Conceptual Ecosystem Models for Glacier Bay National Park and Preserve

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Abstract. As part of a nationwide effort, the National Park Service is developing an inventory and monitoring program for the three national park units in southeast Alaska. To guide the selection of vital signs to be monitored in each park, we are developing conceptual models of park ecosystem components and the global, regional, and local processes affecting those components. Conceptual models of terrestrial, freshwater, and marine ecosystem components incorporate biotic and abiotic processes and include human influences. A common theme among the models is the environmental change (ecological succession) that occurs following natural or anthropogenic disturbance (e.g., glacial retreat, floods, timber or wildlife harvest, global warming).

Introduction

The Southeast Alaska Park Network (SEAN, including Glacier Bay National Park and Preserve, Klondike Gold Rush National Historical Park, and Sitka National Historical Park) is part of a national initiative to establish a long-term and integrated natural resource monitoring program for the National Park Service. Parks were grouped into 32 networks based on geographic proximity and ecological similarities. In 2003 SEAN began the process of planning a long-term natural resources monitoring program (Derr and others, 2004). Central to this program is the identification of vital signs (indicators of park health to be monitored). As part of the vital signs selection process, conceptual ecosystem models of parks within each network are developed.

The Habitats and Environments of Glacier Bay

We have adopted an image of three overlapping ovals to represent the contact, overlap, and interaction among three ecosystem components (marine, freshwater, and terrestrial) and the habitats within them (fig. 1). A key feature of this conceptualization is that biotic and abiotic processes and population and community interactions in habitats within each type of ecosystem component may be dependent upon processes operating in other ecosystem components. Certain habitats are the products of interaction among two or more ecosystem components (the overlaps in fig. 1), but all habitats have some interactions with all three ecosystem components.

Landscape Drivers of Change

We have identified four broad categories of factors that influence the current environmental conditions in Southeast Alaska, and that are most likely to drive future changes within the ecosystem components (fig. 2). These four landscape drivers of change are climate, landform, ocean processes, and human activity.

1. *Climate.* The regional climate has a controlling affect on the landscape of Southeast Alaska. Climate supports the highly productive coastal rainforest, suppliess snowfall to feed alpine glaciers, creates myriad wetland and freshwater ecosystems, and influences marine processes.

2. *Geography, geology and landforms.* The geography, geology and landforms of the coastal region largely determine how the regional climate interacts with the land or water to shape a particular ecosystem. The dramatic coastal mountains and islands of the Alexander Archipelago dominate the landscape and create a spatially complex system of marine environments.

3. *Ocean processes.* Oceanic patterns and processes support productive and diverse marine ecosystems and strongly influence the weather, biochemistry, and biota of freshwater and terrestrial systems.

4. *Human activity.* Human activity (past and present, near and far) has affected all ecosystem components in Southeast Alaska, and has great potential to drive future changes in those components. For example, human effects on Earth's atmosphere, and the unpredictable risk of resulting climate changes may provide the most serious future concern.

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Figure 2 also includes four of the most important interactions among these primary landscape drivers of change:

1. *Climate change*. The long-term influence of humans on global and regional climate (Houghton and others, 2001) is expected to cause substantial changes in the climate of Southeast Alaska during this century. We consider the potential for climate change to be the most important driver of landscape change. The potential environmental stresses caused by the predicted course of global warming could cause unprecedented change in all of the ecosystem components in Southeast Alaska.

2. *Island biogeography.* The geographic interaction between land and sea in the coastal landscape of Southeast Alaska creates a unique spatial matrix of islands, peninsulas and mainland landmasses and the marine and freshwater ecosystem components that connect them. Islands, in the traditional sense of land surrounded by water, and also in the sense of partially bounded marine environments, are a dominant landscape-level feature in Southeast Alaska. Also, most freshwater environments are surrounded by land and are effectively aquatic islands. Much of the lowland terrestrial environment at Glacier Bay has poor connections to other mainland areas due to barriers of marine waters, high mountains, or active glaciers. At a larger scale, all of Southeast Alaska is isolated from the mainland by glaciated mountains; there are only a few scattered low passes or rivers through the mountains to provide easy dispersal corridors between mainland and island populations. This landscape is naturally fragmented at multiple spatial scales. This spatial fragmentation emphasizes the dependence of natural communities and populations on connections, and the importance of recognizing and maintaining them in planning and preservation efforts.

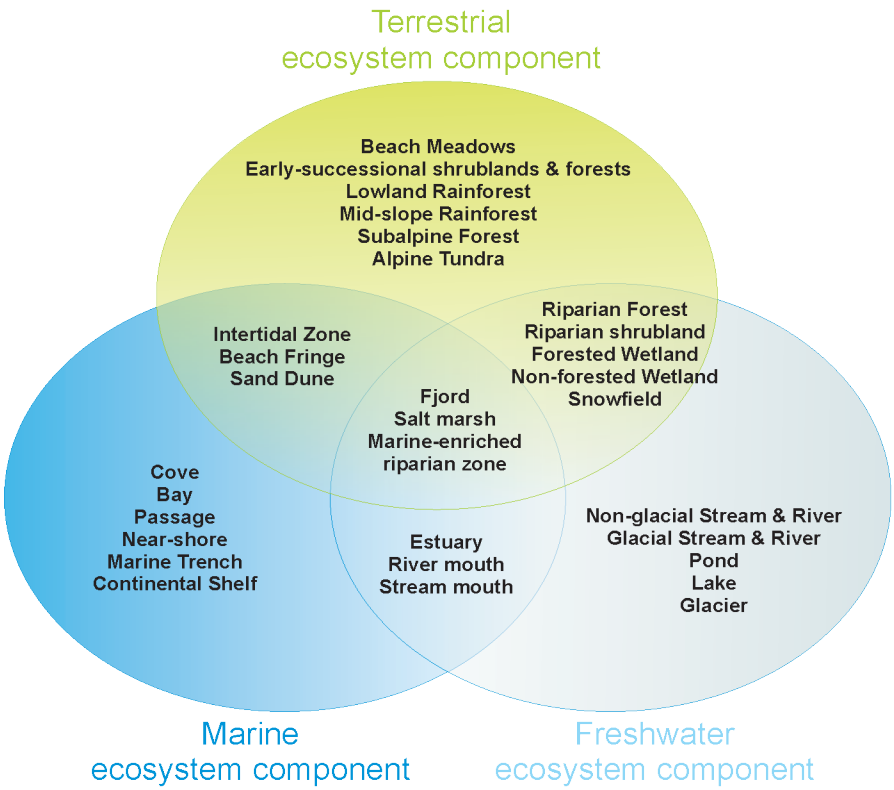

Figure 1. Important habitats within ecosystem components of southeast Alaska. Overlaps include habitats where at least two of the components come in contact. Most habitats exist in mature states and in earlier stages of primary or secondary succession.

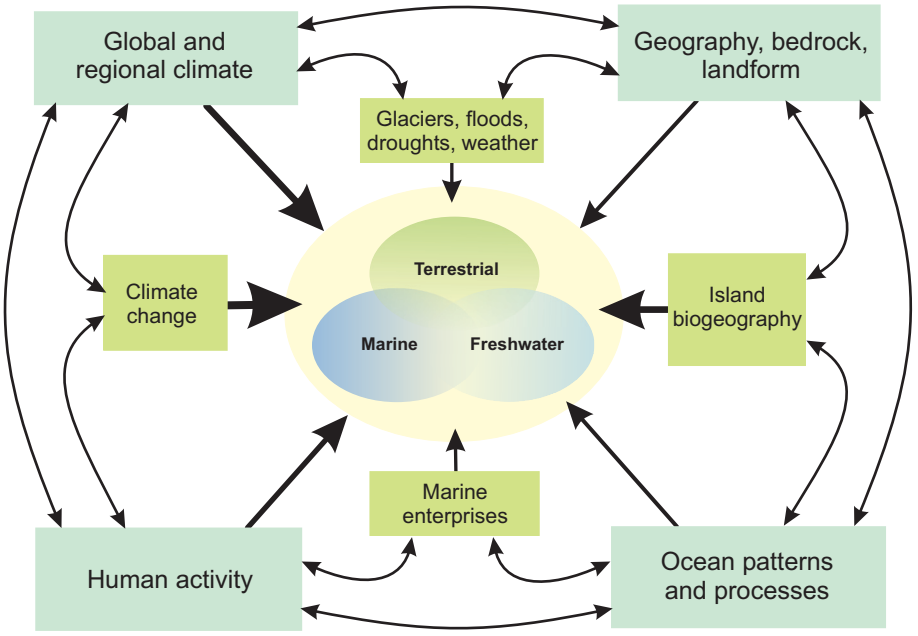

Figure 2. Landscape Drivers of Change. Climate, terrestrial geography, ocean processes, and human activity are the four major driving forces shaping ecosystem components and ecosystem processes in Southeast. Thicker arrows indicate greater influence.

3. *Glaciers, floods, droughts and weather.* The interaction of regional climate and geography produces the conditions responsible for extensive glaciation. Southeast Alaska is at the southern end of the world's fourth largest area of glacial ice. Glacial expansion during the Holocene followed by dramatic retreats in the last few centuries has created a dynamic network of habitats recovering from this recent glacial activity. These retreats at Glacier Bay have created marine, freshwater, and terrestrial habitats in all stages of primary succession from early seral to 300 year-old examples. At a greater temporal scale, the western North American Cordilleran ice sheet covered most of Southeast Alaska the end of the last period of Wisconsin glacial expansion. Retreat of this ice sheet during the early Holocene initiated primary succession throughout most of Southeast Alaska, making long-term (>10,000 year) response to large-scale disturbance a dominant feature of the region. In addition, on the outer coast of Glacier Bay, some refugia have been ice-free for more than 100,000 years (Mann, 1986). Thus, ecosystem recovery from glacial disturbance at a wide range of temporal scales is a distinctive characteristic of the regional environment. In addition to glacial disturbance, small-scale natural disturbance (e.g., avalanche, mass wasting, floods, windthrow, insect outbreaks, fire) has initiated secondary succession in many areas.

4. *Marine enterprise.* Coastal habitats in direct contact with marine waters are vulnerable to the environmental impacts of human activity at sea. Oil spills and other pollution resulting from maritime transport (including cruise ship traffic), and coastal development in support of this maritime activity are a potential threat throughout Southeast Alaska.

Resource Preservation Concerns

Human activity at a wide range of spatial and temporal scales affects the ecosystem components in Southeast Alaska. We describe two categories of human activity that threaten resources in Southeast Alaskan parks. Global industrialization and resource use result in far-field threats, and local and regional human activity result in near-field threats. Far-field and near-field effects overlap and interact with one another. Figure 3 summarizes the primary types of both effects.

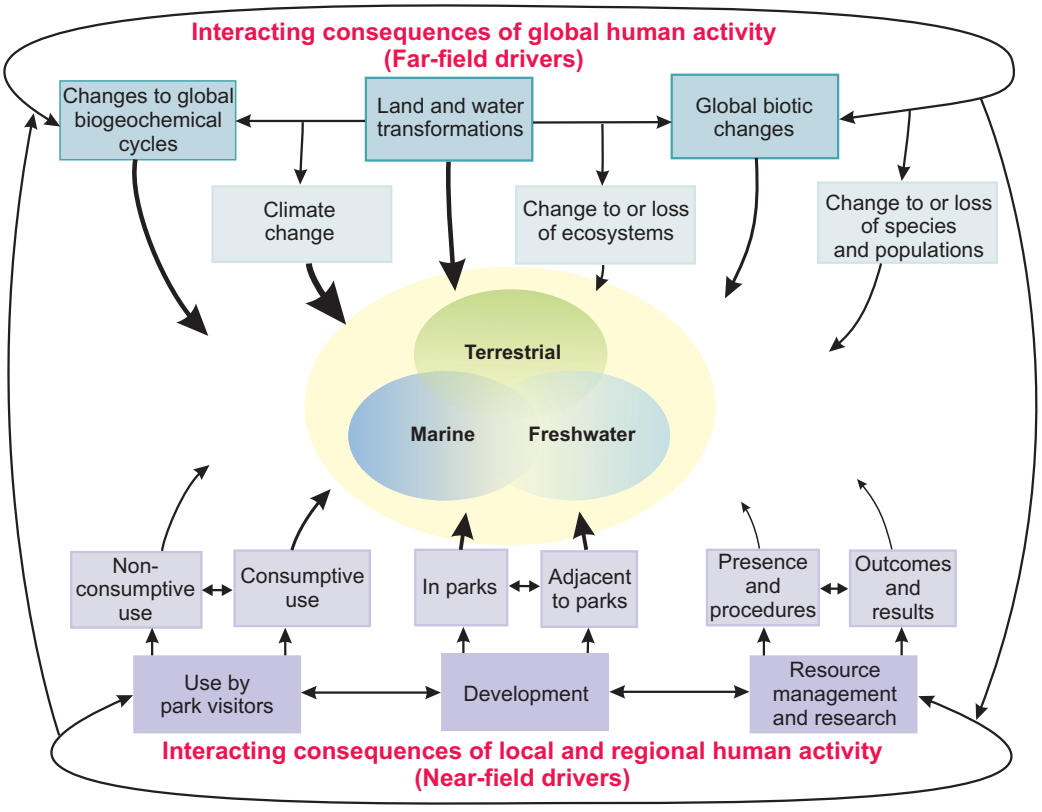

Figure 3. Resource preservation concerns. These interacting far-field (top) and near-field (bottom) drivers of change result from human activity and are likely to affect the natural ecosystem components of Southeast Alaska (thicker arrows indicate greater concern). Arrows between boxes suggest interactions between types of human activity.

Many habitats in Southeast Alaska are as wild and pristine as any on Earth. However, human enterprise around the world has caused changes which affect every place on Earth (Vitousek and others, 1997). Thus the relatively natural environments of Southeast Alaska operate within a global system of physical and biological drivers that have been altered by human activity. Human activities have transformed much of the earth's surface, altered its biogeochemical processes, and eliminated or redistributed species and populations (fig. 3). Three important consequences of these changes are climate change, loss of ecosystem processes and habitats, and loss of species, populations and communities.

Land transformation around the world has altered global biogeochemical cycles by transferring large quantities of carbon from fossil fuels and biomass into the atmosphere, and by fixing non-reactive atmospheric nitrogen (N_2) into reactive compounds (e.g., nitrous oxide, nitric oxide, ammonia) that contribute to the greenhouse effect or alter plant nutrient status. The effects of carbon- and nitrogen-based greenhouse gases have already contributed to global climate change (Houghton and others, 2001), and continued changes threaten to alter natural competitive balances in plant and animal communities and initiate new disturbance regimes.

At the bioregional scale, there are several types of human activity that have the potential to negatively impact park natural resources. Three categories of local or regional human activity which are most likely to affect natural and cultural resources in SEAN parks are park visitation, development in and near parks, and resource management and research activities (fig. 3). The most threatening set of environmental effects is associated with development. Development within parks or near parks could result in toxic contamination of land or water and possible trophic accumulation in food webs, changes in natural populations of animals or plants, and the establishment and spread of invasive introduced species, among other changes

Consumption of natural resources by park visitors can lead to over-harvest of plants or animals, waste and refuse in parks, hardening of sites, and the introduction of new species to park habitats. The most important potential environmental effect of these stressors is disturbance of wildlife and the subsequent changes in populations of animals or plants. Other important effects include the establishment and spread of invasive species and altered successional pathways. Non-consumptive uses such as noise, crowding, or refuse left by park visitors in formerly pristine areas can be an aesthetic concern for other visitors.

Although less threatening than other concerns, resource management or research activity administered by parks, other agencies, or individual researchers has the potential to influence natural environments. The research activity and the specific procedures used may be invasive and result in changes within populations and communities of plants or animals and alterations to successional pathways. Action taken based on the findings of research programs can also lead to population changes and novel successional pathways.

Summary

The SEAN conceptual ecosystem models are a tool to simplify and describe the physical and biological processes and interactions occurring within the parks, and will ultimately aid in identifying network vital signs. Southeast Alaska is influenced by climate, geography, geology and landforms, ocean processes and human activity. These influences overlap at different spatial and temporal scales. Understanding ecosystem component interactions can help focus research questions and aid in management decisions.

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