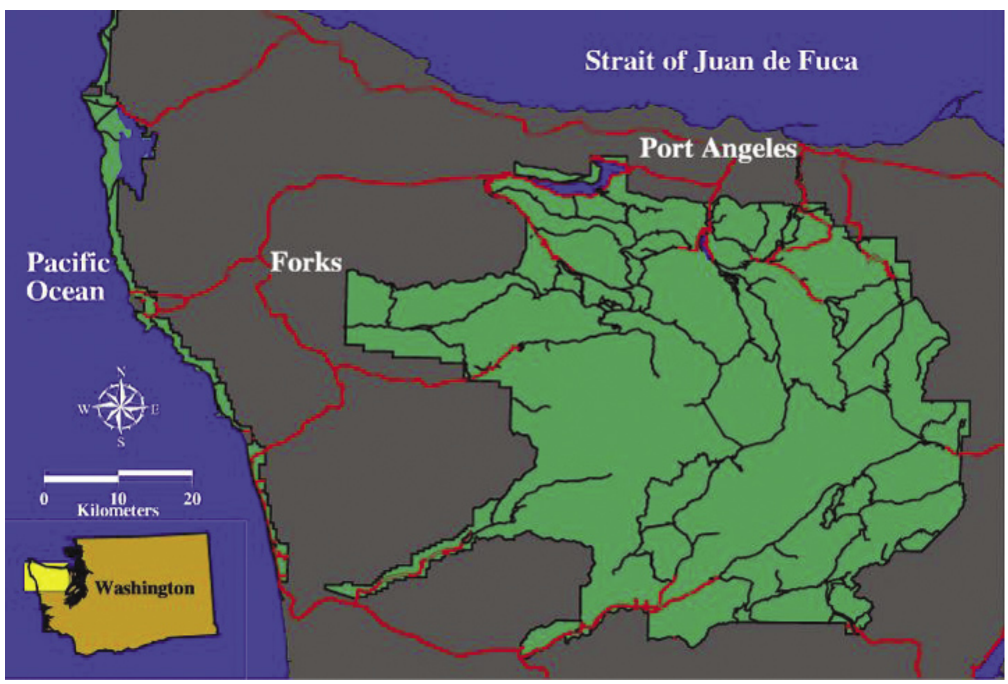

Figure 2.1.2. Roads (red) and trails (black) of Olympic National Park showing limited road access to the park's interior. (map prepared by R. Hoffman, Olympic National Park)

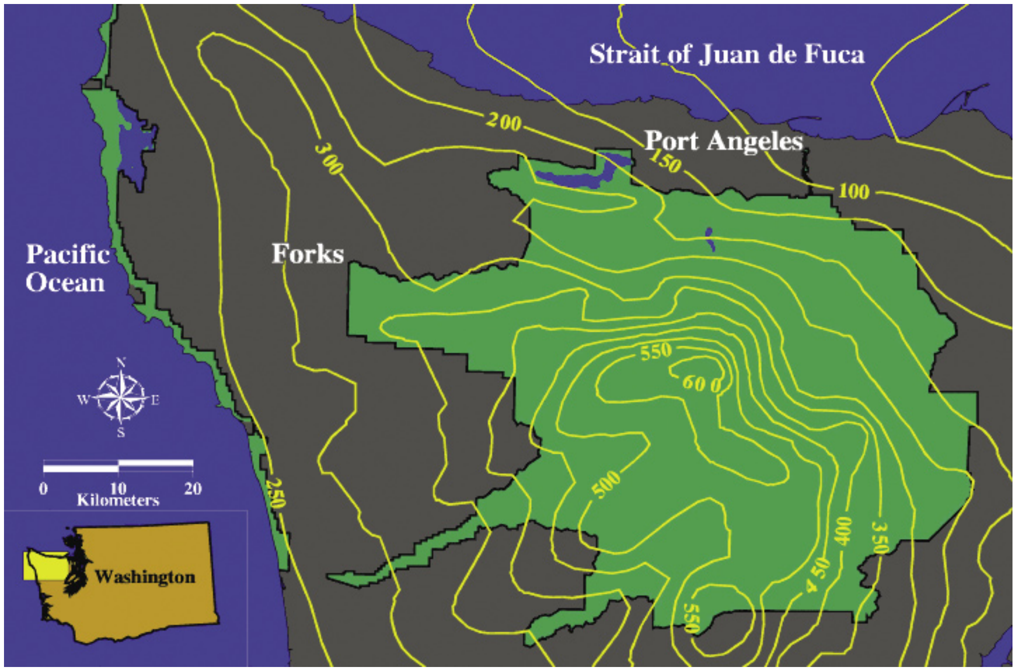

Figure 2.2.1. Isoclines of mean annual precipitation (cm) on the Olympic Peninsula. (map prepared by R. Hoffman, Olympic National Park)

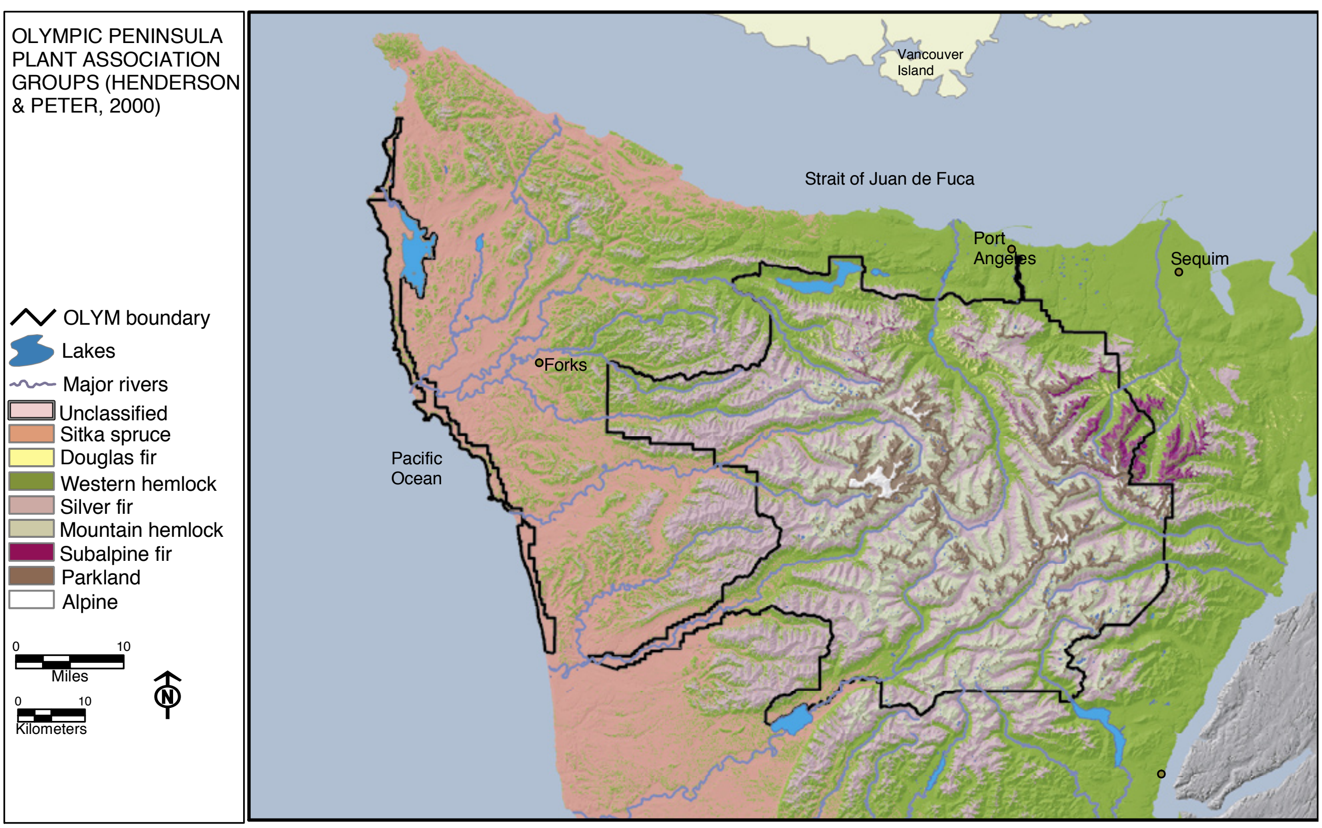

Figure 2.5.1. Forest zones of the Olympic Peninsula (OLYM=Olympic National Park). (map prepared by K. Beirne, Olympic National Park)

2.5 Vegetation Pattern

Studies of pollen preserved in lake bottoms show that vegetation has been dynamic in response to changes in climate. During full glaciation (20,000-17,000 BP), low-elevation areas included some of the species currently found in subalpine parkland. Then as climate warmed during the early Holocene, dry-adapted species became more abundant. These included Douglas fir (*Pseudotsuga menziesii*), red alder (*Alnus rubra*) and some western hemlock (*Tsuga heterophylla*) in the west, and oak (probably *Quercus garryana*) and pines (probably *Pinus contorta*) in the northeast. Charcoal deposits suggest fire was frequent during this time. Current vegetation began to establish after the climate cooled again (5,000-7,000 BP). Moist, temperate species such as western hemlock and redcedar (*Thuja plicata*) increased while Douglas fir and red alder persisted but at lower abundance (Barnosky et al. 1987, Brubaker 1991, Whitlock 1992).

Because vegetation is highly indicative of climate, vegetation zones can be considered to reflect zones of similar environments. In the Olympics, vegetation zones are defined by the abundance and distribution of tree species, and show that the Olympic environment is largely determined by elevation, aspect and precipitation (Figure 2.5.1).

West-side lowland forests are in the Sitka Spruce (*Picea sitchensis*) Zone. This zone includes the temperate coniferous rainforest for which Olympic National Park is famous. Here, massive Sitka spruce trees grow to 90 m and deciduous bigleaf maples (*Acer macrophyllum*) are laden with epiphytes. Lowland and mid-elevation forests on the drier east side and mid-elevation forests on the west side are in the Western Hemlock (*Tsuga heterophylla*) Zone. This is the most widespread zone and it is dominated by Douglas fir (*Pseudotsuga menziesii*) and western hemlock, while western red cedar (*Thuja plicata*) is a fairly common constituent. Montane forests are in the Pacific Silver Fir (*Abies amabilis*) Zone on the cool, moist slopes of the eastern, western and southern parts of the Peninsula, while the Douglas-fir Zone inhabits south-facing montane slopes in the northeast. Subalpine areas are a matrix of tree islands and meadows. Wet areas experiencing snow packs deeper than 3 m are in the Mountain Hemlock Zone (*Tsuga mertensiana*) and include mountain hemlock, subalpine fir (*Abies lasiocarpa*), and sometimes Pacific silver fir. The Subalpine Fir Zone occurs in areas with snow packs less than 3m deep and may also include lodgepole pine (Pinus contorta) or whitebark pine (*P. albicaulis*). Treeline occurs at about 1615 m in wetter areas and 1890 m in drier zones where trees finally give way to alpine meadows (Henderson et al. 1989).

2.6 Biogeography

The glacial history, geographic isolation, and steep climatic gradients have important consequences for the biogeography of the area. First, the Peninsula was never completely covered by ice during at least the Fraser Glaciation when a complex of ridges and mountains were above ice. In addition, sea level was lower when the ice was deep, exposing considerable new lands along the coast for long periods of time (Booth 1987, Tabor 1987).

The role of the Olympic Peninsula as a glacial refugium is conjecture, but the theory is well supported by the present biogeography (Houston et al. 1994, Buckingham et al. 1995). The Olympic Peninsula is home to a surprising number of endemic and disjunct species. Their distribution patterns are consistent with the theory that the Peninsula served as a glacial refugium during at least the Fraser Glaciation. (Table 2.6.1). Of the fourteen endemic or near-endemic plant species, two are coastal or lowland (beyond the ice) and the others are subalpine and alpine (above the ice); four out of five of the endemic mammals are associated with alpine and subalpine areas; and five of eight endemic insects are high montane or subalpine. In addition to Peninsula endemics, several species are endemic to the Peninsula and coastal islands to the north suggesting that species might have evolved and spread along the wide coastal strip to the west of the Cordilleran Ice. Finally, some species are disjunct from populations now present on the other side of the area previously occupied by the Cordilleran ice sheet. These species may have been widely distributed across the continent until they were extirpated in part of their range by ice.

Typical of islands, which the Olympic Peninsula resembles, the Olympic Peninsula has a depauperate fauna compared with nearby continental areas, in this case the Cascade Mountains (Table 2.6.2). Missing large mammals include grizzly bears (*Ursus arctos*), mountain sheep (*Ovis canadensis*), and mountain goats (*Oreamnos americanus*); missing smaller mammals include the pika (*Ochotona princeps*) and the golden-mantled ground squirrel (*Spermophilus lateralis*).

2.7 Human History

Humans have occupied the Olympic Peninsula since nearly the end of the final melting of the Cordilleran Ice Sheet around 11,000-13,000 BP. Humans may have crossed the Bering land bridge to North America from Asia sometime during the height of glaciation, approximately 25-15,000 BP. The first to arrive were hunter-gatherers, probably utilizing caribou, bison, mastodons, mammoths and other cold-climate fauna present at the time (Bergland 1983). Sedentary land use is estimated to have begun 3,000 BP and the livelihood was based on marine shellfish, fish and marine mammals (Bergland 1983, Schalk 1988, Wessen 1990). Humans also made extensive use of plant materials, notably western red cedar for housing, boats, baskets and many other objects (Norton 1979).

Dramatic changes to the Peninsula began with the arrival of Europeans. European contact occurred during the 1770s, if not earlier, and resulted in significant losses of native people to foreign diseases (Capoeman 1990). European settlement began in earnest with the establishment of Port Townsend in 1850 and Sequim in 1854. The first logging company, Pope and Talbot, was formed in 1833, and the first railroad to Forks was completed in 1919 (Campbell 1979). Logging increased through time, peaking during the 1980s, leaving the Park surrounded by a landscape managed for timber. European settlement resulted in changes in animal populations as well. Wolves were hunted to extinction, and elk and cougar nearly so (McLeod 1984). The reduction in elk populations motivated the closure of hunting seasons from 1905-1933, and was largely responsible for the creation of the Olympic National Monument in 1909 and, later, the Olympic National Park in 1938.

One consequence of the high timber harvest levels in the 1980s has been the loss of old-growth forest habitat and the listing of two old-growth dependent species, the northern spotted owl (*Strix occidentalis caurina*) and the marbled murrelet (*Brachyramphus marmoratus*), as threatened species by the U.S. Fish and Wildlife Service. Since then, forest harvest on Federal lands has been sharply curtailed and is now subject to management prescribed in the interagency Northwest Forest Plan, an agreement to which the National Park Service is a signatory (U.S. Department of Agriculture Forest Service and U.S. Department of the Interior Bureau of Land Management 1994). Other recent issues involving dialogue with parties outside of the park include harvest of park resources, salmon genetics, dam removal on the Elwha River, park management of bears, nonnative mountain goats, the reintroduction of wolves, and mining in and near the park boundary.

Meanwhile, as unmanaged areas have been reduced, and the human population of western Washington has increased, visitation to the park has shown a steady increase. In 1939 only 40,650 visits were recorded, increasing to 100,000 in 1945, 1 million in 1958, and 4.2 million in 2001. The park can expect increasing numbers of visitors into the future (Olympic National Park records).

2.8 Natural Disturbance

The major large-scale natural disturbances on the Olympic Peninsula are fire and wind (Figure 2.8.1, Henderson et al. 1989). Fire is most important in drier vegetation types with the fire return interval of 140-240 years compared with 600-900 years in wetter areas. Storms with hurricane force winds move in from the coast, affecting the wetter side of the Peninsula, and occur about every 20 years (Henderson et al. 1989). Smaller-scale disturbances are associated with heavy precipitation and include avalanches, slope failures, soil creep, and scouring of riverbanks. Beach erosion and other coastal processes affect the coastal strip.

Fire suppression policies during the twentieth century may have altered vegetation structure and composition. However, the effects are not yet as dramatic as for geographic areas experiencing fire-return intervals measured in decades rather than the centuries appropriate for the Olympics.

Insects and diseases are a natural part of the forest ecosystem. Most pathogens occurring in the

Table 2.6.1. Endemic fauna and flora of the Olympic Peninsula. See Houston et al. (1994) for primary sources, plus Pyle (2002).

Common Name	Scientific Name
VERTEBRATES	
Mammals	
Olympic marmot	*Marmota olympus*
Olympic yellow-pine chipmunk	*Tamias amoenus caurinus*[a]
Olympic snow mole	*Scapanus townsendii olympicus*
Olympic Mazama pocket gopher	*Thomonys mazama melanops*
Olympic ermine	*Mustela erminea olympica*
Ampibians	
Olympic torrent salamander	*Rhyacotriton olympicus*
Fish	
Olympic mud minnow	*Novumbra hubbsi*[b]
"Beardslee" rainbow trout (lacustrine form)	*Oncorhyncus mykiss irideus*[c]
"Crescenti" cutthroat trout (lacustrine form)	*Oncorhyncus clarki clarki*[c]
INVERTEBRATES	
Insects	
Olympic arctic[d] (lepidopteran)	*Oeneis chryxus valerata*
Hurlbirt's skipper (lepidopteran)	*Herperia comma hurlbirti*
Olympic Parnassian[d] (lepidopteran)	*Parnassius smintheus olympiannus*
Ozette skipper (lepidopteran)	*Ochlodes sylvanoides undetermined*
Spangled Blue (lepidopteran)	*Icaricia acmon spangleatus*
Makah copper (lepidopteran)	*Lycaena mariposa undetermined*
Olympic grasshopper	*Nisquallia olympica*
Mann's gazelle beetle	*Nebria danmanni*
Quileute gazelle beetle	*Nebria acuta quileute*
Sylvan gazelle beetle[d]	*Nebria meanyi sylvatica*
Johnson's snail eater[d] (coleopteran)	*Scaphinotus johnsoni*
Tiger beetle	*Cicindela bellissima frechini*
Millipedes	
Millipede[e]	*Tubaphe levii*
Mollusks	
Arionid slug	*Hemphillia dromedarius*
Arionid jumping slug	*Hemphillia burringtoni*
VASCULAR HERBACEOUS PLANTS	
Pink sandverbena[d]	*Abronia umbellate acutulata*
Olympic Mountain milkvetch	*Astragalus australis* var. *olympicus*
Piper's bellflower	*Campanula piperi*
Flett's fleabane	*Erigeron flettii*
Thompson's wandering fleabane	*Erigeron peregrinus peregrinus* var. *thomsonii*[e]
Henderson's rock spirea	*Petrophytum herdersonnii*
Webster's senecio	*Senecio neowebsterii*
Olympic Mountain synthyris	*Synthyris pinnatifida* var. *lanuginosa*
Flett's violet	*Viola flettii*
Olympic aster[d]	*Aster paucicapitatus*

Table 2.6.1. Endemic fauna and flora of the Olympic Peninsula. See Houston et al. (1994) for primary sources, plus Pyle (2002). (Continued)

Common Name	Scientific Name
VASCULAR HERBACEOUS PLANTS	
Magenta paintbrush[d]	*Castilleja parviflora* var. *olympica*
Lance-leaf spring beauty[d]	*Claytonia lanceolata* var. *pacifica*
Blood-red pedicularis[d]	*Pedicularis bracteosa* var. *atrosanguinea*
Tisch's saxifrage[d]	*Saxifraga tischii*
CRYPTOGAMS	
Liverwort[d]	*Porella noellii* forma *crispate*

[a]Trinomials indicate subspecies.
[b]Occurs south to Chehalis River.
[c]Formerly considered as a distinct species; currently considered a lake-adapted form of the subspecies
[d]Also occurs on Vancouver Island
[e]Not found in Olympic National Park

Table 2.6.2. Mammal and bird species present in the Cascade Mountains but absent historically from the Olympic Peninsula.[a] See Houston et al. (1994) for sources.

Common Name	Scientific Name
Mammals	
Grizzly bear	*Ursus arctos*
Wolverine	*Gulo gulo*
Red fox[b]	*Vulpes vulpes*
Coyote[c]	*Canis latrans*
Lynx	*Lynx canadensis*
Water vole	*Microtus richardsonii*
Golden-mantled ground squirrel	*Spermophilus lateralis*
Northern bog lemming	*Synaptomys borealis*
Porcupine[d]	*Erethizon dorsatum*
Pika[e]	*Orchotona princeps*
Mountain sheep	*Ovis canadensis*
Mountain goat	*Oreamnos americanus*
Birds	
White-tailed ptarmigan	*Lagopus leucurus*
Spruce grouse	*Dendragapus canadensis*

[a] Scientific names from Honacki et al. (1982).
[b]Subsequently introduced.
[c]Colonized the Olympic Peninsula during the early twentieth century.
[d]Occasional dispersing individuals, apparently no established population.
[e]Merriam found no pikas but was uncertain that they were entirely absent.

Olympics affect stressed trees and/or do not always result in tree death. Insects cause local effects but no widespread, devastating outbreaks of insects have been recorded (Henderson et al. 1989). Two non-native insects, the balsam woolly adelgid (*Adelges piceae*) and hemlock woolly adelgid (*A. tsugae*), and one non-native pathogen, white pine blister rust (*Cronarium ribicola*), are of management concern.

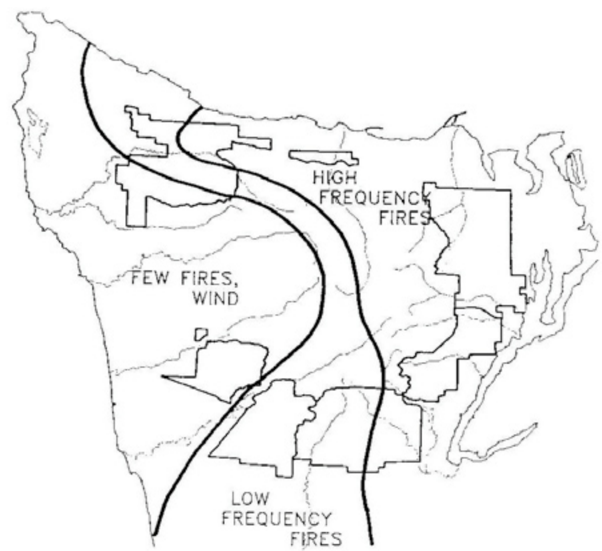

Figure 2.8.1. Areas of Olympic National Park affected by wind or fire (taken from Henderson et al. 1989).

2.9 Anthropogenic Threats.

If Olympic National Park is to meet its mandate to maintain natural resources unimpaired for future generations, the anthropogenic impacts to these resources must be mitigated or prevented. Some threats and their effects are unforeseeable and cannot be specifically described. As such, these threats will be addressed by monitoring indicators of ecosystem integrity expected to provide early detection of changes in the structure and function of park ecosystems.

Anthropogenic threats currently of concern to park management are identified in the park's Resource Management Plan (Olympic National Park 1999). Some threats have local effects on specific resources (e.g., illegal harvest of animal and plant taxa) while others are ubiquitous and have unknown consequences (e.g., ultra-violet radiation may have a wide range of yet undetermined effects). Nevertheless, all management concerns can be seen as symptoms of larger issues (Table 2.9.1). Identifying these issues creates the context for monitoring questions in two ways. First, identifying the larger issue addressed by specific concerns across a region can provide the common ground needed to integrate those programs. For example, different land management agencies have different specific concerns regarding how global climate change might affect their resources (e.g., reduced timber production, increased fire frequency). It is logical to integrate these concerns around the larger issue of climate change. Second, some threats can be addressed directly by park management, either with a policy change, mitigation, or increased enforcement, and others cannot. For threats it cannot act on directly, the park can serve as a natural benchmark for managed systems; monitoring should include the benchmark role as a consideration. Management concerns can also be categorized by whether they are local or have park-wide scope. This perspective will provide a clear context for monitoring questions and approaches. Concerns that affect local areas or a limited number of resources are most likely to be addressed by smaller-scale and maybe shorter-term monitoring. In contrast, concerns with park-wide impacts will require an extensive component.

2.10 Management Objectives.

A monitoring plan must consider not only natural resources, but also the management goals for those resources. The management goals are in turn directed by various pieces of legislation that call for providing public enjoyment of park resources but only in a way that is compatible with their conservation. Specifically, the Resource Management Plan for Olympic National Park (1999) identifies eight objectives to meet its overall goal of conservation:

- Protect the park's natural resources and values in an unimpaired condition and restore altered areas to the condition they would possess without European settlement.
- Protect rare species, restore threatened and endangered species, and minimize harm to indigenous species.
- Use scientific research to gain information about resources, and natural and anthropogenic effects on them.

- Assemble baseline inventories describing the park's natural resources and systematically monitor them in order to understand the governing natural processes and detect change.
- Archive and maintain data and information from research and monitoring, and encourage its dissemination.
- Provide for appropriate wilderness uses and experiences, especially solitude, while protecting wilderness resources.
- Provide appropriate recreational opportunities in environments least vulnerable to resource degradation.
- Promote communication among Olympic Peninsula land managing agencies to identify common natural resource issues, propose solutions and share resources and information.

These objectives are compatible with the approach of monitoring specific management issues, focal species, and indicators of ecosystem integrity. Although specific agents of change are not identified, it is recognized that the agents could be internal or external to the park, and that anthropogenic change and human use are matters of resource concern.

2.11 Implications for Monitoring

Diverse Resources. One of the biggest challenges to monitoring the resources of Olympic National Park is their profound diversity. Steep environmental gradients due to mountainous terrain and a wet maritime climate result in biologically significant environmental differences over short distances. In addition, the park encompasses a broad spectrum of environments from coastal beaches and forests to subalpine meadows and glaciers. The challenge for developing a monitoring program is to select resources or processes that meet monitoring objectives, identify indicators with intensive and extensive scales, choose efficient indicators that apply to as many high priority issues as possible, and repeat this process iteratively. The ultimate goal is to achieve adequate representation in an effective scientifically defensible monitoring program using limited resources.

Difficult Access. The mountainous terrain of the Olympics, the placement of roads peripheral to the park, and the fact that 95% of the park is designated wilderness makes central and/or high elevation areas extremely difficult to reach. Results from a model of travel time to different areas of the park show that it is impossible to sample the entire park with limited resources (Figure 2.11.1). Fortunately there are statistical methods for sampling more difficult areas with less intensity while still allowing inferences to them. However, there are some parts of the park that will be impractical to monitor under modest budgets except with remote sensing technology.

Endemic and Disjunct Species. The island-like geography of the park and its glacial history have resulted in a long period of biologic isolation, enough for many endemic taxa to evolve and several disjunct taxa to persist. Given the park's management goals, these unique organisms deserve individual consideration for monitoring. Whether or not they are chosen for monitoring will depend on their perceived risk, general ecosystem importance, and legal mandates.

Interpretation of Trends. By coincidence, the beginning of European settlement of the Pacific Northwest coincided with the end of the Little Ice Age at around 1850. Since then, a change in anthropogenic regime has coincided with a natural warming trend. Influences of mechanized society (e.g., over-harvesting, and pollution) have been increasing while the influences of aboriginal societies have declined (e.g., selective harvest of cedars, harvest of marine mammals). Meanwhile, climate change due to a natural climatic cycle has perhaps been exacerbated by an anthropogenic influence on climate.

The implications for monitoring are that anthropogenic change will be difficult to distinguish from natural process. It is also difficult to define management goals for restoration, because the system does not have a recorded equilibrium state from which to extrapolate natural process and predict how the current situation should look absent European influence. Therefore, observed trends must be interpreted in light of inherent instability, from both natural and anthropogenic forces.

Table 2.9.1. Summary of anthropogenic threats identified in the Olympic National Park Resource Management Plan. Specific threats are grouped into general categories. Whether the park addresses the concern with management actions and whether the impacts are parkwide are also indicated (Y=yes, N=no).

GENERAL THREAT	MGMT. ACTION?	SPECIFIC CONCERN IDENTIFIED IN RESOURCE MANAGEMENT PLAN	PARKWIDE IMPACTS?
Habitat Outside of the Park	N	Fragmentation outside the park Isolation of animals inside the park Alteration of fish habitat Alteration of marine habitat	Y Y Y N
Climate Change	N	Increased ultra-violet radiation Effect on ocean conditions	Y ?
Pollutants	N	From growing metro area to east From Asia Oil and chemical spills Effects on plants Potential for lake acidification	Y Y N Y N
Genetic Contamination	N	Fish hatcheries	N
Water Rights	N	Dams	N
Consumptive Use Outside Park	N	Hunting Over-harvest of fish Off-shore coastal development Mineral claims	N N N N
Exotic Species	Y	Exotic animals and plants Introduced pests or diseases	Y ?
NPS Development & Policies	Y	Park management (development) Fire suppression	N Y
Visitor Impacts	Y	Trampling Impacts to soil and vegetation Illegal harvest Interactions with wildlife Unknown magnitude of day use Future visitor trends	N N N ? N Y
Consumptive Use Inside Park	Y	Harvest (total amounts and species) of intertidal & marine organisms Illegal harvest	N N

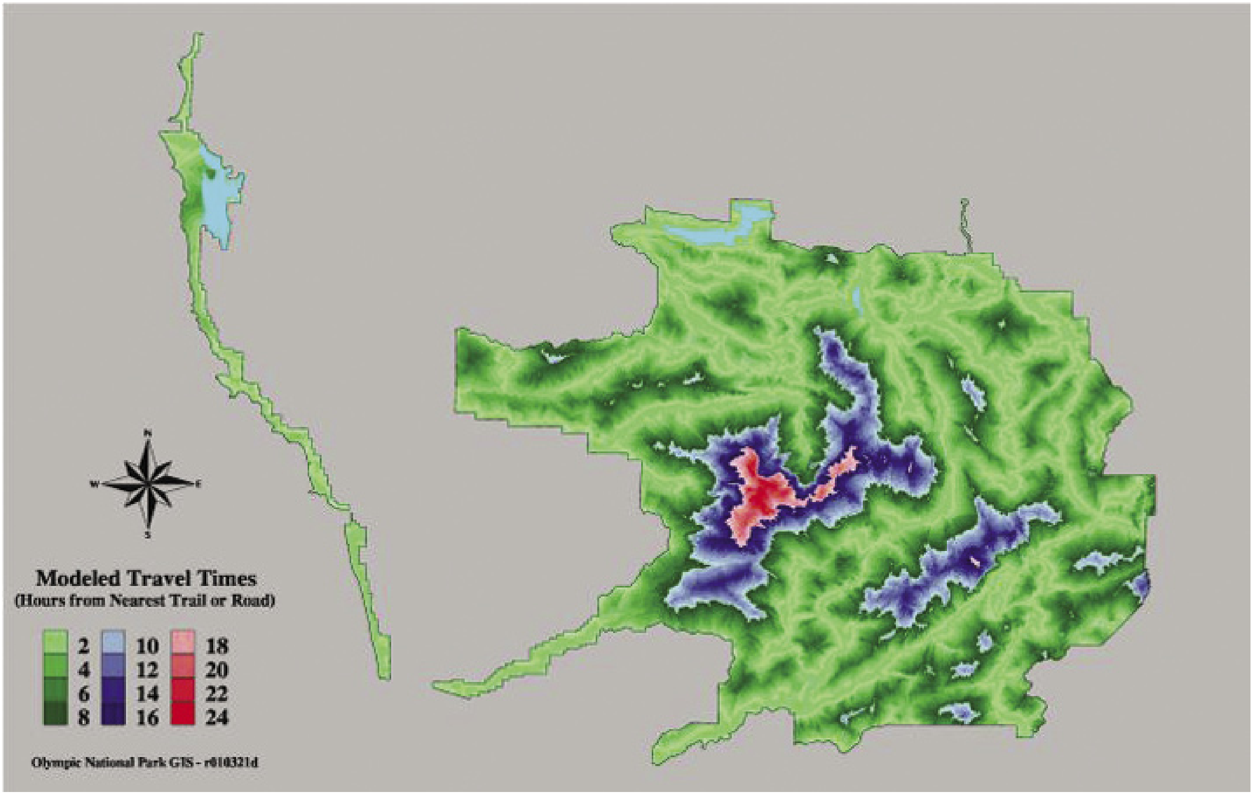

Figure 2.11.1. Estimated times of foot travel from nearest road or trail in Olympic National Park. (map prepared by R. Hoffman, Olympic National Park)

Chapter 3. Scoping and Identifying Indicators

The scoping phase was designed to solicit a wide range of ideas on significant management issues, focal species, and key ecosystems and components to monitor in Olympic National Park. We initiated this process of identifying monitoring needs with the park staff because they are most familiar with its resources, and to ensure a 'grass-roots' contribution to the planning process. However, scoping is an iterative process, so we have continued to solicit new perspectives on important monitoring topics by convening meetings of natural resource specialists from adjacent landowners on the Olympic Peninsula, and from groups of experts who have delved deeper into identifying potential indicators of park integrity. A complete listing of scoping workshops held by U.S. Geological Survey and Olympic National Park and their participants is provided in Appendix A.

3.1 Park-staff Workshop.

We invited all the park's staff to participate in a scoping workshop to help identify the most important monitoring needs in Olympic National Park. The range of this exercise included all terrestrial and aquatic systems within the park, excluding coastal resources. We excluded coastal resources at this time because initially we defined the scope of the monitoring program as coniferous forest ecosystems including aquatic subsystems within them. This definition was consistent with the 1993 Prototype Monitoring Proposal submitted by Olympic National Park. The coastal resource was considered subsequently in the Olympic National Park "vital-signs" workshop described in Section 3.3.

We used nominal group techniques to solicit input on long-term ecological monitoring needs in Olympic National Park in a structured and time-efficient manner. Nominal group technique is a way of organizing a meeting to identify and solve problems, while balancing and increasing participation in the decision-making process (Delbecq et al. 1975, www.institute.virginia.edu/services/CSA/nominal.htm). We asked each park management division (i.e., resource management, resource education, resource and visitor protection, maintenance, and administration) to send at least 5 participants to the workshop; twenty-seven Olympic National Park staff members attended (Appendix A). To keep groups as small as possible and maintain an informal 'round-table' atmosphere, we divided the participants into three work groups, each with a U.S. Geological Survey facilitator and a resource management specialist from the park to record ideas in each group, while also contributing to the discussion. We asked members of each group the two-part question, 'What resources in Olympic National Park should be monitored and why? Within each group, the workshop participants answered the question, presenting one idea at a time without discussion until everyone's ideas were exhausted. The group's comprehensive response was consolidated after a brief discussion aimed at identifying common and different meanings of similar ideas. We then asked participants to prioritize monitoring needs by rating each monitoring need as high, moderate, or low, and independently identify their top 5 choices for monitoring. The entire exercise was completed in one day.

The park staff identified a variety of park resources representing both focal species and potential indicators of ecosystem integrity, as well as potential agents of change affecting those resources (Table 3.1.1). The matrix of relationships between resources and agents of change revealed a complicated array of potential effects and park management issues. The resulting scores revealed that park staff attributed high importance to monitoring focal species, including:

- threatened wildlife species (e.g., northern spotted owls, bald eagles (*Haliaetus leucocephalus*), marbled murrelets and anadromous fish),
- flagship species such as the Roosevelt elk (*Cervus elaphus*) and the endemic trout inhabiting Lake Crescent,

- species associated with current park management issues (e.g., non-native mountain goats [*Oreamnos americanus*], rare plants, exotic plants and fishes), and
- large mammals whose proximity to park visitors poses unique management issues regarding both animal and human safety (e.g., bears (*Ursus americanus*), cougars (*Felis concolor*).

Park staff also attributed high importance to measuring potential indicators of ecosystem integrity. They identified a wide gamut of potential resources to monitor as a gauge of the park's overall health and integrity. These included recommendations to monitor:

- whole ecosystems, notably the park's signature old-growth forested lowlands and riparian forests,
- comprehensive characteristics of those ecosystems, such as biodiversity and forest health, and,
- important ecosystem processes such as fluvial dynamics and biogeochemical cycling.

Workshop participants also identified a wide variety of individual system components (e.g., dead and downed wood) and biotic communities (e.g., cryptogams, forest fungi, migratory birds, amphibians) as potential resources to monitor. Park staff assigned the highest importance values to the most comprehensively stated park resources and lower importance to more narrowly defined system components. Nevertheless, the overall high importance of ecosystem monitoring in Olympic National Park supports the need for basic long-term monitoring studies to provide environmental benchmarks and identify future challenges associated with managing protected areas.

3.2 Meeting of Adjacent Land-owners.

In April 1997 we held a workshop to learn about inventory and monitoring projects being conducted by other agencies on the Olympic Peninsula, and to solicit input on important monitoring projects in Olympic National Park. We invited representatives from Federal and State agencies with responsibilities for natural resources, private timber companies, and Native-American tribes (Appendix A). Prior to the meeting we asked each group to provide a list of on-going inventory and monitoring projects, reasons the selected indicators are of interest, a brief description of indicators, and contact information. We were able to compile the list and provide it at the meeting. A summary of the monitoring indicators and interested agencies appears in Table 3.2.1 and can be used to determine linkages with other agencies regarding indicators eventually chosen by Olympic National Park.

We also asked other agencies to identify their information needs that might be met by ecological monitoring in Olympic National Park. The comments we received emphasized the benchmark role of the park. The participants highlighted the points that healthy salmon populations and forested watersheds are rare resources, available only in the park. The natural variation of these resources and systems must be described and compared with management regimes outside of the park so that management effects can be distinguished from natural variation. Also, the park was encouraged to adopt methods that were identical or equivalent to methods used outside of the park to make comparison as easy as possible. Specific resources were also identified as high-priority subjects for monitoring:

- Physical properties of watersheds with third order streams (water quality, channel properties, large woody debris, mass-wasting frequency)
- Monitor recovery of a watershed after a burn to compare with recovery after clear-cutting or use other ways to provide baseline information for comparison with forest management practices
- Riparian areas
- Headwaters and seeps
- Amphibians
- Biodiversity
- Special forest products (moss, fungi, etc.)
- Intertidal monitoring and link the intertidal and near-shore with freshwater watersheds by considering sedimentation
- Northern spotted owls (territory occupancy, fecundity)
- Threatened and endangered wildlife species
- Neotropical migratory birds

3.3 'Focus-group' Workshops.

Olympic National Park staff convened a "vital-signs" workshop to produce a comprehensive list of important indicators of change in Olympic National Park including coastal resources. In addition to this general meeting, U.S. Geological Survey and Olympic National Park staffs also convened several other more specialized workshops (or participated in workshops organized by the National Park Service) to develop specific monitoring questions and identify useful indicators for monitoring forest vegetation, forest wildlife, biogeochemistry, airborne pollutants, and ultraviolet radiation (Appendix A).

The vital-signs workshop, sponsored by Olympic National Park, was attended by 69 scientists or resource management professionals representing several universities, government and non-government natural resource agencies (Appendix A). Participants were divided among 9 working groups corresponding to the following subject-matter categories: atmospheric resources, coastal resources, aquatic habitat and biota, human use, aquatic physical properties, invertebrates, paleoecology, vegetation resources, and wildlife resources. Participants were asked to identify the most cogent monitoring needs, potential indicators, justifications, and associated considerations in each subject-matter area (Table 3.3.1).

The complete summary of proposed monitoring indicators derived from these focused discussions is contained in Part II of this report. Each chapter contains background on the nature of park management concerns regarding each resource category, recommendations of specific indicators, justification for indicators, linkages to other topics, and conceptual models. Here, we simply provide a summary list of proposed indicators in Table 3.3.2 as a foundation for developing a more focused monitoring framework. During the peer-review of this report, some of the individual elements on this list were questioned, while others not on the list were proposed. We remind the reader that no list of potential indicators is ever complete, nor are the potential indicators equal in importance or usefulness. The list is a starting point for subsequent discussion.

Table 3.1.1. Matrix of relationships among park resources, their importance to monitoring, and potential agents of change in Olympic National Park, as identified by Olympic National Park staff.

	Importance to monitoring		Agents of Resource Change									
Park Resource	**Importance Score[1]**	**No. Top-five Votes[2]**	Atmospheric Deposition	Climate	Fire Suppression	External Habitat Loss	Harvests	Disease	Visitor Use/Facilities	Exotic/Alien spp.	Fisheries Decline	Elwha Dam removal
System Drivers												
Climate												
Atmosphere												
Adjoining land use												
TERRESTRIAL SYSTEMS												
Focal Species												
Northern spotted owl	2.9	13			x	x			x	x		
Eagles	2.9	13	x			x			x		x	x
Marbled murrelet	2.6	13			x	x			x			
Elk/deer	2.6	8			x	x	x	x	x			x
Exotic plants	2.6	6							x	x		x
Rare plants	2.6	2		x	x					x		
Mountain goats	2.3	3		x						x		
Cougars	2.2	2				x	x		x			
Bears	2.1	2			x	x	x		x		x	x
Olympic marmot	1.9	0		x								
Ecosystem Integrity												
Old-growth forest ecosystems	2.8	7	x	x	x	x	x	x	x	x	x	
Forest biodiversity	2.7	4		x	x	x	x	x	x	x	x	
Forest disturbance/succession	2.6	2		x	x	x		x	x			
Forest health	2.6	2	x	x				x				
Riparian forest dynamics	2.5	7		x				x	x	x	x	x
Amphibians	2.4	4	x	x						x		
Forest fungi	2.2	2		x			x					

	Importance to monitoring		Agents of Resource Change									
Park Resource	**Importance Score[1]**	**No. Top-five Votes[2]**	Atmospheric Deposition	Climate	Fire Suppression	External Habitat Loss	Harvests	Disease	Visitor Use/Facilities	Exotic/Alien spp.	Fisheries Decline	Elwha Dam removal
Subalpine/alpine vegetation	2.2	2	x	x	x			x	x	x		
Forest carnivores	2.1	2			x	x			x		x	x
Migratory birds	2.1	2			x	x			x	x		
Wilderness campgrounds	2.1	1							x	x		
Bats	2.1	0		x		x						
Cryptogams	2.0	1	x	x	x		x		x			
Dead and downed wood	1.8	0			x			x	x			
Small mammals	1.5	0			x	x						
AQUATIC SYSTEMS												
Focal Species												
Anadromous fish	2.9	13	x			x	x	x	x	x	x	x
Exotics	2.6	2										
Endemic trout	2.6	0	x	x			x	x			x	
Rare plants (Lake. Ozette)	1.9	1				x				x	x	
Freshwater mussels	1.6	0	x	x								
Ecosystem Integrity												
Water quality	2.7	4	x	x		x			x		x	
Fluvial process/geomorph.	2.5	7		x		x	x		x			x
Riverine habitat	2.4	1	x	x		x	x		x		x	x
Amphibian communities	2.4	4	x	x		x				x		
High mountain lakes	2.4	2	x	x					x	x		
Resident native fish	2.3	3	x	x		x	x		x	x	x	x
Biogeochemical processes	2.3	1	x	x	x		x	x	x	x	x	x
Wetlands	2.2	1	x	x					x	x	x	x
Glaciers	1.9	1	x	x								
Riverine bird communities	1.9	0	x								x	x
Macroinvertebrates	1.9		x	x		x				x	x	x

[1]Average score of respondents rating the resource as low (1), moderate (2), or high (3) importance for monitoring.

[2]Number of Olympic National Park employees voting the resource as one of the top five priorities for monitoring in the park.

Table 3.2.1. Resources currently monitored by other government agencies, tribes and private companies on the Olympic Peninsula.

	Wash. Dept. of Ecology	Wash. Dept. Fish & Wildlife	Wash. DNR[1]	Timber, Fish & Wildlife	Rayonier Inc.	Weyerhaeuser Inc.	Elwha Klallam Tribe	Hoh Tribe	Point No Point Tribe	Suquamish Tribe	Olympic National Forest	Olympic Coast NMS[2]
Streams & Rivers												
Water quality & quantity	X					X	X	X		X		
Large woody debris							X					
Stream channel						X	X					
Salmon spawning habitat				X		X	X	X	X		X	
Macroinvertebrates	X						X	X				
Forests												
Health			X								X	
Restoration projects							X					
Riparian areas				X		X						
Insects & diseases			X									
Wetlands										X		
Timber			X									
Wildlife trees						X						
Windthrow			X									
Wildlife												
Amphibians	X					X		X				
Bald eagles		X			X	X						
Band-tailed pigeon		X										
Black bear		X										
Breeding birds			X									
Butterflies		X										
Cavity nesters					X							
Deer		X										
Diurnal raptors					X							
Elk		X										
Fisher		X										
Game fish	X					X		X				
Geoduck							X					

	Wash. Dept. of Ecology	Wash. Dept. Fish & Wildlife	Wash. DNR[1]	Timber, Fish & Wildlife	Rayonier Inc.	Weyerhaeuser Inc.	Elwha Klallam Tribe	Hoh Tribe	Point No Point Tribe	Suquamish Tribe	Olympic National Forest	Olympic Coast NMS[2]
Goshawk		X			X							
Gyrfalcon					X							
Harlequin ducks		X										
Loon		X										
Marbled murrelet		X	X			X						
Marten		X										
Merlin		X			X							
Neotropical birds		X									X	
Non-game fish	X	X				X		X				
Northern harrier					X							
Northern spotted owl			X			X						
Peregrine falcon		X			X							
Raptors												X
Salmon			X					X	X	X		
Seabirds		X										X
Townsend's big-eared bat		X										
Coastal												
Cetaceans												X
Harmful alga blooms												X
Juvenile rockfish												X
Kelp												X
Marine wildlife												X
Near-shore currents												X
Pinnipeds & porpoise												X
Sea otters												X
Sea urchins												X
Shellfish & biotoxins												X
Subtidal & intertidal habitats												X

[1]Washington Department of Natural Resources
[2]Olympic Coast National Marine Sanctuary

Table 3.3.1. Template of questions used by participants of the vital-signs workshop to identify potential monitoring indicators in Olympic National Park.

NEED: What interest, problem, concern or threat will this monitoring project address (expressed as a monitoring question)?

PROPOSED INDICATOR: What component, process, or function of the ecosystem will be monitored to address the need identified above?

JUSTIFICATION: Why is this the best indicator (e.g., sensitivity, feasibility, integrative properties, sampling or observer errors, keystone attribute, etc.)?

APPLICATION: Is long-term information about this indicator primarily useful to managers within the park, on the Olympic Peninsula, throughout the Pacific Northwest, or over a broader area (specify)? How might such information be useful to land managers?

LINKAGES: How will this monitoring project link with and benefit other known monitoring projects?

DESCRIPTION: Describe the recommended spatial and temporal scales of the proposed monitoring.

PERSONNEL AND COSTS: Identify the personnel and cost requirements of the proposed project.

LIMITATIONS: Are there potential obstacles to developing protocols to monitoring this indicator or to actual monitoring? Are protocols well known or will research be needed to develop protocols?

RESEARCH AND DEVELOPMENT: What research questions must be answered to develop protocols to monitor this indicator?

Table 3.3.2. Indicators identified in scoping meetings and agents to which they are expected to respond.

Ecosystem Component	Proposed Indicators/Topics	Agents of Resource Change									
		Air Quality	Climate	Fire Suppression	External Land Use	Harvests	Disease	Visitor Use/Facilities	Exotic/Alien Species	Fisheries Decline	Dam Removal
Atmosphere and Climate	Weather		X								
	Snow characteristics		X								
	Snow course		X								
	Ultraviolet radiation	X	X								
	Ozone	X						X			
	Wet/dry deposition	X	X								
	Visibility	X		X							
	Foliar response	X									
	Soil response	X									
	Water quality in lakes & streams	X	X		X			X			
	Local air quality	X						X			
Human Activities	Vehicle counts							X			
	Visitor surveys							X			
	Experiential resources							X			
	Illegal harvest							X			
	Legal harvest							X			
	Backcountry impacts							X			
	Facility inventory							X			
	Aerial overflights							X			
	Residence counts							X			
	Incidental Business Permits							X			
	Concession activities							X			

Table 3.3.2. Indicators identified in scoping meetings and agents to which they are expected to respond. (Continued)

Ecosystem Component	Proposed Indicators/Topics	Agents of Resource Change									
		Air Quality	Climate	Fire Suppression	External Land Use	Harvests	Disease	Visitor Use/Facilities	Exotic/Alien Species	Fisheries Decline	Dam Removal
Landscapes	Disturbance		X	X			X				
	Snow cover		X								
	Vegetation phenology		X								
	Land-use outside				X						
	Vegetation structure and chemistry	X	X	X		X	X		X	X	X
	Shoreline		X		X						
Biogeochemical Cycles	Small watershed studies	X	X								
	Water quality	X	X		X			X			
	Marine-derived nutrients					X				X	
Contaminants	Snow chemistry	X	X		X						
	Persistent organic pollutants in fish, lakes, sediments, lichen	X	X		X						
Terrestrial Vegetation Communities	Forest composition and structure	X	X	X		X	X		X	X	X
	Nitrogen and carbon dynamics	X	X	X		X	X		X	X	X
	Demographic processes		X	X			X		X		
	Animal use				X	X		X			
Special Status Plants	Exotic spp.				X			X	X		X
	Listed spp.		X					X			
	Rare plants		X					X			
	Cryptogams	X	X			X					
	Exotic species				X			X	X		X

Table 3.3.2. Indicators identified in scoping meetings and agents to which they are expected to respond. (Continued)

Ecosystem Component	Proposed Indicators/Topics	Agents of Resource Change									
		Air Quality	Climate	Fire Suppression	External Land Use	Harvests	Disease	Visitor Use/Facilities	Exotic/Alien Species	Fisheries Decline	Dam Removal
Terrestrial Faunal Communities	Terrestrial mammals		X				X				
	Terrestrial birds		X		X		X				
	Terrestrial amphibians	X	X				X				X
	Terrestrial arthropods		X						X		
	Terrestrial mollusks	X	X				X		X		
Large Mammal Populations	Elk				X	X	X				
	Deer				X	X	X				
	Parasites		X						X		
	Stress hormones		X		X	X	X	X			
	Understory vegetation				X	X	X				
	Bears							X			
	Human encounters					X		X			
Special-Status Terrestrial Wildlife Populations	Endemic mammals		X				X				
	Northern spotted owl		X		X						
	Marbled murrelets		X		X		X				
	Bald eagles		X		X	X	X				
	Mountain goats		X		X	X	X	X			
Geological Resources	(undetermined)										
Aquatic/Riparian Habitats	Disturbance dynamics		X	X	X	X					
	Water quality	X	X		X			X			
	Glaciers		X								
	Stream habitat		X	X	X					X	X
	Lake & pond habitat		X								
	Riparian vegetation	X	X						X		

Table 3.3.2. Indicators identified in scoping meetings and agents to which they are expected to respond. (Continued)

Ecosystem Component	Proposed Indicators/Topics	Agents of Resource Change									
		Air Quality	Climate	Fire Suppression	External Land Use	Harvests	Disease	Visitor Use/Facilities	Exotic/Alien Species	Fisheries Decline	Dam Removal
Aquatic Biota	Plankton	X	X								
	Macroinvertebrates	X	X								
	Stream amphibians	X	X				X		X		
	Pond/lake amphibians	X	X				X		X		
	Fish	X	X			X			X	X	X
	Spawning salmon	X	X		X	X			X	X	X
	Riverine birds		X								
	Marine-derived nutrients									X	X
Special Status Fish Populations	Lake Ozette sockeye		X			X	X			X	
	Bull trout		X			X	X			X	X
	Lake Cushman/Elwha chinook		X				X				X
	Pygmy whitefish		X				X				
	Lake Crescent trout		X			X	X				
	Dolly varden		X			X	X				X
	Brook trout		X			X	X				
	Atlantic salmon		X			X	X		X		
	Olympic mudminnow		X				X				
Coastal Environments	Intertidal communities		X		X	X	X	X	X		
	Intertidal fish		X		X		X		X		
	Hardshell clams		X		X		X	X	X		
	Watershed inputs		X	X	X	X					
	Ocean conditions		X								
	Domoic acid		X		X		X		X		

Chapter 4. Conceptual Models: Context for Indicators

4.1 What is a Conceptual Model?

Modeling is the process of articulating relationships among ecosystem components, processes, and environmental effects to help select monitoring indicators. Models can also be tools to communicate why specific indicators were selected. Conceptual models are necessary because different people can have distinct views of a system based on their interests, background and experience. For example, a botanist may see vegetation in terms of individual species and their adaptations, while a wildlife biologist may see vegetation in terms of nutritional value and accessibility for herbivores, and as cover or shelter for carnivores. Conceptual models help create a common perspective, operating hypotheses, and experimental design. We hope to avoid the situation of the fabled blind men who individually insisted they were touching a rope, a tree, and a snake instead of the elephant they explored in common. It is also important to recognize that conceptual models are always works in progress representing state-of-the-art syntheses of understanding. As our perspective responds to new information, either from the monitoring itself or from other sources, we must update the conceptual model to reflect new understanding.

A conceptual model should serve the needs of the modeler. It can take any form and be constructed at any time during the process of choosing indicators. The monitoring literature includes examples of conceptual models in the form of tables (Noss 1990), box and arrow diagrams (EMAP 1990), and graphics (Thornton et al.1994) to name a few. Although models can also simply be paragraphs describing system elements and their linkages, groups of people seem to reach common understandings more quickly with visual, rather than verbal models. Regarding timing, models of simple systems might be constructed to aid indicator selection; in more complex systems, models might be used to explain why certain indicators were selected. For example, Roman and Barrett (1999) used models in the form of tables linking agents of change, stresses and ecosystem responses to identify indicators, and box and line diagrams to illustrate how the most important elements link to the rest of the system. Above all, conceptual models are tools to improve communication.

Just as there is no single format for a conceptual model, there is no single model that adequately describes an entire system. The effort is hampered by the impossibility of achieving both model generality and model realism. Model generality is needed to characterize large-scale influences and relationships among park resources; model realism is needed to identify specific potential expressions of change that could be effective monitoring indicators. Consequently, both integrative general models and realistic specific models are needed to represent systems having the spatial scale of national parks.

Models having the generality to describe the entire park will include few details about individual ecosystem components and will instead provide a broad vision of how those components interact. They will express how large categories of biotic and abiotic elements and processes are linked by processes and material cycles to form an integrated ecological system. From this perspective we will be able to discern which monitoring indicators will allow us to build an integrated monitoring program.

Achieving the model realism necessary for indicator selection can be likened to moving a magnifying glass around the park's ecological system. With each change of position, some elements are brought into sharp focus while others are less clear. For example, a model of salmon populations might have individual salmon species and stream characteristics that are important habitat factors in sharp focus; riparian tree species might be indistinctly represented as shade index, and distant trees might be grouped as factors affecting stream chemistry. In contrast, if the focus were red alder, salmon might be represented simply as pulses of marine-derived nutrients while trees would be in sharp focus.

Effective conceptual models for indicator selection can take many forms but all have certain common characteristics. Their primary purpose is to bring a specific ecological element into focus by identifying important interactions with other attributes. Creating a model requires specifying the assumptions underlying the choice of indicators, and facilitates their evaluation and acceptance.

In this chapter, we present conceptual models describing the entire Olympic National Park and terrestrial coniferous ecosystems. These models are extremely general, lacking the resolution necessary to consider individual ecosystem components (e.g., vegetation, atmosphere). Detailed models of system components will be presented in Part II where we describe each component and identify possible indicators.

4.2 Ecosystem Dynamics

Monitoring ecological systems, and especially selecting indicators of ecosystem integrity, should rest on some theoretical conception of how ecosystems work. Presently, the field of ecosystem theory is fairly young, and it can only provide general concepts and has little specific predictive ability. Nevertheless, current ecological theory colors our thinking about building conceptual ecosystem models, monitoring ecological integrity, and achieving ecological integration of the monitoring program.

Theorists consider that a fundamental property of ecosystems is that they are not in thermodynamic equilibrium (Schneider and Kay 1994, Jorgenson and Muller 2000a) because they receive an external source of energy (i.e., usually solar radiation), analogous to a hot burner under a pot of water (Nicolis and Prigogine 1989). Just as a heated pot of water dissipates energy by boiling, ecosystems develop a complexity of structures and linkages to dissipate solar energy by putting it to work. As an ecosystem develops through succession, and more solar energy is put to work, the ecosystem can exist farther away from energetic equilibrium.

An important property of dissipative structures (e.g., ecosystem components and linkages) is that they tend to be self-organizing (Nicolis and Prigogine 1989, Jorgenson and Muller 2000a). This means that ecosystems develop feedback loops, linkages, and high interdependability that result in structures and processes that are more than the sum of their parts. Self-organization has consequences for the theoretical structure of ecosystems. Although many constructs have been used to describe ecosystem structure (e.g., information theory, network theory, etc.; Jorgensen and Muller 2000b) the easiest way to visualize ecosystem structure for field-oriented biologists and land managers is probably that of hierarchy theory (see Allen and Hoekstra 1992). From this perspective, the components and processes of ecosystems may be thought of as "gears" sized according to the hierarchical position of the ecological process they represent. Smaller gears (lower in hierarchy) drive the larger (higher in hierarchy) ones in a sense. For example, forest stand level processes aggregate to landscape level outcomes, which aggregate to regional outcomes. As the system progresses through time, the smaller gears appear to move faster than the larger ones. Observations over a short period of time will document perhaps many cycles of the smaller gears and very little change, or maybe a linear trend in the larger ones. For example, at the time-scale of cell turnover, organisms may seem static. Meanwhile, organisms are part of a longer-term cycle of birth and death. At some time scale, even a static system or linear trend will become cyclical. The coming and going of ice ages, for example, illustrates an apparently static climatic regime that is in fact cyclical.

Another consequence of the thermodynamics of ecosystems is that ecosystems themselves are cyclical. Holling (1986) described the process of ecosystem succession as having four stages. In his scheme, (1) *exploitation* is the juvenile stage of succession when nutrients are rapidly acquired until the system enters the (2) *conservation* or adult stage. Eventually the system experiences disturbance and enters the (3) *creative destruction* stage when organization and connections break down. Finally the system quickly enters the (4) *renewal* stage where nutrients are released and available for the cycle to repeat (Figure 4.2.1). The dynamic properties of stability and resilience characterize early stages, while the potential for chaotic dynamics is typical of older, "over-connected" stages when systems have achieved their limit of thermodynamic instability. While this process is not random, it is

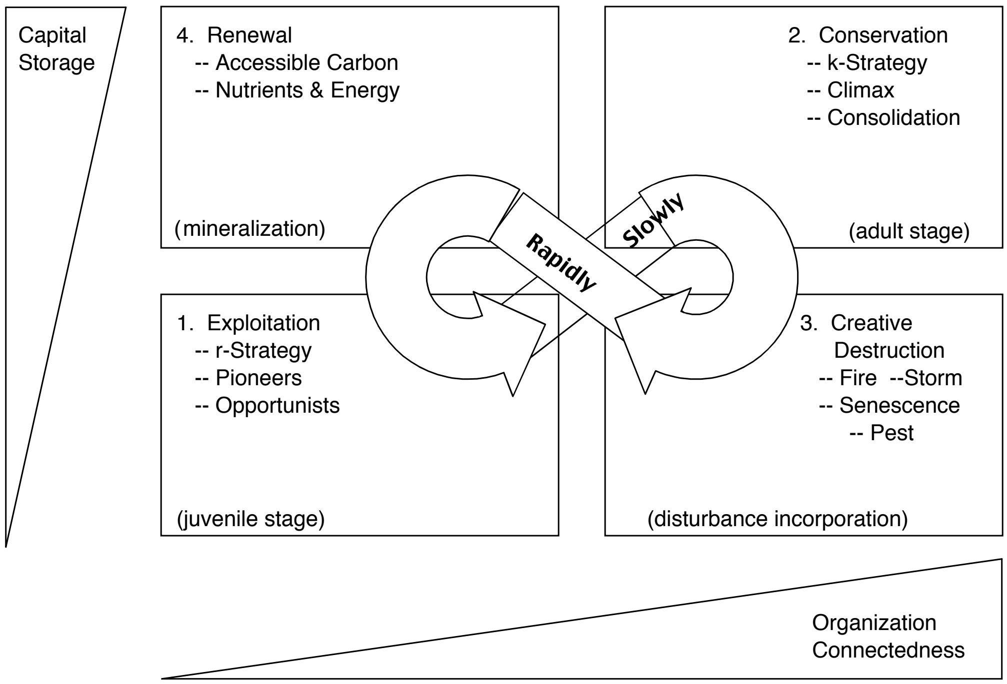

Figure 4.2.1. Conceptual model of ecosystem dynamics (adapted from Holling 1986).

unpredictable in detail because the building blocks (e.g., propagules, organisms, stored nutrients, and climatic conditions) existing at any time and place depend on site history, long-term climate cycles, the immediate disturbance, and chance. Consequently, each ecosystem is unique at some level, and spatial and temporal heterogeneity are the norm.

Despite the imprecise understanding of ecosystems provided by current ecological theory, we can apply some of the ideas to conceptual modeling and indicator selection for monitoring. General conclusions are that indicators of ecosystem status need to be integrative, that is indicate linkages rather than single elements, and they should include both structure and function. Ecological theory also provides the context for evaluating the role of those indicators chosen because they are focal species or management issues to also indicate ecosystem status. The level of biological organization and time frame of indicators are important to consider because there is a time scale appropriate for each. For animal populations the time scale might be years or decades; for catastrophic events it might be decades or centuries. It is also important to realize that the scale one step lower in hierarchy and time will provide the mechanism for what is observed, and the scale one step higher will provide the context. Using the previous example, cells turn over in the context of the organism they comprise. A catastrophic event involving the organism will change the context for its cells, affecting their behavior. We have applied these concepts to our model of coniferous forests described below.

In practical terms, it has been suggested that ecological integrity is most secure when 1) availability of biological information (i.e., genetic diversity, biodiversity), 2) availability of energy and substrates (e.g., nutrients, carbon, and water), and 3) the already existing degree of self-organization (or hierarchical structure) is preserved. These broad concepts suggest a number of more specific items to monitor (compiled from Odum 1985, Rapport et al. 1985, Noss 1990, Franklin et al. 1981, Schneider and Kay 1994, Muller and Jorgensen 2000):

- Flows of energy and materials
- Cycling of energy and materials
- Biodiversity (e.g., total, trophic structure, r/K adapted species)
- Respiration and transpiration

- Biomass
- Organization and hierarchical structure

and the following general principals for selecting a core set of monitoring indicators:

- Select indicators from important hierarchies in the ecosystem, for example trophic structure, disturbances ordered by size, or levels of organization within kingdoms of taxa (cell, organism, population, community, landscape, region).
- Monitor both structure and function (process) of ecosystems. Look for places where a functional component might be added to a structural measurement (e.g., measure mortality and recruitment in forests as well as canopy structure).

4.3 Modeling Olympic National Park

Because it is not possible to develop one comprehensive detailed conceptual model that describes all of the possible anthropogenic influences on park resources, system drivers, and potential expressions of ecological change that might be monitored, we will present models at a succession of scales. First we will illustrate our simplest view that the entire park ecosystem consists of four major subsystems: (1) alpine and subalpine areas, (2) terrestrial forests, (3) aquatic systems including streams, rivers, lakes, ponds and riparian areas, and (4) the coastal zone (Figure 4.3.1). When Olympic National Park was selected as a prototype park its managers were charged with developing monitoring protocols for coniferous forests. Consequently, most progress has been made on this subsystem. Meanwhile, monitoring for aquatic/riparian areas is under development by North Cascades National Park in its role as a prototype park responsible for developing monitoring protocols for lake and stream ecosystems. Coastal area monitoring is being developed in a separate effort in Olympic National Park. The subalpine has been the subject of ongoing monitoring of plant and animal communities in Olympic National Park around the issue of non-native mountain goats, and will receive further attention in the future.

As we increase the focus of our park view, we recognize that each subsystem has certain key categories of components and attributes in common (Figure 4.3.2). These include flora, fauna, geology and soils, and structure (e.g., physical, demographic). We also recognize that park subsystems are dynamic. They respond to system drivers and components of these subsystems interact within a subsystem and with components of other subsystems. The goal of monitoring is to discern critical changes to these dynamic systems. The chapters in Part II describe questions and indicators for resources of the entire park, but they are not completely organized according to this conceptual model. Hence, we have cross-referenced this model with Part II by indicating the chapters that cover specific elements in the model.

As we narrow our focus to one subsystem, namely coniferous forests, and try to express our understanding of it in terms of ecosystem theory, the necessary conceptual model becomes much more complex. We take a three-dimensional view of the terrestrial forest system at any point in its development (Figure 4.3.3). The vertical axis indicates that the elementary parts of forests are above- and below-ground organisms categorized into kingdoms plus soil, which have specific roles and associated processes, are acted upon by drivers, and are subject to export losses. The precise elements and complexity depend on where the system is in the successional cycle. Fundamentally, these elements interact through, and mediate flows of, the carbon, mineral and hydrological cycles, and implicitly the energy cycle. In other words, vertical flows of organic and inorganic material and energy exist at any point on the landscape.

The other two axes acknowledge that the observable features of each system component depend on both the level of organization and time frame viewed by the observer. We represent time and organizational level with discreet values, although we recognize that they are continuous, and that different ranges of each apply to different subjects. However, we feel that specific discreet examples will make it easier to visualize that appropriate indicators of change vary along these axes by considering specific intersections of the grid they form. For example, it might be important to monitor individual species if the monitoring question indicates interest in forest composition at annual time

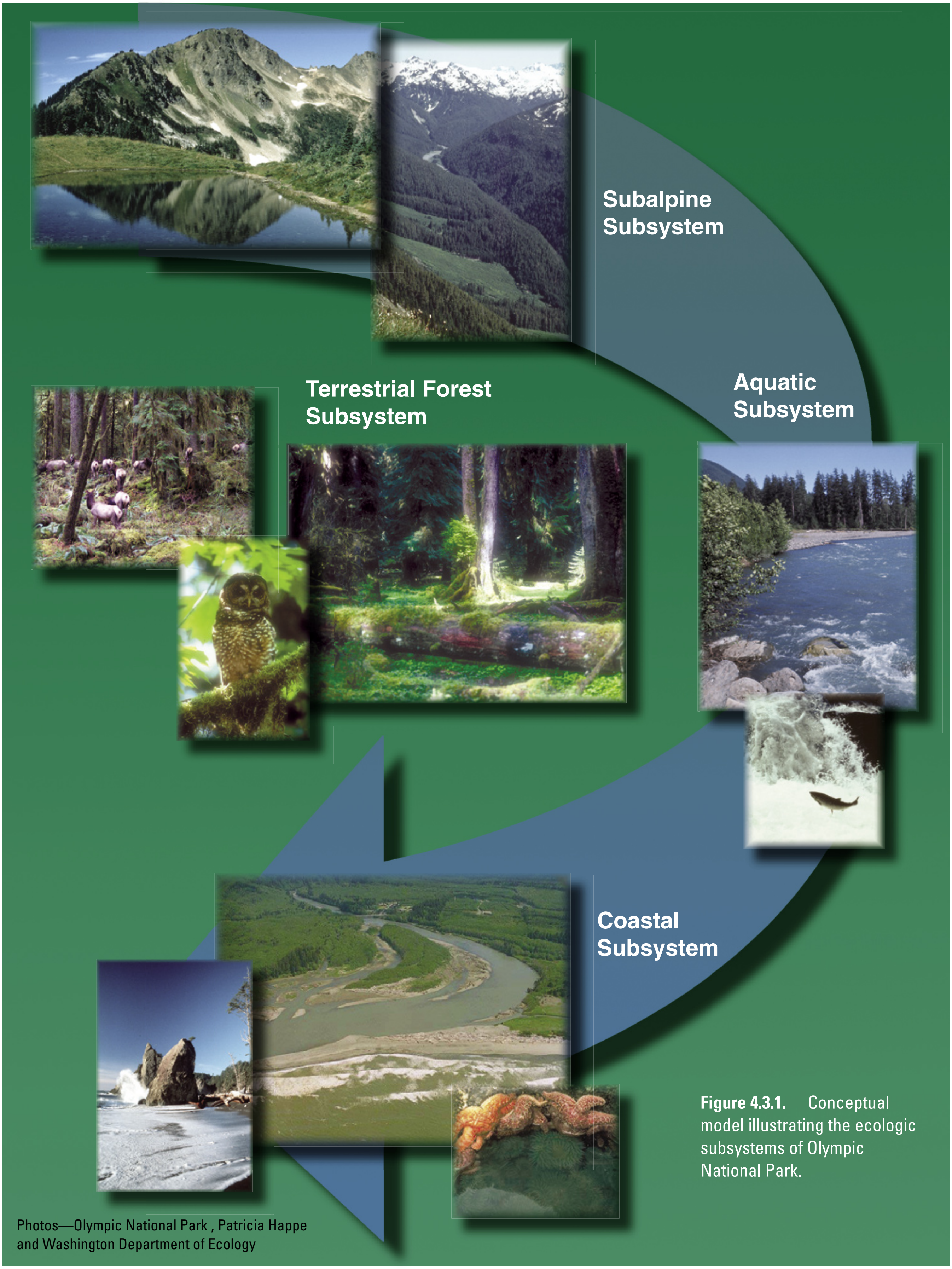

Figure 4.3.1. Conceptual model illustrating the ecologic subsystems of Olympic National Park.

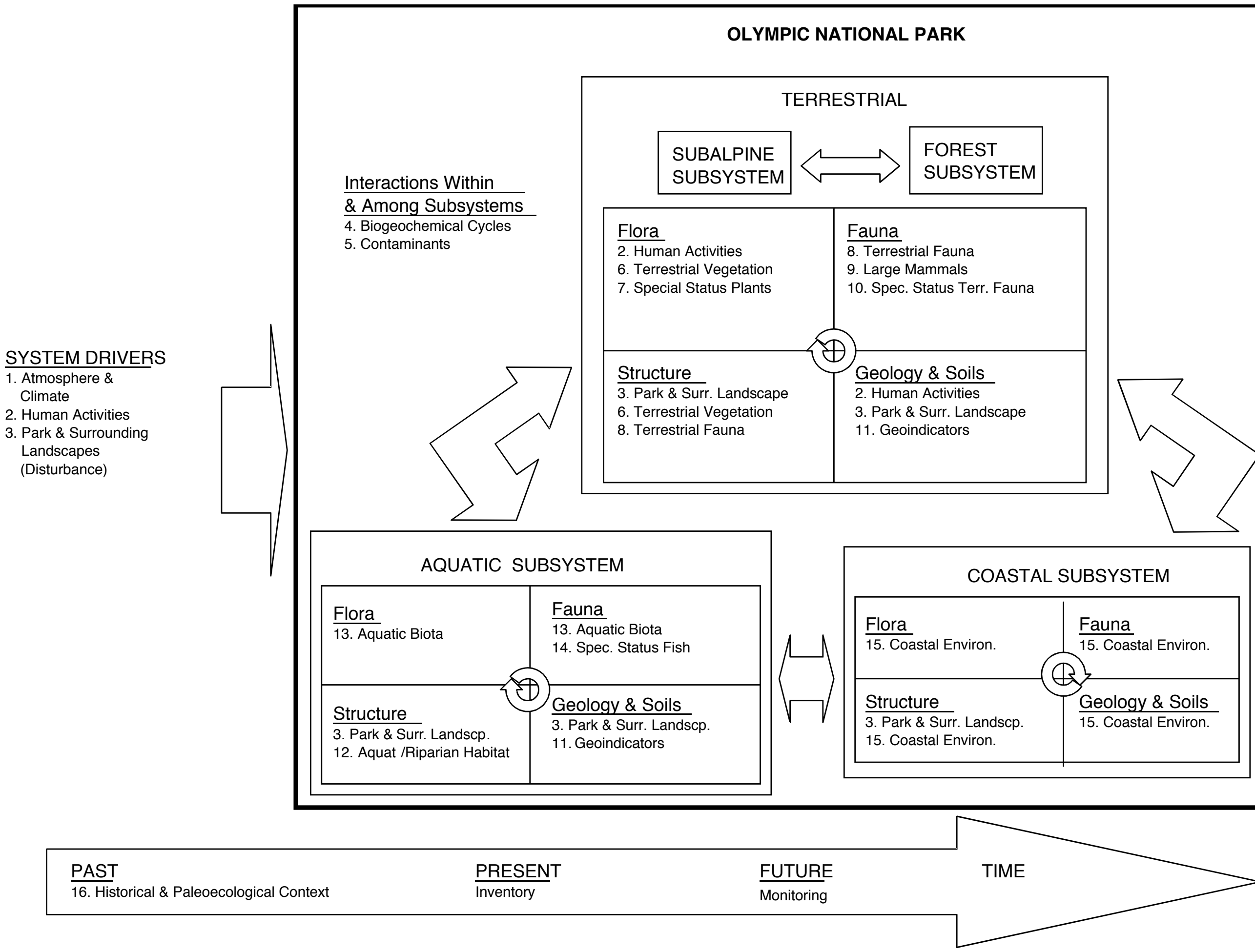

Figure 4.3.2. Conceptual model illustrating the components of, and interactions among ecologic subsystems of Olympic National Park. Correspondence of subject matter with the chapters of Part II is also shown.

steps. However it may be appropriate to monitor forest communities or stands at the decadal scale, and to monitor changes in landscape pattern of composition over an even longer time step. Likewise, while individual species might be important indicators of productivity at the stand level, it might be appropriate to monitor leaf-area index at larger spatial scales. Finally, one might monitor carbon dynamics using photosynthesis hourly at the leaf level, carbon allocation daily or seasonally at the plant (organismal) level, annual net primary production at the stand or community level, and carbon sequestration at the regional or global level.

Each monitoring question indicates the organizational and temporal scales of interest and therefore the appropriate variables, and suggests triggers for management response. We expect that in the process of indicator selection, each subject-matter focus will have pertinent questions at various temporal and spatial scales. Conceptual models and possible indicators for subject-matter areas are presented in Part II.

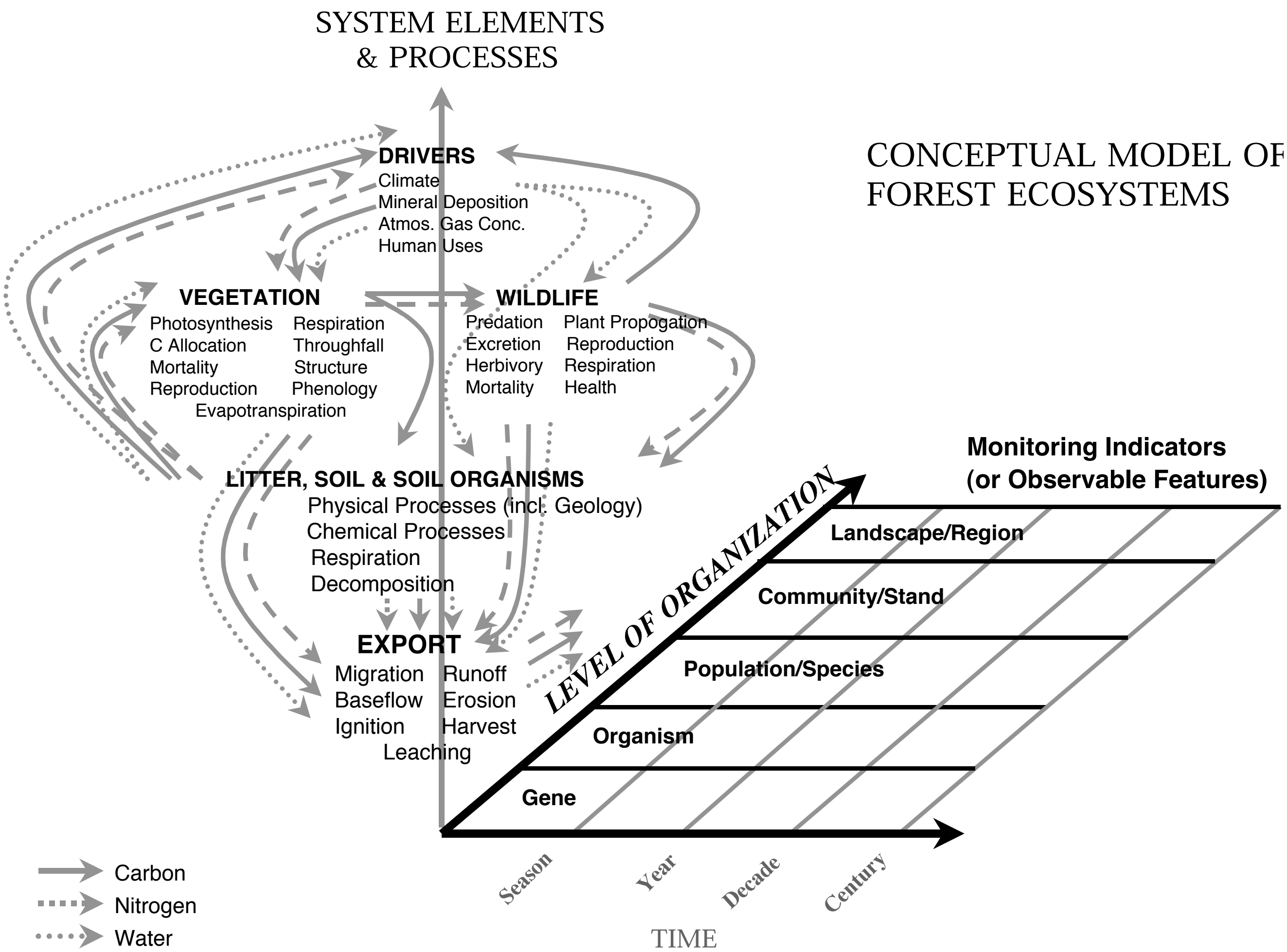

Fig. 4.3.3. Conceptual model of the terrestrial coniferous forest ecosystems showing flows of carbon, nitrogen, and water, and illustrating the dependence of time frame of observable change on the hierarchical position (i.e., level of ecological organization) of the indicator.

Chapter 5. Framework for Monitoring Coniferous Forest Ecosystems

All scientists and researchers working in Olympic National Park quickly encounter a common set of sampling issues having to do with how best to distribute samples spatially while considering trade-offs associated with the high costs of access. Among others, each researcher must answer the following questions:

- What is the targeted population to which inferences will apply (i.e., population in the statistical sense of the complete set of objects to be studied)?
- How should samples be distributed most efficiently throughout the population of interest?
- Should samples be distributed systematically or randomly?
- Is stratification a useful tool to enhance sampling efficiency?

Left to his or her own designs, each monitoring scientist will develop unique solutions to these generic questions, often to the detriment of integration goals. While defining the spatial population of interest is project-specific and objective-driven, the development of a generic sampling framework can help immensely to facilitate the co-location of sampling efforts where mutual interests overlap spatially. Agreeing upon an 'umbrella' sampling design is an important step in the development of an integrated monitoring program.

In the following sections, we develop a generalized framework for sampling and monitoring coniferous forest ecosystems. We consider the generic issues of scale inherent in designing any sampling framework. We develop a conceptual model for integrated sampling in the coniferous forest subsystem, discuss general sampling principles, and present examples for implementing the integrated sampling model in Olympic National Park.

5.1 The Economy of Scales

Spatial integration of monitoring projects involves co-locating multidisciplinary components of the monitoring program on common study plots. Ideally, we would like to monitor several related attributes of ecological systems to promote understanding of interrelationships within ecological systems and be able to explain possible causes of observed patterns of change. Unfortunately, financial and logistical constraints make it impossible to measure everything everywhere, so the planning process must consider trade-offs in how best to allocate limited financial resources to best meet the overall monitoring goals.

Recently, Hall (1999) described the challenge of designing a monitoring framework as a process of optimizing trade-offs among scale, scope, and statistical power of sampling.

- Scale, as used here, refers to "the temporal and spatial dimension at which and over which phenomenon are observed" (O'Neill and King, 1998), or in our case, measured. Measurement scale, consists of two parts: grain, the smallest interval of space or time measured, and extent, the total area or the length of time over which observations are made (O'Neill and King, 1998). Observations made frequently in many small plots have very high temporal and spatial grain, respectively, whereas observations made infrequently or in large plots have lower temporal and spatial grain. With respect to extent, observations made over very long periods of time and large geographic areas are often referred to as having large temporal or spatial scales. The spatial scale and temporal scales of measurement are important considerations in designing a monitoring program because they define the extent of area to which the monitoring results apply, and they greatly influence costs of monitoring.

- Scope refers simply to the amount of information that is gathered at each sampling site. As mentioned, having information about a variety of related ecological attributes promotes better understanding of changes. If scale refers to the extent of area to which understanding applies, scope refers to the depth of understanding attained.

- Statistical power refers to the ability of sample measurements to reveal actual changes in the population being measured. Power of a monitoring program depends upon many variables, notably the variability in the attribute measured and the number of independent measures obtained, e.g., the number of independent sample plots. Inadequate sampling effort would negate the value of monitoring at any spatial scale or scope if it fails to detect a meaningful level of change (Gerrodette 1987, Hayes and Steidle 1997).

The most luxurious monitoring program would include comprehensive measurements of diverse system components, sampled broadly, and replicated abundantly to maximize understanding, inference, and detection simultaneously.

Alas, there are no free samples in the real world, so trade-offs must be considered in choosing among sampling frequency and intensity, sample size, and spatial scale of statistical inference during the design phase of monitoring development. The point may be illustrated by representing a monitoring program, schematically, as a cube, the volume of which is limited by the total amount of resources available for monitoring, and the shape of which is controlled by the allocation of monitoring effort to the three axes (Figure 5.1.1). Spatial effort, controlling the height of cube, refers to the spatial extent, or scale, over which the sample will be distributed and to which legitimate inferences may be drawn. Measurement effort, controlling the width of the cube at its base, refers to the detail and complexity of sampling, or scope, conducted at each sample point. Replication effort, depicting the depth of the cube, refers to the number of sample units possible, given any combination of fixed resource levels available for monitoring and chosen spatial and measurement efforts. By necessity, monitoring projects with the greatest scope and complexity are conducted at comparatively small spatial scales (e.g., consider the U.S. Geological Survey/National Park Service's small watershed ecosystem studies or the National Science Foundation's Long-term ecological research network) and they are rarely replicated sufficiently to allow inference beyond the study site at the local level. At the other extreme, comparatively shallow studies of presence/absence or relative abundance of specific taxa typically are conducted more extensively across broader spatial scales, and are replicated more easily than are intensive long-term-monitoring efforts. We identify these two opposite ends of the allocation-of-effort spectrum as 'extensive design' and 'intensive design,' although there are all possible gradations of 'intermediate designs' in between.

Economics of the scaling issue are particularly acute in large wilderness-area parks where high costs of access to sampling sites greatly affects both the measurement and replication efforts possible under fixed funding constraints. In our effort to integrate many monitoring projects of diverse scope and scale in Olympic National Park, and to accommodate as many monitoring projects as possible, our conceptual framework for monitoring requires explicit consideration of sampling scales and trade-offs.

5.2 Conceptual Framework for Integrated Monitoring in Coniferous Forests

Here, we propose a generic framework for monitoring the coniferous forest subsystem of Olympic National Park. In this conceptual framework we recommend several 'core' components of long-term monitoring in coniferous forests, spatial linkages among these program elements, and implicit trade-offs in the scope (or complexity) of each monitoring project and spatial scale of sampling (Figure 5.2.1). Although the generic model presented here identifies several of the key monitoring themes identified for the coniferous forest subsystem, final decisions on specific monitoring projects will come after the park staff reconsiders monitoring priorities for all the ecological subsystems (see Chapter 6). The framework illustrates a nested sampling design with intensive monitoring projects co-located with more extensively designed monitoring projects on nested subsets of sampling plots. Though limited to the coniferous forest subsystem, key features of this framework apply to monitoring aquatic, coastal, and subalpine subsystems of the park.

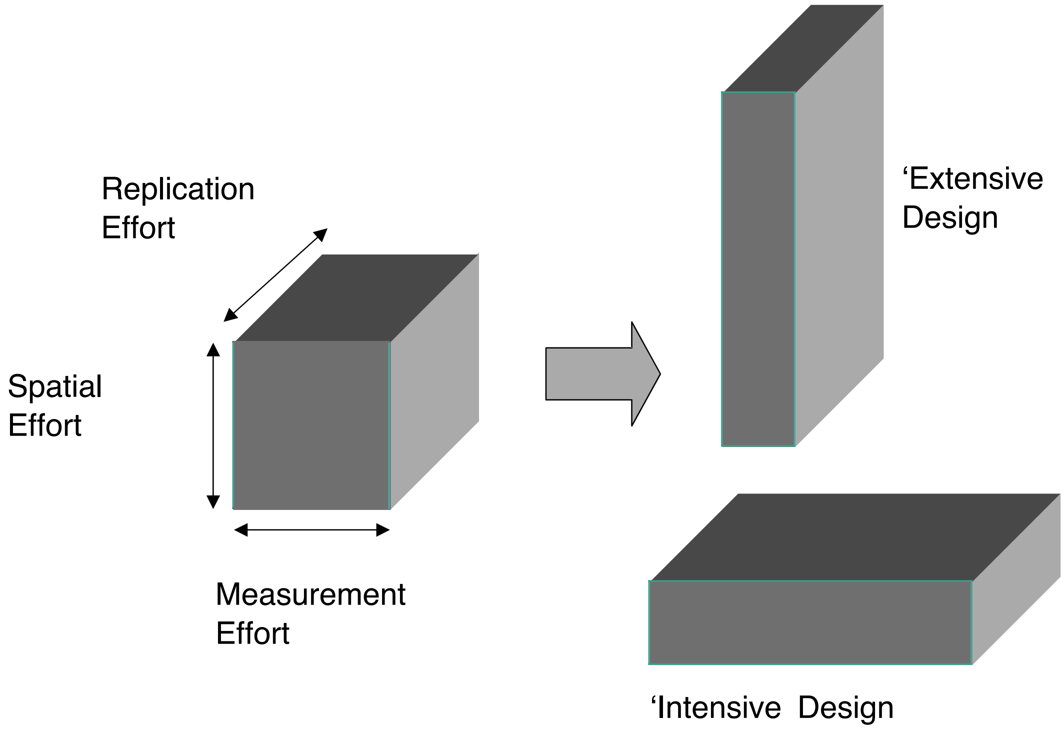

Figure 5.1.1. Allocation of sampling effort among axes of spatial scale, measurement effort (i.e., scope), and replication effort in 'extensive' and 'intensive' sampling designs.

At the broadest of scales possible, representing the 'extensive design', we envision parkwide monitoring of the composition and disturbance history of park landscapes and vegetation (Figure 5.2.1). Such monitoring would address the large-scale questions: 'Are changes in regional stressors affecting disturbance regimes? Composition of park landscapes? Composition of forest communities?' Although patterns in landscapes might be examined through remote sensing virtually throughout the park, monitoring changes in selected vegetation attributes on the ground might also lend themselves to sampling at the parkwide scale (e.g., presence/absence of exotic plant species). Certain broad-scale studies of animal distribution patterns, for example that of forest breeding birds, might also be linked to the most extensively distributed plot network.

Many other projects may require that sampling is restricted to a smaller area of the park due to the nature of the monitoring question asked, or perhaps because sampling requirements or logistical constraints preclude sampling at the parkwide scale. An example of such an 'intermediate-scale' monitoring study might include monitoring the effects of ungulate herbivory on forest vegetation or perhaps monitoring of indices of ungulate abundance (e.g., pellet group surveys). Monitoring the intensity of ungulate herbivory, as an example, would require additional effort in vegetation measurement that may not be practically implemented on a parkwide scale, but could realistically be implemented in a subset of the park that encompasses the majority of elk and deer winter ranges.

Other 'intensive' monitoring projects may have parkwide importance, but high sampling requirements force an economy of scales. For example, consider the following monitoring questions:

- Are long-term changes in climate or atmospheric deposition influencing key biogeochemical cycling processes in forest ecosystems?
- Are densities of key wildlife populations changing?

Although any of these questions are of park-wide importance, the expense of instrumentation or the frequency sampling requirements, data retrieval, or maintenance schedules (for instrumentation) precludes distributing such monitoring effort representatively throughout remote wilderness. Such studies must be restricted to subsets of the total sample area and subsets of potential sampling plots inscribed by the vegetation-plot sampling frame. The congruence of scale implied by many of these relatively intensive projects suggests a high potential for integrated monitoring of a suite of indicators on intensive monitoring plots, as demonstrated by overlapping circles in Figure 5.2.1.

5.3. A Sampling Primer

a. Identifying the Population

For each monitoring project, the important first step in designing the sampling scheme is to clearly identify the target and sampled population to which inferences from monitoring will be made. The target population is the population of interest (i.e., about which information is sought), whereas the sampled population is that from which the sample is actually drawn. Ideally, the sampled and target populations are identical, but sometimes the sampled population is more restricted in spatial extent than the target population due to practical or logistic considerations. For example, areas where the slope is too steep to safely sample may be excluded from the sampled population. It is important to clearly indicate that conclusions drawn from the sample apply only to the sampled population.

b. Probability-Based Sampling

The next step is to design a probability-based sampling scheme, meaning that all members of a population have a known probability of being chosen for the sample. In the past, there was a tendency for biological research to be conducted on ‘representative’ sites as defined by the researcher. While this may satisfy the researcher’s sense of the typical condition, the data can not be extrapolated reliably

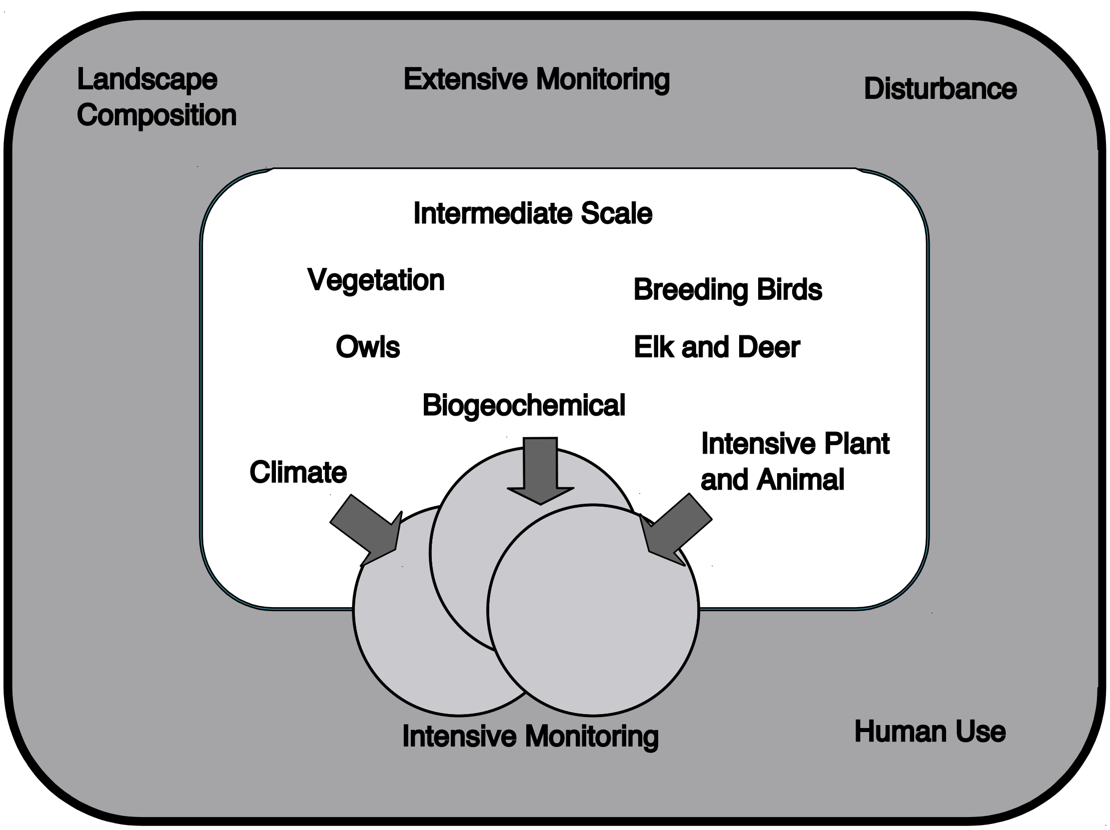

Figure 5.2.1. Monitoring framework showing recommended core elements of proposed monitoring in the coniferous forest subsystem in Olympic National Park and spatial relationships among extensive and intensive monitoring designs.

to other than the sampled sites. Only results from a probability-based sample from a specific population can be extrapolated beyond individual sites to the larger population.

Among the many variants of probabilistic sampling, simple random, cluster, and systematic sampling are the most commonly used. With simple random sampling, each point is randomly selected independently from the whole population. With systematic sampling, sample points are evenly spaced, often on a grid after a random start. Cluster sampling begins with a random or systematic sample of points and at each point a cluster of samples is taken (e.g., subplots on a transect). Any of these sample types (i.e., simple random, compact cluster, or systematic) can be distributed probabilistically throughout the sampled population using equal probability, stratified, or unequal probability sampling (Figure 5.3.1). With equal probability sampling, all areas are equally likely to be selected. With stratified sampling, the park is divided into relatively homogeneous areas called strata. Equal probability sampling is used within strata; the selection probability and sample density can be different for different strata. With unequal probability sampling, the probability of selection and sample density can vary continuously across the park. Stratified sampling is a special case of unequal probability sampling where probabilities of selection differ among strata.

c. Selecting the Sample

Intuitively, most biologists and ecologists gravitate toward choosing a stratified random sample to distribute plots among different resource categories that exist on the landscape (e.g., plant communities, habitat types). Stratified random sampling allows researchers flexibility to allocate effort differently among resource categories, depending upon sampling variation within and among strata or upon the abundance or rarity of resource categories. Many biologists prefer stratified random sampling because results grouped by category have a biological basis for interpretation.

Despite these considerations, stratified random sampling is not always the most flexible or efficient method of detecting spatial patterns of change (e.g., change in relation to a park boundary, elevation or other environmental gradients). Strata boundaries may change physically over time (e.g., consider the effects of forest disturbance and succession), and biologists frequently differ over what constitutes the biologically meaningful categories for stratification.

Based on the pros and cons of sample types and distributions (Tables 5.3.1 and 5.3.2), many statisticians advocate distributing a systematic sample in either a stratified or unequal probability distribution pattern. This sample scheme ensures representative survey coverage throughout the targeted area while allowing for acquiring enough samples of common resources as well as an adequate sample of rare ones. Our discussion of sampling methods considered these as well as financial and logistical issues in formulating the following sampling recommendations for Olympic National Park.

5.4. A Generalized Sampling Design

We recommend the following generalized sampling scheme to meet the many considerations of monitoring in a large wilderness park with limited access:

For each project, delineate verbally and visually the sampled population to which inferences will apply. The sampled population will be delineated uniquely for each monitoring project depending upon monitoring objectives, as well as biological and practical considerations. Delineations (strata) should be defined by practically unchanging geographic or topographic criteria (e.g., elevation and/or slope, but not vegetation category). For safety reasons, we recommend omitting slopes >35° from the sampled population. It may also be practical for logistical or biological reasons to limit sampling to specified areas of the park. For each monitoring project we recommend mapping the sampled population, or alternately, to shade black those areas of the park that have been deleted from the sampled population.

For many monitoring projects in Olympic National Park, it is necessary for practical reasons to delineate sampled populations on the basis of human accessibility. Many regions of the park require several days of foot travel to get to sampling locations (Figure 2.11.1), and helicopters are not recommended due to high costs, wilderness considerations, or impacts to threatened or endangered

Table 5.3.1. Characteristics of simple random, cluster, and systematic sampling methods.

	Pros	Cons
Simple Random	• Simple and has straight-forward statistical properties	• The distribution of random points is usually clumped
Cluster	• Most useful when travel costs among sites are high	• Degrees of freedom for analysis are based on the number of sites rather than the number of plots
Systematic	• Spreads sample evenly in space	• Under-samples rare resources and over-samples common ones

Table 5.3.2. Characteristics of equal probability, stratified, and unequal probability samples.

	Pros	Cons
Equal Probability	• Simple to implement • All areas are equally important • Emphasizes common species	• Can be inefficient • Provides little information on less-common species
Stratified	• Sample density can be increased to provide adequate samples for less-common species • Sample density can be increased in more accessible areas to increase sample size	• More complicated than equal probability sampling • Strata must remain fixed forever, although one can switch to unequal probability sampling, which will allow changes
Unequal Probability	• It has the advantages of stratification without need to define discrete strata • One can add samples without regard to the initial strata • Probability of selection can vary continuously	• More complex than stratified sampling • One must keep track of the selection probabilities

species. To permit flexibility in delineating sampled populations and varying sampling probabilities in relation to access costs, we recommend stratifying the park according to the following categories of accessibility and human use (Figure 5.4.1) :

High Accessibility/Human Use: areas <1.5 km from a maintained park road
Moderate Accessibility/Human Use: areas <1.5 km from a maintained hiking trail.
Low Accessibility/Human Use: areas >1.5 km from a maintained road or hiking trail.

On occasions, a tremendous effort is required to hike more than 1.5 km from maintained trails in Olympic National Park due to dense understory vegetation and obstacles in the form of large dead and downed trees, root masses, and difficult terrain. Therefore, these stratification categories have proven useful to help researchers allocate monitoring effort in relation to costs and practical considerations in several inventory projects in Olympic National Park. While such restriction would limit parkwide inference, it is encouraging to know that >25% of each primary vegetation class falls within these two most accessible sampling zones (Figure 5.4.2). Thus, inference drawn from the two most accessible categories captures a significant area of the park.

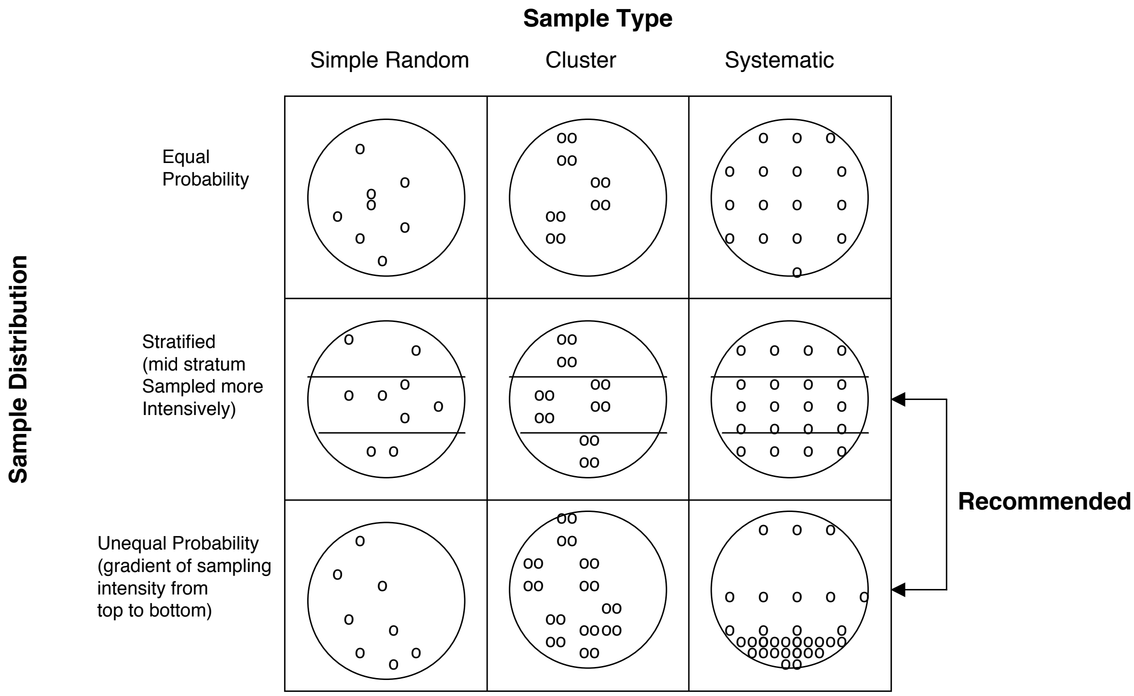

Figure 5.3.1. Primary sampling methods and strategies for sampling distribution.

We recommend developing a generic grid-based sampling frame to select sample units for monitoring within Olympic National Park. We also recommend using a 100-m grid superimposed over the entire park as the most basic sampling frame. Although this represents an immensely dense grid for large-scale sampling purposes, it provides enough potential sampling sites for localized sampling of rarer resources. This grid can be sampled across different spatial scales or at different sampling intensities depending upon the specified sample population and goals. For example, remotely sensed attributes could be sampled extensively, ostensibly at every sampling location throughout the park. Most attributes will be measured at lower intensity, either throughout the park (by selecting every nth sampling point systematically) or at a more restricted scale by limiting the sampled population to specified elevation zones, accessibility zones, or other definable criteria.

To increase sampling efficiency, we recommend using unequal probability sampling to allocate effort among the defined human access/use zones. For many monitoring projects it will be desirable to concentrate sampling efforts in the most cost-effective zones. As an example, consider the goal of developing a parkwide network of vegetation monitoring plots. Assuming the goal of such a project was parkwide inference, we recommend establishing a network of plots with low survey coverage in the Low Accessibility stratum and greater coverage in the High and Moderate Strata (Figure 5.4.3). Such a scheme would allow parkwide inference while enhancing cost effectiveness.

We recommend co-locating monitoring efforts on the network of vegetation monitoring plots to the extent possible. Individual monitoring projects, however, will require adjustments in sampling distribution and intensity depending upon the specific monitoring objectives. It will be necessary to augment the sampling intensity for monitoring projects that focus on comparatively rare resources or those requiring a greater sampling intensity than that provided by the generalized vegetation sampling frame. For example, if monitoring ungulate fecal pellets or other indices of ungulate use called for a greater concentration of sampling points in lowland winter ranges of Roosevelt elk than that provided by vegetation sampling, then an additional layer of points could be superimposed on the above sampling frame (Figure 5.4.4). The additional sample must be with replacement, and the probability associated with the new points is determined by the intensity of the second round of sampling.

Alternatively, cost constraints associated with intensive monitoring projects will force a reduction in spatial scale relative to generic vegetation sampling. We recommend co-locating intensive monitoring projects within a subset of points sampled under the more extensive designs. For example, it may be desirable to sample microclimate of forest vegetation as a subset of general vegetation plots. Because instrumentation associated with such monitoring may require frequent site visits, it may be advantageous to specify a restricted sample of vegetation monitoring points within the high-access sampling zone. Figure 5.4.5 depicts a hypothetical random selection of vegetation monitoring points for monitoring forest climate within forest plots located within the most accessible sampling stratum.

Over time, the use of a common sampling frame for all monitoring projects will create overlapping samples, with each sample layer defined by project-specific objectives and clearly defined sample populations. Though points may be selected for different purposes with different selection probabilities initially, and distributed across different spatial scales, data may be analyzed for any domain of data at a later time, provided that common measurement protocols are used and the sample selection probabilities are known.

As demonstrated in these examples, the generalized sampling frame promotes spatial integration of sampling sites chosen for a wide variety of monitoring projects. It provides flexibility for the development of practical sampling plans by explicitly considering accessibility in determining sampling probabilities for each project. Systematic samples may be combined with other independently derived samples to increase efficiency and interpretation and ensure adequate sampling of rare resources.

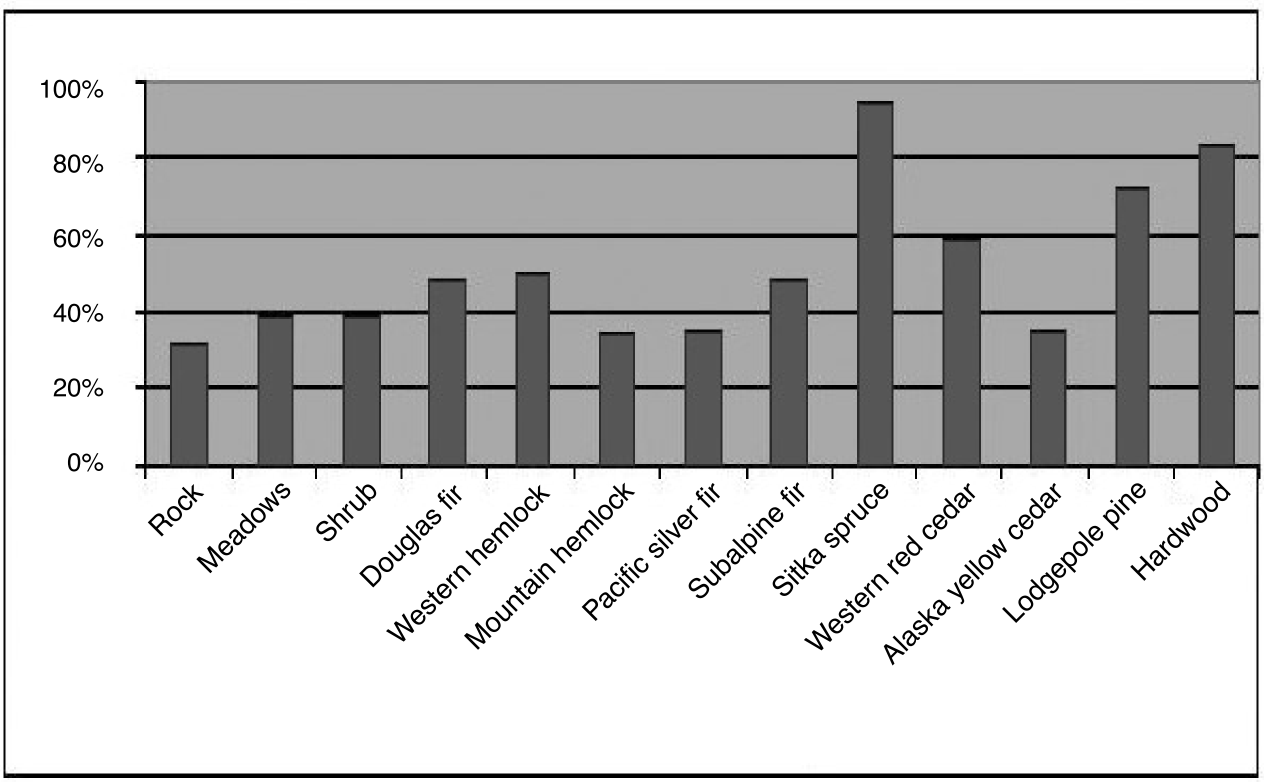

Figure 5.4.2. Percentages of mapped vegetation types falling within the combined high and moderate zones of human access/use in Olympic National Park.

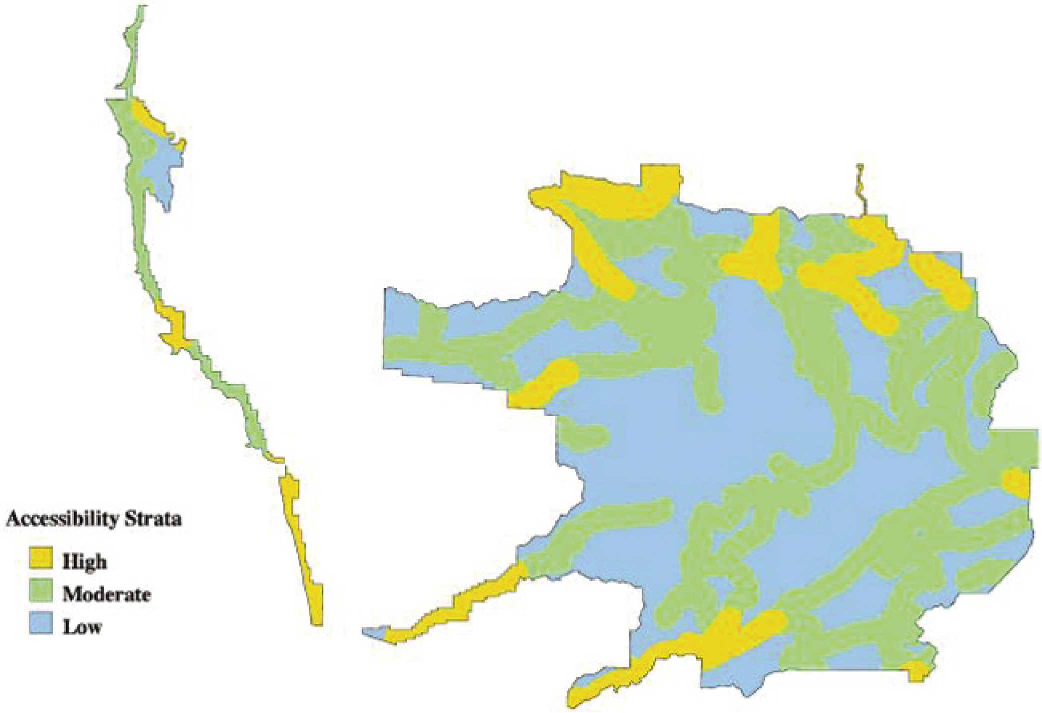

Figure 5.4.1. Stratification of human access/use zones for sampling in Olympic National Park. (map prepared by R. Hoffman, Olympic National Park)

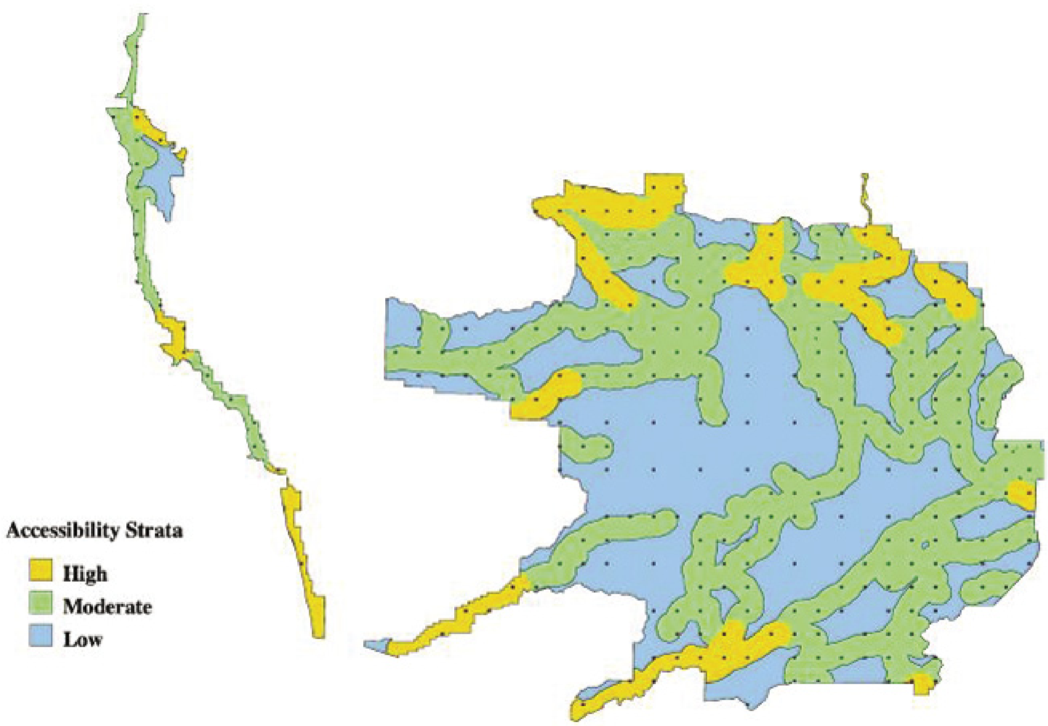

Figure 5.4.3. Hypothetical systematic distribution of vegetation monitoring plots in Olympic National Park with unequal probability of selection in zones of high, moderate, and low human access/use (probability of selection decreases from highest to lowest human access/use). (map prepared by R. Hoffman, Olympic National Park)

Figure 5.4.4. Hypothetical selection of sample plots for monitoring ungulate 'sign' on lowland winter ranges of Roosevelt elk in Olympic National Park. The hypothetical sample includes the previous selection of vegetation monitoring plots supplemented with additional randomly selected points to achieve a greater sample size. Park area excluded from the sampled population is shown in black.
(map prepared by R. Hoffman, Olympic National Park)

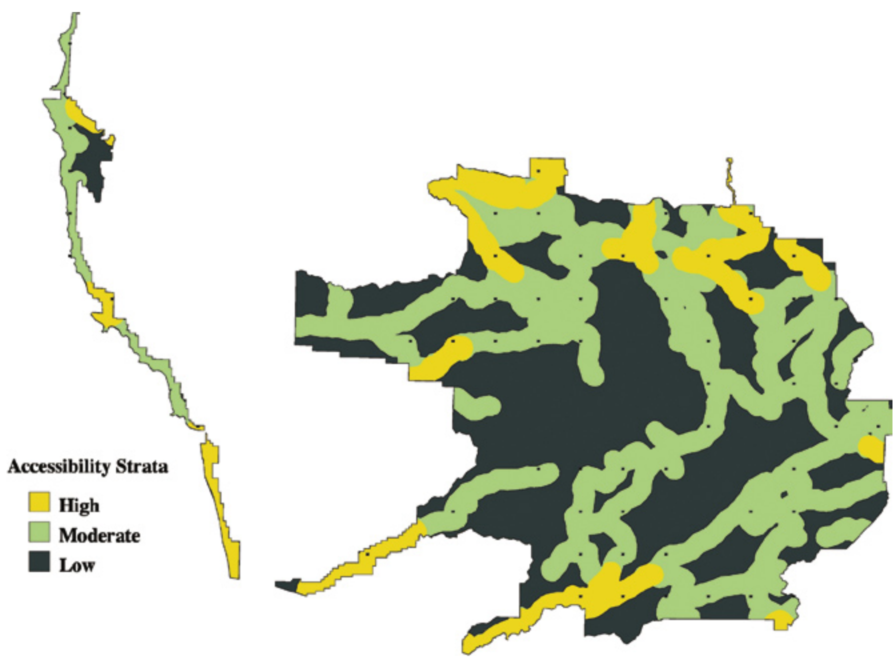

Figure 5.4.5. Hypothetical selection of sample plots for monitoring microclimate of forest stands. The hypothetical sample is a systematic subsample of forest vegetation monitoring plots restricted to those plots within the high and moderate-access sampling zone. Park area excluded from the sampled population is shown in black.
(map prepared by R. Hoffman, Olympic National Park)

Chapter 6. Next Steps

6.1 Setting Priorities

The scoping meetings and conceptual modeling identified a large set of possibilities for monitoring in Olympic National Park. To date, the Olympic Park staff has assigned only crude priorities to broad topic areas (see Table 3.1.1). Since that early exercise, the program has received additional input resulting in an increased number of topic areas. Working with Olympic National Park staff, we honed the topics to specific questions within topic areas, and then identified indicators to answer each question (see Part II for the outcome). The next step is for the Olympic Park staff, working in close coordination with the North Coast and Cascades Network and personnel involved with the North Cascades prototype program, to undertake a structured and well-documented approach to prioritize indicators and determine which protocols are available or should be developed.

Several structured approaches for reaching group consensus have been developed (e.g., Delphi, nominal group technique (Delbecq et al. 1975). One promising approach to prioritization is the analytical hierarchy process (Saaty 1980) as applied to ecological monitoring and natural resource management by Peterson, et al. (1994, 1995). The process seems most productively applied to monitoring questions (rather than indicators), and can be summarized as having the following steps:

- Identify the objectives of the monitoring program. The objectives should be based on those of the national program (Chapter 1.2) but may include some additional ones reflecting the local program. For example, an additional objective for Olympic National Park might be to meet the expectations of a prototype park. Peterson et al. (1995) recommend working with no more than seven objectives.
- Identify criteria that can be used to determine how well each monitoring question meets each objective.
- Determine a quantitative weight for each objective, and criterion within objectives, according to its importance relative to other objectives and criteria. For example, all criteria may be considered equal, or some may have greater importance than others.
- Rate each monitoring question for each criterion across all objectives on a scale of 1-5 according to how well it meets the criterion.
- Calculate the final rating for each question by weighting the scores for each question as determined above and sum across all criteria.
- Identify a cut-off point or some other criterion for determining which questions will be included in the monitoring program and which will not. Those that will not be included at this stage may be considered at a later time should resources or priorities change.

Many monitoring questions can be addressed using more than one indicator (Part II). Thus, priorities also need to be established for the potential indicators within each monitoring question. Indicators could be chosen for each question by repeating the analytical hierarchy process within each question using different objectives. Objectives for indicators may include cost, availability of protocols, desirable statistical properties, etc. Alternatively, chosen indicators could simply reflect the priority of the question. Accordingly, questions with a higher priority are appropriate for a more intensive effort than those with lower priority.

The analytical hierarchy process, or any other formal process for setting priorities, is merely a tool—decisions are ultimately made by, and the responsibility of resource managers. A formal process allows decision-makers to explicitly specify assumptions and explore their consequences. In the end, the process of setting priorities is inescapably subjective, based on current knowledge, and the outcome must be generally intuitive to resource managers to be acceptable. If the outcome is not intuitive, then it is appropriate to explore the causes by reassessing the weights given to the importance of criteria and objectives and repeating the exercise. This process should be considered iterative and can be revisited as knowledge, resources, and political and environmental factors change. In the meantime, the first outcome agreeable to the group should describe the general outline of the monitoring program and provide a worthy starting point.

6.2 Agency Roles in Protocol Development and Implementation

The protocol development and implementation phases follow the initial design phase of long-term ecological monitoring (Figure 2.5.1). **Protocol development** involves selecting core monitoring components, developing study plans, conducting research and testing monitoring protocols, developing data management systems, and preparing written protocols (Figure 2.5.1). The U.S. Geological Survey is committed to help protocol park programs with protocol development. The **implementation** phase includes all aspects of operational monitoring, including data collection, data management and analysis, project reporting, and periodic review of monitoring protocols. In previous prototype monitoring programs, the U.S. Geological Survey received funding for protocol development a few years in advance of the National Park Service prototype parks receiving funds for program implementation. This funding sequence led to discrete stages of protocol development, orchestrated by U.S. Geological Survey scientists, followed by implementation of monitoring programs by the National Park Service (as in Figure 2.5.1).

In contrast to that model, Olympic National Park and the rest of the North Coast and Cascades Network received funding from the National Park Service's 'Natural Resources Challenge' to implement its monitoring program at the same time the U.S. Geological Survey was funded to develop the protocols. Consequently, the North Coast and Cascades Network has added staff dedicated largely to the development and implementation of monitoring. The synchronous funding and professional staff capabilities at both the North Coast and Cascades Network and U.S. Geological Survey blurs the separate timelines and agency responsibilities for protocol 'development' and 'implementation' phases.

Specifically, synchronous funding presents a unique opportunity for joint-funding and agency collaboration in the development of monitoring protocols. The North Coast and Cascades Network and U.S. Geological Survey have entered into a memorandum of understanding agreeing to develop monitoring protocols cooperatively whenever subject-matter expertise and staff workloads permit. In some circumstances, primarily the U.S. Geological Survey principal investigator will provide funding, supervision, and employees, whereas in other cases National Park Service ecologists will provide the principal leadership. In the case of U.S. Geological Survey leadership, at least one person from the National Park Service will have responsibility for setting the direction for each protocol. Frequent communication will be the key to cement effective collaboration between U.S. Geological Survey and the National Park Service scientists and managers, and ensure that U.S. Geological Survey work in protocol development compliments park efforts. Primary responsibilities will be worked out during the study-planning phase for each individual protocol. We recommend both agencies follow a similar process—study plan, research and development, data management, protocol development, and peer review. The process must be carefully documented, leaving an administrative record of decisions, study plans, research reports and peer review. Either the U.S. Geological Survey or the National Park Service may administer the documentation and peer review process, depending upon project leadership. In preparing protocols, we recommend that U.S. Geological Survey, National Park Service, or cooperating ecologists follow recommendations of the National Park Service Inventory and Monitoring Program for protocol development and data management (see www.nature.nps.gov/im/monitor; for recommendations on monitoring protocols see Oakley and Boudreau 2000).

6.3 Developing a Work Plan

Priority monitoring projects determined by Olympic National Park and the rest of the North Coast and Cascades Network are expected to require an ambitious amount of protocol development. The next step following prioritization is to begin work on a handful of the identified elements by deciding which to address first. The recommended monitoring program will be built based on programmatic objectives while the choice of starting point will take other issues into consideration as well. Specifically, each recommended monitoring indicator should be evaluated for:

- Availability of protocols developed by others
- Progress already made toward developing the protocol during previous pilot studies or other monitoring efforts in parks (e.g., Amphibian Research and Monitoring Initiative, previous deer and elk research)
- Whether the element is being developed by another park in the network or elsewhere
- Feasibility
- Opportunity to build on other monitoring that is already underway by the park
- Management considerations
- Available financial and human resources

This analysis should lead to a logical work plan because the element-specific answers to the above evaluation indicate the amount and type of needed work and what to do next. For example, the initial stage of work might focus on finishing protocols already under development, investigating the feasibility of those ecologically important elements currently undergoing theoretical development, and investigating efficiencies or effectiveness of alternative protocols. Once a work plan has been established describing the initial elements, the type of work needed (e.g., complete the protocol, investigate other protocols, work on theory), and the progress desired in the first stage, protocol development can begin.

Part II. Indicators of Ecological Condition in Olympic National Park

This section describes monitoring questions and potential indicators for monitoring ecological condition of natural resources in Olympic National Park. Here, we have assembled an unranked (i.e., no priorities established), comprehensive summary of all monitoring questions identified thus far for all the major ecosystems of Olympic National Park, including terrestrial, aquatic, and marine resources. Each chapter covers one subject area and includes a justification for monitoring, monitoring questions and potential indicators, linkages with other sections, the spatial and temporal scales, and research and development needs. Time intervals are recommended in advance of power analysis and other estimates of variation. They should be considered preliminary. The organization of material by sections reflects the content of the vital-signs workshop, various meetings, and other topic-oriented workshops (interrelationships are shown in Figure 4.3.2, Part I). Consequently, there is much overlap among sections (e.g., water quality is identified as an indicator in at least six chapters) and one could easily defend an alternate organization of the material. Each chapter should not be considered a potential protocol. Instead, a protocol could be written for each indicator. These chapters present the raw material from which Olympic National Park, in cooperation with the network, must choose monitoring indicators:

In the course of writing specific monitoring questions for each subject, we encountered some challenges. While identifying quantitative objectives for monitoring is a universally recognized need (Elzinga et al. 1998, Noon 1991), being able to specify exactly the amount of change necessary to detect over a given time period is not always easy. The specificity of the monitoring questions we could write depended on the type of information being monitored, knowledge of biologically significant changes, and some idea of natural variation. Consequently, we recognize three types of monitoring questions:

1) Questions with Quantitative Monitoring Goals. These are questions that express the need for monitoring in terms of quantitative changes in a specific metric over a given amount of time. The metric may be the mean of some response evaluated based on its variance.
    a) Monitoring is often used to learn whether management actions are working or are needed. In these cases, the monitoring question can specify quantitative detection goals based on Limits of Acceptable Change or other criteria. For example, one might want to monitor whether some percentage of plants in a revegetation project have persisted after a set amount of time.
    b) Some non-management monitoring questions can be asked with specific goals if there is some knowledge or intuition about what constitutes a biologically significant change. For example, one might want to detect when a rare plant population has declined below a certain percentage of its baseline size.
2) Questions Reflecting the Need to Obtain Trend Data. Especially for system drivers, such as weather and human activities, it is important to monitor trends over time without specifying a need to detect a quantitative change. These variables are out of the control of management, but will help anticipate future changes and will enable interpretation of other monitoring results. These questions will be phrased as the need to detect a trend in some variable.
3) Questions Regarding Resources About Which We Have Limited Knowledge. Some monitoring of ecosystem responses might have quantitative goals when we know more about what is a biologically significant change. In this case we frame questions that ask whether a change has occurred and take an educated guess at what level of sampling will be required, or conduct a pilot research project to determine variance of the indicator. As monitoring proceeds, experience will teach us how to effectively monitor each subject. These are the questions that are most in need of re-evaluation and mid-course correction of the monitoring approach.

The value of being able to state quantitative monitoring goals for a specific indicator is that, along with some knowledge of natural variation, one can design a sampling protocol with sufficient replication to achieve the goal. As discussed in Part I, Chapter 5, financial limitations require monitoring to be a trade-off among scope, scale, and intensity. Having a quantitatively stated question can lead to a quantitative understanding of the trade-off for each question.

With these ideas in mind, in the following sections we present the comprehensive list of monitoring indicators identified thus far for Olympic National Park.

Chapter 1. System Drivers: Atmosphere and Climate

Monitoring Need/Justification:

The climate of the Olympic Peninsula is driven by air masses coming from the west and southwest, which collect moisture while moving across the Pacific. When intercepted by the barrier posed by the Olympic Mountains, these air masses release most of their moisture on the windward side, leaving little for the leeward side (Renner 1992). The combination of the quantity of moisture stored in maritime air masses and tall mountains able to extract that water out causes the Olympics to have one of the steepest precipitation gradients in the world. Climate drives ecological systems and in the Olympics the geographically and elevation-driven temperature and precipitation gradients make a complex pattern that is extremely difficult to interpolate between the few existing weather stations (Figure 1.1 Map). The problem is compounded by the predominance of low elevation weather stations, making high elevation climate difficult to infer.

In addition to being moist, air masses crossing the Pacific are relatively unimpacted by local or continental pollution sources. Consequently, the coastal and rainforest areas of the park have cleaner air than many other ecosystems in the coterminous United States (Thomas et al. 1989). Under the Clean Air Act (1977, www.epa.gov/oar/oaq_caa.html) Olympic National Park is designated as a Class I air quality area. In Class I areas very little deterioration of air quality is allowed. Additionally, values that may be affected by changes in air quality (termed Air Quality Related Values; ARQVs) must also be protected in Class I areas. These values in Olympic include visibility, odor, flora, fauna, and geological, archeological, soil, and water resources. Within the National Park Service, management of resources is guided by a number of Service-specific pieces of legislation. Standards for baseline knowledge and monitoring of atmospheric resources are provided in NPS 75 (National Park Service, 1992). At Olympic National Park, baseline information regarding atmospheric and meteorologic resources for existing monitoring stations is adequate to meet Level I (i.e., Phase I which is the minimum level) of these standards. Level II standards are not met for the entire geographic area within the park boundary.

Despite the relatively pristine condition of Olympic's air, studies have shown that airborne pollutants affect even the mountainous core of the peninsula. Industrial and urban emission sources affecting the north side of the park are located in Port Angeles. However, SO_2 levels measured nearby at the park's air quality site do not violate federal or state air quality standards and they are lower than those measured in Port Angeles itself. Ozone concentrations increase with elevation and are monitored along an elevation gradient on the north side of the park. Acid precipitation has been examined only on the west side of the park. The average pH of rainfall at the Hoh is approximately 5.2 (NADP, http://nadp.sws.uiuc.edu). Nitrate concentrations during the year vary little at this site, but during the summer, inputs of SO_4, another acid-forming ion, are greatest. The source is partly biogenic, from oceanic planktonic algae, but long-range transport from Asia may also influence the chemical composition of the atmosphere. Another threat to park air quality is increasing pollution that is emerging from the rapidly growing metropolitan area from Vancouver, British Columbia to Portland, Oregon. Pollutants are carried from these sources by easterly winds. Finally, the consequences and magnitude

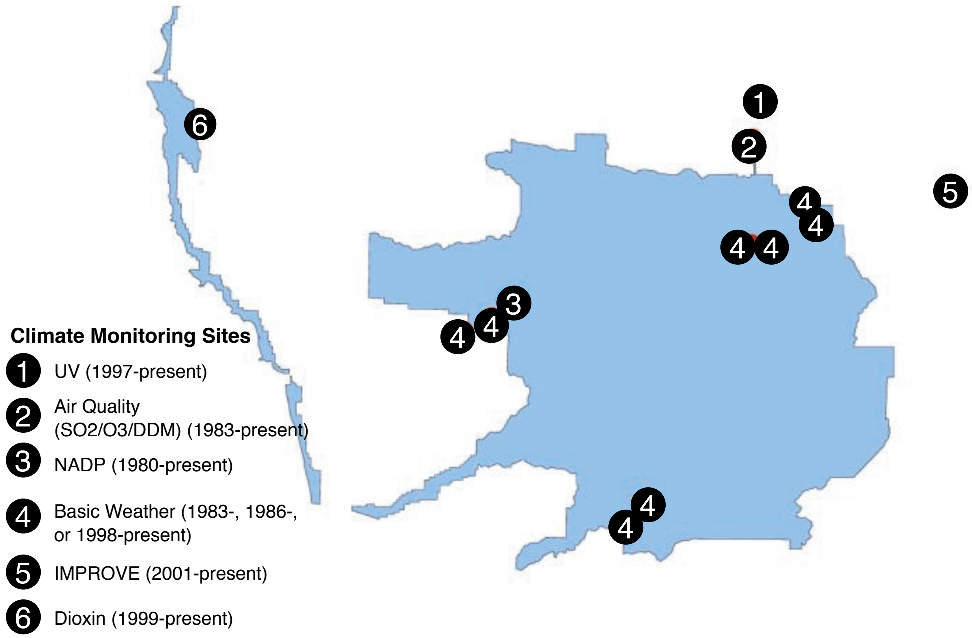

Figure 1.1. Map of extant atmosphere and climate monitoring stations in Olympic National Park plus an IMPROVE site outside. (map prepared by R. Hoffman, Olympic National Park)

of increasing ultraviolet radiation penetrating the atmosphere at northern latitudes is unknown.

While air pollutants do not appear to pose a significant threat to terrestrial resources in the park at present (Eiler et al. 1994), there are examples of national parks that have been impacted. The park houses potentially sensitive vascular plants, lichens and mosses, which could be early-responders to pollution if methods for monitoring them are devised. Meanwhile, climate, independent of considerations of pollutants, drives all terrestrial and aquatic systems and it must be understood in order to interpret nearly all research and monitoring done in the park. Consequently needs exist for models of weather, air pollution dispersal, and deposition patterns in the complex situation caused by orographic influences on airflow by the Olympic Mountains.

Monitoring Questions and Indicators:

Question: What are the status and trends of geographic and elevational patterns of weather?

- **Indicator**: Meteorologic Variables. Add additional weather stations to those already existing and operated by various authorities. Existing permanent stations include the Elwha Ranger Station, Quinault Ranger Station, Port Angeles, Hurricane Ridge, South Mountain and the Hoh River; a temporary station exists at Deer Park. Additional stations are recommended for Mt. Anderson, Hoh Lake and the upper Sol Duc drainage, but placement should be determined in consultation with climate modelers. Measured variables should include air and soil temperatures, radiation and energy flux, relative humidity, and wind speed and direction. *Justification*: These are standard climatic and energy variables, and they are used to predict climatic variation and resource impacts in various ecosystem models. The additional sites will provide linkage to glacier monitoring and will give better geographic coverage at high elevations. *Limitations*: There will be challenges with maintenance, data analysis and locating sites having a large enough canopy opening. Spatial interpolation will be difficult.

Conceptual Model:

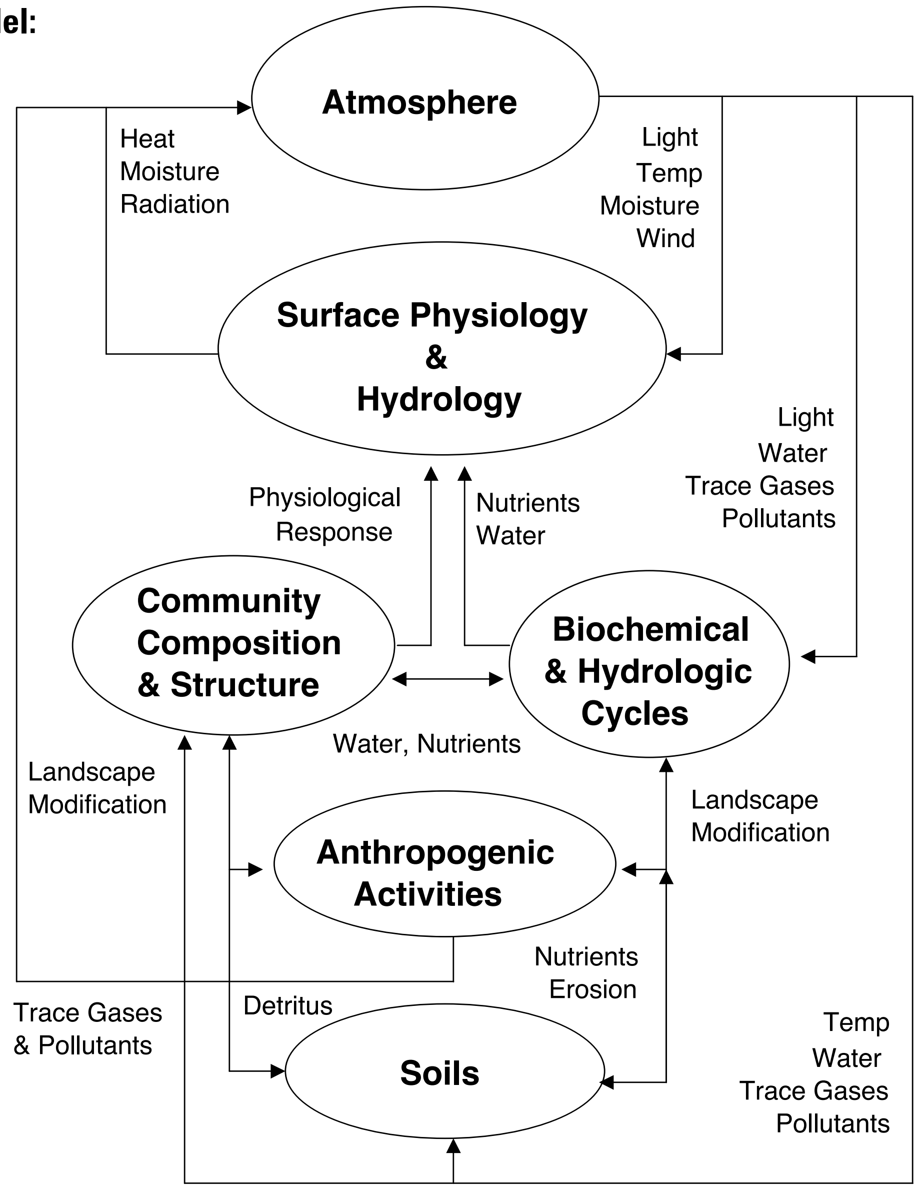

Figure 1.2. Conceptual model of the interactions among atmospheric and terrestrial ecosystem components (modified from Hall et al. 1989).

- Indicator : <u>Snow Characteristics</u>.
  - <u>Depth and Timing of Snow</u>. One Snowpack Telemetry (SNOTEL) site currently operates at Hurricane Ridge, providing continuous data on snow depth, snow water equivalent, and timing of snowfall. Add three additional SNOTEL sites at Mt. Anderson, Blue Glacier, and the upper Sol Duc River. *Justification*: Eighty-percent of annual precipitation falls during the winter meaning that snow depth and water content have critical effects on hydrologic resources, which affect terrestrial and aquatic ecosystems. The data can be used to validate models of snowpack and hydrology. *Limitations*: As with the met stations, siting, maintenance and data analysis will be challenging.
  - <u>Snow Depth and Water Equivalent</u>. Measure rain and snow deposition and distribution (depth and snow water equivalent) more widely in the park by making some snow course measurements on the west side of the

peninsula. *Justification*: We need a better understanding of climatic variation and better estimates for inputs into hydrologic models describing distribution of water and soluble chemicals. Snow course measurements are relatively easy and inexpensive. *Limitations*: Access to high elevation areas on the west side is difficult.

- Park-wide Snow Cover. Use aerial photos and/or satellite imagery to map and quantify snow-covered areas. *Justification*: This will contribute to understanding climate variation in time and space and will help estimate inputs into hydrologic budgets. *Limitation*: Cost.

Question: Are there trends in ultraviolet radiation interception?

- Indicator: Ultraviolet Radiation. Continue to monitor continuous broad spectrum UV radiation at the present site on Ediz Hook. Perhaps add less expensive monitors to other parts of the park. *Justification*: UV radiation is predicted to change due to global climate change, and may have important consequences for biota. UV monitoring is part of a national program of the Environmental Protection Agency. *Limitations*: The UV monitor is expensive to maintain.

Question: What are the geographic and elevational patterns of ozone?

- **Indicator**: Ozone Patterns. Add a continuous ozone monitor permanently at Hurricane Ridge and two temporary analyzers on the east side of the park and at the Hoh to supplement the one already operating near Port Angeles. Passive analyzers might be recommended, especially at high elevation, following analysis of data collected over the last 5 years. *Justification*: These new analyzers will describe elevational and spatial distribution of ozone. The one at the Hoh will indicate "background" ozone levels for the Olympic Peninsula and perhaps all of western Washington. *Limitations*: Analyzers require a power source but must also be located away from vehicle traffic. Also, it is difficult to find locations in the park that meet the siting requirements for size of canopy opening.

Question: What are the status and trends of geographic patterns of wet and dry deposition?

- **Indicator**: Patterns of Wet and Dry Deposition. Add measurements of wet deposition to the dry deposition site in Port Angeles, and measurements of dry deposition to the wet deposition site in the Hoh. Wet deposition includes dissolved ions such as nitrate, ammonium, and sulfate. Dry deposition includes other, undissolved chemical compounds. *Justification*: These are standard measurements used nationally by NADP. They will provide information regarding the effects of nitrogen and sulfur on terrestrial and aquatic ecosystems by describing rain and snow chemistry, and dry deposition. The new sites will improve geographic coverage. *Limitations*: Finding representative sites will be difficult due to high spatial variation and it will be difficult to extrapolate the data to large areas. Also, the accuracy and meaning of dry deposition estimates is questionable.

Question: What is the geographic distribution of changes in airborne particulates and impairment of visibility?

- **Indicator**: Visibility. Add another Interagency Monitoring of Protected Visual Environments (IMPROVE) site to the one already existing on the east side of the park. The new site should be located on the west side of the park to capture the low-pollution condition there. *Justification*: Adding monitoring to the west side of the park would give better geographic coverage. *Limitations*: Expense.

Question: Are terrestrial resources changing, including pollution-sensitive vegetation and soils?

- **Indicator**: Foliar Diagnoses of Pollution Effects. Monitor foliar diagnostic symptoms of pollution effects (e.g., chlorosis, needle retention) and effects on lichens with other vegetation monitoring. *Justification*: These measurements will link ecological effects with changes in pollutant concentrations and can be incorporated with other vegetation monitoring efforts. *Limitations*: Minimal because little effort is needed to identify appropriate locations, vegetation types and species to monitor. The main expense would be field time.

- **Indicator**: Soil Chemistry and Microbes. Measure temporal variation in soil nitrogen, soil microflora and microfauna, and carbon to nitrogen ratio. *Justification*: These measurements can be made in conjunction with vegetation monitoring and will describe ecosystem response to changes in air quality and precipitation chemistry. *Limitations*: Cost of analysis.

Question: Is water quality changing in sensitive lakes and streams (i.e., those that are oligotrophic or have low acid neutralizing capacity [ANC])?

- **Indicator**: Water Quality in Lakes and Streams. Measure surface water quality, including pH, ANC, conductivity, and major anions in lakes and streams with the lowest ANC. Water bodies having low ANC are the most sensitive to SO_4 and NO_3 anions because of the H^+ cations that accompany them. Lakes having low ANC will have to be identified with an initial survey. *Justification*: These methods are used nationally in surface water surveys and will indicate changes in the most sensitive systems as an early warning of ecosystem effects. *Limitations*: If sensitive lakes are in the backcountry, they will be more costly to access.

Question: Is local air quality near road corridors and campgrounds changing?

- **Indicator**: Local Air Quality. Temporarily measure air quality, especially visibility, sulfur dioxide, carbon monoxide, and ozone in areas where management may have particular concerns (e.g., road corridors, campgrounds, fee kiosks, etc.). *Justification*: This will easily address management concerns. *Limitations*: No areas are currently of concern.

Linkages with Other Disciplines:

- Park and Surrounding Landscape. Snow cover.
- Aquatic/Riparian Habitat. Lake and stream chemistry, especially in low ANC lakes.
- Biogeochemical Cycles. Lake chemistry, soil chemistry.
- Terrestrial Vegetation Communities. Foliar response to air pollution and radiation.

Research and Development Needs:

- How can sampling be optimally designed to facilitate accurate interpolation of climatic data, including wet and dry deposition, both geographically and elevationally? What are the best statistical/quantitative techniques for doing this?
- How can lapse rates (change in temperature with elevation) be accurately quantified? Data from the Quillayute weather balloon will be helpful.
- Perhaps short-term monitoring on elevation gradients would be a fruitful approach.
- What is the quantitative relationship between passive and continuous ozone data? (Project is underway.)
- What are the quantitative relationships between air pollutants and ecosystem effects (e.g., symptomatic impacts for plants, relative sensitivity of different soil types to elevated atmospheric nitrogen inputs)?
- How many lakes in Olympic National Park are sensitive to deposition of the acid-forming ions SO_4^{-2} and NO_3^- because they are oligotrophic or low-ANC systems?

Spatial and Temporal Context: Where and How Often to Monitor:

This table indicates existing monitoring (E) and recommended additional monitoring (R).

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Meteorology	E	E	E	E(e)	E(e) R(w)	E(e) R(e)	E	R	R	Hourly
SNOTEL	R	E				E, R	E	R	R	Daily
Snow Course	R	E			E	E	E			Monthly
UV		E	E				E			½ Hourly
Ozone	R	E	E(e) R(w)		R(e)		E	R		?
Dry Deposition	R	E	E(e) R(w)				E(e)R(w)			Monthly
Wet Deposition	E	R	E(w) R(e)				E(w) R(e)			Monthly
Visibility	R	E		E, R			R	E		Daily
Foliar Effects	R	R				R	?			Annually
Local Air Quality										Daily

(e) indicates east side of park (drier areas) (w) indicates west side of park (wetter areas)

Chapter 2. System Drivers: Human Activities

Monitoring Need/Justification:

As human population increases, so does visitation to national parks and the consequent risks to park resources, both natural and experiential. The population of Washington State alone is projected to increase from 5.9 million in 2000 to 7.5 million by 2025. Meanwhile, visits to Olympic National Park have increased from 100,000 in 1945 to 3 million in 1984 and 4.2 million in 2001 (park records). Thus, anthropogenic threats to park resources are increasing both inside and outside the park.

Effects of human activity occur immediately outside of the park and are due largely to forest management practices. Examples of impacts within the park from these activities include blow-down of park trees adjacent to clear-cut logging on the boundary, slash burns escaping into the park, water pollution due to herbicide spraying, and increased siltation of park waters (Olympic National Park 1999). Additionally, over 85 km of roads provide unofficial access to the park and facilitate timber theft, poaching of wildlife and plants, and illegal harvest of shellfish. Non-forest activities affecting the park include such things as local industries and transportation, fish hatcheries, increasing residential development, ocean vessels, and mining. Other anthropogenic effects are regional and global. Examples include regional and global habitat degradation for migratory species, ocean fishing, particulates from Asia, effects on air quality caused by increasing industry/vehicle traffic between Vancouver, B.C. and Portland.

Inside the park, high visitor use directly affects wilderness values. Unsanctioned campsites, social trails, and unacceptable trail widening have resulted from intense backcountry use and have caused unacceptable vegetation loss and on-going erosion (Olympic National Park 1999). Changes in experiential values, such as solitude and quiet, have not been measured. High numbers of visitors may require management to change the placement of facilities such as ranger stations, trail bridges, boardwalks, privies and bear-wires, all affecting wilderness resources.

Recognizing the need to manage visitor use proactively to protect experiential and biologic resources, the National Park Service advocates use of the Visitor Experience and Resource Protection (VERP; National Park Service 1997) planning framework by parks, similar to the Limits of Acceptable Change (LAC) framework. These are dynamic processes for developing indicators and standards to address visitor carrying capacity and management issues for both experiential and biologic resources. The goal is to set standards for the limits of acceptable change in indicators of resource quality (e.g., percent bare ground, number of others encountered on trails) and link those indicators with more easily measured indicators of visitor numbers (e.g., number of cars in the parking lots, number of vehicles passing fee stations). When the standards are exceeded, management action is required. The standards must protect against both ecological harm to biologic resources and disappointment of visitor expectations because these are both part of the National Park System mandate (U.S. Congress 1916).

Conceptual Model:

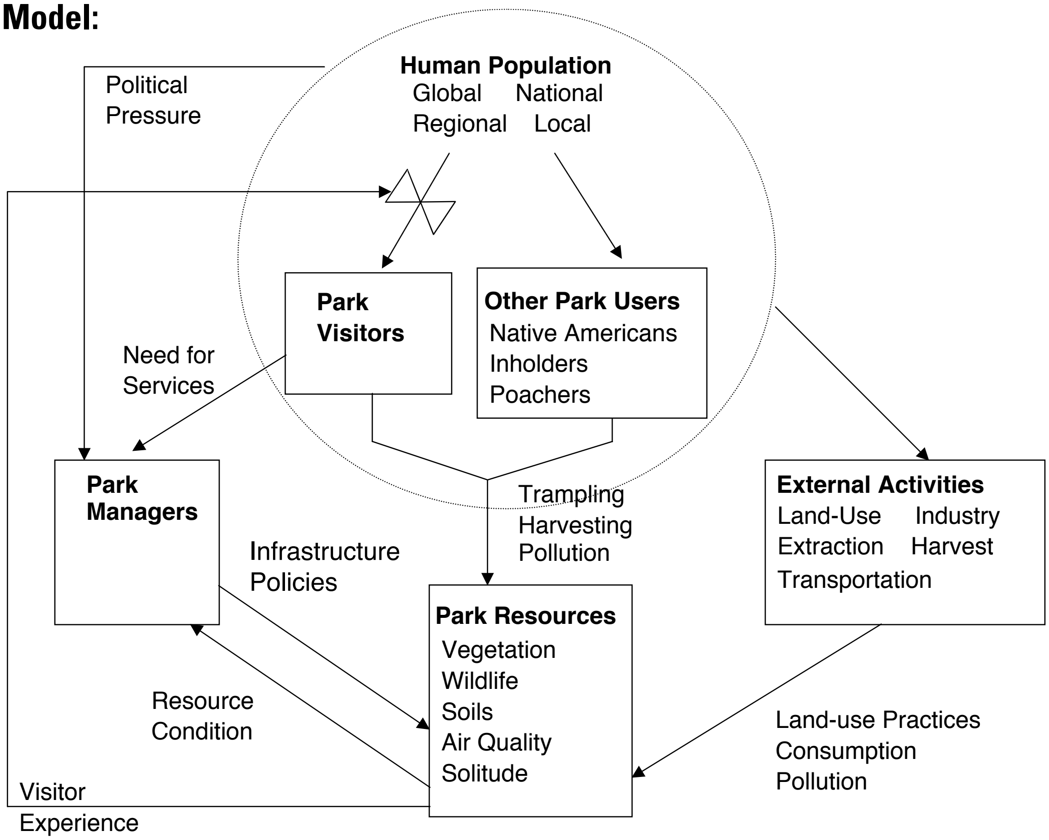

Figure 2.1. Conceptual model of interaction among human activities, park resources, and park management.

Monitoring Questions and Indicators:

Question: Are visitor numbers and uses of the park changing?

- **Indicator:** Visitor Census**.** Maintain the automated vehicle counters on all park entrances and collect data annually. *Justification:* After initial determination of correction factors for visitors/vehicle and commercial and park traffic, automated vehicle counts will give an economical and accurate picture of park visitation. It will also serve as an early warning sign of visitor impacts on park resources. Finally, park visitation counts can be disaggregated according to the location of counter to give a rough idea of visitor distribution. *Limitations*: The initial calibration phase will be somewhat costly.
- **Indicator**: Visitor Activities. Conduct social surveys of individual and party activities at specific park locations at five-year intervals to describe types of park use. The sites where surveys are conducted should reflect primary natural resource concerns. They should also recognize that the greatest increase in effects of human use is occurring in more remote off-trail areas rather than near trails. *Justification*: These detailed surveys of activities are needed to indicate what specific impacts may occur as a result of visitor activities, and to refine estimates of park visitation. This information will be useful for managers in and out of the park because it will suggest trends in recreation demand and potential impacts on surrounding recreation areas. *Limitations:* Designing a sampling strategy that has inference to the entire visitor population is a complex task.
- **Indicator:** Visitor Distribution. Collect data on visitor numbers at widely distributed sites throughout the park along with conducting social surveys. This would also be done at five-year intervals. *Justification:* This monitoring will indicate the spatial distribution and

intensity of visitor impacts to park resources. *Limitations:* This sampling strategy will also be difficult to design, and the study could be costly depending on the size of the sample and the number of locations in the park.

Question: Are visitors' desires for, expectations of, and actual experiences in Olympic National Park changing?

- **Indicator:** (Under development). The Park Service recognizes that experiential resources are in need of protection as much as biological resources and has developed the VERP planning framework in response. The VERP framework uses indicators and standards for those indicators to define the limits of acceptable change to park resources. In the realm of visitor use indicators, standards are fairly easy to define (e.g., < 20% bare ground, > 10 other people encountered on a particular trail), and they can be specific to different areas of the park. However, the linkage between easily measured parameters, such as vehicle numbers in parking lots and trailhead counts, and effects on park resources in relation to visitor expectations are poorly understood. This question is a subject of research at Mount Rainier National Park where visitor densities are high and much sociological research has already been conducted. Results from Mount Rainier provide guidance for other parks throughout the Pacific Northwest.

Question: Is management responding to the needs of visitors by adding or moving infrastructure?

- **Indicator:** Numbers of Facilities. Record the number and location of facilities according to category (e.g., hard-sided ranger stations, ranger tents, shelters, wilderness campsites, etc.) and the number of miles of roads, trails, riprap, etc., parkwide on an annual basis. *Justification:* Changes in the amount of infrastructure will indicate a change in management activities that might impact park resources. *Limitations:* Some facilities may be created without the knowledge of park staff (e.g., wilderness campsites).
- **Indicator:** Number of Over Flights. Monitor the number, altitude and frequency of permitted flights passing over the park at 5 to 10 year intervals. *Justification:* Cumulative aircraft use impacts many wilderness values of the park.

Question: Are the amounts of legal and illegal harvest of park vegetation increasing?

- **Indicator:** Number and Size of Interceptions by Law Enforcement. Following law enforcement actions will indicate the trend in illegal harvests. *Justification*: Records are easy to obtain. *Limitations*: This approach does not describe the total amount of illegal harvest.
- **Indicator:** Number and Amounts of Legal Harvest. To be determined.

Question: Is the extent of impacts caused by visitor use changing?

- **Indicator:** Surveys of Backcountry Campsites and Trail Dimensions. Survey trail dimensions, maybe with the help of trail crew, on selected trails. Survey the size and number of backcountry campsites, maybe with the help of backcountry rangers. *Justification*: These groups of people are in the backcountry regularly, and the needed tasks are simple and need no unusual equipment. *Limitations*: None.

Question: Are the activities of park residents and inholders changing?

- **Indicator:** Residences and Sewer Systems. Monitor the number of residences and number and type of water and sewer systems in the park and on inholdings. *Justification:* Indication of whether these facilities are increasing, decreasing or staying constant will indicate the need for concern about park resident and inholder impacts. *Limitations:* Data on inholdings may be difficult to obtain.

Question: Are the number and activities of concessionaires, Incidental Business Permits (IBP) and Special Use Permits changing?

- **Indicator:** Contracts and Permits. Monitor the numbers and types of contracts or permits granted by the park annually using park records. *Justification:* This is an inexpensive way to determine whether there is need for concern about these activities.

- **Indicator:** Concession activity. Monitor the number, type, frequency, location and people/trip for concession activities. *Justification:* This is an inexpensive way to monitor changes in concession activity and assess the need for concern.

Linkages with Other Disciplines:

- Terrestrial Vegetation Communities. Impacts of visitors and management on vegetation and soils.
- Aquatic/Riparian Habitat. Impacts of visitors and management on aquatic and riparian vegetation and habitat quality.
- Aquatic Biota. Fisheries.
- Coastal Environments. Impacts of visitors on coastal intertidal areas.
- System Drivers: Atmosphere and Climate. Effect of campfires on air quality near campgrounds.
- Terrestrial Fauna. Effects of poaching on animal resources, relationship between visitor numbers and human-animal interactions.
- Park and Surrounding Landscape. Land-use changes outside of the park.
- U.S. Census. Local, regional and statewide human demographic changes.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Vehicle Counts	X	X	X	X			X			1 yr
Activity Surveys	X	X	X	X	X	X	X	X		5 yr
Distribution Surveys	X	X	X	X	X	X	X	X	X	5 yr
Facility Inventory	X	X	X	X	X	X	X	X		1 yr
Internal Aircraft Flights	X	X								1 yr
Residences, Water & Sewer	X	X	X							1 yr
IBP Contracts & Permits	X	X	X	X	X	X	X	X	X	1 yr
Concession Activity	X	X	X	X	X	X	X	X	X	1 yr

Research and Development Needs:

- Continued work with VERP or LAC to develop relationships among visitor numbers, limits of acceptable change, and visitor expectations.
- Develop an accurate census method for visitation (day and overnight use) and specify adequate equipment.
- Who is engaging in poaching various resources and what are their motivations?
- What are the impacts of trampling on biodiversity and plant processes?
- Is there a need for an indicator of legal and illegal collection of plant material (e.g., mushrooms, salal, moss, beargrass)? If so, develop the indicator(s).
- What effect is wood collection having on woody debris resources?
- What is the relationship between external changes in demographics and changes in the nature and number of park visitors?
- Research is needed to determine the average number of visitors per vehicle to adjust vehicle counter data to indicate number of visitors. The data will also need to be corrected for commercial and park vehicle traffic.
- What is the impact of legal and illegal harvest of park resources having on plant communities?

Chapter 3. Park and Surrounding Landscape

Monitoring Need/Justification:

National Park managers face several threats to park integrity that call for a regional or even global perspective. Detecting the extent and intensity of changes to park resources caused by large-scale problems such as acid precipitation, climate change, airborne pollutants or urbanization requires park management to take an expansive view of the park. This necessitates considering the park in the context of surrounding managed lands and gaining an understanding of how regional and global processes such as atmospheric circulation patterns affect park ecosystems.

Natural and human-caused disturbances are important large-scale phenomena affecting the structure and function of ecosystems, including forest-dominated ecosystems of the Pacific Northwest (Spies 1997). These disturbances include fire, avalanches, windstorms, mass wasting, flooding, beach erosion, insects and diseases, tsunamis, and forest fragmentation outside of the park. Each of these has a characteristic spatial and temporal scale, and together with other environmental patterns, they create a mosaic of habitats and communities across the park. Landscape patterns have important implications for many ecosystem processes such as dispersal rates of old-growth forest dependent organisms, the invasion of exotic species, and disturbance type and frequency (Pickett and White 1985, Perry and Amaranthus 1997). Comprehensive protection of a park requires an understanding of the status and dynamics of disturbance patterns and processes. Remote sensing is a powerful tool that, when used over time, can indicate landscape-level trends in landscape patterns, including the availability of habitat patches, presence of corridors and connectivity with areas outside of the park for species of concern, disturbance levels along riparian corridors, and the size and frequency of windthrow, fire and other disturbances (Wilkie and Finn 1996). Remote sensing tools (aerial photographs and satellite imagery) tend to be expensive, but no other means provide the large-scale perspective.

Landscape pattern is clearly a large-scale issue best addressed by remote sensing. Additionally, some important ecosystem processes that can be meaningfully measured over small areas, can only be evaluated using remote sensing techniques to understand the landscape-scale changes they affect. For example, primary productivity can be measured in single forest stands but it is difficult to extrapolate from individual plots to the entire park unless remote sensing tools are used. Parameters such as canopy nitrogen can be measured remotely, and using plot data for validation, can be used to estimate productivity on a park-wide basis (Ollinger et al. In press, Smith et al. 2002). Remote sensing promises to bridge the gap between intensive ecological research or monitoring and the evaluation, understanding, and management of landscapes.

In addition to using repeat photography and imagery, other regional sources provide landscape-scale data. Examples include the USDA Forest Service Pest Management aerial surveys in national forests and national parks (Dave Bridgwater, dbridgwater@fs.fed.us), the Intra-agency Vegetation Mapping Program (Melinda Mouer, mmouer@fs.fed.us) and Olympic National Park data on the frequency, cause and size of fires since 1940. In addition, National Oceanic and Atmospheric Administration produces coastal change detection information, and Bureau of Land Management provides lightning strike data throughout the western U.S., including frequency maps for strikes.

Conceptual Model:

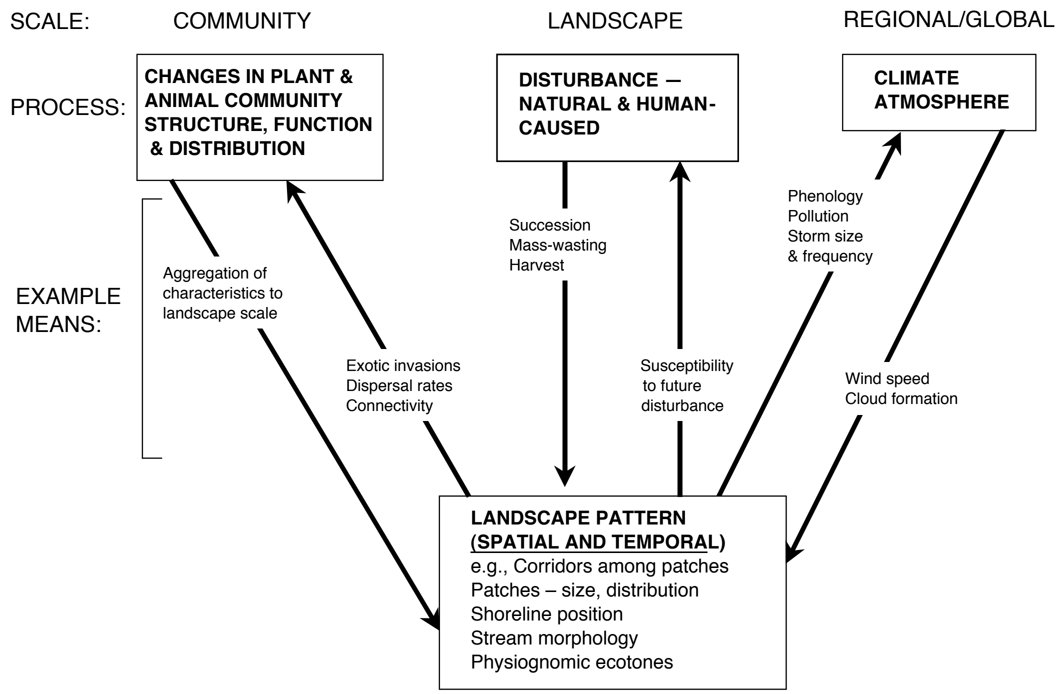

Figure 3.1. Conceptual model of the interactions among the forces determining landscape pattern in Olympic National Park.

Monitoring Questions and Indicators:

Question: What are the trends in the frequency, size, and distribution of disturbance events**,** namely wind throw, flooding, mass-wasting, changes in river channels, fire, insects and disease?
Question: What are the trends in extent of snow cover and in plant phenology?
Question: What are the trends in landscape-scale patterns of vegetation and land-use outside of the park?
Question: What are the trends in coastal shoreline position?

- **Indicator:** Change Detection. Obtain satellite imagery (Landsat Thematic Mapper [TM], light detection and ranging [lidar], or other airborne imagery as newer sensors become available and affordable) and subject them to automated image processing techniques to detect change. These techniques are good at finding change, but they are not as good at determining the type of change. Once areas that have changes have been identified, we can quantify the extent of change and identify the mechanism through a combination of aerial photo interpretation and site visits. In many cases site visits (ground-truthing) will not be necessary, effective, or feasible due to inaccessibility of sites. Many common mechanisms of change (i.e., clear cuts, regeneration, snow melt, river meanders, fire, etc.) are identifiable from imagery. In fact, the mechanism of change is sometimes more easily discerned from the imagery or photo pairs than on the ground because field crews do not have the benefit of seeing two snapshots in time. Aerial photos should be at 1:15,840 resolution (R. Hoffman, Olympic National Park, Personal communication) and could be taken every 10 years, or maybe half of the park every 5 years. Satellite imagery may be inexpensive enough that change detection analyses could be done annually or biannually. Changes due to all of the processes described in the questions above could be described with this approach (Lefsky et al. 2001, Lefsky et al. 2002).
Justification: The combination of satellite imagery and aerial photos increases the effi-

ciency of change detection and identification by using an automated procedure to narrow the focus of the analysis. Interpreting aerial photos is the most accurate way to identify remotely-sensed features but it is time consuming and requires special expertise. Aerial photos would also have other uses for monitoring, including recording permanent plot locations. *Limitations:* Aerial photos and their interpretation are expensive, and qualified personnel are few. Timing of imagery to describe snow cover and phenology might be difficult to achieve. There can be problems with photo registration, distortion, and quality.

Question: What are status and trends of forest structure, composition and function?

- **Indicator:** Vegetation Chemistry. The Airborne Imaging Spectrometer (AIS) is able to detect the differences in spectra emitted from compounds based on chemical bond structure (Ollinger et al. In press, Smith et al. 2002). Consequently it can be used to measure such things as species composition, leaf lignin, forest productivity, decomposition rates, rates of nutrient release and assimilation, rates of nitrogen cycling, landscape transitions, and vegetation stress across forested landscapes. *Justification:* This new technology shows promise for allowing detailed detection of important, integrative forest processes. *Limitations:* The technique is still experimental and expensive, although the park service may be able to acquire it for a discount. Extensive ground-truthing is required.
- **Indicator:** Vegetation Structure and Composition. Acquire Landsat TM or Systeme Probatoire d'Observation de la Terre (SPOT) data from which some of the above vegetation processes, composition and structure can be estimated, but less directly and at a lower level of resolution. *Justification:* These data are widely available and have great utility. *Limitations:* Requires extensive ground-truthing, which is expensive.

Linkages with Other Disciplines:

- Aquatic/Riparian Habitat. Changes in snow cover and stream morphology.
- Terrestrial Vegetation Communities. Changes in snow cover, phenology, and vegetation structure and composition.
- Geoindicators. Mass-wasting, stream channel morphology, and extent of wetlands if possible.
- System Drivers: Atmosphere and Climate. Snow cover, disturbance, land-use outside of the park.
- System Drivers: Human Activities. Land-use outside of the park.
- Biogoechemistry. Vegetation chemistry.
- Populations and Communities of Large Mammals. Phenology.
- Coastal Environments. Sea level change, shoreline position alterations.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Disturbance	X	X	X	X	X	X	X	X	X	1-2 yrs
Snow Cover	X	X	X	X	X	X	X	X	X	1-2 yrs
Vegetation Phenology	X	X	X	X	X	X	X	X	X	1-2 yrs
Land-use Outside Park	X	X	X	X			X			1-2 yrs
Vegetation Struct. & Chemistry	X	X	X	X	X	X	X	X	X	5-10 yrs
Shoreline Position	X		X				X	X		5-10 yrs

Research and Development Needs:

- How great is the ability of remotely sensed data to detect significant changes in land cover and resource condition at small spatial (e.g., 30 x 30 m) and temporal (e.g., annual) scales?
- Retrospective studies using historic records, historic photos, historic aerial photos and models are needed to reconstruct past patterns of disturbance events. Geologic methods can be used to date historic mass-wasting events, and dendrochronological methods can be used to determine fire histories.
- Employ change detection analyses to determine size and frequency of disturbance events such as windthrow and flooding using Landsat™ images from as far back as possible (ca. 1974).
- Compare spatial and temporal patterns of fire described by the aerial photos with results from retrospective fire history studies to compare recent fire behavior with historic and pre-historic behavior.
- Coordinate data collection between plot-level and remotely sensed data so that smaller-scale measurements represent the same process detectable remotely. The details will depend on which type of remotely sensed data can be acquired.

Chapter 4. Biogeochemical Cycles

Monitoring Need/Justification:

Comprehensive monitoring programs must reflect the fact that ecosystems are not static collections of biotic units. Rather, they are functioning entities that process nutrients among biotic and abiotic components in biogeochemical cycles. Biogeochemists see biogeochemical cycles as the foundation of ecosystems, and that organisms merely represent "repackaging" of energy and nutrients into different stages of the cycles (stated at Biogeochemical Processes Workshop, see Appendix A). The importance of process in ecosystems is recognized in the mandate of national parks to achieve "preservation of a total environment, as compared with the protection of an individual feature or species" (National Park Service 1968).

It may be hard to convince the public that imperceptible chemical processes are important indicators of ecosystem status when their more obvious interests for protection are populations of animal and plant species. However, biogeochemical cycles are the network that links all ecosystem components, biotic and abiotic (Likens et al. 1977, Sollins et al. 1980). The importance of these cycles is more obvious if, for example, one defines a stressed ecosystem as one that is experiencing a decrease in photosynthesis, a fundamental ecosystem process. This definition reduces the effect of many possible stressors (e.g., climate change, air pollution, acid rain, disease) to an effect on one step in the carbon cycle, and thereby makes it possible to predict how a stressor will ramify throughout all other parts of the system. Changes in biogeochemical cycles may also be more sensitive indicators than biota because they show less variation (Edmonds et al. 1998). In addition to giving a clearer signal than biota, they may also provide "early warning" of ecosystem change because they may respond before biota (Perry 1994). Finally, some biogeochemical measurements give an integrated assessment of system status. For example, stream chemistry reflects not only streambed characteristics but also includes the runoff of water and nutrients from the entire watershed (Likens et al. 1977, Sollins et al. 1980, Edmonds et al. 1998). Consequently, biogeochemical indicators can give a comprehensive and integrated assessment of ecosystem status (Waring and Running 1998).

One important subset of the biogeochemical network in Olympic National Park involves the transfer of nutrients from the marine environment to terrestrial forests by anadromous fish. When anadromous fish return from the ocean to spawn and die, they provide marine-derived nutrients to freshwater ecosystems through their excretion, gametes and carcasses (Bilby et al. 1996). These nutrients are important to the productivity of the lakes and streams in which they spawn (Larkin and Slaney 1997). Nutrients are also transferred directly to scavengers and indirectly through the soil to vegetation. As salmon populations fluctuate, naturally and due to anthropogenic influences on habitat and harvest, park resource managers are concerned about the impact to the forest and aquatic ecosystems. Fish numbers are hard to monitor directly, but marine derived nutrients can be detected in vegetation by analyzing isotopes of nitrogen and carbon (Ben-David et al. 1998). In this way, salmon can be monitored indirectly by monitoring one of their ecological roles. A change in salmon populations could propagate throughout the food chain. Small reductions in the numbers of anadromous fish might significantly degrade ecosystem processes and productivity, which, in turn, could contribute to a "positive feedback loop" due to lessened biological productivity/oligotrophication and increasingly reduced production levels.

Because biogeochemical cycles include abiotic as well as biotic elements, some predicted environmental changes are expected to affect biogeochemical processes directly. These include expected changes in air quality and precipitation chemistry, including toxic deposition. Changes in hydrology resulting from development in and around parks, changes in precipitation, and in the amount and timing of glacier melt water, due to climate change, will also affect biogeochemical cycling. Therefore monitoring of biogeochemical cycling is closely tied to monitoring of system drivers.

Conceptual Model: Figures 1.2 for Biogeochemical Cycles and 4.1 for Marine-Derived Nutrients

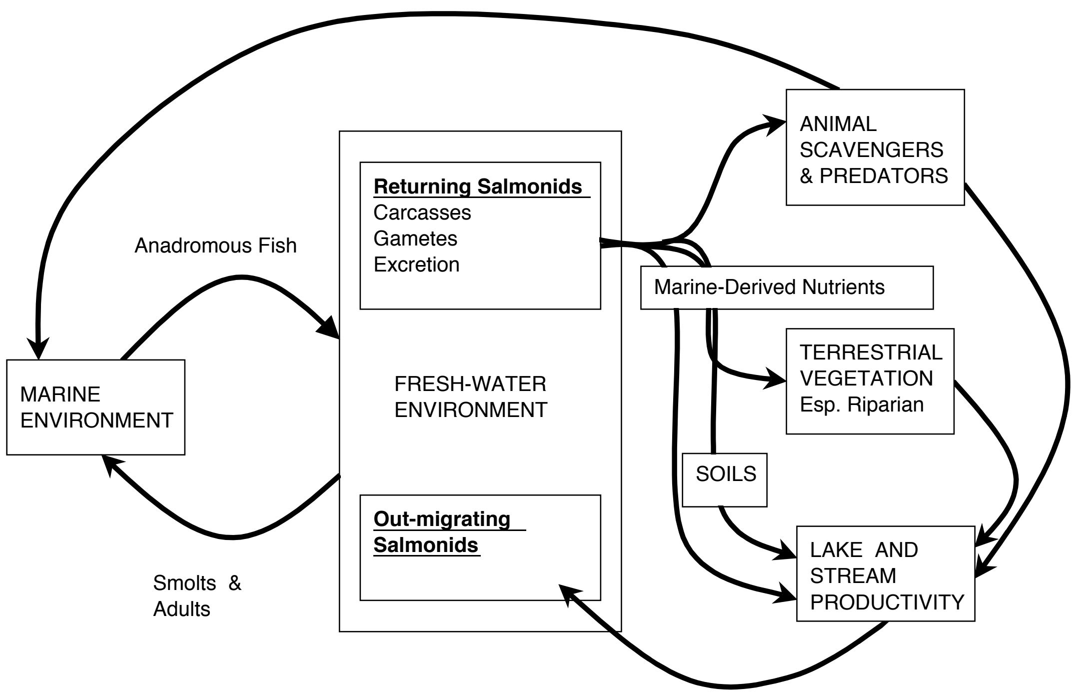

Figure 4.1. Conceptual model describing the impact of marine-derived nutrients on terrestrial and aquatic environments in Olympic National Park.

Monitoring Questions and Indicators:

Question: Are precipitation chemistry measurements from the Hoh Small Watershed Project deviating from the nearly twenty-year norm already observed?

- **Indicator:** Small Watershed Precipitation Measurements**.** The Small Watershed Project in the Hoh River valley should continue to measure monthly bulk precipitation chemistry, precipitation amount, dissolved organic carbon and nitrogen, and conductivity monthly. The park should consider adding continuous measurements of conductivity and temperature. (The site has recently experienced mass wasting so water quality and flow are not representative of the conditions described by earlier measurements. Therefore it might be a useful research opportunity to study stream recovery, but it is not as useful to continue them for the purpose of adding to the established record of water flow and quality.) *Justification:* The Small Watershed Project has produced informative results by establishing baseline conditions so that a temporary increase in atmospheric nitrogen could be detected, although the source is not known. It is important to have a few intensively monitored sites, like the Hoh site, so that system dynamics can be comprehensively understood on a greater geographic basis. *Limitations:* Intensive studies are expensive to maintain.

Question: Are basic properties of water quality changing in the park?

- **Indicator:** Level I Water Quality**.** Level I Water Quality parameters were identified by the National Park Service's Water Resources Division as the basic set of measurements to be collected service-wide. They include alkalinity, pH, conductivity, dissolved oxygen, total suspended particulates, rapid bio-assessment baseline (EPA/state protocols involving macro-invertebrates and fish), temperature, and flow. *Justification:* These protocols provide minimum baseline data for water quality assessment and are used throughout the National Park Service. *Limitations*: Equipment, maintenance, and contracted analysis (if the park goes beyond Level I parameters), could be costly.
- **Indicator:** Extensive Measurements of Water Quality and Biogeochemistry**.** Datasonde units should be used to measure dissolved organics, pH, conductivity, temperature and turbidity of stream water at 8 replicate sites (conclusion of Biogeochemistry Workshop) in the park. In addition, some units should be rotated around the park to survey other sites temporarily in order to establish baselines and characterize eco-regions. At the 8 sites a stilling well and recorder should be used to measure stream flow. Litterfall, litter chemistry, dissolved organic carbon and soil respiration should also be measured. Finally, the full suite of anions and cations should be measured twice per year. *Justification:* An intensive monitoring site is far more useful if its results can be put in the context of a spatially broader sample. The measurements described here would be less expensive than an intensive site and would allow for scaling up from the intensive site, though with less detail. Also, these sites would meet the requirement for Level I Water Quality monitoring if the rapid bio-assessment baseline protocols were added. *Limitations*: Though less expensive than the Hoh intensive site, these sites would also be expensive.

Question: Is the ecological role of anadromous fish to transport marine-derived nutrients to freshwater ecosystems changing in aquatic/riparian zones and lowland forests?

- **Indicator:** Marine-Derived Nutrients. Determine isotopic ratios of ^{15}C and/or ^{13}N in samples of resident trout, macroinvertebrates, algae, alders, salmonberry, and cores of spruce or fir trees. Following research, some of these may prove to be more effective indicators than others. *Justification*: Collecting these samples is relatively simple, and many rivers are easily accessible by trail for their length. *Limitations:* The ecological importance and historic levels of marine-derived nutrients are not known.

Linkages with Other Disciplines:

- System Drivers: Atmosphere and Climate. meteorological data, air quality including ozone, and wet and dry deposition.
- System Drivers: Human Activities. Changes in human use and management response that might affect biogeochemical cycles.
- Park and Surrounding Landscape. Nitrogen in tree canopy and lignin via remote sensing
- Terrestrial Vegetation Communities. Stand-level biogeochemical measurements (i.e., litterfall, decomposition, leaching, mineralization).
- Aquatic/Riparian Habitat:. Large woody debris in streams, sediment loading, changes in glaciers
- Special-status Plant Species: Rare and Exotic Species. Trends in exotic species because they may cause a shift in plant community composition.
- Aquatic Biota. Changes in anadromous fish runs or lotic/lentic biotic communities.
- Coastal Environments. Changes in estuarine environment.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Small Watershed Project	X		X					X		As before
Extensive Stream Quality--Level I	X	X	X	X	X	X	X	X		6 mo.
Marine Derived Nutrients	X		X					X		5-10 yr.

Research and Development Needs:

- Interpret GIS layers in terms of biogeochemical processes.
- Work with modelers of local weather patterns to determine large scale atmospheric flow patterns (e.g., wind).
- What factors control nitrogen retention and release from forested ecosystems?
- How much stress (e.g., nitrogen inputs) can be added to the system before ecosystem change/breakdown/reorganization occurs?
- What measures need to be collected synoptically to enable scaling from small watershed studies to the landscape scale?
- What are the "trigger points" in specific biogeochemical measurements that signal a need for management action?
- What role and importance do marine-derived nutrients have in terrestrial ecosystems?
- What were historic levels (pre-Columbian and mid-20th century) of marine-derived nutrients in riparian and lowland trees?
- Identify the most effective indicators of marine-derived nutrients.
- Determine large-scale patterns of atmospheric flow.

Chapter 5. Contaminants

Monitoring Need/Justification:

Environmental contaminants originate primarily from industrial processes and agricultural practices. One category of contaminants is known as persistent organic pollutants (POPs), of which twelve are covered in an international treaty to reduce their use. They include pesticides (e.g., DDT, chlordane, dieldrin, etc.) and compounds used in or produced by industry (e.g., PCBs, dioxins, furans, etc.). Toxic metals, also produced by industry, include mercury, lead, zinc, and cadmium. All of these chemicals are troublesome because they are toxic at low concentrations, persist in the environment, bioaccumulate, and are semi-volatile, meaning that they easily vaporize into the atmosphere (Simonich and Hites 1995). In addition, there are new chemicals whose behavior is not yet understood, including brominated compounds, flame retardant coatings and substitutes for CFCs. Contaminants can reside and move in the air, water and in food webs, but because many large, natural-area national parks are geographically remote and centered in mountains, atmospheric deposition is the most important source of contamination.

Olympic National Park experiences prevailing winds from the southwest and west in the fall and winter, and from the west and northwest in spring and summer. These air masses moving inland from the Pacific Ocean are relatively unaffected by local or continental emissions. The coastal and rain forest areas of the park, therefore, have been suggested as having among the cleanest air in North America (Thomas et al. 1989). Even on the north side of the park, which is close to industrial and urban emissions, air quality does not violate federal or state air quality standards. Nevertheless, the park has received long-range transport of chemicals possibly from the Asian continent (Edmonds et al. 1998). Consequently, the concern for air quality in the park is based on the park's role as a benchmark for the rest of the continental U.S., the potential for increasing pollutants from growing metropolitan areas in the region, and a concern for trans-Pacific transport.

From the national perspective, western and Alaskan mountainous national parks are important baseline and sentinel sites for a number of atmospheric contaminant concerns. First, contaminants are expected to accumulate in the snow packs of arctic and near-arctic areas, and mid-latitude mountains due to the processes of 'cold-condensation' and 'global distillation' (Biddleman 1999). Both processes involve the physical properties of the atmosphere as it cools with higher elevation and latitude. Snow packs are at the headwaters of river systems, and hence the effect of contaminants can easily spread from them. Also, there is national concern about transport of contaminants across the Pacific, and western parks will give the clearest signal. Finally, these compounds bioaccumulate up food chains and with age in individual animals (Jansson, et al. 1993). Little is known quantitatively about the effects of contaminants, and the unmanaged ecosystems in national parks could serve as useful laboratories, with monitoring as one component. Because of these concerns, the National Park Service's Air Resources Division is designing a contaminants-monitoring program for the western continental U.S. and Alaska.

One specific question regarding contaminants nationally is also particularly important in Olympic National Park. Anadromous fish have been shown to accumulate contaminants during their residence in the ocean (Ewald et al. 1998). When they return home to spawn and die, salmon bring important nutrients into the system, but they also may bring significant amounts of contaminants.

Conceptual Model: Figure 1.2

Monitoring Questions:

Following a meeting held in June 2001 with subject matter experts and representatives from western national parks, the National Park Service's Air Resources Division is designing an air toxics monitoring scheme for the western parks. The monitoring questions will be regional in scope and will probably take advantage of the latitudinal gradient from southern California to Alaska, and the coastal-to-inland gradient from Olympic National Park eastward to Glacier National Park. Elevation gradients within parks will also likely be exploited, as well as the relationship of individual parks to synoptic air patterns. Olympic National Park falls into three of five high-priority geographic and ecosystem categories identified by the group: high elevation areas, areas not affected by local sources of emissions, and areas that are influenced by transpacific air masses. Finally, several media are under consideration for sampling that would be appropriate for Olympic National Park: snow, air, fish, freshwater lakes, sediments, and lichens. The details of this monitoring plan are forthcoming and will include some subset of the indicators described below (www.aqd.nps.gov/ard/aqmon/air_toxics/index.html).

Monitoring Indicators: (Monitoring questions are being developed on a national basis)

- **Contaminants in Snow.** Measure concentrations of pesticides used currently and of 'new POPs' whose behavior and effects are unknown. *Justification*: Snow is an effective scavenger of the compounds of concern, it makes a major contribution to annual water balance. Samples are inexpensive, don't require a power source, are easy to collect and handle, and are easy to archive. *Limitations*: Snow tells only part of the contaminants' story, and because it is so labile, data may be difficult to interpret. Samples must be collected before early-season melting events, and rain-on-snow events can destroy samples. Finally, a large volume is required for archiving.
- **Contaminants in Air and Precipitation.** Measure concentrations of POPs and metals in air and precipitation at IMPROVE (visibility monitoring) sites (see Part II, Chapter 1). *Justification*: Data are universally comparable and a true measure of concentration. Air data are fairly easy to collect and they are good for model evaluation. The source can be determined from meteorology. *Limitations*: The monitoring sites are expensive and require power and maintenance so spatial representation is necessarily limited. Precipitation data are harder to collect and require special methodological care.
- **Contaminants in Fish.**
  - **Resident Fish.** Collect samples of resident trout that are non-migratory, predatory, old, and preferably from oligotrophic systems. Trout have been selected because they occur in many western parks. Samples should be homogenized and analyzed for 12 POPs plus mercury and maybe some emerging contaminants. *Justification*: Trout are at the top of the aquatic food chain so they should accumulate contaminants if they are present in the ecosystem. Fish are charismatic, economically important and are consumed by subsistence cultures. Fishermen might be able to collect some of the samples for free. *Limitations*: Destructive sampling may not be allowed in parks. It is difficult to know the source of the contaminant. Analyses are expensive.
  - **Anadromous Fish.** Same as above. *Justification*: Parks with anadromous fish need to know what amount of contaminants the fish are bringing back to the park from the ocean. *Limitations*: Knowing the amount of contaminants does not indicate the effects on the system. Analyses are expensive.
  - **Contaminants in Freshwater Lakes.** Install semi-permeable membrane devices (SPMD) in some representative sample of lakes to measure concentrations of contaminants deposited from precipitation or air. *Justification:* Water samples realistically describe

exposure for aquatic organisms and levels can be compared with lab toxicity tests. SPMD technology may help overcome some of the problems with other methods. Much water chemistry work is being done by other agencies, so sample results can be integrated with other results. *Limitations:* Some lakes are difficult to access and timing may be important. Large volumes of water may be needed to detect some compounds. Some compounds may be unstable in water, either before or after sampling.

- **Contaminants in Sediments.** Collect sediment cores from lake bottoms and analyze them for POPs, mercury and emerging contaminants. *Justification*: Lake sediment cores can describe spatial patterns of contaminants. Lake sediments are one of the best indicators of environmental contamination (Puget Sound Action Committee, 2000). *Limitations*: Some pollutants of interest do not accumulate in sediments. Access to remote lakes may be difficult. Cores are expensive to process and analyze.
- **Contaminants in Lichens.** Collect samples of the same species of lichen throughout the park, and hopefully from all of the parks in a region. Analyze the samples for metals. *Justification:* Historic samples are archived. Lichens have been widely used already in the Pacific Northwest and Alaska, where they are an important part of the vegetation, so there is a large database for comparison. Lichens can be collected in conjunction with other monitoring. Lichens can indicate synergistic effects of multiple pollutants and offer a potentially denser sample than can be affordably obtained with instruments (Nimis and Purvis 2002). *Limitations*: Concentrations of pollutants in lichens cannot be equated with concentration or timing of exposure. Lichens are not effective accumulators of contaminants with low concentrations or for POPs.

Linkages with Other Disciplines:

- Terrestrial Vegetation Communities. Lichens.
- Aquatic/Riparian Habitat.. Chemistry of freshwater lakes.
- System Drivers: Atmosphere and Climate. Chemistry of freshwater lakes, air and precipitation chemistry.
- Special-status Fish Species. Resident trout and anadromous salmonids.

Spatial and Temporal Context: Where and How Often to Monitor: (to be determined)

Research Needs:

- Determine concentrations of toxics at which threshold responses or other effects (e.g., on development, non-lethal effects on reproduction) occur in the food web and biogeochemical cycles.
- Determine source of contaminants through mass balance or trajectory studies.
- Determine patterns in the distribution of contaminants in relation to air, land and water.
- Compare results from SPMDs with other collection technologies to evaluate effectiveness.
- Determine effects of contaminants brought by returning anadromous fish on the larger ecosystem.
- Determine historic levels and distribution of POPs from lake sediment cores.

Chapter 6. Terrestrial Vegetation Communities

Monitoring Need/Justification:

Vegetation is the great integrator of biological and physical environmental factors, and is the foundation of trophic webs and animal habitat (Gates 1993) as well as having a major role in geologic, geomorphologic and soil development processes (Schumm 1977, Jenny 1941). Consequently, results from monitoring vegetation and associated ecological processes are an essential tool for detecting changes occurring in park ecosystems. For example, monitoring herbivory may be a good indirect method of determining whether herbivore populations or habitat use patterns have changed. Also, permanent plot measurements may help managers detect changes in tree mortality patterns or invasions of exotic plant species. In addition, when vegetation is monitored in conjunction with monitoring of associated wildlife groups such as small mammals, connections between vegetation, habitat characteristics and the behavior of small mammal populations may be revealed. Monitoring of vegetation and associated ecological processes such as the rate of nitrogen mineralization and soil water chemistry are likely to provide a direct link with climate and atmospheric changes (Pastor and Post 1986, 1988). Finally, monitoring vegetation in a statistically representative manner offers management the opportunity to extend plot data to a larger scale such as entire watersheds and perhaps the park as a whole. Changes in vegetation means changes in primary productivity and habitat quality and will be reflected throughout the ecosystem.

Olympic National Park contains steep environmental gradients, due to the interaction between the mountainous topography and maritime climate. This has resulted in a wide range of vegetation types existing in proximity to one another (Buckingham et al. 1995). Conditions on the coastal lowlands give rise to the spectacular 'temperate coniferous rainforests' with massive trees whose branches are laden with epiphytes. Xerophytic vegetation such as prickly pear cactus reside in the dry lowlands of the northeastern Olympic Peninsula. Mountainous vegetation in the northeastern Olympics has characteristics similar to those found in the Rocky Mountains. These diverse vegetation types will respond to environmental changes in different ways. Consequently, patterns of vegetation change in relation to environmental gradients offer a superb opportunity to interpret the mechanisms driving the observed changes.

Forest structure and composition are physical manifestations of cumulative biological and physical processes that are difficult to measure but that drive changes in forest integrity. Changes in forest composition will result when particular habitats respond to factors such as climate change, precluding suitability for particular species (Barnosky 1984, Davis 1981). As human development restricts species migration across landscapes and regions, significant loss of biodiversity is expected to result when displaced species cannot access hospitable habitats. Additionally, changes in forest structure and composition affect resource values such as habitat quality, biodiversity, the hydrologic cycle, and carbon storage (Pastor and Post 1986, 1988). Forest health is a regional and national issue, and measurements of forest structure and composition are the most commonly used measurements for forest assessment.

Forests ecosystems are not intact unless processes, as well as components, are at natural levels. It is not clear whether processes or components are more responsive to stress, but process variables tend to be less variable than components, and changes may be easier to detect using processes (Carpenter et al. 1993). Although some of the process measurements may be relatively expensive compared with measurements of structure, the cost may be offset by the early-warning capability. Additionally, these variables will allow the system to be modeled (Dunham 1993). Models will enable prediction and extrapolation and allow us to distinguish between expected changes in these naturally dynamic processes and unexpected changes signaling a change in the process itself.

Conceptual Model:

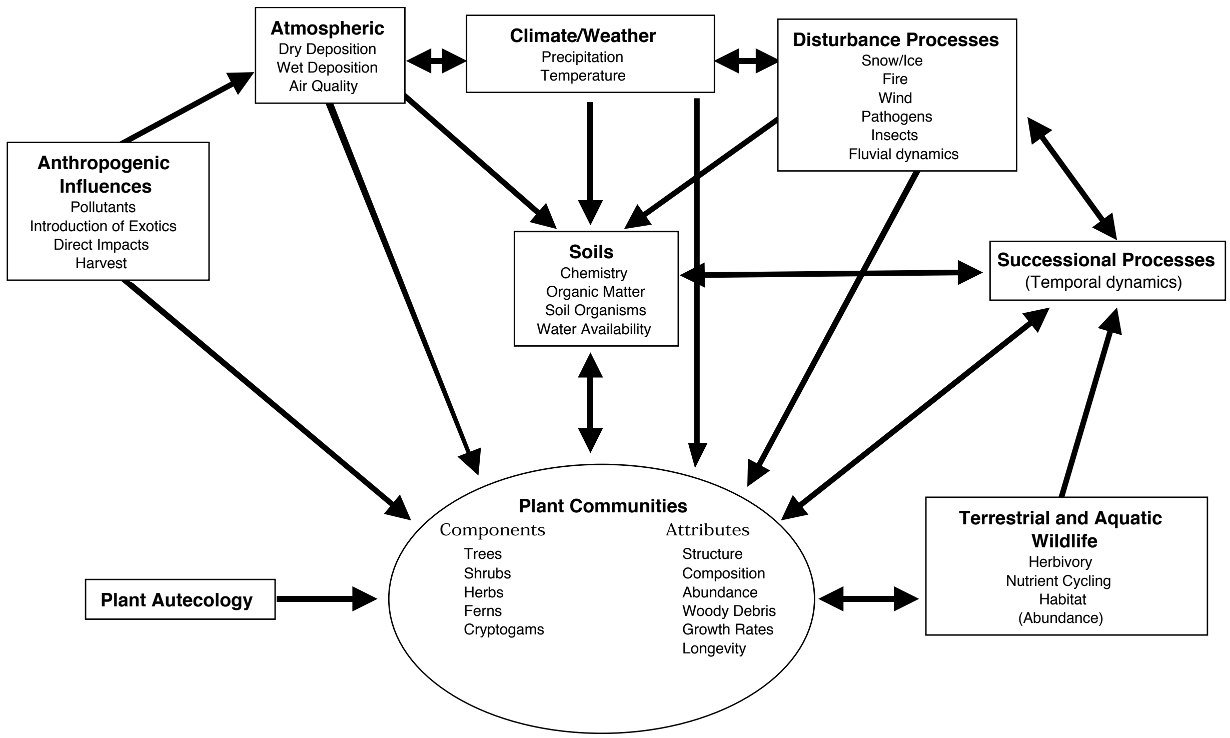

Figure 6.1. Conceptual model describing the factors shaping plant communities in Olympic National Park.

Monitoring Questions and Indicators:

Question: Are the abundance of frequent species and parameters of forest structure changing?

- **Indicator:** Forest Structure and Composition. Permanent vegetation plots should be distributed across elevation, soil, climatic, and successional gradients. Plots should be distributed in forested, riparian, coastal, high-elevation (subalpine) and non-forested plant associations. Specific methods should be the same as or be capable of being summarized with those used by other regional and national permanent plot networks. Forest structure should be measured along several dimensions:
  - Horizontal structure: including gap size and frequency, fragmentation patterns and layering.
  - Vertical structure: including canopy condition, snags, understory, shrubs, and herbs.
  - Species composition, cover and thickness of all layers, including exotic plants.
  - Biomass distribution: living versus dead, foliage, stems, large woody debris, forest floor and soils.
  - Presence of exotic and/or native insects and diseases.

Justification: Forest health is a national and regional issue and information from relatively undisturbed areas such as national parks will serve as a benchmark for disturbed areas. Changes in species distributions at tree line may be indicative of climate change (Walker 1991, Rochefort et al. 1994). These measurements and methods will be directly comparable with data from other agencies. *Limitations*: All gradients may not be well covered due to financial limitations on the number of plots that can be supported.

Question: Are the rates of ecosystem processes changing?

- **Indicator:** Forest Processes.
  - **Nitrogen and Carbon Dynamics.** Indicators of N and C dynamics should be monitored on a subset of the permanent vegetation plot network that is relatively accessible. Specifically, the following indicators should be monitored using available protocols:
    - **Net Primary Production.** (i.e., litterfall, tree growth using litter traps and tree cores)
    - **Soil Nutrient and Organic Matter Dynamics.** (i.e., decomposition, leaching, N-mineralization)

    Justification: Methods are available to measure these variables at remote sites. These variables will allow the system to be modeled to enable prediction and extrapolation. *Limitations:* Sample analyses can be expensive. Repeated litter collection and sorting is time consuming and costly.
  - **Demographic Processes.** Plant mortality and regeneration should be monitored in all permanent plots according to methods used in other permanent plot networks. Measurements of growth and seed traps indicate productivity. *Justification:* These measurements are easy and inexpensive to include with data already being collected on structure. They are likely to be early-warning indicators of impending structural changes. *Limitations:* Crews must be taught to recognize the cause of mortality.
  - **Animal Use.** Indicators of herbivory and animal disturbance or presence (e.g., hoof marks, droppings, etc.) should be recorded for all permanent vegetation plots. Methods for describing herbivory should be determined in consultation with wildlife biologists and should focus on known palatable plant species. *Justifications:* Animals have an important role in shaping the structure of vegetation and influencing other forest processes. This will be related directly to monitoring of mountain goats in the subalpine zone, and elk in lowland forests. *Limitations:* Methods for evaluating herbivory are always difficult to design because they essentially involve measuring something that isn't there anymore. However, some indices are available.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Forest Structure & Composition	X	X	X	X	X	X	X	X		10 yr
N & C Dynamics	X	X	X	X	X	X	X			5 yr
Demographic Processes	X	X	X	X	X	X	X	X		10 yr
Animal Use	X	X	X	X	X	X	X	X		5 yr

Linkages with Other Disciplines:

- Populations and Communities of Large Mammals. Animal use.
- Special-status Plant Species: Rare and Exotic. Exotic plants.
- System Drivers: Atmosphere and Climate. Forest processes.
- Park and Surrounding Landscape. Linkage between landscape-scale and plot-scale measurements of forest processes.

- Biogeochemical Cycles. Forest processes.
- Aquatic Habitat. Aquatic vegetation.
- Coastal Environments. Marine vegetation.

Research and Development Needs:

- Compare methods used by other regional and national vegetation monitoring projects to ensure that our methods are the same or can be summarized into the same categories.
- Develop soils and vegetation maps, including age class for vegetation.
- Develop models of vegetation dynamics and processes to enable extrapolation and prediction.

Chapter 7. Special-Status Plant Species: Rare and Exotic

Monitoring Need/Justification:

The exceptionally complex environment in the Olympics has resulted in a diverse array of plant communities and species. Factors contributing to this complexity include steep precipitation and elevation gradients, complicated geology, geographic isolation, and Pleistocene glaciation (Buckingham et al. 1995). The park is home to eight vascular plant taxa endemic to the Olympic Peninsula, more than 50 species rare in Washington State (Washington Natural Heritage Program (WNHP) 1997), and at least 100 other species that are rare within the park. Two categories of rare vascular species are recognized for the purposes of monitoring: (1) federally or state-listed rare endemic species (i.e., U.S. Fish and Wildlife Service [USFWS] Species of Concern and WNHP Threatened Species), and WNHP Sensitive Species known from only one location in the park, and (2) species rare in the park. These are important resources for the park to protect as it tries to meet its legal mandates to maintain natural biodiversity.

In addition to rare vascular plants, Olympic National Park houses many rare and several extremely rare (i.e. two or fewer known locations) non-vascular cryptogams, commonly known as mosses, liverworts and lichens (M. Hutten, Contract Researcher, Olympic National Park, Personal communication). Cryptogams contribute significantly to the aesthetic beauty of park forests as they drape from branches and carpet the ground. They also play important roles in ecological processes, such as nutrient cycling, water balance, and providing nesting materials. In general, they are more sensitive to changes in air quality and precipitation chemistry than many other organisms. Additionally, many cryptogams are listed in the Record of Decision of the Northwest Forest Plan (U.S. Department of Agriculture and U.S. Department of the Interior 1994) as needing special protection. Because we are only beginning to develop a taxonomic inventory of Olympic National Park, the list of rare cryptogams will continue to evolve.

The primary threats to rare vascular and nonvascular plants in Olympic National Park are related to human-caused disturbance. Indirect human-caused effects include the introduction of exotic ungulates (i.e. mountain goats) and increased soil disturbance from trampling in the vicinity of rare plant populations. Direct effects result from walking on plants, new construction, road or trail reroutes, and, in unusual cases, road or trail maintenance activities (e.g., brushing). There is also the possibility of direct effects from fire line construction and helicopter landing areas.

In addition to an abundance of rare species, Olympic National Park is also home to more than 300 species of exotic plants (Buckingham et al. 1995). Species of greatest concern are those that spread rapidly, have both vegetative and sexual reproductive abilities, can invade beneath closed forest canopies in the absence of human disturbance, and those that can readily invade "sensitive habitats" such as riparian areas. Species of particular concern include reed canarygrass (*Phalaris arundinacea*), herb Robert (*Geranium robertianum*), Canada thistle (*Cirsium arvense*), giant knotweed (*Polygonum sachalinense*), and Japanese knotweed (*Polygonum cuspidatum*). These species are of concern mainly in the Western Hemlock Zone in Olympic National Park and also present problems elsewhere in the Pacific Northwest. Consequently, there may be opportunities to collaborate with other agencies that also monitor these species (e.g., USDA Forest Service, Washington Department of Natural Resources, and Clallam, Jefferson, Grays Harbor, and Mason Counties).

The primary concern with exotic plants is their effect on native plant species and communities. For example, exotic species make up 60-80% of the biomass in the understory of red alder (*Alnus rubra*) stands along floodplains of the Hoh River (based on data in Fonda 1974). Exotic plants are also known to inhibit succession of native species in abandoned homestead pastures and there is the possibility that reed canarygrass has displaced some rare plant taxa at Lake Ozette. Finally, reed canarygrass may have compromised sockeye salmon spawning habitat on the shores of Lake Ozette (Beauchamp 1995).

Monitoring should also be incorporated into any management activities that restore native plant populations or remove exotics. The details will depend on the objective of the specific management project and will not be discussed here.

Conceptual Model:

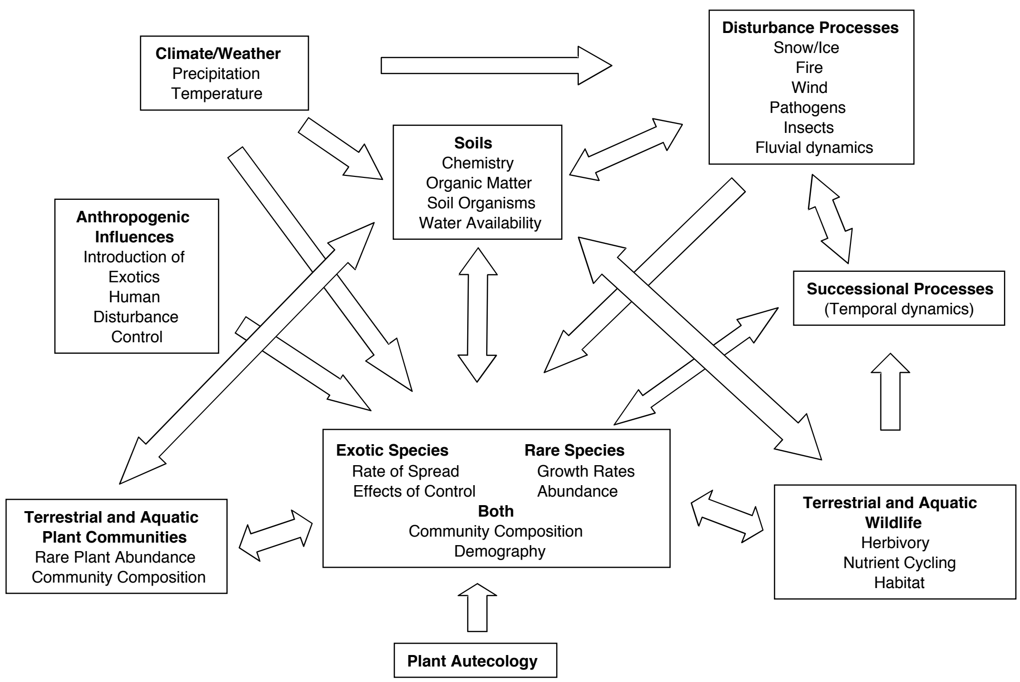

Figure 7.1. Conceptual model of biotic and abiotic factors affecting populations of rare and exotic plant species in Olympic National Park.

Monitoring Questions and Indicators:

Question: Detect change in the population sizes and ranges of listed rare vascular plants (USFWS Sensitive, WNHP Threatened, selected WNHP Sensitive).

- **Indicator:** Population Size and Range of Listed Rare Plants
  - Species Occurring at One or a Few Sites. Populations of these species should be completely mapped, and dimensions or cover and reproductive status should be recorded for individuals. High priority species should be measured for three consecutive years at five-year intervals. Sites with suitable microhabitat but not currently occupied by rare species should be monitored for colonization. Low priority species should be monitored for 1 year at 3-5-year intervals. Indicators of disturbance such as hoof marks, droppings, torn or bitten leaves, human foot prints, etc. should also be noted to help explain declines in populations. In addition, temperature, snowmelt, and precipitation should be monitored concurrently with population sampling. Justification: The indicators are comprehensive and feasible given the small populations. The intervals reflect the time intervals at which change might be expected to be noticeable while

accounting for annual variation. Some indication of the cause of population fluctuations would give managers a decision-making tool to decide if protection is necessary. If populations decline due to direct or indirect effects of human activities the data give managers a place to start for designing a protection strategy. Limitations: The process of monitoring could put these populations at risk for damage due to trampling or altering of their substrate. The characteristics of suitable habitat have not been completely identified for all rare species. Lists of rare species are changeable.

- Species That Are More Widespread. These species should be monitored in the same way as small populations, but using randomly selected subsamples.

Question: Detect a change in the range and abundance of vascular plant species that are rare in the park.

- **Indicator:** Plant Populations in Specific 'Hot Spots' of Rarity. There are far too many rare plant species (more than 100) in Olympic National Park to consider individually. However, many occur in a limited number of geographic areas. A strategy to monitor these species would be to concentrate permanent plots on one or several species in specific geographic areas. Example areas include Mink Lake, Griff Creek, Lake Ozette, Deer Park, and Royal Basin. *Justification:* Targeting areas is more efficient than targeting individual plant species when there are more than one hundred species. These places will be visited while monitoring the listed species described above. *Limitations:* Monitoring rare species is labor intensive.
- **Indicator:** Populations of Rare Plants Occurring in One Known Location and Not Covered Above. Fourteen plant species are known from only one location in the park and are not found in the areas listed above. These populations should be visited and photographed at least every 5 years or have their size indicated in some other way. *Justification:* Lone populations of rare plants are especially endangered and are an important part of the park's biodiversity. *Limitations*: Some populations are in remote areas and difficult to access. This list changes as more locations are discovered.

Question: Detect changes in the population size of selected rare non-vascular cryptogams.

- **Indicator:** Populations of non-vascular cryptogams occurring at no more than two known locations in the park. These populations should be visited and photographed at least every 5 years or have their size indicated in some other way. *Justification:* Lone populations of rare plants are especially endangered and are an important part of park biodiversity. *Limitations*: Some populations are in remote areas and difficult to access. This list changes as more locations are discovered.

Question: What is the rate of range expansion of selected exotic species (e.g., those that are especially aggressive or can spread under forest canopies)?

- **Indicator:** Distribution of Exotic Species.
  - Reed canarygrass, giant knotweed, Canada thistle, and Japanese knotweed. These species have many known sources from which the populations spread. Indication of population expansion could be observed using survey transects from inside to outside of the establishment zones. Once thorough range maps have been constructed, all park staff should be made aware of, and report occurrences of these species because they may show up unexpectedly in new locations. Systematic surveys and measurements should be made biannually. Coordination between monitoring results and removal efforts should be made. *Justification:* This is the most efficient way to monitor especially worrisome species that propagate concentrically from a discrete source. *Limitations:* The large number of species and locations to track.

- Herb Robert. Herb Robert spreads quickly over large distances, especially along trails. It could be monitored by annual mapping of specific sites, chosen to describe its invasion away from trails into forests, and deeper into the park along trails. In addition, occurrence of herb Robert and other exotics should be surveyed annually along road corridors, rivers, trails, and near horse corrals. Other park divisions and crews working on other monitoring projects such as trail crew, vegetation and wildlife monitoring crews, might be able to help with documenting backcountry sightings. As above, coordination between monitoring results and eradication efforts should be made. *Justification:* This a potentially very damaging exotic and these measurements might dramatize the need for support for exotic control in the park. *Limitations:* None.

Question: Have management activities been effective in eliminating or slowing invasion of exotic species?

- **Indicator:** It is very important to know whether management activities are effectively addressing the invasion of exotic plants. The specific indicators and sample design will depend on the management actions and plant species involved and will not be addressed in detail here.

Linkages with Other Disciplines:

- System Drivers: Atmosphere and Climate. Weather records.
- Park and Surrounding Landscape. Snow melt.
- Terrestrial Vegetation Communities. Species composition.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Exotic Species										
Geranium robertianum Herb Robert	X	X	X	X			X			2 yr
Phalaris arundinacea Reed canarygrass	X	X	X	X			X	X	X	2 yr
Cirsium arvense Canada Thistle	X	X	X	X	X		X	X	X	2 yr
Polygonum sachalinense Giant knotweed	X		X				X	X		2 yr
P. cuspidatum Japanese knotweed	X		X				X	X		2 yr
Listed Rare and/or Endemic Taxa										
Austragulus australis v. olympicus		X				X		X	X	5 yr
Botrychium ascendens	X				X			X		5 yr
Botrychium lunaria		X				X	X	X		5 yr
Carex anthoxanthea		X				X		X		5 yr
Carex buxbaumii	X		X				X	X		5 yr

Cimicifuga elata		X		X			X	X		5 yr
Cochlearia officinalis	X		X				X	X		5 yr
Coptis asplenifolia	X			X				X		5 yr
Dryas drummondii		X				X			X	5 yr
Epipactis gigantea		X	X				X	X		5 yr
Lobelia dortmanii	X	X	X				X	X		5 yr
Parnassia palustris ssp. *neogaea*	X	X		X				X	X	5 yr
Poa nervosa var. *wheeleri*		X			X			X		5 yr
Polemonium carneum					X			X		5 yr
Sanguisorba menziesii	X			X				X		5 yr
Taxa listed Rare in Park	X	X	X	X	X	X		X	X	5 yr
Non-Vascular Cryptogams										
Brachydontium olympicum		X			X				X	5 yr
Crumia latifolia		X		X			X			5 yr
Rhytidem rugosum		X			X		X			5 yr
Ramalina thrausta		X		X				X		5 yr
Bundophoron melanocarpum	X		X					X		5 yr
Hydrotheria venosa		X			X			X		5 yr
Karnefeltia californicum	X		X				X			5 yr
Usnea spaecelata		X				X		X		5 yr
Vulpicida tilesii		X			X	X		X		5 yr
Management Effectiveness										

Research and Development Needs:

- What effects are exotic species, especially herb Robert, having on native plant communities and ecosystem function?
- What effects are exotic species having on food habits of herbivores?
- To what extent are exotic plants distributed by faunal species?
- What are the potential habitats of rare species and the distribution of those habitats on North Coast and Cascades Network lands?
- The life history traits are not known for all of the rare species in the park.
- Imperfect knowledge of the distribution of rare species will inhibit protocol development. Surveys are needed to enable monitoring.
- What are the causes of exotic species invasions? Are there underlying causes of invasion that might be ameliorated?
- Determine effective tools for exotic species elimination appropriate for the Pacific Northwest.
- What environmental conditions promote invasion?

Chapter 8. Terrestrial Fauna

Monitoring Need/Justification:

The park's staff and subject-matter experts placed high importance on the need to monitor the overall health and integrity of terrestrial ecosystems, from the flagship low-elevation ancient forests to high-elevation alpine and subalpine meadows. Meetings with park staff and disciplinary experts focused on the need to monitor diversity of the park's fauna, overall, as well as status and trends of key faunal groups, such as forest amphibians, terrestrial birds and mammals (including bats), and invertebrates (primarily arthropods and mollusks), as indicators of the long-term integrity and functional resiliency of park systems. In this section we explore potential indicators of monitoring selected faunal assemblages as indicators of the long-term ecological integrity of park ecosystems. Though also critically important to ecosystem health, we identify indicators of large mammal populations (Chapter 9), threatened and endangered or endemic species (Chapter 10), and amphibians (Chapter 13) in subsequent sections.

Properties of faunal assemblages and populations may be important indicators of environmental change because animals serve a great diversity of ecological functions that affect ecosystem productivity, resilience, and sustainability (Walker 1992, Risser 1995, Marcot et al. 1998). Some particularly important functional relationships include those between pollinators and rare or endemic plant species, small mammals and spore dispersal of mycorrhizal fungi, predators and prey, and relationships between generalist species that respond favorably to human activities (including many exotic species) and ecological specialists that commonly do not (mostly native species). Monitoring wildlife assemblages may detect the effects of both local and regional stressors on components and properties of ecosystems, including effects of developed areas on park wildlife communities, forest disturbance on mammalian prey of spotted owl populations, expansion of alien wildlife species in the park, and global climate change on many taxa, notably populations of bats and amphibians. In addition to gauging effects of potential stressors, monitoring wildlife communities in Olympic National Park would establish benchmarks for comparison to more intensively managed coniferous forest landscapes throughout the Pacific Northwest and would help to define management targets on both managed and protected lands. Lastly, terrestrial fauna are desirable subjects for long-term ecological monitoring because animals have widespread public appeal, and changes in the park's fauna are likely to garner a high level of public interest and generate support for corrective or remedial management actions.

Our scoping meetings generated considerable discussion over what constitutes the most important indicators of the integrity of the park's fauna and best methods of monitoring. Our dialogues reflected a recent theme debated in the literature over whether it is best to monitor status and trends in population characteristics of selected species (e.g., a taxonomic approach) or whether the structure of faunal assemblages could be effectively monitored to provide a more comprehensive view of changes in park ecosystems (e.g., Goldstein 1999, Walker 1999). The resulting conceptual model portrays a tiered approach reflecting monitoring of park fauna at several levels of ecological hierarchy and spatial scale depending upon monitoring questions (Figure 8.1). Tier 1 indicators are aimed at identifying changes relative abundance and community structure indices based on relatively low intensity survey efforts. Tier 2 indicators involve more intensive monitoring and estimation of population abundance and demography.

Conceptual Model:

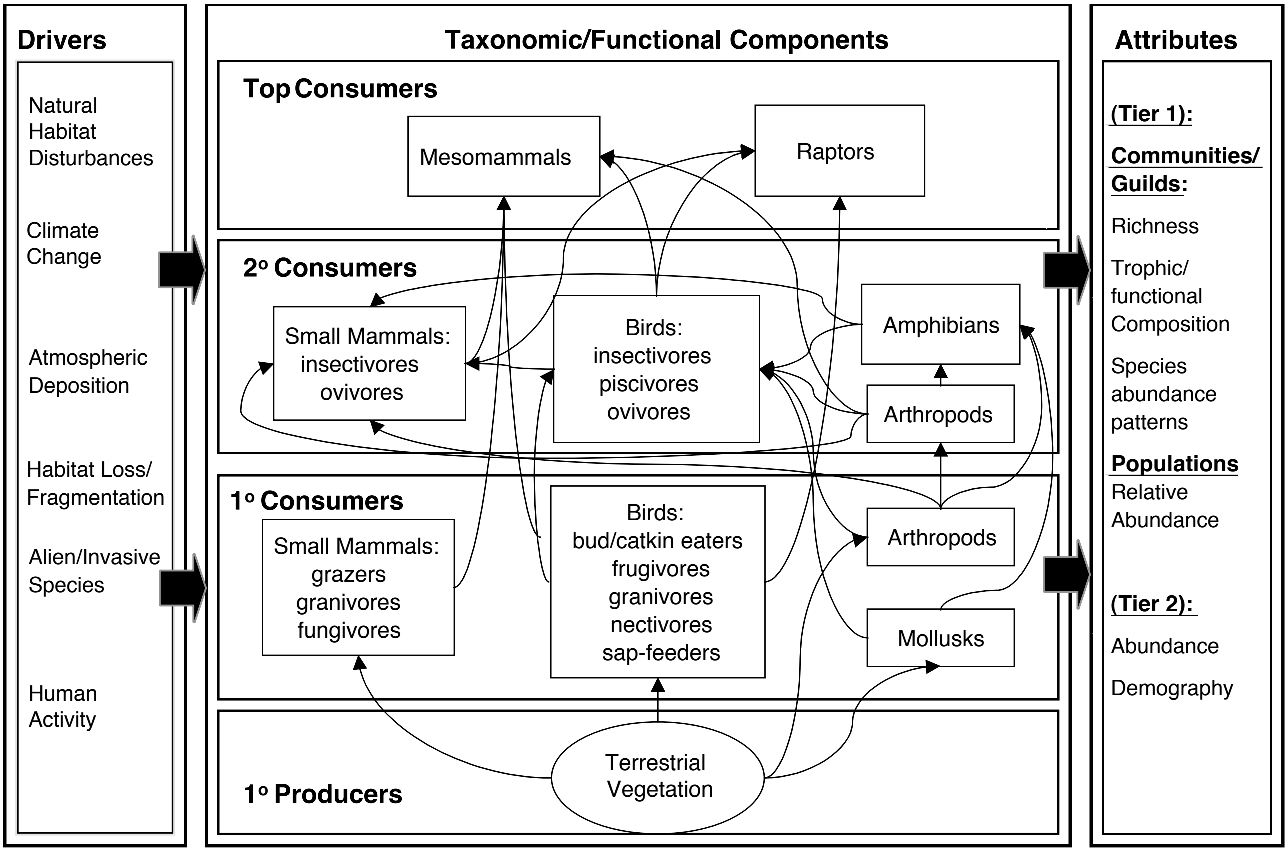

Figure 8.1. Trophic relationships among key faunal assemblages within coniferous forest ecosystems of Olympic National Park.

Monitoring Questions and Indicators:

Tier 1: Low intensity/extensive-scale monitoring

Question: Are there changes in the species composition of key animal communities that could signal changes in trophic structure, ecosystem function, or sustainability (e.g., breeding landbirds, mammals, arthropods, and mollusks)?

- **Indicator:** Indices of Community Composition. Sample presence/absence or relative abundance of terrestrial vertebrates and invertebrates. These indices should be developed separately for each category, as sampling constraints are likely to be quite variable. Develop a suite of metrics that, in aggregate, describe changes in community composition, including but not limited to:

- Species Richness. Measure species richness from observed species lists or computed from heterogeneous species detection probabilities (e.g., see Boulinier et al. 1998).
- Trophic Composition. Measure richness of species within trophic levels for terrestrial amphibians, mammals, and birds.
- Life-history Traits. Measure numbers of species with generalist life history traits that are adapted to exploiting ecological disturbances (i.e., r-selected species) and specialist species that are better adapted to exploit stable ecosystems (K-selected species).
- Native:Alien Richness. Measure numbers of native and alien species of terrestrial amphibians, mammals, birds, arthropods, and mollusks.

- Richness of Key Functional Groups. Measure numbers of key functional groups present in the community.
- Redundancy within Key Functional Groups. Measure numbers of species representing each key functional group.

  Justification: Aggregates of easily obtained community metrics may signal warnings of changes in community structure that may influence biotic integrity (Marcot et al. 1998). Such coarse-grained sampling may reveal the need for more intensive population-level research on species or species relationships. *Limitations:* Indices of biotic integrity based on patterns of species abundance have not been developed for terrestrial ecosystems. Indices based on species composition measure loss of species in stepwise manner and do not provide anticipatory warning of change.

Question: Are there changes in distribution or relative abundance that could portend threats to long-term viability of selected species (signaling the need for more intensive monitoring)?

- **Indicator:** Site Occupancy Rate. The proportion of sites occupied by a species may be a useful indicator of relative abundance of species that are difficult to estimate directly (MacKenzie et al. 2002). This indicator may be useful for monitoring large-scale trends in abundance of selected species of arthropods, mollusks, terrestrial amphibians, mammals, or birds. *Justification:* Surveys may be implemented more easily and less expensively than methods used for abundance estimation. *Limitations*: Indices may not be sensitive to changes in abundance for rare or common taxa.
- **Indicator:** Abundance Indices of Avian Species. Monitor long-term changes in distribution and relative abundance of selected avian species using plot sampling and distance-based or double-observer estimation methods (Buckland et al. 1993, Nichols et al. 2000). *Justification:* Abundance indices are easily derived from point counts. Relative ease of measurement allows comparatively extensive survey coverage. *Limitations:* Biases in distance-based sampling are poorly understood in such highly structured forest ecosystems.
- **Indicator:** Distribution and Abundance Indices of Mammalian Species. Monitor long-term changes in distributions and abundance indices of mammals using pitfall trapping arrays linked with constant-effort trapping grids. *Justification:* Abundance indices are easily derived from limited effort, allowing more extensive replication than is possible from more intensive estimation models. *Limitations:* Interpretation of indices is based on the assumption that capture probabilities do not vary among capture events.
- **Indicator:** Relative Activity of Bats. Monitor relative activity levels of bats in selected forest plots using echolocation call recording devices. *Justification*: Data may be obtained remotely at relatively low cost. *Limitations*: Most species of bats present in the park cannot be reliably distinguished from recorded echolocation calls.

Tier 2: High Intensity Monitoring

Question: Are there changes in demographic rates and abundance of key wildlife taxa?

- **Indicator:** Abundance and Demography of Breeding Birds. Establish 8-10 ha reference plots for territory mapping, nest searches, and constant-effort mist netting of bird populations. *Justification:* Intensive studies measure change directly and provide insights into demographic causes of observed changes. Methods are suitable for monitoring effects of specific stressors, for example, influences of human-developed areas on breeding bird communities. *Limitations:* High efforts and costs limit replication and constrain inference to small spatial scales.
- **Indicator:** Abundance and Demography of Mammals. Abundance and demography of small mammals. Establish 100-150-station trapping grids and estimate abundance, survival, and births in open populations of small mammals. *Justification:* Intensive studies measure change directly and provide insights into demographic causes of observed changes. *Limitations:* High

efforts and costs limit replication and constrain inference to small spatial scales

Linkages with Other Disciplines:

System Drivers: Atmosphere and Climate. Effects of climate on arthropods and bats.
System Drivers: Human Activities. Effects of developed areas on faunal assemblages.
Park and Surrounding Landscape. Relationships of vertebrate distribution to landscapes.
Terrestrial Vegetation Communities. Integrate monitoring of vegetation and wildlife communities.
Special-status Wildlife Populations. Effects of small mammals on northern spotted owls.
Aquatic/Riparian Habitat. Riparian wildlife communities.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Tier-1 (presence/no detection, site occupancy, relative abundance)										
Terrestrial mammals	X	X	X			X	X	X		1 yr
Terrestrial birds	X	X	X			X	X	X		1 yr
Terrestrial amphibians	X	X	X			X	X	X		1 yr
Terrestrial arthropods	X	X	X			X	X	X		1 yr
Terrestrial mollusks	X	X	X			X	X	X		1 yr
Tier-2 (demographic studies)										
Terrestrial mammals	X	X	X			X	X			1 yr
Terrestrial birds	X	X	X			X	X			1 yr

Note: The spatial emphasis is placed on (but need not be restricted to) low-elevation forests, where reference plots are most needed, and high elevation zones where effects of global climate change are expected to be most pronounced. Focus on high- and moderate-use zones accommodates access constraints in wilderness.

Research and Development Needs:

- Develop methods to integrate sampling across taxonomic boundaries in a single sampling scheme.
- Investigate properties of estimating site occupancy rates for terrestrial amphibians, small mammals, and invertebrates, for potential use in monitoring changes in spatial patterns of species distribution.
- Explore means of integrating Tier-1 indicators into indices of biotic integrity of terrestrial faunal associations in coniferous forests.
- Examine sensitivity of integrative indices of biotic integrity to gradients of resource disturbance on the Olympic Peninsula.
- Examine statistical power of potential indicators to detect resource change.
- Examine reliability of distance-based and double-observer methods of estimating avian bird populations in structurally complex environments.

Chapter 9. Populations and Communities of Large Mammals

Monitoring Need/Justification:

Native populations of large mammals, including Roosevelt elk, Columbian black-tailed deer, black bear, and cougar, are key components of conifer forest ecosystems of Olympic National Park. Roosevelt elk were so important politically at the turn of the 20th century that Olympic National Park was created in large measure to protect the last stronghold of this unique coastal form of elk. Today, Roosevelt elk and the other large mammal species generate broad appeal with the visiting public for the viewing opportunities they provide, while also creating management concerns for human safety, particularly in the case of large carnivores. Further, grazing and trampling activities of large ungulates (i.e., deer and elk) affect structure and composition of the parks renowned low-elevation temperate rain forest ecosystems (Happe 1993, Schreiner et al. 1996, Woodward et al. 1994). Predators may influence abundance of ungulates, suggesting that changes in top-level carnivores may create cascading influences on park ecosystems (McLaren and Peterson 1994).

There are several legitimate concerns over the future protection and welfare of the park's large mammalian fauna (Houston et al. 1990). Many populations of large mammals range widely across park boundaries. Therefore, they are affected by habitat conditions, forest management practices, and hunting regimes outside the park. Elk populations have declined by approximately 40% outside Olympic National Park since 1980, due primarily to changing land use practices (Smith 2001), raising concerns that migratory elk leaving the park could be subject to similar pressures. Declining opportunities for hunters outside the park may increase illegal hunting of elk inside the park, as well as legal and illegal harvests of elk leaving the park. Concerns of a 'boundary' effect are heightened by recent findings that many mature male elk leave the park during the rutting season and may be susceptible to harvest (P. Happe, Olympic National Park, Unpublished data). Also, recent aerial surveys of elk on key winter ranges suggest that fewer elk are observed near the park boundary than in recent decades (P. Happe, Olympic National Park, Unpublished data).

Much less is known about Columbian black-tailed deer than Roosevelt elk. Over the last several years, however, many debilitated deer have exhibited symptoms of excessive hair-loss and extreme emaciation, related to high abundance of both internal and external parasites (K. Jenkins, U.S. Geological Survey, Unpublished data). This condition has been reported in many low-lying areas in western Washington, leading to concern over whether mortalities resulting from hair loss are having a major impact on populations (Washington Department Fish and Wildlife 2002:71). State biologists continue to investigate potential disease vectors that could be affecting the state's deer herds. Recent outbreaks of hoof and mouth and mad cow disease in Europe have heightened awareness of the potential for non-native disease vectors to affect native ungulates in U.S. national parks.

Populations of large mammalian carnivores are poorly understood in the park, although close-range and potentially dangerous encounters with both black bears and cougars appear to have increased in recent years (P. Happe, Olympic National Park, Personal communication). Each year, park managers respond to concentrated activities of black bears and cougars by closing popular destination areas to the visiting public. Recent changes in legal harvest methods outside the park (i.e., banned use of hounds and baits) could reduce harvest pressures on native carnivores and influence interactions of large carnivores with humans using the park and populations of their ungulate prey.

Conceptual Model:

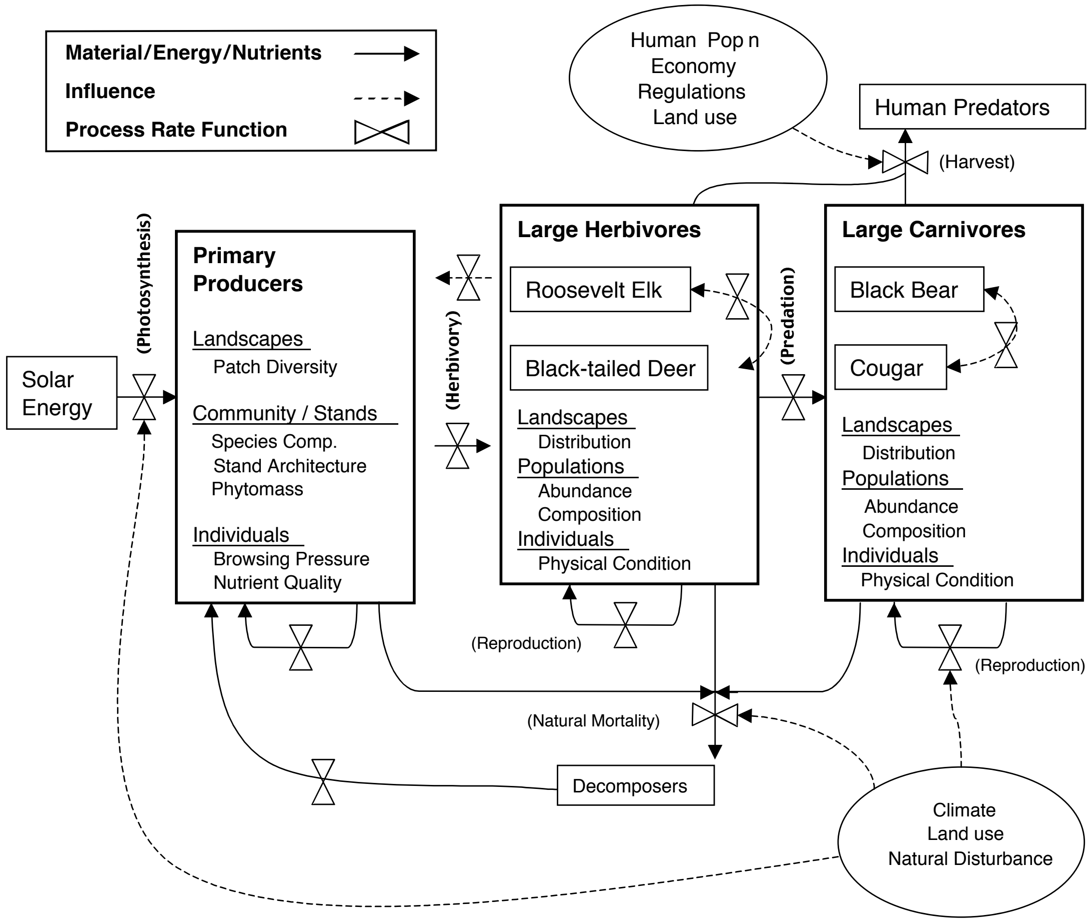

Figure 9.1. Conceptual model of vegetation/prey/predator system behavior characterizing dynamics of vegetation and mammal communities in Olympic National Park.

Monitoring Questions and Indicators:

Question: Is the status of elk or deer populations changing?

- **Indicator:** Abundance Indices of Elk. Conduct replicated aerial surveys of elk in two west-side watersheds of Olympic National Park during spring 'green-up' when the majority of elk are drawn to riparian deciduous forest types and before overstory trees have leafed out. *Justification:* Aerial trend counts of Roosevelt elk have been conducted in two west-side watersheds of Olympic National Park sporadically for almost two decades. Such counts of elk have been shown to have high repeatability in the Hoh and Queets drainage (Houston et al. 1987). *Limitations:* Aerial surveys are not practical in more densely forested drainages (those with less hardwood bottomland forest). Limited scale of study restricts inference to key watersheds. Variation in visibility biases of aerial surveys has not been determined.

- **Indicator:** Abundance of Deer. Conduct replicated ground-based counts of deer during winter from 30 km of trails in the Elwha Valley. *Justification:* Ground-based counts of deer have been conducted in the Elwha Valley for three years with high repeatability of results (K. Jenkins, U.S. Geological Survey, Unpublished data). Ground-surveys provide estimates of female:male:young ratios. *Limitations:* Limited scale of study restricts inference.

- **Indicator:** Abundance of Deer and Elk Pellets. Conduct surveys of deer and elk pellet groups. *Justification*: Rapid and relatively easy survey procedures allow monitoring relative abundance of elk and deer at large spatial scales. Extensive surveys would provide indices of changes in relative abundance of deer and elk, changes in distribution, and would allow extrapolation of survey results conducted on limited areas (see above). Recent advances in survey methodology and analytical methods allow correction for visibility biases, to allow correction for differences in visibility of elk and deer pellets, vegetation effects, and observers (K. Jenkins, U.S. Geological Survey, Unpublished data). *Limitations:* Pellet deposition rates and persistence of deer and elk pellets are poorly understood and may require additional research.
- **Indicator:** Composition of Elk Populations. Conduct aerial surveys of elk group composition during rutting aggregations during the fall. *Justification:* Such aerial surveys were conducted three years in the 1980s with high repeatability of results (Olympic National Park, Unpublished data). Change in male: female ratio may be an indicator of population change due to hunting pressure on males. Change in female:young ratio may be an indicator of change in reproductive productivity or high mortality of young animals. *Limitations:* Changes in composition ratios have ambiguous meaning without corresponding data on population trends.

Question: Are there changes in physical condition of elk that could signal population level changes in abundance?

- **Indicator:** Abundance of Internal Parasites. Collect fresh fecal samples of deer and elk during mid-winter. Count numbers of larvae, eggs, and oocytes of common internal parasites. *Justification:* Fresh fecal pellets are easily collected. Parasite abundance indicates the general health status of individuals. *Limitation:* Sampling variability and repeatability of results unknown.
- **Indicator:** Levels of Stress Hormones in Fecal Samples. Monitor concentrations of common corticosteroid hormones in fecal samples. *Justification:* Fresh fecal pellets are easily collected. Monitoring corticosteroid hormones might be an efficient screening method to signal the need for more detailed research. *Limitation:* Sampling variability and relationships to nutritional stress require additional study.

Question: Are key plant taxa changing in abundance, cover, fruit abundance, or morphologic stature?

- **Indicator:** Understory Structure and Composition. Measure cover, density, height, fruiting, or morphologic characteristics of key plant taxa that are sensitive to changes in herbivory (e.g., salmonberry, ladyfern, deerfern, graminoids; Happe 1993). Measure structural form class and browsing history of salmonberry. *Justification:* Previous research indicated that certain understory plant species are sensitive indicators of and provide an early indication of change in herbivores (Happe 1993, Schreiner et al. 1996). Measurement of understory characteristics may be linked to more general monitoring of forest communities (see Part II, Chapter 5). *Limitations:* Causes of change cannot be interpreted definitively without complex research designs.

Question: Is the abundance of bears and cougar changing?

- **Indicator:** Population Trends of Black Bears. Count black bears observed using high-elevation meadows during summer and fall. *Justification:* Trends in black bears can be monitored coincidental to conducting aerial mountain goat surveys during mid-summer (see Part II, Chapter 5) and monitoring composition of elk populations during fall (see above: Composition of elk populations). *Limitations:* Repeatability of bear surveys is unknown. Variability associated with changing visibility biases is not known.

- **Indicator:** Frequency of Bear and Cougar Encounters with Humans. Maintain mandatory reporting of all bear and cougars sighted by park staff, and all threatening encounters with large carnivores reported by park visitors. *Justification:* Cost-effective trend data. Data collection is consistent with other staff duties. *Limitations:* Changes in reported sightings confound changes in human use patterns with changes in carnivore density.

Linkages with Other Disciplines:

- System Drivers: Human Activities. Elk harvest trends outside the park. Poaching violations.
- Park and Surrounding Landscape. Habitat composition.
- Terrestrial Vegetation Communities. Influences of herbivory on forest composition and structure.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Abundance of elk	X		X				X	X	X	5 yr
Abundance of deer		X	X				X	X		1 yr
Pellet group abundance	X	X	X	X			X	X		5 yr
Composition of elk populations	X	X				X		X	X	5 yr
Abundance of internal parasites	X	X	X				X			1 yr
Stress hormones										1 yr
Understory structure and comp.	X		X				X	X		10 yr
Bear trends	X	X				X	X	X	X	5 yr
Frequency of bear and cougar encounters	X	X	X	X	X	X	X	X	X	1 yr

Research and Development Needs:

- Determine differential persistence and visibility bias associated with detectability of elk and deer pellet groups. Such understanding is needed to compare densities of deer and elk pellet groups between ungulate species and among geographic areas of the park (research is in progress).
- Determine sampling variability and repeatability of counts of parasite eggs, larvae and oocytes in feces of deer and elk (research is in progress).
- Determine seasonal variation in fecal stress hormones and relationship to nutritional status.
- Determine variability in sightability of black bears from summer or fall aerial surveys.

Additional research that may lead to other indicators or refinements to proposed indicators:

- Determine visibility biases of aerial surveys of elk.
- Evaluate non-invasive (camera or DNA-based) methods of estimating abundance of large-carnivores.
- Determine relationships between abundance estimates of deer and elk and fecal pellet group indices.

Chapter 10. Special-Status Terrestrial Wildlife Populations

Monitoring Need/Justification:

The mountainous insular geography of the Olympic Peninsula has promoted the evolution of several unique taxa of terrestrial wildlife found only on the Peninsula, primarily within Olympic National Park (Houston et al. 1994). Loss or fragmentation of late-seral coniferous forest habitats throughout the Pacific Northwestern U.S. has further insularized populations of several old-growth dependent wildlife species and has contributed to the federal or state listing of some as threatened or 'species of concern' throughout their ranges. Notably, Olympic National Park is home to at least 4 endemic mammalian taxa (including the Olympic marmot and endemic subspecies of yellow-pine chipmunk , Mazama pocket gopher, and Townsend's mole), one endemic amphibian (Olympic torrent salamander), as well as several taxa with disjunct distributions that may also have endemic subspecific forms. Olympic National Park also supports important populations of three species of terrestrial vertebrates on the U.S. Fish and Wildlife Service's threatened species list, including the northern spotted owl, marbled murrelet, and northern bald eagle. Presence of several other federally-listed species of concern, including three bat species, three amphibian species, Pacific fisher, northern goshawk, and olive-sided flycatcher may also serve as indicators of long-term health of terrestrial ecosystems of Olympic National Park. As most of the rare and unique amphibian species are aquatic, monitoring of those species is covered in Part II, Chapter 13 (Aquatic Biota).

There are several concerns regarding the long-term conservation of this unique fauna. The endemic mammals, which inhabit primarily high-elevation subalpine communities, may be affected by long-term changes in climate that influence patterns of snow deposition, snowmelt, rates of tree invasion, and ultimately, distributions of subalpine meadow habitats. Old-growth forest obligate species, occurring primarily at lower elevations, may be threatened by increased insularization of forests protected within Olympic National Park, which could disrupt natural colonization and dispersal patterns, dynamics of metapopulations, and exchange of genetic materials among population segments. Further, loss and fragmentation of habitats outside the park's boundaries may promote expansion of generalist predators or competitors inside the park, potentially to the disadvantage of protected species. For example, recent research revealed lower nesting densities of spotted owls near the boundaries of Olympic National Park, as well as displacement of spotted owls from several low-elevation nesting territories by the more aggressive and generalist barred owl (S. Gremel, Olympic National Park, Personal communication). Similarly, recent research points to potential effects of habitat fragmentation outside the park and human developments within the park on both the distributions of generalist predators and their potential effects on nesting success of the marbled murrelet (J. Marzluff, University of Washington, Personal communication). Because Olympic National Park provides regionally significant populations of both spotted owls and marbled murrelets, monitoring their long-term persistence and health is a high priority at both local and regional scales.

In addition to challenges of managing this unique array of native species within the park, other unwanted 'alien' or 'exotic' species threaten ecological values of the park and, therefore, also warrant a concerted monitoring effort at the population level. Of greatest concern, an exotic population of mountain goats was established in Olympic National Park in the early 1920s from a founding population of 11-12 mountain goats introduced from British Columbia and Alaska (Houston et al. 1994). The population increased to about 1100 goats by the mid-1980s, during which time grazing, trampling, and wallowing activities appeared to threaten ecological values of high-elevation plant communities in alpine and subalpine zones. Experimental reduction programs reduced mountain goat populations to approximately 380 mountain goats during the mid-1990s, but continued vigilance of population status of mountain goats and influences of mountain goats on plant communities and high-elevation ecosystems is needed to chronicle the extent and magnitude of undesirable effects. This information will factor into the future debate over how best to manage introduced populations of mountain goats and preserve subalpine and alpine vegetation communities.

Conceptual Model:

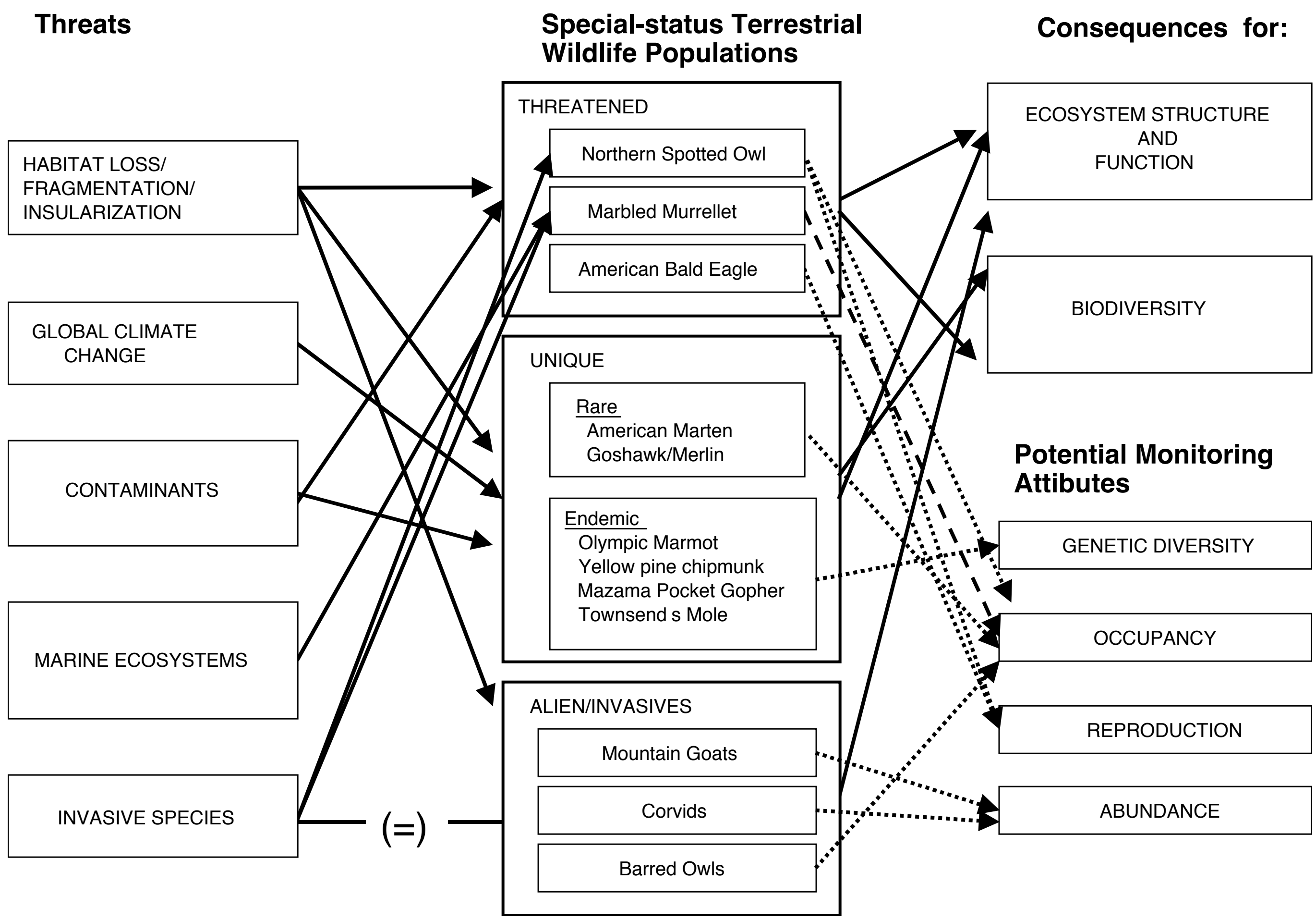

Figure 10.1. Conceptual model of factors affecting populations of special-status wildlife species.

Monitoring Questions and Indicators:

Question: Are endemic populations of Olympic marmots changing?

- **Indicator:** Colony Occupancy. Determine occupancy of all historically known marmot colonies at approximately 5-year intervals. *Justification:* Baseline records of marmot colonies exist back to the 1960s in selected regions of the park. Changes in the number of occupied colonies may indicate large-scale changes in metapopulation processes. Occupancy is easily determined.

- **Indicator:** Colony Size, Reproductive Indices. Determine maximum numbers of adults and juveniles observed as an index of colony size and composition. *Justification:* Many known colonies are quite accessible. Quick index could signal changes in overall status of individual colonies and factors influencing productivity and recruitment. *Limitations:* Interpretation may be difficult.
- **Indicator:** Genetic Diversity. Measure genetic variability within and among colonies of marmots at a 5-10 year frequency, aimed at detecting long-term (decadal) change in gene frequencies and heterozygosity. *Justification:* Research underway in Olympic National Park is investigating potential applications of genetic techniques for monitoring genetic exchange among maternal colonies. Genetic techniques may provide early warning of geographic isolation in marmot colonies and disruption of metapopulation processes.

Question: Is the genetic diversity of other endemic mammalian subspecies changing in Olympic National Park?

- **Indicator:** Genetic Diversity. Measure genetic variability from a sample of tissues collected from specific endemic mammalian taxa in Olympic National Park. Samples could be collected at 5-10-year frequency to detect change at the decadal time-scale. *Justification:* As with marmots, disjunct distributions of other mammalian taxa may increase risk of inbreeding depression, reduction in genetic variability, or increased expression of deleterious alleles. Research underway in Olympic National Park is establishing empirical baselines of genetic diversity of selected endemic taxa (J. Kenagy, University of Washington, Personal communication).

Question: Are population parameters of northern spotted owl deviating from long-term patterns, signaling a change in population abundance?

- **Indicator:** Territory Occupancy. Monitor a sample of known territories of northern spotted owls annually to determine percentages of territories occupied by single owls, breeding pairs, and barred owls. *Justification:* Olympic National Park has been monitoring 50-60 known territories since at least 1995. Monitoring the occupation of known territories has provided important information on large-scale patterns of nesting distributions of spotted owls and revealed barred owl expansion into northern spotted owl territories. *Limitation:* Research is needed to determine fate and reproductive success of displaced pairs of spotted owls.
- **Indicator:** Fecundity and Survival. Determine the number of female young produced per territorial female by monitoring the same known territories annually. Additionally, contribute to Peninsula-wide estimates of survival rate by banding new fledglings and adults each year and reporting annual sightings of each. *Justification:* Demographic studies may provide early warning of changes in population status. Olympic National Park has been monitoring demographic performance of spotted owls since 1989, producing one of the longest running population data sets in the park. The 1994 President's Northwest Forest Plan directed federal agencies to work cooperatively in monitoring the effectiveness of forest conservation measures that were adapted to conserve the northern spotted owl throughout its range. Olympic National Park is one of 8 demographic study areas used to study population demographics and rates of population change throughout the owl's range; it is the most important National Park Service contribution to the interagency regional monitoring effort. *Limitation*: Demographic monitoring is expensive and generally exceeds monies available for long-term monitoring programs. It is important to derive outside funding to sustain this interagency monitoring effort.
- **Indicator:** Abundance. Because estimation of abundance is extremely expensive, we recommend only repeating the survey as concerns and auxiliary funding might dictate and permit. *Justification:* The population of nesting owl pairs was estimated in Olympic National

Park between 1992-1995 and provides a baseline for future population comparison (Seaman et al., 1996). A repeat estimation might be justified if demographic monitoring suggests grave concerns for future conservation outlook for the species, or if there is local need for a comparative population estimate. *Limitation:* Estimation is costly.

Question: Are there changes in distribution and status of marbled murrelets?

- **Indicator:** Presence/no detection of Probable Breeding Birds. Monitor the percentage of sample stands occupied by probable breeding birds (recognized as birds flying below the canopy). *Justification:* The Marbled Murrelet Technical Committee of the Pacific Seabird Group has developed survey standards for determining presence or probable absence of nesting activities (Evans et al. 2000). Olympic National Park staff has inventoried presence/no detection in many areas of the park associated with Elwha River restoration (Hawthorn et al. 1996), front country campgrounds and paired undeveloped sites (Hall 2000). *Limitations:* The relationship between probable nesting behavior and population density is not known.
- **Indicator:** Relative Abundance. Monitor relative abundance of marbled murrelets flying up selected watersheds using high-frequency marine radar. *Justification:* Radar surveys may be the most reliable method of estimated marbled murrelet numbers in specific watersheds (Burger 1997). Standard methodologies have been employed in many areas of British Columbia (Cooper and Hamer 2000) *Limitations:* Sampling variation and optimal sampling design are poorly understood.

Question: Are there deviations in productivity of bald eagle populations from the long-term norm that would signal changes in population status?

- **Indicator:** Territory Occupancy and Nesting Success. Determine territory occupancy of known nesting territories of bald eagles on Olympic National Park's outer coastline and in the interior Olympic Peninsula. Also monitor reproductive success of eagles occupying territories. *Justification:* Olympic National Park occurs within 2 of 11 recovery zones in the state of Washington. Monitoring within these two recovery zones is necessary to contribute to U.S. Fish and Wildlife Service recovery efforts for these two species. The U.S. Fish and Wildlife Service and Washington Department of Fish and Wildlife currently share responsibilities and costs of monitoring. *Limitations:* An insufficient number of nesting territories has been identified in the park interior to permit reliable monitoring of reproductive indicators for interior-nesting birds. Additional surveys are needed to locate additional nest sites.

Question: Are populations of introduced mountain goats or their effects on high-elevation plant communities increasing, triggering the need for more intensive management?

- **Indicator:** Relative Abundance of Mountain Goats. Monitor relative abundance of mountain goats, by conducting aerial counts in randomly selected sample units at approximately 3-5 year intervals. *Justification:* Aerial survey sampling methods have been designed previously and have been used to monitor trends in mountain goat populations since the mid-1980s (Houston et al. 1986, 1991). Precision of estimates and sampling costs is known. *Limitations:* Influences of observer and environmental variability on detection biases is not known.
- **Indicator:** Distribution and Abundance of Rare or Endemic Plant Populations. See Part II, Chapter 7 (Special Status Plant Species: Rare and Exotic).

Linkages with Other Disciplines:

- System drivers: Atmosphere and climate. Effects of climate change on marmots and habitat.
- System drivers: Human Activities. Park development and activities.

- Park and Surrounding Landscape. Insularization, fire history, forest succession.
- Contaminants: Persistent organic pollutants.
- Terrestrial Vegetation Communities. Community-level effects of introduced mountain goats.
- Special-status Plant Species. Population-level effects of introduced mountain goats effects.
- Terrestrial Fauna. Prey, predators, or competitors of special-status wildlife.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Olympic Marmots.	X	X				X	X	X		1 yr
Endemic mammalian popn.s	X	X				X	X			10 yr
Northern spotted owls	X	X	X	X	X		X	X	X	1 yr
Marbled murrelets	X	X	X	X			X	X		1 yr
Bald eagles	X		X				X	X	X	1-2 yr
Mountain goats	X	X				X	X	X	X	5 yr

Research and Development Needs:

- Develop genetic markers and baseline understanding of genetic variability and spatial patterns of heterogeneity in Olympic marmots and other endemic mammalian taxa (research is in progress, conducted by independent researchers).
- Optimal sampling designs need to be developed and evaluated for both presence/no detection and radar-based sampling of marbled murrelets. Spatial and temporal patterns of sampling variation and its relationship to monitoring costs should be evaluated further.
- Visibility biases of aerial mountain goat surveys should be evaluated.
- Develop methods for monitoring goshawks and Pacific marten populations.
- Develop methods for monitoring changes in abundance of bat species of concern.

Chapter 11. Geoindicators

Monitoring Need/Justification:

In 2000, the National Park Service's Geologic Resources Division introduced geoindicators to park resource managers as an important ecosystem management tool. Geoindicators are measures of physical processes on the earth's surface that may undergo significant change in less than 100 years and may be affected by human actions. Geoindicators differ from geologic processes in that they are parameters that can be used to assess changes in rates, frequencies, trends, or magnitudes of geologic processes. For example, glaciation is the *process* by which ice accumulates, flows and recedes, shaping the land as it does so. Glacier fluctuation is the *geoindicator* that tracks changes in ice mass balance and position, which are important in understanding and forecasting changes to mountain and river ecosystems.

Nearly all of the important geologic processes in Olympic National Park that might change in a 100-year time frame are related to solid or liquid water, and soil. Throughout its geologic history, glaciers and flowing water have physically shaped the Olympic Peninsula. River levels, amount and timing of flow, and the effects of erosion on river morphology determine the quality of aquatic habitat. Coastal areas are influenced by sea level and shoreline position. Steep topography, sedimentary soils, and heavy precipitation in some areas of the park make slope failure and "stream blow-out" a frequent disturbance. Lakes and wetlands are also important sources of biodiversity that may need geologic monitoring. Changes in these geologic processes will be greatly affected by changes in precipitation and air temperature, both predicted to change due to anthropogenic forces. Monitoring how these processes respond to climate change will indicate how habitat quality throughout the park will be affected.

Conceptual Model: See factors below identified in other sections.

Monitoring Questions and Indicators:

Olympic National Park has identified nearly a dozen geoindicators of processes that are highly important to park ecosystems, highly likely to be impacted by humans, and have a high level of significance to park management. Questions and indicators for these geoindicators will be developed at the national level:

- Frozen ground activity (especially solifluction lobes)
- Glacier fluctuations
- Groundwater chemistry in the unsaturated zone
- Lake levels (including subalpine lakes)
- Relative sea level
- Shoreline position
- Slope failures
- Soil and sediment erosion
- Soil compaction
- Stream flow
- Stream channel morphology
- Stream sediment and load
- Surface water quality
- Ground water chemistry
- Nutrient dynamics
- Wetlands—extent, structure and hydrology

Nearly all of these geoindicators have been identified under other subject matter headings as important to monitor. Specific protocols for monitoring these indicators may be coordinated nationally by the National Park Service Geological Resources Division in the near future.

Linkages with Other Disciplines:

- Aquatic/Riparian Habitat. Stream sediment load, stream channel morphology, lake levels, glacier fluctuations, water quality.
- Park and Surrounding Landscape. Shoreline position, slope failures, wetlands.
- Biogeochemistry. Water quality, stream flow.
- Coastal Environments. Relative sea level, shoreline position.

Spatial and Temporal Context: Where and How Often to Monitor: (will be completed pending national guidance)

Research Needs:

- How do observed changes in river flow rate and temperature affect stream morphology, stream chemistry, and aquatic ecosystem development? How sensitive are fish populations to those changes?
- How will changes in sea level affect the amount and type of estuarine habitat and how would such changes affect fish populations that spawn in the park?
- What are the effects of increased or decreased erosion on stream morphology and consequently for fish populations?
- How will riparian areas respond to changes in river flow rate?

Chapter 12. Aquatic/Riparian Habitat

Monitoring Need/Justification:

The water resources and associated riparian zones of Olympic National Park include a full array of high- and low-elevation lakes, ponds, bogs, mineral and freshwater springs, and glacial and non-glacial rivers and streams. In addition, one reservoir and one dam reside within park boundaries. These areas, in turn, provide habitat for a diversity of anadromous and resident fish, amphibians, and invertebrates. Despite the abundance and vital importance of these resources as habitat, no integrated monitoring program exists. A specific example shows how poorly the resources are understood. In one study, the acidification potential of lakes in Seven Lakes Basin was found to be fairly low, in keeping with predictions (Welch and Spyridakis 1984). Based on these results and geomorphologic considerations, other high-elevation lakes were also predicted to have low acidification potential. Nevertheless, a one-season examination of several eastside alpine lakes found these to have high acidification potential (Larson 1995).

The physical, hydraulic, and chemical properties of streams and rivers determine their suitability as habitat for aquatic wildlife. Conditions appropriate for spawning are defined by water depth, water velocity, size of substrate, and availability of cover provided by overhanging vegetation, undercut banks, submerged logs and rocks, among other stream characteristics (Bjornn and Reiser 1991). These factors are also important along with debris dams in determining migration success for anadromous fish. Successful incubation of embryos of fish and amphibians depend on conditions that are conducive to development, and that allow young fish to emerge from under gravel. Some of the important factors include dissolved oxygen concentration, water temperature, substrate size, channel gradient, channel configuration, and water depth, among others (Bjornn and Reiser 1991). Food resources depend on the availability of coarse particulate organic matter accumulating behind debris dams and supporting invertebrate communities. Likewise, lake morphology determines many important habitat properties such as temperature gradients and light penetration in the water column and substrate characteristics (Bain and Stevenson 1999). Lake and stream characteristics are linked to terrestrial ecosystems because they are formed and maintained by interactions among landscape-scale features such as topography, geology, climate, vegetation, and drainage area.

Riparian vegetation structure, composition and dynamics also play a major role in creating suitable habitat for fish and other aquatic, semi-aquatic, and riparian wildlife (Naiman et al. 1993, Gregory et al. 1991). Streamside vegetation is important in preventing sedimentation and mass failure, influencing channel structure and floodplain processes, and controlling stream temperatures (Murphy 1995). Riparian vegetation also provides significant nutrient inputs and structural elements to the river system including plant litter and large woody debris. Large woody debris is also linked to the coast because it may wash to the ocean and contribute to the driftwood element of beach environments. The importance of riparian vegetation to riparian and stream habitats is recognized by the forest industry as it protects riparian buffer strips from harvest (Gregory et al. 1987).

The major threats to water resources inside the park include climate change, which will affect disturbance regimes, water temperature, spatial and temporal aspects of hydrology (Grimm 1993), and air-borne contaminants. Outside the park, land management practices and other human activities affect park waters, even though most rivers and streams originate inside the main body of the park (excluding the coastal strip). Contaminants from the air and from herbicides used on lands managed for timber outside of the park may pollute waters (Rashin and Graber 1993), removal of riparian vegetation may reduce the suitability of streams for migration and spawning (Gregory 1995), and harvest of anadromous fish diminishes the substantial quantity of nutrients from salmon carcasses historically present (Cederholm and Peterson 1985). Contaminants, marine-derived nutrients, and water chemistry are addressed elsewhere. Here we focus on the hydrologic and physical properties of lakes and streams.

Conceptual Model:

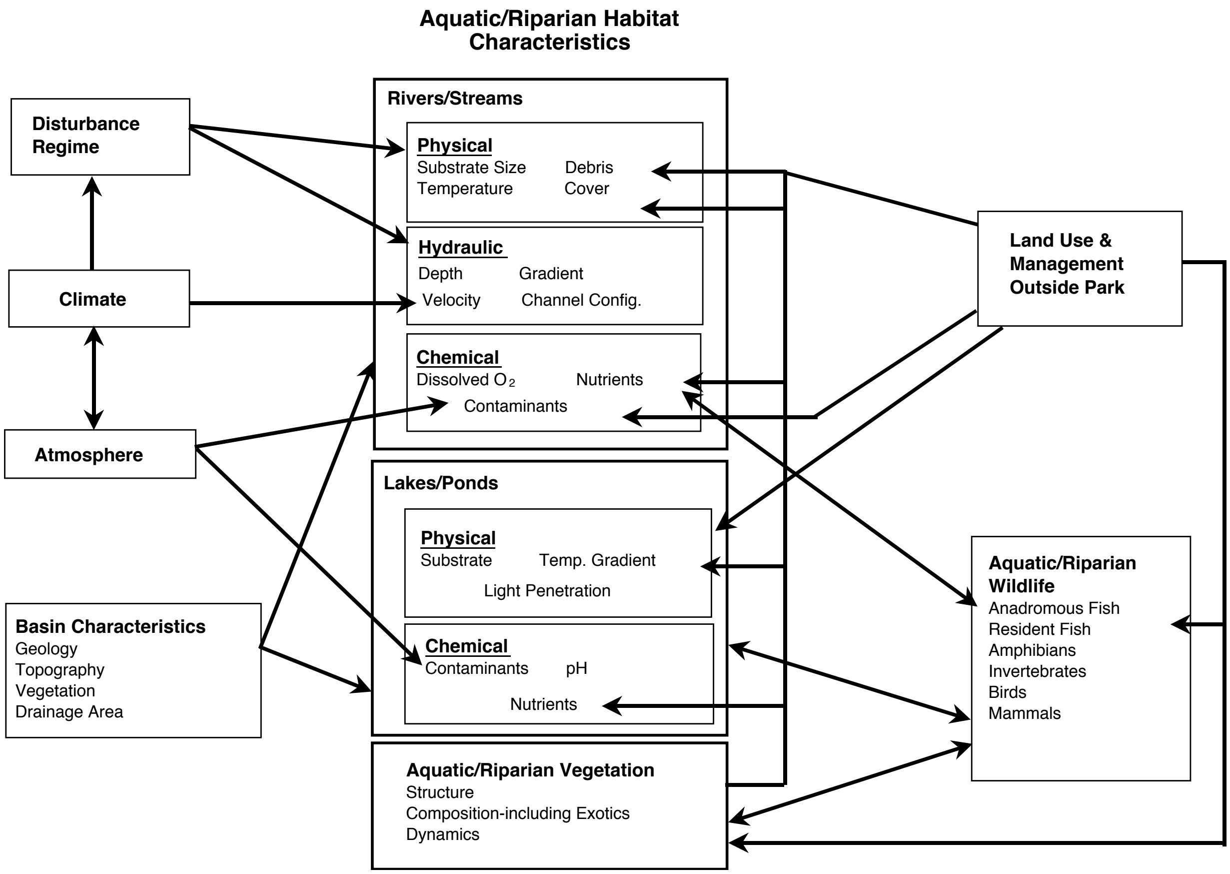

Figure 12.1. Conceptual model of physical, chemical, and biologic aspects of aquatic/riparian habitat and their interactions with system drivers in Olympic National Park.

Monitoring Questions and Indicators:

Question: Describe changes in features providing inputs to river systems (i.e., disturbances and riparian vegetation types).

- **Indicator:** Size and Distribution of Disturbance and Vegetation. Analyze repeat aerial photographs and Landsat imagery at 5-year intervals for distribution and frequency of all types of disturbance along a subsample of the river systems. Changes in the amount and distribution of riparian vegetation types, especially cottonwoods, should also be monitored. *Justification:* Both riparian vegetation and disturbances such as mass-wasting events provide inputs and structural elements to river systems. Changes in the frequency and distribution of these features could have serious consequences for rivers. Aerial photos and Landsat images will be important for monitoring all types of disturbance throughout the park. *Limitations:* Remote sensing is expensive and expertise to analyze aerial photos is rare. Ground-truthing current aerial photos is expensive and unrealistic for historic ones.

Question: Is water quality changing in selected lakes and streams?

- **Indicator:** Water Quality.
  - Rivers with ongoing monitoring. Add physical and chemical water quality parameters to rivers with ongoing hydrologic monitoring (i.e., timing and amount of flow) by other agencies; especially, add chemical measurements to rivers in the U.S. Geological Survey network (Hoh, Dungeness, Skokomish rivers). Physical and chemical parameters for rivers should include: quantity, sediment, temperature, dissolved oxygen, pH, nutrients, turbidity, conductivity, and pollutants. The Clean Water Act Total Maximum Daily Load (TMDL) protocol (Butler and Snouwaert 2002) should be followed for temperature and sediment. *Justification:* These additional measurements would give a more complete picture of sites where there is already a long-term record and regular visits for maintenance. *Limitations:* Expense.
  - Rivers and lakes without existing monitoring.
    - Coastal creeks and the Ozette River should be monitored for the parameters listed above.
    - Lake Ozette should be monitored for sediments using lake-bed cores.
    - Lake Crescent should be monitored for hydrocarbons and inholder activities at first fall rains.
    - High-elevation lakes should be monitored for level, sediment, ions, dissolved organic nitrogen and carbon, pH, nutrients, temperature profile, conductivity, phyto-and zooplankton, pollutants, turbidity, and light penetration (Dissolved organic carbon might be a surrogate).
    - Expanding measurements to other sites would also be desirable but of lower priority.

    Justification: These are sites with specific management concerns that also include a range of resource types. *Limitations*: Expense.

Question: Describe changes in glacier size.

- **Indicator:** Glacier terminus position and mass balance. Insure that monitoring of Blue Glacier continues. Staff members of the University of Washington are currently monitoring Blue Glacier with some help from the park in maintaining a camera. Adding monitoring to Anderson or Eel glacier would be desirable, but of lower priority. A protocol for monitoring mass balance using arrays of stakes is being developed by Jon Reidel at North Cascades National Park. *Justification:* There is a very long record of the terminus position already (>100 years). Blue is a sentinel glacier in a larger glacier monitoring network. Many rivers in Olympic are glacier fed so that changes in amount and timing of glacier melt will affect their properties. *Limitations*: None.

Question: Are parameters describing physical habitat-related characteristics of lakes and streams changing?

Indicator: Physical characteristics of streams and lakes.

- **Streams**. In addition to the chemical and flow measurements described above, streams should be monitored for large woody debris, channel morphology, habitat units (e.g., ponds and riffles), substrate, and structures (e.g., boulders and submerged woody debris). The protocols should incorporate those developed by Timber Fish and Wildlife (TFW, Schuett-Hames et al. 1994) and Reed Glesne at North Cascades National Park. *Justification:* Physical features of streams besides water quality are important descriptors of aquatic habitat. Using TFW protocols will help the park serve as a benchmark for managed lands. *Limitations:* Extent depends on funding.
- **Lakes and Ponds**. In addition to the parameters described above, lakes should be monitored for large woody debris, littoral habitat/vegetation, substrate, morphology/bathymetry and structure. Protocols should complement those of TFW for streams and incorporate protocols under development by Gary Larson of U.S. Geological Survey.

Justification: Changes in these parameters indicate a change in habitat quality for lake and pond dwellers. *Limitations:* Expense.

Question: Are abundance of frequent plant species and vegetation structure changing?

Indicator: Structure and composition of riparian vegetation. The structure and composition of riparian vegetation should be monitored similarly to forest vegetation (see Part II, Chapter 6) with the additional need to indicate distance from river. Snags, tree allometry, and mortality are especially important. Protocols should be based on the protocols under development by Dean Berg and the Regional Riparian Forest Permanent Sample Plot System (Reeves et al. 2001, www.reo.gov/monitoring/watershed). Vegetation plots should be co-located with stream habitat monitoring. *Justification:* Riparian vegetation contributes important components to stream systems as well as modifying microclimate and stream temperature. Following the protocols used by others will widen the use of our data. *Limitations:* Expense.

Linkages with Other Disciplines:

- Park and Surrounding Landscape. Snow cover and duration, disturbance.
- Geoindicators: Glaciers, lake morphology, channel morphology.
- System Drivers: Atmosphere and Climate. Meteorologic stations, snow course.
- Biogeochemistry. Water quality.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Disturbance & Riparian Veg.	X	X	X	X	X	X	X	X	X	5-10 yr
Wat. Qual. – Rivers with monitoring	X	X		X	X		X	X		1 yr
Wat. Qual. – Coastal creeks	X		X				X	X		1 yr
Wat. Qual. – Lake Ozette	X		X				X			1 yr
Wat. Qual. – Lake Crescent	X		X				X			1 yr
Wat. Qual. – High Lakes	X	X			X	X		X	X	1 yr
Glaciers	X					X		X		1 yr
Habitat - Stream	X	X		X	X		X	X		1-2 yr
Habitat – Lakes & Ponds	X	X		X	X		X	X		5 yr
Ripar. Vegetation – Plot Level	X	X		X	X		X	X		10 yr

Research Needs:

- Complete a thorough inventory of glaciers, geologic features, lakes, ponds, rivers and streams by stream classes, avalanche paths, wetlands, riparian vegetation, and shoreline position.
- Repeat survey of the western lake survey sites.
- Pilot efforts to develop parameters and spatial relationships to determine if there are surrogates.
- Hydrologic models are needed to extrapolate point measurements to larger areas.
- Determine what amount of change is biologically significant in terms of impacting fauna.

Chapter 13. Aquatic Biota

Prepared with assistance from J. Meyer[1]

Monitoring Need/Justification:

The rivers, streams, lakes, and ponds of Olympic National Park support diverse assemblages of plankton, macroinvertebrates, amphibians, and finfish. These faunal communities make significant contributions to the productivity and stability of both aquatic and terrestrial ecosystems of the park. The diversity of macroinvertebrates found in freshwater ecosystems, for example, contribute to a number of critical ecological functions related to processing organic material, such as leaf litter, consuming autochthonous inputs (i.e., periphyton) and distributing nutrients through diverse trophic pathways (Cummins 1974). Further, the park's anadromous fish are widespread and, because all Pacific salmon die after spawning, their gametes and carcasses provide a pulse of nutrients that fuel aquatic systems and provide food for over 130 species of aquatic and terrestrial wildlife species including several species of birds and mammals (Cederholm et al. 2001). Positive benefits of salmon-derived nutrients include increases in invertebrate, phytoplankton, and periphyton production, invertebrate diversity, and fish growth rates (Cederholm et al. 1989).

Olympic National Park's fresh waters are also home to 7 species of pond-breeding and 4 species of stream- or seep-breeding amphibians, including the Olympic torrent salamander that is found only on the Olympic Peninsula (Good and Wake 1992). Collectively, amphibian communities are important consumers of zooplankton and macroinvertebrates, while also providing food for fish, birds, and other amphibians. A primary goal of the National Park Service's mission is to preserve the biological integrity in the composition and function of these complex aquatic systems.

[1] Olympic National Park

Aquatic faunal communities of Olympic National Park face a number of threats. Migratory salmon, trout, and char are especially vulnerable because they migrate to coastal and ocean areas outside the park for large portions of their life cycle. Consequently, they are subject to the full spectrum of resource exploitation and habitat degradation that has driven many Pacific salmon stocks to low or critical levels of abundance. One of the principal threats to anadromous salmonids is the high rate of harvest during their marine and estuarine migration, which affects the size of annual salmon runs returning to the park (Emmett and Schiewe 1997, Francis 1997). Degradation of water quality and aquatic habitat is most acute in the park's coastal strip and lands that extend into developed areas, where intensive logging and habitat degradation upstream has reduced both the quality and quantity of downstream spawning habitats in the park (Bottom 1995). A third threat faced by the park's anadromous fish resources are artificial enhancement programs, including hatcheries, which operate around the Olympic Peninsula supplementing native fish runs with introduced stocks, and potentially compromising the genetic integrity of native stocks (Bottom 1995).

Changes in system drivers, discussed in other chapters of this report, including changes in atmosphere, human use and associated contaminants, also threaten the integrity of biotic assemblages in Olympic National Park waters. For example, depletion of the earth's ozone layer has caused levels of ultraviolet radiation-B (UVB) to increase in northern latitudes over the past 20 years (World Meterological Organization 1998). Some studies have shown that eggs of amphibians protected from UVB have greater hatching success than those not protected, suggesting that increases in UVB could negatively impact amphibian communities at broad ecological scales (Blaustein et al. 1994, but see Palen et al. 2002). Many contaminants may also affect quality of park waters, affecting the integrity of plankton, macroinvertebrate, and amphibian communities, and potentially accumulating in higher trophic levels. Recently, increased atmospheric nitrogen inputs at West Twin Creek (and presumably elsewhere in the park) were associated with a dramatic drop in stream pH (from 7.0 to as low as 4.5; Edmonds et al. 1998). It is known that pH decreases of this magnitude can have a profound effect on aquatic communities (U.S. Environmental Protection Agency 1986). On a more local scale, nutrient inputs to Lake Crescent from human shoreline developments (including septic systems, outhouses, and sedimentation) may accelerate eutrophication of this deep, oligotrophic lake, potentially influencing plankton and algal communities and spawning beds of endemic trout residing in Lake Crescent. Similarly, sedimentation associated with local developments in the Lake Ozette basin plus invasion of exotic plants may be influencing nutrient budgets and trophic structure within Lake Ozette and spawning grounds of the threatened Lake Ozette sockeye salmon stock (Beauchamp 1995).

Lastly, introduction of non-native fishes to many park waters constitutes a profound perturbation to structure and composition of biotic communities, primarily those of high-elevation lakes in which brook trout are now abundant. Past research has shown negative relationships of introduced trout on abundance and diversity of amphibians breeding in high mountain ponds and lakes, as well changes in the abundance and community structure of plankton and macroinvertebrate communities (Markle 1992).

These and several other resource concerns have led park staff, working with many disciplinary experts, to highlight the need to monitor biodiversity of park aquatic fauna and status of key groups, such as planktonic communities, aquatic invertebrates, amphibians, fish, interdependent terrestrial species, and marine-derived nutrients as indicators of long-term integrity and functional resiliency. Population-level monitoring of selected 'special-status' aquatic species is elaborated in the following chapter.

Conceptual Model:

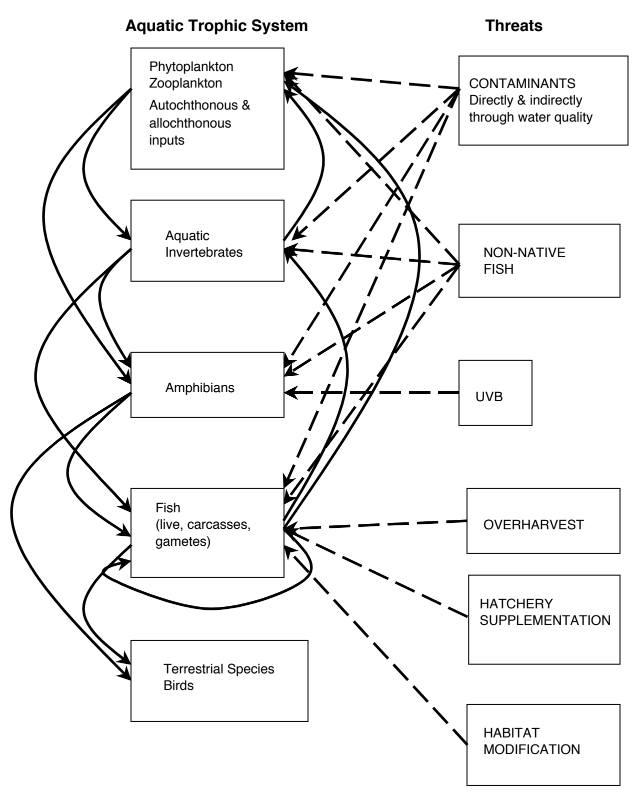

Figure 13.1. Conceptual model for the aquatic trophic system and impacts caused by human activities.

Monitoring Questions and Indicators:

Question: Are there changes in the species composition and structure of phytoplankton and zooplankton communities of park lakes that could signal changes in trophic structure, ecosystem function, or sustainability?

- **Indicator:** Composition and structure. Specific indicators and metrics to be identified and developed by U.S. Geological Survey/ North Cascades Lakes and Rivers Prototype Monitoring Program.

Question: Are there changes in the species composition and structure of macroinvertebrate communities of park rivers and streams?

- **Indicator:** Abundance. Specific indicators and metrics to be identified and developed to be consistent with U.S. Environmental Protection Agency's rapid bioassessment of macroinvertebrates. *Justification:* The National Park Service's Water Resources Division proposes rapid assessment of macroinvertebrates as part of a core suite of monitoring variables.
- **Indicator:** Composition and structure. Indicators and metrics to be identified and developed by U.S. Geological Survey/North Cascades Lakes and Rivers Prototype Monitoring Program. *Justification*: Changes in the composition and structure of macroinvertebrates can signal fundamental changes in ecosystem processes and ecological functions in freshwater ecosystems. Such monitoring can be integrated with existing U.S. Geological Survey monitoring of macroinvertebrates in the Elwha watershed (National Air and Water Quality Assessment Program). *Limitations:* Taxonomic analysis of macroinvertebrates is notoriously tedious and potentially costly.

Question: Are there changes in aquatic amphibian communities that could signal impacts associated with UVB, introduced fish, disease, contaminants, or climate change.

- **Indicator:** Abundance of stream-breeding amphibians. Count amphibians present in belt-transects placed across sampled stream reaches to get abundance index. *Justification:* U.S. Geological Survey has completed an inventory of stream-breeding invertebrates in Olympic National Park and has provided sampling recommendations for designing a monitoring program. *Limitations:* Cost.
- **Indicator:** Presence/no detection of pond-breeding amphibians. Record presence/no detection of pond and seep-breeding amphibian species. *Justification:* U.S. Department of Interior Amphibian Research and Monitoring Initiative is currently conducting presence/no detection surveys of amphibians breeding in Olympic National Park lakes and ponds. Protocols are developed and linked with monitoring of core water quality variables and disease screening of amphibians. *Limitations:* Presence/no detection may provide relatively insensitive indicator of subtle changes, but estimation of population abundance is beyond scope of this project.
- **Indicator:** Species diversity. Use abundance indices and presence/no detection surveys (above) to measure changes in species richness, evenness, and other metrics indicating changes in the overall structure of amphibian communities.

Question: Are fish communities changing in structure or populations declining due to changes in freshwater habitat?

- **Indicator:** Abundance of fish. (focusing here on those species that require an extended period of rearing in freshwater, including coho and cutthroat trout). Assess annual abundance through electrofishing and snorkel surveys in randomly selected stream reaches. Where feasible, construct smolt traps to provide more reliable estimates of annual abundance, including coho smolts produced from selected tributaries or river systems. *Justification:* Coho salmon require an extended period of rearing in freshwater and their annual abundance is more closely linked to freshwater and terrestrial habitat (e.g. water quality and quantity, pool/riffle ratios, woody debris loading) than other salmon species. Methodologies suitable for surveying freshwater fish in stream systems, including coho, are being developed in conjunction with North Cascades National Park as part of the Lakes and Rivers Prototype Monitoring Program. *Limitations:* High-gradient streams and large main-stem river channels are not easily sampled. Sampling biases may differ according to gradient, habitat complexity, conductivity, and other sampling difficulties.

- **Indicator:** Abundance of spawning salmon. Conduct redd (nest) surveys in stream reaches where spawning by adult salmonids is possible. *Justification:* This is currently the best means of assessing annual abundance of large numbers of salmonid stocks, especially those that do not spend large amounts of time rearing in freshwater systems such as chinook, pink, and chum salmon. These activities need to be coordinated with state and tribal managers who conduct these types of surveys in the park. *Limitations:* None.
- **Indicator:** Spawning escapement. As funding allows, install weirs in small and moderate-sized representative streams to provide more reliable estimates of annual spawning escapement. *Justification:* Trapping estimates are much more reliable than other methods of assessing spawning escapement and should be done over a brood cycle and in conjunction with redd surveys and used as a correction factor for years when no surveys are conducted. *Limitations:* Cost.
- **Indicator:** Genetic composition of native stocks. Monitor potential introgression of hatchery strains into genome of native stocks. Indicators to be developed further.

Question: Are there manifest ecosystem-level effects associated with changes in salmon abundance?

- **Indicator:** Marine-Derived Nutrients. (See also Part II, Chapter 4 - Biogeochemical Cycles). In conjunction with fish abundance surveys, monitor marine-derived nutrients in aquatic and riparian vegetation, aquatic invertebrates, and juvenile fish. *Justification:* Marine-derived nutrients are important contributors to the productivity of aquatic and terrestrial ecosystems. Prior studies suggest they directly influence rates of growth of juvenile fish, which translates into high rates of survival to maturity. *Limitations:* Quantitative relationships between salmon and nutrient inputs to stream and lake systems is lacking for the Olympic Peninsula but could become an important factor in future salmon management.
- **Indicator:** Abundance of riverine birds. Count numbers of individual birds, broods, and fledglings per brood (as appropriate) for common mergansers, red breasted mergansers, harlequin ducks, dippers, and kingfishers. *Justification:* Each of these species has been identified as having a strong, consistent relationship or recurrent relationship with salmon in Oregon and Washington (Cederholm et al. 2001). The ecology of these species may be benefited by salmon through nutrients provided in the form of gametes, fry, or carcasses, or indirectly from increased productivity of other food species. It may be particularly interesting to monitor effects of salmon restoration in the Elwha watershed following dam removals. *Limitations:* Changes in community structure of consumers may be a lagging, rather than leading, indicator of changes in lotic ecosystems.

Linkages with Other Disciplines:

- System Drivers: Atmosphere and Climate. UVB that may influence amphibian populations. Climate change that may influence aquatic biota.
- System Drivers: Human Activities. Changes in human development along lake shores, changes in fishing pressure.
- Park and Surrounding Landscape. Changes in logging patterns and landscape composition upstream from park rivers and lake watersheds.

- Biogeochemical Cycles. Changes in water quality parameters that influence all biotic communities. Changes in wet and dry deposition.
- Contaminants. Changes in contaminants that influence biota and may accumulate in higher trophic levels.
- Geoindicators. Changes in shoreline, mass wasting, erosion, stream flow, channel morphology that all influence aquatic habitats.
- Special-status Terrestrial Wildlife. Bald eagle populations are strongly dependent on salmonids, particularly those nesting along park rivers.
- Aquatic/Riparian Habitat. All measures of aquatic/riparian habitat directly affect aquatic biota.
- Special-status Fish Species. Threatened or endemic species of fish depend upon salmon-based nutrient budgets, plankton, and macroinvertebrates. Exotic trout may influence amphibian communities of lakes and ponds.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Plankton Communities	X	X	X			X	X	X		1 yr
Macroinvertebrates	X	X	X	X	X	X	X	X		1 yr
Stream Amphibians	X	X	X	X	X	X	X	X		1 yr
Pond/Lake Amphibians	X	X	X	X	X	X	X	X		1 yr
Fish	X	X	X	X	X	X	X	X	(?)	1 yr
Spawning Salmon	X	X	X	X			X	X		1 yr
Riverine Birds	X	X	X	X			X	X		1 yr
Marine-Derived Nutrients	X	X	X	X			X	X		5-10 yr

Research and Development Needs:

- Examine reliability of currently available stream sampling techniques (snorkeling and electrofishing) to detect the occurrence of native freshwater rearing fish species and assess their relative abundance.
- Explore sampling techniques suitable for assessing species composition and relative abundance of fish in larger main-stem river systems where sampling techniques are very limited and/or costs are high.
- What is the relationship between salmon spawning escapement (e.g. carcasses) and productivity of aquatic systems, especially abundance of fish in the same and other species in future brood years?
- How do stream channel characteristics (amount of large woody debris, deep pools, side channels, and unaltered natural stream banks) influence the deposition and retention of salmon carcasses for utilization by terrestrial and aquatic fauna as well as nutrient recycling?
- Study population processes, fresh water habitats, breeding behavior and reproductive ecology to understand what constitutes minimal populations size.
- Explore effects of current management regimes on salmon resources.

Chapter 14. Special-Status Fish Species: Threatened, Rare, Non-native, and Endemic

Prepared with assistance from S. Brenkman[1]

Monitoring Need/Justification:

Olympic National Park contains some of the last remaining undisturbed, contiguous habitat throughout the range of several west-coast fish species. Olympic National Park supports at least 29 native species and is the only national park in the lower 48 states that contains substantial numbers of native anadromous salmonids, some of which are listed as threatened under the Endangered Species Act. Some special-status species may serve as important "seeds" or genetic reservoirs to recolonize nearby extirpated populations in adjacent watersheds. In addition, all salmon species contribute nutrients and organic matter to aquatic habitats, providing an important nutrient subsidy to freshwater and terrestrial ecosystems, and influencing stream productivity at all trophic levels. Consequently, fish populations in Olympic National Park are an integral part of the biological integrity of aquatic ecosystems, and are of major ecological and economic importance and of public interest.

Three species of fish have been listed as threatened under the Endangered Species Act. Lake Ozette sockeye were listed in March 1999 because they are genetically distinct from all other sockeye populations in the Pacific Northwest (Gustafson et al. 1997), and they are among the last remaining wild sockeye in Washington State. Other unique attributes of Lake Ozette sockeye include early river-entry timing, relatively large adult body size, and large average smolt size (Gustafson et al. 1997). Lake Ozette once supported a harvestable run of sockeye salmon until overexploitation and degradation of spawning habitats caused a significant decline (Beauchamp 1995). Extirpation of these fish would impact ecosystem processes within the coastal portion of the Park. In November 1999, bull trout were listed as a threatened species in Puget Sound and coastal Washington. Substantial declines in distribution and abundance of bull trout throughout their range have been attributed to habitat degradation (Fraley and Shepard 1989), overfishing (Ratliff and Howell 1992), dams and irrigation projects (Rieman and McIntyre 1993), and displacement by non-native brook trout (*Salvelinus fontinalis*; Markle 1992). Finally, Puget Sound Chinook salmon were listed in March 1999, including Chinook salmon that inhabit the Elwha River Basin, Dungeness River Basin, and North Fork Skokomish River. Based on life history and genetic attributes, Elwha Chinook appear to be transitional between populations from the Puget Sound and the Washington Coast. Lake Cushman Chinook are unique because the population is one of the last remaining Chinook populations adapted to a freshwater life history. Factors for decline of Chinook include changes in flow regime, hydroelectric development, high water temperatures, and loss of large woody debris.

Olympic National Park is home to other rare or unique species. Pygmy whitefish (*Prosopium coulteri*) are remnants from the last ice age. In North America they are distributed across the northern tier of the United States, throughout western Canada and north into southeast Alaska. Pygmy whitefish are also found in one lake in Russia. Washington State is at the extreme southern edge of their native range in North America (Washington Department of Fish and Wildlife 2001), and they have been observed in Lake Crescent. Historically, pygmy whitefish resided in at least 15 lakes in Washington. Now they inhabit only nine and are likely to become endangered or threatened in a significant portion of their remaining range. Beardslee and *crescentii* trout are locally adapted trout species that inhabit Lake Crescent in Olympic National Park. These fish once supported popular fisheries in the lake until catch-and-release regulations were implemented

[1] Olympic National Park

recently. The Quinault River in Olympic National Park is at the extreme southern edge of the range of Dolly Varden (*Salvelinus malma*) in North America. In the lower 48 states, this species is only found on the Olympic Peninsula, in the upper Sol Duc and Quinault Rivers, and in Puget Sound. Additionally, Pacific (*Lampetra tridentata)* and river (*L. ayresi*) lampreys are considered federal species of concern by the U.S. Fish and Wildlife Service.

One important endemic species is the Olympic mudminnow (*Novumbra hubbsi)*, which is one of five species worldwide in the family Umbridae and is the only member of the genus *Novumbra*. Three other species are found in North America and one in Eastern Europe. Olympic mudminnows are found only in Washington State and no other members of the family Umbridae are found in Washington (Washington Department of Fish and Wildlife 2001). The current distribution of the Olympic mudminnow includes the southern and western lowlands of the Olympic Peninsula including Lake Ozette and the lower Queets River. Olympic mudminnows are listed as Sensitive by Washington State.

At present, there is a paucity of information related to rare species in Olympic National Park. Throughout the years, there has been inadequate monitoring of the distribution and abundance of fish species. The primary goals related to monitoring special status species are to: 1) prevent the loss of native fish species categorized as special status, 2) preserve the genetic integrity of federally listed populations of salmonids, and 3) reduce the likelihood of displacement of native species by non-native species. Meanwhile, the monitoring program must consider that the list of special status fish is likely to change.

There are several potential threats to the persistence of threatened, rare, and endemic fish populations in Olympic National Park. Substantial declines in distribution and abundance of native fish species can result from overharvest associated with recreational, commercial, and treaty fisheries; displacement of native fish species by non-native species; habitat degradation associated with logging and hydroelectric development; hatchery supplementation programs; and possibly global climate change.

Potentially significant threats to native fish species in Olympic National Park may be the invasion of Atlantic salmon (*Salmo salar)* and brook trout *(Salvelinus fontinalis)* and related competition with native species. Atlantic salmon are commercially raised in marine net pens in Washington State and British Columbia. Annual escapes of salmon from pens in British Columbia are estimated to be approximately 60,000 fish. Catastrophic events resulted in the escape of 107,000; 369,000; and 115,000 Atlantic salmon in 1996, 1997, and 1999, respectively, in Washington State (Amos and Appleby 1999). Atlantic salmon have been observed in the lower Elwha River and Quillayute River on the Olympic Peninsula. The presence of Atlantic salmon is of particular regional interest because of the recent listing of many salmon populations in Washington as *endangered* or *threatened* under the Endangered Species Act. Potential impacts of escaped Atlantic salmon include competition, predation, disease transfer, hybridization, and colonization (Amos and Appleby 1999).

Non-native brook trout were introduced into numerous high mountain lakes in Olympic National Park. Hybridization between brook trout and bull trout is a recognized problem, particularly in isolated streams. The distribution of brook trout in streams remains unknown although individuals have been observed in small streams in the park. Persistence of small isolated populations of native char may be seriously threatened by the presence of non-native brook trout (Markle 1992). Brook trout likely have a reproductive advantage over bull trout because they mature at an earlier age.

An understanding of reference conditions for special-status fish species will be essential to the establishment of appropriate management and conservation strategies in Olympic National Park. Additionally, knowledge of reference conditions in Olympic National Park will be useful in understanding patterns observed in more degraded systems. We designated four categories of special-species status in decreasing order of priority for monitoring: threatened, rare, non-native, and endemic.

Conceptual Model:

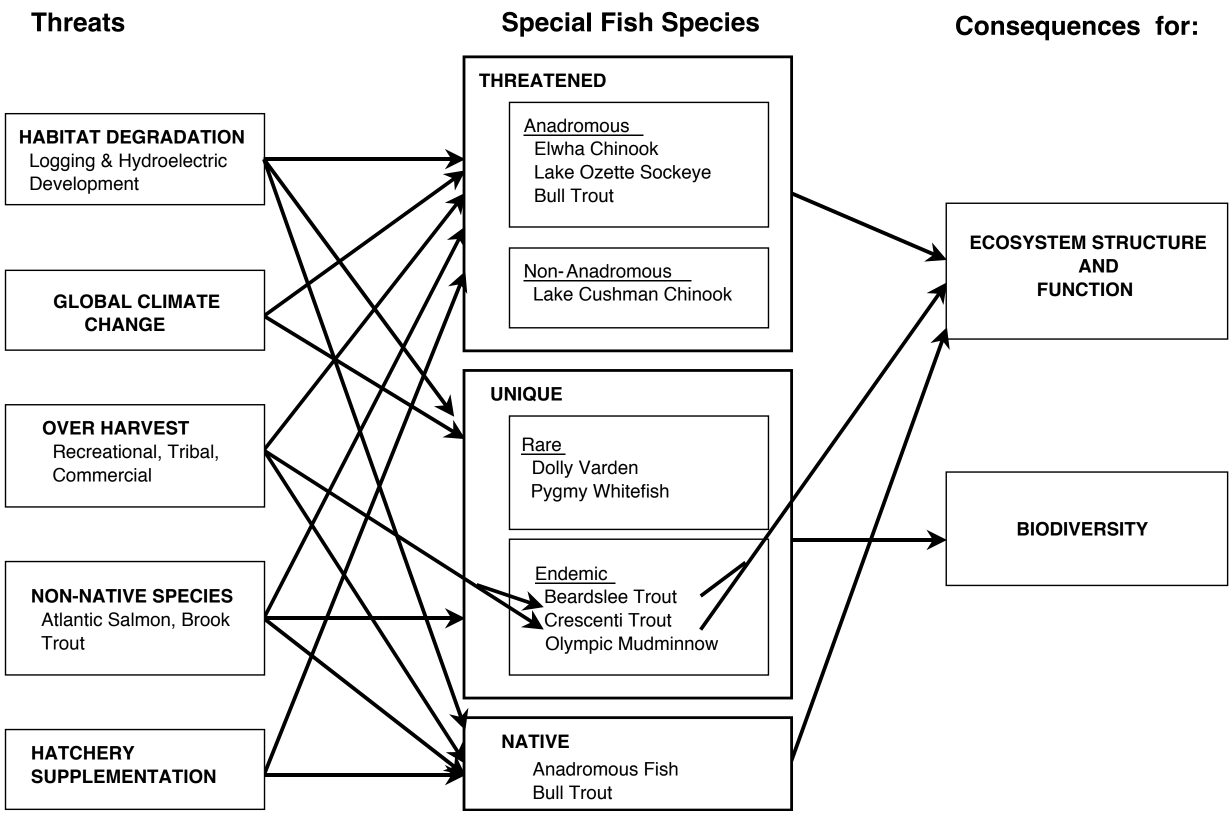

Figure 14.1. Conceptual model of threats to special-status fish species and the consequences of extinction.

Monitoring Questions and Indicators:

Question: Are there changes in population parameters for species listed as threatened?

- **Indicator:** Abundance, genetic diversity, health and competition with hatchery fish for Lake Ozette Sockeye salmon.
  - **Relative Abundance:** Monitor the relative abundance of adult sockeye at the weir near the Lake Ozette outlet. Coordinate efforts with the Makah Tribe.
  - **Genetic Diversity:** Conduct genetic sampling and analysis to ensure persistence of wild strain of Lake Ozette sockeye on decadal basis. To detect gene flow from hatchery to wild fish, collect genetic samples from every tributary once every five years.
  - **Fish Pathogens:** Determine the extent of fish pathogens in juvenile sockeye.
  - **Hatchery Supplementation:** Obtain data on number, timing, and location of released sockeye in Lake Ozette Basin. *Justification:* These indicators of population status will describe changes that might be caused by known threats. *Limitations*: Cost.
- **Indicator:** Population and habitat measurements for bull trout.
  - **Relative Abundance**. Conduct annual monitoring of abundance of adult bull trout in North Fork Skokomish River. Annual monitoring of this population has occurred during most years since 1973. Conduct annual redd surveys of bull trout in selected reaches of South Fork Hoh, Queets, or Hoh River.

- **Genetic Diversity.** Collect non-lethal fin samples from bull trout in selected rivers every 10 years to detect changes in genetic make-up within and among populations.
- **Population Structure**. Collect scales to determine population structure of bull trout in selected rivers. Scales can indicate genetic structure, age composition and life history composition of populations.

  Justification: These indicators will describe population status in relation to known threats. *Limitations*: Cost of analysis.

- **Indicator:** Abundance of Lake Cushman/Elwha Chinook salmon. Determine relative abundance of adult Chinook in North Fork Skokomish River annually (may be accomplished when sampling for bull trout). Determine relative abundance of Elwha Chinook and classify as to hatchery or wild in origin. *Justification:* These indicators will describe population status in relation to known threats. *Limitations:* None.

Question: Are there changes in population parameters for rare species in Olympic National Park?

- **Indicator:** Existence of Pygmy Whitefish in Lake Crescent. Determine presence vs. non-detection of pygmy whitefish in Lake Crescent at 5-10 year intervals. *Justification:* A minimum amount of information is needed to determine whether the pygmy whitefish population still exists. *Limitations:* None.
- **Indicator:** Abundance of Lake Crescent Trout. Determine abundance of Lake Crescent trout species using redd counts in Barnes Creek, lake outlet, and upper Lyre River. *Justification:* Abundance is easy to estimate with this species. *Limitations:* Cost.
- **Indicator:** Existence of Dolly Varden in Known Sites. Conduct presence vs. non-detection surveys in upper Sol Duc River and upper Quinault River every 5 to 10 years. *Justification:* A minimum amount of information is needed to determine whether the Dolly Varden populations still exist. *Limitations:* Cost.

Question: What is the extent of invasion of the non-native fish species, brook trout, and Atlantic salmon?

- **Indicator:** Distribution. Determine the distribution of Atlantic salmon and brook trout in Olympic National Park. Focus should be on streams with immediate threats (e.g., upper Sol Duc where Dolly Varden and brook trout may co-occur, Atlantic salmon observed in Elwha River). *Justification:* Distribution of these species in the park is the best indicator of their threat to park resources. *Limitations:* Cost.
- **Indicator:** Extent of Hybridization with Native Char. Conduct genetic monitoring of char populations in streams where brook trout overlap with native char. *Justification:* Hybridization is a potentially significant impact of brook trout on native char. *Limitations:* Expense of sample analyses.

Question: Are there changes in population parameters for endemic species in Olympic National Park?

- **Indicator:** Distribution and Abundance of Olympic Mudminnow. Obtain data from Washington Department of Fish and Wildlife on annual trends in distribution and abundance of mudminnows in Olympic National Park. Select a certain number of sites to revisit on one- to five-year cycles. *Justification:* Verifying data collected by another agency is an efficient way to monitor mudminnows. *Limitations:* None.

Linkages with Other Disciplines:

- Aquatic/Riparian Habitat: Status of habitat quality in areas where these species are present.
- Aquatic Biota: Status of food resources in areas where these species occur.

Spatial and Temporal Context: Where and How Often to Monitor:

	Geographic Zones		Elevation Zones (m)				Human Use Zones			Frequency
Proposed Indicator	West	East	<500	501-1000	1001-1500	>1500	Hi	Mod	Low	(Interval)
Lake Ozette Sockeye	X		X				X	X		1 yr
Bull Trout	X	X		X				X		1 yr
Lk. Cushman/Elwha Chinook		X	X				X	X		1 yr
Pygmy White Fish		X	X				X	X		5-10 yr
Lake Crescent Trout		X	X				X	X		1 yr
Dolly Varden	X				X			X		5-10 yr
Brook Trout	X	X			X	X		X	X	1 yr
Atlantic Salmon	X	X	X	X				X		1 yr
Olympic Mudminnow	X		X				X	X		1-5 yr

Research Needs:

- In what ways are non-native fish species influencing native fish species?
- What are the genetics, habitat requirements, density, life history, ecology, and population limiting factors for special-status species?
- Determine statistical power of bull trout monitoring in the North Fork Skokomish River to evaluate sampling sufficiency.
- Determine sampling requirements for Dolly Varden and pygmy whitefish.
- Address the potential decline of amphibians as a result of brook trout plantings in high mountain lakes.
- Identify general spawning locations in coastal river basins.
- Determine extent of life-history diversity in coastal rivers (e.g. anadromous, fluvial, resident, and adfluvial morphs).
- Evaluate otolith methodology. Describe and evaluate life-history variation among years and fish populations.

Chapter 15. Coastal Environment

(Prepared by S. Fradkin, Olympic National Park)

Monitoring Need/Justification:

The 65-mile coastal strip of Olympic National Park contains both upland terrestrial and marine intertidal habitats. This section focuses primarily upon the intertidal marine environment, while needs of the coastal terrestrial area are considered elsewhere in the monitoring plan.

The Pacific Coast intertidal zone hosts a diverse array of habitats, from sandy beaches, to boulder fields, to rocky platforms. Each of these habitats supports diverse assemblages of macroalgae, invertebrates, and fish. Seasonal upwelling from February to July brings nutrient-rich cold water from the ocean bottom to the surface, providing food for many animals. This extraordinary habitat and resource diversity, along with the remote nature of the Olympic coast, make it a unique ecosystem that does not exist elsewhere in the coastal United States (Ricketts et al. 1985).

The Olympic coast intertidal zone is not a closed system, either ecologically or jurisdictionally. Because of this, consideration of linkages between the intertidal and subtidal/nearshore zones is necessary for adequate treatment of intertidal monitoring needs. Ecologically there are substantial physical and biological linkages between these zones that are critical in determining zonal community structure. From a jurisdictional perspective, the Park's intertidal zone is within the boundaries of the Olympic Coast National Marine Sanctuary (OCNMS), the usual and accustomed use areas of the Makah, Quileute, Hoh, and Quinault tribes, and the offshore island National Wildlife Refuge is managed by the U.S. Fish and Wildlife Service. Each of these entities monitor some aspect of marine resources, creating the opportunity for important collaborations that can expand the scope of monitoring beyond what the park can support by itself.

Olympic National Park staff place a high importance on the need to monitor the ecological integrity of the intertidal communities. This approach was favored over one that focused on monitoring specific 'focal' species, an approach followed by several monitoring programs in other areas of North America (e.g., Channel Islands National Park, Davis 1989) that have a simpler community structure or harvested species of particular importance (e.g., abalone). In April 2002, the park sponsored a workshop to review the intertidal community monitoring program. The workshop included a comprehensive group of marine-oriented National Park Service, OCNMS, and Washington Department of Fish and Wildlife staffs, and academic subject matter experts from southern California to Alaska. The recommendations from the workshop agreed with the current community level monitoring approach. The primary focus of the major Park monitoring components is to track long-term temporal changes (>decadal time scale) in the structure and function of intertidal assemblages across a broad geographical coverage (Tier 1). Emphasis is currently being placed upon methods to improve the spatial inference capacity of the program. Intensive studies of population dynamics or functional relationships among species are considered a secondary priority (Tier 2). The major threats to intertidal health come from harvest, nonconsumptive human use (e.g. trampling), spills of toxic chemicals, and global climate change.

Conceptual Model:

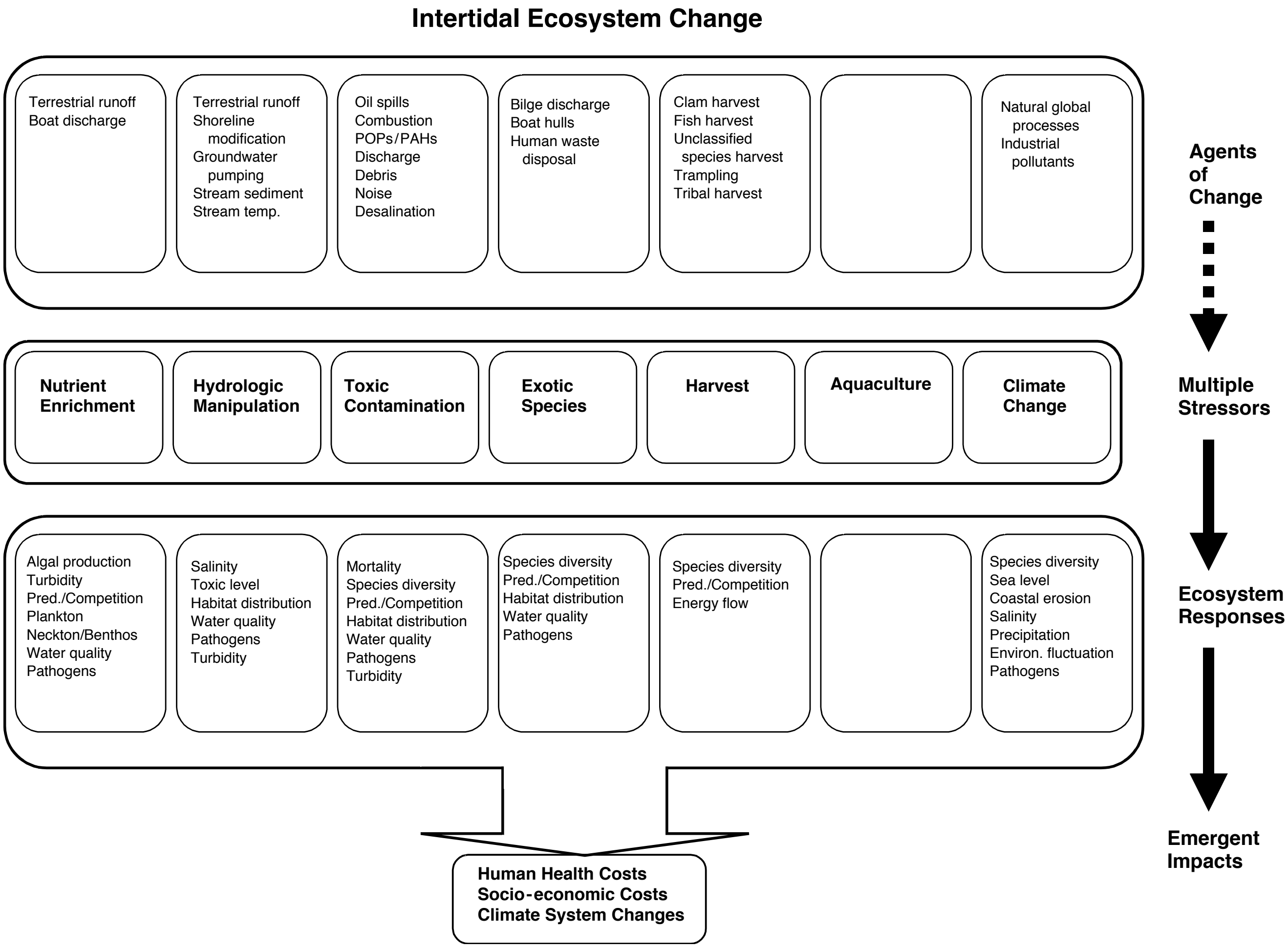

Figure 15.1. Conceptual model of the coastal ecosystem.

Monitoring Questions and Indicators:

Question: Is intertidal community composition changing over time?

Tier 1:

- **Indicator:** Intertidal Invertebrate and Macroalgae Community Composition. Sample abundance/percent cover of intertidal species. *Justification*: Different habitat types (i.e., sandy beaches, cobble fields, rocky platforms) support distinct communities composed of complex suites of invertebrates and macroalgae. They are expected to respond to changes in consumptive use, climate change, ocean conditions and catastrophic events (e.g., oil and toxin spills). Because they are at the bottom of the food chain, changes in these indicators will have consequences throughout the system.

Tier 2:

- **Indicator:** Intertidal Fish. Establish a set of permanent tidepools and track changes in intertidal fish species composition over time. *Justification*: Relatively little is known about the temporal dynamics of intertidal fish communities. Community and species population structure may serve as a useful indicator of environmental change.

- **Indicator:** Hardshell clams. Establish transects in appropriate clam habitat and track changes in community compositions, species abundance, size frequency, and growth rates. *Justification*: Hardshell clams provide valuable ecological services such as nutrient cycling and particle filtration, in addition to being important organisms for recreational harvest. The standard invertebrate and macroalgal-community monitoring program is not adequate to monitor hardshell clams, requiring a separate monitoring program.

Question: Are physical and chemical features of the intertidal environment changing?

- **Indicator:** Watershed Inputs. A coastal water quality monitoring program is currently being developed in collaboration with National Park Service-Water Resources Division as part of a comprehensive Olympic National Park water quality monitoring program. *Justification*: Inputs of sediments and warm water from coastal streams influenced by local land management practices (e.g., Quileute jetty construction and maintenance) have the potential to markedly alter intertidal and nearshore environments.

- **Indicator:** Ocean Conditions. Aside from assessing changes in intertidal community composition and the monitoring of intertidal water temperature as part of the broader Olympic National Park water quality monitoring program, monitoring of ocean conditions entails collaboration with the OCNMS, the University of Washington, the Partnership for the Interdisciplinary Study of Coastal Oceans (PISCO, a consortium of academic institutions funded by the David and Lucile Packard Foundation), and coastal tribes. The OCNMS and PISCO have embarked on a program to study ocean condition (temperature, salinity, currents, chlorophyll) using an array of moorings along the Olympic coast. The park is currently collaborating with the OCNMS and University of Washington to monitor the temporal dynamics of dead seabird beachings, an indirect indicator of ocean conditions. *Justification*: Most intertidal invertebrates and macroalgae have complex life-histories where different life-stages utilize both nearshore waters and intertidal benthic habitats. Changes in ocean conditions can therefore have profound impacts on the recruitment of intertidal organisms, in addition to directly affecting intertidal organisms by altering physical conditions and/or resource levels.

Question: Are levels of toxins changing in coastal waters?

- **Indicator:** Domoic Acid. While the park does not currently monitor domoic acid, the Quileute tribe, Washington Department Fish and Wildlife, and Washington Department of Health have monitoring programs to determine domoic acid levels in water and in bivalve tissue. *Justification*: Domoic acid is a naturally occurring toxic secondary metabolite produced by certain strains of the marine diatom *Pseudonitczhia*. Domoic acid causes mortality in fish, and can bioaccumulate in bivalves, presenting a substantial human health risk. Its occurrence in nearshore waters has increased dramatically over the past decade, presumably due to changed ocean conditions.

Linkages with Other Disciplines:

- Terrestrial Vegetation Communities. Terrestrial vegetation composition and structure.
- Aquatic/Riparian Habitat. Stream hydrology and sediment load.
- Biogeochemistry. Stream water quality.
- Park and Surrounding Landscape. Shoreline position.
- Off-shore Monitoring. Juvenile fish life history requirements.

Spatial and Temporal Context: Where & How Often to Monitor:

Currently the park monitors intertidal communities in three general habitat types (sandy beaches, cobble beaches, and rocky platforms) that span the 65-mile coastline.

Proposed Indicator	**Tidal Elevation**					**Human use Zones**				**Frequency**
	V. High	High	Mid	Low	Near-shore	V. High	High	Mid	Low	
Tier 1										
Intertidal community composition	X	X	X			X	X	X		annual
Tier 2										
Intertidal Fish	X	X	X			X	X	X		?
Hardshell clams		X	X	X			X	X	X	?
Watershed inputs					X					?
Ocean conditions					X					annual
Domoic acid					X					annual

Research and Development Needs:

- Determine population trends of key non-classified intertidal species (i.e. barnacles, seastars, etc.).
- Determine effects of visitor trampling on intertidal communities.
- Determine population trends of hard-shell clams and mussels.
- Determine status and susceptibility of the intertidal zone for invasion by exotic species (OCNMS collaboration).
- Create sociological/political/bureaucratic habitat inventory to lay groundwork for multi-agency cooperative habitat protection.
- Determine linkages between indicators.
- Determine trends and effects of sediment transport in the intertidal/subtidal zone.
- Determine patterns of long-shore and cross-shore water movement.
- Determine contingency monitoring plans for response to oil spills as augmentation to existing monitoring plans.
- Develop methods to improve spatial inference of the current intertidal community monitoring program.
- What are current background toxin levels?

Chapter 16. Historical and Paleoecological Context for Monitoring Results

Ecosystems follow a cyclical developmental path involving organization, destruction by a disturbance, and regeneration, with each ecosystem rebuilding from the remains of what came before it (Holling 1986). For example, the amount of soil organic matter and other soil properties reflect previous vegetation and the type of disturbance that destroyed it. The biota that can potentially re-establish are determined by propagules left in the soil or that can be produced by surrounding areas, or are within migration range. Consequently, the structure and function of any ecosystem reflects its history, including the effects of humans. In addition, many of the environmental forces influencing ecosystem development are also cyclical, and on time scales that are much longer than our lifetimes or even historic records. For example, the observations of climate warming since the industrial revolution must be interpreted in the context of the longer-term trend in warming since the end of the Little Ice Age (Gates 1993). Without a long-term context for our monitoring observations, we may misinterpret changes we observe. There are a variety of data sets that might be useful in providing the environmental and human context for monitoring at Olympic National Park (Table 5.17.1). While adding to or summarizing these data are not strictly monitoring activities, the information they provide would be useful to the monitoring program.

Time Frame	Type of Data	Information
Past 100 yr	Photographic Record	Conditions existing at specific time and place; vegetation coverage and character
Past 150 yr	Written Record- diaries, scientific notes, park and forest records	Conditions existing at specific time and place; helps complete picture of park cultural landscapes and human-environment interactions
150-250 BP	Ethnographic Record	Pre-European population dispersal, flora and faunal use, fire use,
Past 2K yr	Dendrochronology possibly Remote Sensing and Trace Element Analysis	Climate change, fine-grained climate change last 1,000 years, fire history, cultural history of bark stripping
Past 12K yr	Archeological Record	Human dispersal, prehistoric faunal populations, plant and animal use
Past 12K yr	Soils including paleosoils and relic soil properties	Characteristics of past environments, changes in plant communities, encroachment of forest on anthropogenic prairies, changes in treelines and subalpine settings
Past 18K yr	Quaternary Geology, esp. glacial and tectonic; sea level changes, tsunami events, Cascade volcano tephra	Aids understanding of the development of park landforms; Pleistocene glaciations determine beginning of Olympic NP vegetation, soil development and human populations; describes major climatic cycles and events
Past 30K yr	Palynology	Quaternary plant communities, climate and ecosystem change, fire history, logging or other community altering events from fluctuations in sediment deposition
> 30K yr	Bedrock Geology	Knowledge of substrate that terrestrial and climatic processes operate on to produce soils, landforms, and biotic resources; address river bank and slope stability, location of rare and endemic plants, potential extractive areas for prehistoric populations.

Table 5.17. Data sets that could provide context for monitoring results on a variety of time scales.

For each type of data there are three areas of concern, 1) what specific studies or information are needed for long-term ecological monitoring, 2) are any of these data being lost to neglect, been overlooked, and is there a strategy for collecting, analyzing and archiving any data that comes available, and 3) do we have a strategy to expand our analysis of these data? These questions can be answered at two levels: 1) by providing an overview and assessment of these data sets, and 2) by identifying the need for specific research and protection strategies in each data category. These needs should be addressed as funding and time are available.

Literature Cited

Allen, T. F. H. and T. W. Hoekstra. 1992. Toward a unified ecology. Columbia University Press, NY. 384 pp.

Amos, K. H. and A. Appleby. 1999. Atlantic salmon in Washington State: A fish management perspective. Washington Department of Fish and Wildlife, Olympia.

Armstrong, J. E., D. R. Crandell, D. J. Easterbrook and J. B. Noble.1965. Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington. Geological Society of America Bulletin 76:321-330.

Bain, M. B. and N. J. Stevenson (eds.). 1999. Aquatic Habitat Assessment, Common Methods. American Fisheries Society, Bethesda, MD.

Barnosky, C. W. 1984. Late Pleistocene and early Holocene environmental history of southwestern Washington, U.S.A. Canadian Journal of Earth Sciences 21:619-629.

Barnosky, C. W., P. M. Anderson, and P. J. Bartlein. 1987. The northwestern U.S. during deglaciation: vegetational history and paleoclimatic implications. Pages 289-321 *in* W. F. Ruddiman and H. E. Wright, Jr., editors. North America and Adjacent Oceans During the Last Deglaciation. Geological Society of America, Boulder CO.

Beauchamp, D., M. LaRiviere, and G. Thomas. 1995. Evaluation of competition and predation as limits to juvenile kokanee and sockeye salmon production in Lake Ozette, Washington. North American Journal of Fisheries Management 15: 193-207.

Ben-David, M., T. A. Hanley, and D. M. Schell. 1998. Fertilization of terrestrial vegetation by spawning Pacific salmon: The role of flooding and predator activity. Oikos 83:47-55.

Bergland, E. O. 1983. Prehistory and ethnography of Olympic National Park. National Park Service, Seattle WA. 89 p.

Biddleman T. F. 1999. Atmospheric transport of pesticides and exchange with soil, water, and aerosols. Water, Air and Soil Pollution 115:115-166.

Bilby, R. E., B. R. Fransen, and P. A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Canadian Journal of Fisheries and Aquatic Science 53:164-173.

Bjornn, T. C. and D. W. Reiser. 1991. Habitat requirement of salmonids in streams. American Fisheries Society Special Publication 19:83-138.

Blaustein, A. R., P. D. Hoffman, D. G. Hokit, J. M. Kisecker, S. C. Walls, and J. B. Hays. 1994. UV repair and resistance to solar UV-B in amphibian eggs: a link to population declines? Proceedings of the National Academy of Science 91:1791-1795.

Booth, D. B. 1987. Timing and processes of deglaciation along the southern margin of the cordilleran ice sheet. Pages 71-90 *in* W. F. Ruddiman and H. E. Wright, Jr., editors. North America and Adjacent Oceans During the Last Deglaciation. Geological Society of America, Boulder CO.

Bottom, D. L. 1995. Restoring salmon ecosystems – myth and reality. Restoration and Management Notes 13,2:162-170.

Boulinier, T., J. D. Nichols, J. R. Sauer, J. E. Hines, and K. H. Pollock. 1998. Estimating species richness to make inferences in community ecology: the importance of heterogeneity in species detectability. Ecology 79:1018-1028.

Brubaker, L. B. 1991. Climate change and the origin of old-growth Douglas-fir forests in Puget Sound lowland. Pages 17-24 *in* Wildlife and Vegetation of Unmanaged Douglas-fir Forests. U.S. Forest Service General Technical Report PNW-GTR-285.

Buckingham N. M., E. G. Schreiner, T. N. Kaye, J. E. Burger, and E. L. Tisch. 1995. Flora of the Olympic Peninsula. Northwest Interpretive Association. Seattle, WA. 199 pp.

Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance sampling: estimating abundance of biological populations. Chapman and Hall, New York.

Burger, A.E. 1997. Behavior and numbers of marbled murrelets measured with radar. Journal of Field Ornithology 68:208-223.

Butler, A. and E. Snouwaert. 2002. Guidance document for developing total daily minimum loads (TMDLs) water cleanup plans. Washington Department of Ecology, 99-23-WQ, p. 26.

Campbell, P. 1979. A history of the North Olympic Peninsula. Peninsula Publishing, Port Angeles, WA. 68 p.

Capoeman, P. K., editor. 1990. Land of the Quinault. Quinault Indian Nation Publication, Taholah, WA. 315 pp.

Carpenter, S. R., T. M. Frost, J. F. Kitchell, and T. K. Kratz. 1993. Species dynamics and global environmental change: a perspective from ecosystem experiments. Pages 267-279 *in* P. M. Kareiva, J. G. Kingsolver and R. B. Huey, editors. Biotic Interactions and Global Change. Sinauer, Sunderland, MA.

Cederholm, C. J. and N. P. Peterson. 1985. The retention of coho salmon (*Oncorhynchus kisutch*) carcasses by organic debris in streams. Canadian Journal of Fisheries and Aquatic Sciences 42: 1222-1225.

Cederholm, C. J., D. B. Houston, D. L. Cole, and W. J. Scarlett. 1989. Fate of coho salmon (*Oncorhynchus kisutch*) carcasses in spawning streams. Canadian Journal of Fisheries and Aquatic Science 46:1347-1365.

Cederholm, C. J., D. H. Johnson, R. E. Bilby, L. G. Dominguez, A. M. Garrett, W. H. Graeber, E. L. Greda, M. D. Kunze, B. G. Marcot, J. F. Palmisano, R. W. Plotnikoff, W. G. Pearcy, C. A. Simenstad, and P. C. Trotter. 2001. Pacific salmon and wildlife: ecological contexts, relationships, and implications for management. Pages 628-687 *in* D. H. Johnson and T. A. O'Neil, editors. Wildlife-Habitat Relationships in Oregon and Washington. Oregon State University Press, Corvallis.

Committee on Environment and Natural Resources. 1997. Integrating the nation's environmental monitoring and research networks and programs: a proposed framework. National Science and Technology Council Report, Environmental Monitoring Team. Washington, D.C. (www.epa.gov/cludygxb/pubs/html)

Cooper, B. A., and T. E. Hamer. 2000. Appendix H: Use of radar for marbled murrelet surveys. Pages 28-34 *in* D. M. Evans, W. P. Ritchie, S. K. Nelson, E. Kuo-Harrison, P. Harrison, and T. E. Hamer, editors. Methods for surveying marbled murrelets in forests: an update to the protocol for land management and research. Pacific Seabird Group, unpublished document. 15 April 2000. Available at www.nmnh.si.edu/FIRDNET/PacBirds/.

Cummins, K. W. 1974. Structure and function of stream ecosystems. BioScience 24:631-641.

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

Davis, M. B. 1981. Quaternary history and the stability of forest communities. Pp. 132-153 *in* D. S. West, H. H. Shugart and D. B. Botkin, editors. Forest Succession: Concepts and Applications. Springer-Verlag, New York.

Delbecq, Andrew L., Van de Ven, Andrew H. and Gustafson, David H. 1975. Group Techniques for Program Planning, a Guide to Nominal Group Technique and Delphi Processes, Scott Foreman, New York.

Dunham, A. E. 1993. Population responses to environmental change: operative environments, physiologically structured models, and population dynamics. Pages 95-119 *in* P. M. Kareiva, J. G. Kingsolver and R. B. Huey, editors. Biotic Interactions and Global Change. Sinauer, Sunderland, MA.

EMAP. 1990. And overview of the Environmental and Assessment Program. EMAP Monitor. EPA Office of Research and Development, Washington, D. C. EPA-600/M-90/022.

Edmonds, R. L., R. D. Blew, J. L. Marra, J. Blew, A. K. Barg, G. Murray, T. B. Thomas. 1998. Vegetation patterns, hydrology, and water chemistry in small watersheds in the Hoh River valley, Olympic National Park. Scientific Monograph NPSD/NRUSGS/NRSM-98/02. U.S. Department of the Interior, National Park Service.

Eiler, J. M., C. L. Rose, and T. J. Sullivan. 1994. Status of air quality and effects of atmospheric pollutants on ecosystems in the Pacific Northwest region of the National Park Service. Technical Report NPS/NRAQD/NRTR-94/160. National Park Service, Denver, CO.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and monitoring plant populations. Report No. BLM/RS/ST-98/005+1730. Government Printing Office, Washington, D.C.

Emmett, R. L. and M H. Schiewe (eds.) 1997. Estuarine and Ocean Survival of Northeast Pacific Salmon: Proceedings of a Workshop. U.S. Department of Commerce NOAA Technical Memorandum NMFS-NWFSC-29.

Ewald, G., P. Larsson, H. Linge, L. Okla, and N. Szari. 1998. Biotransport of organic pollutants to an inland Alaska lake by migrating sockeye salmon (*Oncorhynchus nerka*). Arctic 51:40-47.

Evans, D. M., W. P. Ritchie, S. K. Nelson, E. Kuo-Harrison, P. Harrison, and T. E. Hamer, editors. Methods for surveying marbled murrelets in forests: an update to the protocol for land management and research. Pacific Seabird Group, unpublished document. 15 April 2000. Available at www.nmnh.si.edu/FIRDNET/PacBirds/.

Fonda, R. W. 1974. Forest succession in relation to river terrace development in Olympic National Park, Washington. Ecology 55:927-942.

Fraley, J. J. and B. B. Shepard. 1989. Life history, ecology, and population status of migratory bull trout (*Salvelinus confluentus*) in the Flathead Lake and river system, Montana. Northwest Science 63:133-143.

Francis, R. C. 1997. Sustainable use of salmon: Its effects on biodiversity and ecosystem function. Pages 626-670 *in* C. H. Freeze, editor. Harvesting Wild Species – Implications for Biodiversity Conservation. Johns Hopkins University Press, Baltimore.

Franklin, J. F., K. Cromack, W. Denison, et al. 1981. Ecological characteristics of old-growth Douglas-fir forests. USDA Forest Service General Technical Report PNW-118. Pacific Northwest Forest and Range Experiment Station, Portland Oregon.

Gates, D. M. 1993. Climate Change and its Biological Consequences. Sinauer, Sunderland, MA.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology 68:1364-1372.

Goldstein, P. Z. 1999. Functional ecosystems and biodiversity buzzwords. Conservation Biology. 13:247-255.

Good, D. A. and D. B. Wake. 1992. Geographic variation and speciation in the torrent salamanders of the genus *Rhyacotriton* (Caudata:Rhyacotritonidae). University of California Publications in Zoology 126, Berkeley.

Gregory, S. V. 1995. Riparian management for the 21st Century. Pages 69-85 *in* K. A. Kohm and J. F. Franklin, editors. Creating a Forestry for the 21st Century. Island Press, Washington, D.C.

Gregory, S. V., G. A. Lamberti, D. C. Erman, K. V. Koski, M. L. Murphy, and J. R. Sedell. 1987. Influence of forest practices on aquatic production. Pages 233-255 *in* E. O. Salo and T. W. Cundy, editors. Streamside Management: Forestry and Fishery Interactions. Institute of Forest Resources, University of Washington, Seattle.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41:540-551.

Grimm, N. 1993. Implications of climate change for stream communities. Pages 293-314 *in* P. M. Kareiva, J. G. Kingsolver and R. B. Huey, editors. Biotic Interactions and Global Change. Sinauer, Sunderland, MA.

Gustafson, R. G., T. C. Wainwright, G. A. Winans, F. W. Waknitz, L. T. Parker, and R. S. Waples. 1997. Status review of sockeye salmon form Washington and Oregon. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWESC-33, 282 p.

Hall, F., et al. 1989. Advances in Geophysics, Vol. 30.

Hall, R. J. 1999. Monitoring change in protected areas: problems of scope, scale, and power. Pages 271-277 *in* D. Harmon, editor. On the Frontiers of Conservation: Proceedings of the 10th Conference on Research and Resource Management in Parks and on Public Lands. The George Wright Society, Hancock, MI.

Hall, S.L. 2000. Land management strategies and marbled murrelet occurrence on the Olympic Peninsula, WA. MS thesis. University of Washington, Seattle, WA. 76 pp.

Hammond, A. L. 1976. Paleoclimate: ice age earth was cool and dry. Science 191:455.

Happe, P. J. 1993. Ecological relationships between cervid herbivory and understory vegetation in old-growth Sitka spruce-western hemlock forests in western Washington. Ph.D. dissertation. Oregon State University, Corvallis.

Hawthorn, A.W., C. Byrnes, T. DaSilva, and P. Happe. 1996. Marbled murrelet surveys in the lower Elwha River Valley, Olympic National Park and vicinity. Unpublished final report. Olympic National Park files. 31 pp.

Hayes, J. P., and R. J. Steidle. 1997. Statistical power analysis and amphibian population trends. Conservation Biology 11:273-275.

Henderson, J. A., D. H. Peter, R. D. Lesher, and D. C. Shaw. 1989. Forested plant associations of the Olympic National Forest. USDA Forest Service, Pacific Northwest Region R6 Ecological Technical Paper 001-88.

Holling, C. S., editor. 1978. Adaptive environmental assessment and management. John Wiley & Sons, New York, New York.

Holling, C. S. 1986. The resilience of terrestrial ecosystems: local surprise and global change. Pages 292-320 *in* W. M. and R. E. Munn, editors. Sustainable Development of the Biosphere. Oxford University Press.

Honacki, J. H., K. E. Kinman, and J. W. Koeppl. 1982. Mammal species of the world: a taxonomic and geographic reference. Allen Press and Association of Systematics Collections, Lawrence, KS.

Houston, D. B., B. B. Moorhead, and R. W. Olson. 1986. An aerial census of mountain goats in the Olympic Mountain Range, Washington. Northwest Science 60:131-136.

Houston, D. B., B. B. Moorhead, and R. W. Olson. 1987. Roosevelt elk density in old-growth forests of Olympic National Park. Northwest Science 61: 220-225.

Houston, D. B., B. B. Moorhead, and R. W. Olson. 1991. Mountain goat population trends in the Olympic Mountain Range, Washington. Northwest Science 65:212-216.

Houston, D. B., E. G. Schreiner, B. B. Moorhead, and K. A. Krueger. 1990. Elk in Olympic National Park: will they persist over time? Natural Areas Journal 10:6-11.

Houston, D. B., E. G. Schreiner, and B. B. Moorhead. 1994. Mountain goats in Olympic National Park: Biology and management of an introduced species. Scientific Monograph NPS/NROLYM/NRSM-94/25, U.S. Department of the Interior, National Park Service.

Jansson, B., R. Andersson, L. Asplund, K. Litzen, K. Nylund, U. Sellstrom, U. B. Uvemo, C. Wahlberg, W. Widequist, T. Odsjo, and M. Olsson. 1993. Chlorinated and brominated persistent organic compounds in biological samples from the environment. Environmental Toxicology and Chemistry 12:1163-1174.

Jenny, H. 1941. Factors of Soil Formation. McGraw-Hill, New York.

Jorgensen, S. E. and F. Muller, eds. 2000a. Handbook of ecosystem theories and management. Lewis Publishers, NY. 584 pp.

Jorgensen, S. E. and F. Muller. 2000b. Towards a unifying theory. Pages 465-471 *in* S. E. Jorgensen and F. Muller, editors. Handbook of ecosystem theories and management. Lewis Publishers, New York.

Karr, J. R. and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management. 5:55-68.

Larkin, G. A. and P. S. Slaney. 1997. Implications of trends in marine-derived nutrient influx to south coastal British Columbia salmonid production. Fisheries 22:16-24.

Larson, G. L., C. D. McIntire, E. Karnaugh-Thomas, and C. Hawkins-Hoffman. 1995. Limnology of isolated and connected high-mountain lakes in Olympic National Park, Washington, USA. Archive fur Hydrobiologie 134:75-92.

Lefsky, M. A., W. B. Cohen, et al. 2002. Lidar remote sensing for ecosystem studies. Bioscience 52:19-30.

Lefsky, M. A., W. B. Cohen, and T. A. Spies. 2001. An evaluation of alternate remote sensing products for forest inventory, monitoring, and mapping of Douglas-fir forests in western Oregon. Canadian Journal of Forest Research 31:78-87.

Likens, G. E., F. H. Bormann, R. S. Pierce, J. S. Eaton, and N. M. Johnson. 1977. Biogeochemistry of a Forested Ecosystem. Springer-Verlag, New York. 146 p.

Long, W. A. 1975. Salmon Springs and Vashon continental ice in the Olympic Mountains and relation of Vashon continental to Fraser Olympic ice. U.S. Forest Service, Olympia, WA. 123 p.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255.

Marcot, B. G., L. K. Croft, J. F. Lehmkuhl, R. H Naney, C. G. Niwa, W. R. Owen, and R. E. Sandquist. 1998. Macroecology, paleoecology, and ecological integrity of terrestrial species and communities of the interior Columbia Basin and northern portions of the Klamath and Great Basins. USDA Forest Service General Technical Report PNW-GTR-410. 131 pp.

Markle, D. F. 1992. Evidence of bull trout x brook trout hybrids in Oregon. Pages 58-67 *in* P. J. Howell and D. V. Buchanan, editors. Proceedings of the Gearhart Mountain Bull Trout Workshop. Oregon Chapter of the American Fisheries Society, Corvallis.

McLaren, B. E., and R. O. Peterson. 1994. Wolves, moose, and tree rings on Isle Royale. Science 266:1555-1558.

McLeod, R. L. M. 1984. An American wilderness: the origins of Olympic National Park. MA Thesis. University of California, Santa Barbara, CA 158 p.

Mix, A. C. 1987. The oxygen-isotope record of glaciation. Pages 111-136 *in* W. F. Ruddiman and H. E. Wright, Jr., editors. North America and Adjacent Oceans During the Last Deglaciation. Geological Society of America, Boulder CO.

Muller, F. and S. E. Jorgensen. 2000. Ecological orientors: a path to environmental applications of ecosystem theories. Pages 561-575 *in* F. Jorgensen and S. E. Muller, editors. Handbook of Ecosystem Theories and Management. CRC Press, Boca Raton, FL.

Murphy, M. L. 1995. Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska: requirements for protection and restoration. NOAA's Coastal Ocean Program, decision analysis series No. 1. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Coastal Ocean Office, Washington, D.C.

Naiman, R. J., H. Dechamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3: 209-212.

National Oceanic and Atmospheric Administration. 1978. Climate of Washington. Climatology of the United States 60. National Oceanic and Atmospheric Administration, Washington, D.C.

National Park Service. 1968. Administrative Policies for Natural Areas. Government Printing Office, Washington, D.C.

National Park Service. 1992. The Natural Resources Inventory and Monitoring Guideline (NPS-75). Government Printing Office, Washington, D.C.

National Park Service. 1995. Natural Resource Inventory and Monitoring in National Parks. U.S. Department of the Interior, National Park Service.

National Park Service. 1997. Visitor experience and resource protection (VERP) framework: a handbook for planners and managers. Government Printing Office, Washington, D.C.

National Park Service. 1999. National Resource Challenge: The National Park Service's Action Plan for Preserving Natural Resources. National Park Service, Washington, D.C.

Nicolis, G. and I. Prigogine. 1989. Exploring Complexity: an Introduction. W. H. Freeman, New York.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117:393-408.

Nimis, P. L. and O. W. Purvis. 2002. Monitoring lichens as indicators of pollution, an introduction. Pages 7-10 *in* P. L. Nimis, C. Scheidegger, and P. A. Wolseley, editors. Monitoring with Lichens—Monitoring Lichens. Kluwer Academic Publishers, Boston.

Noon, B. R. 1991. Scientific framework for effectiveness monitoring of the Northwest Forest Plan. Pages 49-68 *in* B. S. Mulder, B. R. Noon, T. A. Spies, M. G. Raphael, C. J. Palmer, A. R. Olsen, G. H. Reeves, and H. H. Welsh, Technical coordinators. The Strategy and Design of the Effectiveness Monitoring Program for the Northwest Forest Plan. General Technical Report PNW-TTR-437, USDA Forest Service Regional Ecosystem Office Portland, OR.

Norton, H. H. 1979. The association between anthropogenic prairies and important food plants in western Washington. Northwest Anthropological Research Notes 18:175-200.

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

Oakley, K. L., and S. L. Boudreau. 2000. Conceptual design of the long-term ecological monitoring program for Denali National Park and Preserve. U.S.G.S., Alaska Biological Science Center, Anchorage, AK 99503.

Odum. E. P. 1985. Trends expected in stressed ecosystems. BioScience 35:419-422.

Ollinger, S. V., M. L. Smith, M. E. Martin, R. A. Hallett, C. L. Goodale, and J. D. Aber. In press. Regional variation in foliar chemistry and soil nitrogen status among forests of diverse history and composition. Ecology.

Olympic National Park. 1999. Resource Management Plan. Olympic National Park, Port Angeles, WA.

O'Neill, R.V., and A. W. King. 1998. Homage to St. Michael; or, why are there so many books on scale? Pages 3-15 *in* D.L. Peterson and V. T. Parker, editors. Ecological Scale: Theory and Applications. Columbia University Press. New York, NY.

Palen, W. J., D. E. Schindler, M. J. Adams, C. A. Pearl, R. B. Bury, and S. A. Diamond. 2002. Optical characteristics of natural waters protect amphibians from UV-B in the U.S. Pacific Northwest. Ecology 83:2951-2957.

Pastor, J. and W. M. Post. 1986. Influence of climate, soil, moisture and succession on forest carbon and nitrogen cycles. Biogeochemistry 2:3-27.

Pastor, J. and W. M. Post. 1988. Response of northern forests to CO_2 induced climate change. Nature 334:55-58.

Perry, D. A. 1994. Forest Ecosystems. Johns Hopkins University Press, Baltimore, MD.

Perry, D. A. and M. P. Amaranthus. 1997. Disturbance, recovery and stability. Pages 31-56 *in* K. A. Kohm and J. F. Franklin, editors. Creating a Forestry for the 21st Century. Island Press, Washington, D.C.

Peterson, D. L., D. G. Silsbee, and D. L. Schmoldt. 1994. A case study of resources management planning with multiple objectives and projects. Environmental Management 18:729-742.

Peterson, D. L., D. G. Silsbee, and D. L. Schmoldt. 1995. A planning approach for developing inventory and monitoring programs in national parks. Natural Resources Report NPS/NRUW/NRR-95/16, National Park Service. 49 pp.

Phillips, E. L. and W. R. Donaldson. 1972. Washington climate for Clallam, Grays Harbor, Jefferson, Pacific and Wahkiakum Counties. Cooperative Extension Service Publication EM 3708. Washington State University, Pullman. 39 p.

Pickett, S. T. A. and P. S. White, eds. 1985. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, New York.

Porter, S. C. and G. H. Denton. 1967. Chronology of neoglaciation in the North American cordillera. American Journal of Science 265:177-210.

Puget Sound Action Committee. 2000. 2000 Puget Sound Update: Seventh Report of the Puget Sound Ambient Monitoring Program. Puget Sound Action Committee, Olympia, Washington.

Pyle, R. M. 2002. The Butterflies of Cascadia. Seattle Audubon Society. 420 pp.

Rapport, D. J., H. A. Regier, and T. C. Hutchinson. 1985. Ecosystem behavior under stress. American Naturalist 125:617-640.

Rashin, E. and C. Graber. 1993. Effectiveness of best management practices for aerial application of forest pesticides. Report TFW-WQ1-93-001. Washington Department of Natural Resources Forest Practices Division, Olympia.

Ratliff, D. E. and P. J. Howell. 1992. The status of bull trout populations in Oregon. Pages 10-17 *in* P. J. Howell and D. V. Buchanan, editors. Proceedings of the Gearhart Mountain Bull Trout Workshop. Oregon Chapter of the American Fisheries Society, Corvallis.

Reeves, G. H., D. B. Hohler, D. P. Larsen, D. E. Busch, K. Kratz, K. Reynolds, K. F. Stein, T. Atzet, P. Hays and M. Tehan 2001. Aquatic and riparian effectiveness monitoring program for the Northwest Forest Plan. Pre-publication draft. Corvallis, OR.

Renner, J. 1992. Northwest mountain weather: understanding and forecasting for the backcountry user. Mountaineers, Seattle, WA.

Ricketts, E. F., J. Calvin, and J. W. Hedgpeth, revised by D. W. Phillips. 1985. Between Pacific Tides, 5th Edition. Stanford University Press, Stanford, CA. 652 p.

Rieman, B. E. and J. D. McIntyre. 1993. Demographic and habitat requirements for conservation of bull trout. USDA Forest Service, Intermountain Research Station, General Technical Report INT-302. Ogden, Utah.

Risser, P. G. 1995. Biodiversity and ecosystem function. Conservation Biology 9:742-746.

Rochefort, R., R. Little, A. Woodward, and D. Peterson. 1994. Changes in subalpine tree distribution in western North America: a review of climate and other causal factors. Holocene 4:89-100.

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

Saaty, T. L. 1980. The Analytic Hierarchy Process. McGraw-Hill, New York.

Schalk, R. 1988. The evolution and diversification of native land use systems on the Olympic Peninsula. Institute for Environmental Studies, University of Washington, Seattle. 213 pp.

Schneider, E. D. and J. J. Kay. 1994. Life as a manifestation of the second law of thermodynamics. Mathematical and Computer Modelling 19:25-48.

Schreiner, E. G., K. A. Drueger, P. J. Happe, and D. B. Houston. 1996. Understory patch dynamics and ungulate herbivory in old-growth forests of Olympic National Park, Washington. Canadian Journal Forest Research 26:255-265.

Schuett-Hames, D., A. Pleus, L. Bullchild, and S. Hall. 1994. Ambient monitoring program manual. Northwest Indian Fisheries Commission, TWF-AM9-94-001.

Schumm S. A. 1977. The Fluvial System. John Wiley and Sons, New York.

Seaman, D. E., S. Gremel, S. Roberts, and D. Smith. 1996. Spotted owl inventory and monitoring in Olympic National Park. Final Report. February 1992-September 1995. USGS Forest and Rangeland Ecosystem Science Center, Olympic Field Station, and Natural Resources Management Division, Olympic National Park. Unpublished report. Port Angeles, WA.

Silsbee, D.G. and D. L. Peterson. 1991. Designing and implementing comprehensive long-term inventory and monitoring programs for National Park System Lands. Natural Resources Report NPS/NRUW/NRR-91/04.

Simonich, S. L. and R. A. Hites 1995. Global distribution of persistent organochloride compounds. Science 269:1851-1854.

Smith, J. 2001. Historical populations of elk on the Peninsula: 100 years of landscape and population trends. Pages 11-13 *in* M. E. Ferry, T. S. Peterson, and J. C. Calhoun, editors. Status of Elk Populations on the Olympic Peninsula. Olympic Natural Resources Center Conference Proceedings. University of Washington, Olympic Natural Resources Center, Forks, WA.

Smith, M.L., S. V. Ollinger, M. E. Martin, J. D. Aber, R. A. Hallett, C. L. Goodale. 2002. Direct estimation of above-ground forest productivity through hyperspectral remote sensing of canopy nitrogen. Ecological Applications 12:1286-1302.

Sollins, P., C. C. Grier, F. M. McCorrison, K. Cromack Jr., R. Fogel, and R. L. Frederickson. 1980. The internal element cycles of an old-growth Douglas-fir ecosystem in western Oregon. Ecological Monographs 50:261-285.

Spies, T. 1997. Forest stand structure, composition, and function. Pages 11-30 *in* K. A. Kohm and J. F. Franklin, editors. Creating a Forestry for the 21st Century. Island Press, Washington, D.C.

Tabor, R. W. 1987. Guide to the geology of Olympic National Park. Pacific Northwest Parks and Forest Association, Seattle, WA. 144 p.

Thomas, T., J. J. Rhodes, R. L. Edmonds, and T. W. Cundy. 1989. Precipitation chemistry and ecosystem function in Olympic National Park: baseline research and precipitation studies, 1987 Annual Report to the National Park Service, Seattle, Washington Cooperative Agreement No. CA-9000-8-0007, subagreement No. 6, College of Forest Resources, University of Washington, Seattle.

Thornton, K. W., G. E. Saul and D. E. Hyatt. 1994. Environmental Monitoring and Assessment Program assessment framework. EPA/620/R-94/016, US EPA Office of Research and Development, Research Triangle Park, NC.

U.S. Congress. 1916. Hearing before the committee on the public lands on HR 434 and HR 8668, bills to establish a national park service, April 5 and 6. 64th Congress, 1st Session. Government Printing Office, Washington D.C.

U.S. Department of Agriculture and U.S. Department of Interior. 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl: Standards and guidelines for management of habitat for late successional and old-growth forest related species within the range of the northern spotted owl.

USDA Forest Service and USDI Bureau of Land Management, Washington, DC.

U.S. Environmental Protection Agency. 1986. Quality criteria for water 1986.U.S. Environmental Protection Agency, Office of Water Regulations and Standards, EPA 440/5-86-001, Washington, D.C.

Walker, B. H. 1991. Ecological consequences of atmospheric and climate change. Climate Change 18:301-316.

Walker, B. H. 1992. Biodiversity and ecological redundancy. Conservation Biology 6:18-23.

Walker, B. H. 1999. The ecosystem approach to conservation: reply to Goldstein. Conservation Biology 13:436-437.

Walters, C. 1986. Adaptive management of renewable resources. Macmillan, New York, New York.

Waring, R. H. and S. W. Running. 1998. Forest Ecosystems, 2nd Edition. Academic Press, New York, NY.

Washington Department of Fish and Wildlife. 2001. http://www.wa.gov/wdfd/wlm/diversity/soc/status/whitfish/wfshxsum.htm.

Washington Department of Fish and Wildlife. 2002. Final Environmental Impact Statement: Game Management Plan, July 2003-June 2009. Wildlife Program. 600 Capitol Way North, Olympia.

Washington Natural Heritage Program. 1997. Endangered, threatened and sensitive plants of Washington. Washington Department of Natural Resources, Olympia.

Welch, E. B. and D. E. Spyridakis. 1984. Acidification potential in high mountain lakes in Washington. Final Report Research Contract C-84039. Washington Department of Ecology, Olympia.

Wessen, G. 1990. Prehistory of the ocean coast of Washington. Pages 412-421 *in* W. Suttles, editor. Handbook of North American Indians. 7: Northwest Coast. Smithsonian Institution, Washington, D.C.

Whitlock, C. 1992. Vegetational and climatic history of the Pacific Northwest during the last 20,000 years: implications for understanding present-day biodiversity. Northwest Environmental Journal 8:5-28.

Wilkie, D. S. and J. T. Finn. 1996. Remote Sensing Imagery for Natural Resources Monitoring: A Guide for First-Time Users. Columbia University Press, New York. 295 p.

Woodley, S. 1993. Monitoring and measuring ecosystem integrity in Canadian National Parks. Pages 155-175 *in* S. Woodley, J. Kay, and G. Francis, editors. Ecological Integrity and the Management of Ecosystems. St. Lucie Press. Delray Beach, FL.

Woodward, A., E. G. Schreiner, D. B. Houston, and B. B. Moorhead. 1994. Ungulate-forest relationships in Olympic National Park: retrospective exclosure studies. Northwest Science 68:97-110.

Woodward, A., K. J. Jenkins and E. G. Schreiner. 1999. The role of ecological theory in long term ecological monitoring: report of a workshop. Natural Areas Journal 19:223-233.

World Meteorological Organization. 1998. Scientific Assessment of Ozone Depletion: Report 44. World Meteorological Organization.

Appendix A. List of Workshops and Participants for Developing a Prototype Long-term Ecological Monitoring Program in Olympic National Park.

Olympic National Park Staff Scoping Workshop, 27 February 1997, Port Angeles WA

Objectives: To introduce park staff to the long-term ecological monitoring program and planning process. To solicit input from park staff on the most important monitoring topics.

Facilitating: Kurt Jenkins, Andrea Woodward, D. Erran Seaman, Ed Schreiner

Participating: Olympic National Park and USGS Olympic Field Station Staffs

John Aho—
Olympic National Park, Management Assistant
Matt Albright—
Olympic National Park, Horticulturist
Marie Birnbaum—
Olympic National Park, Wilderness
Janis Burger—
Olympic National Park, Resource Educator
Keith Flanery—
Olympic National Park, Ranger
Matt Graves—
Olympic National Park, Resource Educator
Mike Gurling—
Olympic National Park, Resource Educator
Richard Hanson—
Olympic National Park, Trails Foreman
Patti Happe—
Olympic National Park, Supervisory Wildlife Biologist
Cat Hawkins Hoffman—
Olympic National Park, Chief of Natural Resource Management
Doug Houston—
USGS-FRESC-Olympic Field Station, Research Biologist
Martha Hutchinson—
Olympic National Park, Ranger
Steve Joel—
Olympic National Park, Ranger and Dispatcher
Dan Johnson—
Olympic National Park, Resource Educator
Mike Kalahar—
Olympic National Park, Mainenance
Francis Kocis—
Olympic National Park, District Ranger
Bruce Moorhead—
Olympic National Park, Wildlife Biologist (retired)
David Morris—
Olympic National Park, Superintendent
Bill Rhode—
Olympic National Park, District Ranger
Roger Rudolph—
Olympic National Park, Assistant Superintendent
Curt Sauer—
Olympic National Park, Chief Ranger
Susan Schultz—
Olympic National Park, Historian
Ruth Scott—
Olympic National Park, Natural Resource Specialist
D. Erran Seaman—
USGS-FRESC-Olympic Field Station, Research Ecologist
Michael Smithson—
Olympic National Park, Chief of Resource Education
Don Tinkham—
Olympic National Park, Maintenance
Ron Whattnem—
Olympic National Park, Ranger
Jacilee Wray—
Olympic National Park, Anthropologist
John Wullschleger—
Olympic National Park, Coastal Ecologist

Olympic Peninsula Long-term Ecological Monitoring Workshop, 10 April 1997, Olympic Natural Resources Center, Forks WA

Objectives: To exchange information among agencies on inventory and monitoring activities on the Olympic Peninsula. To identify high priority or useful monitoring projects in Olympic National Park.

Facilitating: Andrea Woodward

Participating: Scientists and resource managers from land-management agencies on the Olympic Peninsula.

Ed Bowlby—
Olympic Coast National Marine Sanctuary
John Calhoun—
Olympic Natural Resources Center
Bob Davies—
—
Richard Fredrickson—
Washington Department Fish and Wildlife
Cat Hawkins Hoffman—
Olympic National Park
Ward Hoffman—
Olympic National Forest
Larry Jones—
U.S.D.A. Forest Service
Cathy Lear—
Hoh Tribe
Mike McHenry—
Lower Elwha Tribe
Loyal Mehrhoff—
U.S. Fish and Wildlife Service
Dave Schuett-Hames—
Northwest Indian Fisheries Commission
Kate Sullivan—
Weyerheauser Company
Tom Terry—
Weyerheauser Company
Dan Varland—
Rayonier
George Wilhere—
Washington Department Natural Resources
Brian Winter—
Olympic National Park

Indicator Selection for Ecological Monitoring: In Theory and Practice, 6-9 May 1997, Best Western Olympic Lodge, Port Angeles WA

Objectives: To explore ecological advances in the process of selecting ecological indicators using the long-term ecological monitoring program in ONP as a case example for discussion. To examine the theoretical and scientific basis for selecting ecological indicators and determine how to set priorities for indicator selection.

Facilitating: Barry Noon (U.S.D.A. Forest Service-Redwoods Sciences Lab) and Kurt Jenkins

Participating: Olympic National Park and USGS Olympic Field Station staffs and invited monitoring scientists:

John Bart—
USGS-FRESC-Snake River Field Station
Ted Case—
University of California, San Diego
Gary Davis—
Channel Islands National Park
John Emlen—
USGS-Western Fisheries Research Center
Dan Fagre—
USGS-Glacier National Park
Paul Geissler—
USGS
David Graber—
Sequoia and Kings Canyon National Parks
Patti Happe—
Olympic National Park
Kim Hastings
University of Montana
Roger Hoffman—
Olympic National Park
Doug Houston—
USGS-FRESC-Olympic Field Station
Cat Hawkins-Hoffman—
Olympic National Park
John Meyer—
Olympic National Park
L. Scott Mills—
University of Montana
James Nichols—
USGS-Patuxent Wildlife Research Center
David Peterson—
USGS-FRESC-Cascadia Field Station
James Quinn—
University of California, Davis
Rusty Rodriguez—
USGS-Western Fisheries Research Center
Ed Schreiner—
USGS-FRESC-Olympic Field Station
D. Erran Seaman—
USGS-FRESC-Olympic Field Station
Peter Stine—
USGS-California Science Center
David Tallmon—
University of Montana
Hart Welsh—
U.S.D.A. Forest Service-Redwood Sciences Lab
B. Ken Williams—
U.S. Fish and Wildlife Service

Brian Winter—
Olympic National Park
Andrea Woodward—
USGS-FRESC-Olympic Field Station
R. Gerald Wright—
Idaho Cooperative Fish and Wildlife Research Unit

Coniferous Forest Monitoring Focus Group Meeting, 28 August 1997
Western Fisheries Research Center, Seattle WA

Objectives: To (1) review research and monitoring objectives, (2) explore general approaches to study design relative to monitoring objectives and park management needs, and (3) discuss sampling methods for vertebrate monitoring.

Facilitating: Andrea Woodward

Participating: Olympic National Park and USGS Olympic Field Station staffs and invited forest scientists:

Joe Ammirati—
University of Washington
Jan Henderson—
U.S.D.A. Forest Service
Kurt Jenkins
USGS-FRESC-Olympic Field Station
Dave Peter—
U.S.D.A. Forest Service
Charlie Halpern—
University of Washington
Cat Hawkins Hoffman—
Olympic National Park
Dave Shaw—
Wind River Canopy Crane Research Facility
Ed Schreiner—
USGS-FRESC-Olympic Field Station

Terrestrial Wildlife (Coniferous Forests) Focus Group Meeting, 19 December 1997
Olympic National Forest District Office, Quilcene WA

Objectives: To (1) review research and monitoring objectives, (2) explore general approaches to study design relative to monitoring objectives and park management needs, and (3) discuss sampling methods for vertebrate monitoring.

Facilitating: Kurt Jenkins

Participating: Olympic National Park and USGS-FRESC-Olympic Field Station staffs and invited wildlife research scientists:

Don Major—
USGS-FRESC
Keith Aubrey—
U.S.D.A. Forest Service
Bruce Bury—
USGS-FRESC
Patti Happe—
Olympic National Park
Cat Hawkins Hoffman—
Olympic National Park
John Marzluff—
University of Washington
L. Scott Mills—
University of Montana
Martin Raphael—
U.S.D.A. Forest Service
D. Erran Seaman—
USGS-FRESC-Olympic Field Station
Ed Schreiner—
USGS-FRESC-Olympic Field Station
Steve West—
University of Washington
Andrea Woodward—
USGS-FRESC-Olympic Field Station

Olympic National Park Vital Signs Workshop, 26-28 January 1999, Red Lion Hotel, Port Angeles WA

Objectives: To identify vital signs for monitoring the health of all ecosystem components in Olympic National Park. To review results of indicator selection from previous focus group workshops (wildlife and terrestrial forest vegetation).

Facilitating: Gary Davis, Channel Islands National Park, Cat Hawkins Hoffman, Olympic National Park

Participating: Olympic National Park and USGS Olympic Field Station staffs and invited resource specialists:

Steve Acker—
U.S. D.A. Forest Service
Mike Adams—
USGS-FRESC
Jim Agee—
University of Washington

Matt Albright—
Olympic National Park
Bill Baccus—
Olympic National Park
Kathy Beirne—
Olympic National Park
Bob Bilby—
National Marine Fisheries Service
Ed Bowlby—
Olympic Coast National Marine Sanctuary
Sam Brenkman—
Olympic National Park
Dave Conca—
Olympic National Park
Howard Conway—
University of Washington
Paul Crawford—
Olympic National Park
Patte Danisiewicz—
Olympic National Park
Dave DeSante—
Institute of Bird Populations
Megan Dethier—
University of Washington
Bob Edmonds
University of Washington
Dan Fagre—
USGS-Northern Rocky Mountains Science Center
Steve Fancy—
National Park Service
Bruce Freet—
North Cascades National Park
George Galasso—
Olympic Coast National marine Sanctuary
Jack Galloway—
Olympic National Park
Bob Gara—
University of Washington
Paul Geissler—
USGS
Paul Gleeson—
Olympic National Park
Reed Glesne—
North Cascades National Park
Rich Gregory—
National Park Service
Bob Gresswell—
USGS-FRESC
Mike Gurling—
Olympic National Park
Matt Hagemann—
National Park Service
Charlie Halpern—
University of Washington
Patti Happe—
Olympic National Park
Pat Heglund—
University of Idaho
Jan Henderson—
U.S.D.A. Forest Service
Cat Hawkins-Hoffman—
Olympic National Park
Roger Hoffman—
Olympic National Park
Bill Hogsett—
U.S. Environmental Protection Agency
Doug Houston—
USGS-Olympic Field Station
Gay Hunter—
Olympic National Park
Kurt Jenkins—
USGS-Olympic Field Station
Darryll Johnson—
USGS-Cascadia Field Station
Bob Kuntz—
North Cascades National Park
Jim Marra—
University of Washington
Bob McKane—
U.S. Environmental Protection Agency
John Meyer—
Olympic National Park
Bob Mierendorf—
North Cascades National Park
Rich Olson—
Olympic National Park
Mark O’Neill—
Olympic National Park
Dave Peter—
U.S.D.A. Forest Service
Dave Peterson—
USGS-Cascadia Field Station
Reg Reisenbichler—
USGS-Western Fisheries Research Center
John Riedel—
North Cascades National Park
Gina Rochefort—
North Cascades National Park
Roger Sanquist—
U.S.D.A. Forest Service

Curt Sauer—
Olympic National Park
Carl Schoch—
Oregon State University
Ruth Scott—
Olympic National Park
Ed Schreiner—
USGS-Olympic Field Station
Erran Seaman—
USGS-FRESC-Olympic Field Station
Richard Siddeway
Washington Department of Ecology
Michael Smithson—
Olympic National Park
Ed Starkey—
USGS-FRESC
Bob Stottlemeyer—
USGS-Midcontinent Ecosystem Science Center
Jim Tilmant—
National Park Service
Kathy Tonnessen—
National Park Service
Jim Warner—
Olympic Air Pollution Control Authority
Beth Willhite—
U.S.D.A. Forest Service
Brian Winter—
Olympic National Park
Andrea Woodward—
USGS-FRESC-Olympic Field Station
John Wullschleger—
Olympic National Park

Biogeochemical Processes: Parameters for Long-term Monitoring Programs of Pacific Northwest National Parks, 16-17 January 2001, Seattle WA

Objectives: To review biogeochemical research and monitoring in Pacific Northwestern National Parks. To identify the most critical information needs to inform about anticipated environmental changes in the Pacific Northwest. To assess adequacy of existing monitoring programs. To identify additional parameters for long-term monitoring.

Facilitating: Kathy Tonnessen , National Park Service-Rocky Mountains Cooperative Ecosystem Studies Unit, and Cat Hawkins Hoffman, Olympic National Park

Participating: USGS Scientists, National Park Service, invited biogeochemical specialists.

Steve Acker—
NPS, Pacific West Region
Bob Black—
USGS-Water Resources Division
Tamara Blett—
NPS, Air Resources Division
Dave Busch—
USGS-FRESC
Don Campbell—
USGS-Water Resources Division
Marsha Davis—
NPS, Columbia-Cascades System Support Office
Bob Edmonds—
University of Washington
Annie Esperanza—
Sequoia-Kings Canyon National Park
Dan Fagre—
USGS-Glacier National Park
Mark Flora—
NPS, Water Resources Division
Jerry Franklin—
University of Washington
Bill Hogsett—
U.S. Environmental Protection Agency
Roy Irwin—
NPS, Water Resources Division
Darryll Johnson—
USGS-Cascadia Field Station
Peter Kiffney—
National Marine Fisheries Service
Dixon Landers—
U.S. Environmental Protection Agency
Ken Mabery—
NPS, Regional Ecosystem Office
Tonnie Maniero—
NPS, Air Resources Division
Stephanie McAfee—
University of Washington
Jon Riedel—
North Cascades National Park
Gina Rochefort—
North Cascades National Park
Roger Rudolph—
Olympic National Park
Barbara Samora—
Mount Rainier National Park
Ed Schreiner—
USGS-Olympic Field Station
Kathie Weathers—
Institute of Ecosystem Studies
Andrea Woodward—
USGS-Olympic Field Station

Statististics of Sampling for Long-term Ecological Monitoring in Olympic National Park, 2-3 April 2001, Red Lion Hotel, Port Angeles WA

Objectives: To identify useful tools to determine an adequate sampling effort. To examine strengths and weaknesses of potential sampling frames for monitoring in Olympic National Park. To recommend practical means of integrating monitoring across spatial scales.

Facilitating: Kurt Jenkins and Andrea Woodward

Participating: Staffs of USGS-Olympic Field Station and Olympic National Park. Invited monitoring specialists and biometricians.

Steve Acker—
NPS, Pacific West Region
Jean-Yves Pip Courbois—
University of Washington
Steven Fradkin—
Olympic National Park
Oz Garton—
University of Idaho
Paul Geissler—
USGS
Patti Happe—
Olympic National Park
Roger Hoffman—
Olympic National Park
Gail Irvine—
USGS-Alaska Biological Science Center
Lyman McDonald—
Western Ecosystems, Inc
Eric Rexstad—
University of Alaska
Susan Roberts—
USGS-Olympic Field Station
Regina Rochefort—
North Cascades National Park
Ed Schreiner—
USGS-Olympic Field Station

National Park Service Air Toxics Workshop, 26-27 June 2001, Seattle WA (workshop organized and supported by the National Park Service's Air Resources Division)

For workshop participants and summary report see www.aqd.nps.gov\ard\aqmon\air_toxics\index.html.

Ultraviolet Radiation Monitoring, 16-17 July 2001, Red Lion Hotel, Port Angeles WA (workshop organized and supported by Olympic National Park)

Objectives: To discuss latest findings regarding unltraviolet radiation and effects of ultraviolet radiation on plants, animals and people. To identify options for how to monitor ultraviolet radiation in national parks.

Facilitating: Cat Hawkins Hoffman, Olympic National Park and Betsy Weatherhead, National Oceanic and Atmospheric Administration.

Participating: USGS and NPS resource managers and scientists, invited specialists, and resource education and interpretation staffs.

Dave Busch—
USGS-Regional Ecosystem Office
Sarah Ehlen—
North Cascades National Park
Gregg Fauth—
Fort Vancouver National Historic Site
Bill Gleason—
San Juan Islands National Historic Park
Roger Hoffman—
Olympic National Park
Les Inafuku—
Kaloko-Honokohau National Historic Park
Ken Mabery—
NPS-Regional Ecosystem Office
Maureen McGee-Ballinger—
Mount Rainier National Park
Paula Ogden—
North Cascades
Steve Ralph—
North Coast and Cascades Network Coordinator
Ruth Rhodes—
North Cascades National Park
Barbara Samora—
Mount Rainier National Park
Michael Smithson—
Olympic National Park
Kathy Steichen—
Olympic National Park
Scott Stonum—
Fort Clatsop National Historic Park
Betsy Weatherhead—
National Oceanic and Atmospheric Administration
Andrea Woodward—
USGS-Olympic Field Station