Toward an Integrated Science Plan for Glacier Bay National Park and Preserve: Results from a Workshop, 2004

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Introduction

In October 2004, Glacier Bay National Park and Preserve and the U.S. Geological Survey's Alaska Science Center invited 34 scientists from a wide array of backgrounds to a one and one-half day workshop to aid in developing a long-term Integrated Science Plan (ISP) for Glacier Bay. The goal of the ISP is to identify the research, inventory, and monitoring necessary as a foundation for understanding resource threats and to enable informed management decisions and actions. The guest scientists convened in three groups based on individual areas of expertise in terrestrial, freshwater, or marine ecosystems. Each group was asked to respond to the following questions:

1. Which physical and biological processes are important in modifying habitats and influencing the abundance and structure of populations and communities representing the marine, freshwater, and terrestrial ecosystems in Glacier Bay?
2. Which of these processes provide the most accurate, sensitive, and efficient measurements to detect changes in environments, populations, and communities representing marine, freshwater, and terrestrial ecosystems in Glacier Bay?
3. Which key species would provide the most accurate, sensitive, and efficient measurements to detect changes in environments, populations (biomass, abundance, and distribution), and communities representing the marine, freshwater, and terrestrial ecosystems in Glacier Bay?
4. What are the important processes or taxa that provide linkages among the different ecosystems?

Terrestrial Ecosystem

The terrestrial ecosystem group identified and grouped physical and biological processes that are active in the terrestrial environment. The team noted that the manifestations of four processes—the tectonic regime, climate, human influences, and glaciers—define Glacier Bay National Park and Preserve (Glacier Bay) and make it unique.

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Key Processes

- Tectonic regime
- Climate (long term)/weather (immediate, time-related)
- Anthropogenic
- Glacial change

Key Drivers, Resulting from Key Processes

- Glaciers, glacial change
- Community succession (colonization, immigration, emigration, extinction etc.)
- Biogeochemical cycling

Other Important Processes

- Human harvest
- Herbivory/Predation/Disease/Pest Eruptions
- Insect infestation
- Soil development, structure
- Paludification
- Post-glacial rebound
- Mass wasting events/erosion/sedimentation
- Blow down, windthrow
- Wildfires
- Bedrock geology
- Genetic drift/evolution
- Flooding, storm surges

Key Species

- Spruce
- Alder
- Sphagnum
- Moose
- Bear
- Eagles (or a more common predator, e.g. seaducks or gulls)

Key Species—Continued

- Seed dispersers—These include bear, some land birds, and several small mammals.
- Western toad (essentially the park's only amphibian)
- Beaver

Ecosystem Linkages

Physical Processes that Affect and Link all Ecosystems.

Examples include climate/weather (including rain and wind), tectonic forces, and gravity.

Linkages that Flow from High to Low Altitude or from the Terrestrial Ecosystem to Others.

These linkages include animals and plants, both vascular and non-vascular, which live in the terrestrial ecosystem, die, break down, and then send nutrients through the ecosystems. Another is the physical effect of large woody debris from the terrestrial ecosystem that falls into riparian streams, and affects and links the terrestrial ecosystem with the freshwater ecosystem. Glaciers are another example of a link among all the ecosystems; they originate in the terrestrial ecosystem and provide water for the terrestrial hydrosphere, which travels to the ocean. They also provide sediment that is transported throughout the environment.

Linkages from the Marine or Freshwater Ecosystem that Affect the Terrestrial Ecosystem.

This type of linkage in Glacier Bay is the fjord-tidewater system, which affects the behavior of tidewater glaciers. Similarly, alluvial and lacustrine processes leave surfaces behind that affect vegetative communities. A storm event, where wave energy hits the land at the peri-marine zone, is an example of marine events that affect the freshwater and terrestrial ecosystems. Isostatic rebound in Glacier Bay is another example as it creates former marine surfaces that are now terrestrial surfaces and the host for terrestrial communities. (Note that the reverse process occurs too, where formerly terrestrial surfaces and communities are now marine surfaces.)

Species that Move Back and Forth or Cycle Among the Ecosystems.

These include but are not limited to salmon, ravens, humans, marine birds, insects, eagles, river otters and beavers. In general, these linkages follow a path from sea to land, and the terrestrial environment serves as the 'nursery' or incubator. Seeds are another linkage that cycles among the ecosystems.

Freshwater Ecosystem

Key Processes

- Climate—solar radiation, precipitation (rain, snow), temperature, wind, altitudinal effects
- Glaciers and glacial change
- Tectonic processes/uplift/mountain building
- Land cover change—vegetation and geomorphology changes
- Air quality
- Anthropogenic influences

Specific Freshwater Processes, Variables as Surrogates of Processes, and Indicators of Community Structure and Function

- Flow/Discharge
- Sediment deposition, erosion, suspension
- Source of water input to freshwater system (glacial, precipitation, groundwater)
- Water temperature
- Nutrients—Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC), nitrogen, phosphorus, benthic and free carbon
- pH/alkalinity
- Channel morphology changes
- Change in lake association with stream (older streams "lose" their lakes)
- Coarse woody debris recruitment and abundance
- Canopy closure/density
- Hyporheic and groundwater processes
- Primary productivity/chlorophyll-*a*
- Organisms—presence/ absence/ relative abundance of fish and amphibians, diatoms (lake environments), benthic species productivity and richness

Key Species

- Benthic invertebrate abundance and diversity
- Diatoms (an important and sensitive indicator of freshwater lake ecosystem health)
- Presence/absence and relative abundance of resident or anadromous fish
- Presence/absence of amphibians

Specific Physical and Biological Metrics:

- Stream stage
- Turbidity
- Water temperature
- pH
- Chlorophyll-*a*
- Nitrogen, phosphorus, TOC, DOC quality (SUVA value), benthic organic carbon, free carbon
- Diatoms (essential taxa for lakes)
- Benthic organisms—biovolume Orders *Ephermeropters* (mayflies), *Plecoptera* (stoneflies) and *Trichoptera* (caddisflies) richness sensitive for water quality
- Aerial imagery—channel morphology changes, lake presence/size, wetland presence/size, coarse woody debris (size and density), canopy density/closure (affects light, temperature, litter input)
- Fish presence/absence (minnow traps in streams)
- Amphibian presence/absence (important wetland taxa)

Important Tools to Study Important Freshwater Processes Could Include Remote Sensing (e.g. Aerial Imaging and Watershed Specific Study) Based on the Following Criteria:

- Of different scales, gradient, and levels of complexity (stream order)
- Lakes present and absent
- Active glacial input present or absent
- Ice remnants present and absent
- Within the bay proper and on the outer coast
- In various successional stages and pathways (e.g., N-S, and E-W, which may illustrate succession pathway with alder and without)
- Where baseline data and/or a significant body of research exists

Key Linkages

Physical Processes that Affect and Link all Ecosystems

- Climate/weather solar radiation, precipitation (rain, snow), temperature, wind, altitudinal effects
- Tectonic forces (uplift and mountain building)
- Glacier change

Terrestrial to Freshwater

- Land cover changes—especially percent cover in alder, wetlands/peat
- Drainage
- Surficial geology/soils

Freshwater to Marine

- Effects of freshwater input on the marine environment, including the delivery of carbon and nutrients, and temperature and salinity change. Note that effects would differ for subglacial streams (direct glacial to marine) than for freshwater entering the marine environment at a non-tidewater glacier setting.
- Movement of sediment/material from the watershed to the marine environment
- Successional changes of nitrogen contributions (and attendant productivity) to the marine system; with different successional stages (time) and pathways (e.g., alder, no alder).

Marine to Freshwater

- Marine-derived nutrients coming from the marine environment to the freshwater and terrestrial environment
- Contribution of chloride to the freshwater and terrestrial environments due to sea spray
- Evaporation, condensation, precipitation

Freshwater to Terrestrial

- Marine-derived nutrients
- Aquatic insects

Marine To Terrestrial

- Marine-derived nutrients
- Birds, mammals (vectors and pathways)

Marine Ecosystem

Key Processes

- Glacial Dynamics—e.g., ice velocity, calving, melting by seawater, mass balance, debris concentrations
- Stream Dynamics—e.g., submarine glacial discharges and upwelling, deltaic discharges
- Sediment Dynamics—e.g., fluxes, settling velocities, dispersal patterns, fjord floor re-sedimentation processes, mass wasting
- Ocean Dynamics—e.g., stratification, vertical mixing and baroclinic flows, salinity, temperature and current velocities, replenishment and water-column turnover, turbidity, wave climate, tides, hydrology
- Base Level Dynamics—e.g., tectonics, earthquakes, isostasy, eustasy, bathymetry
- Atmospheric Dynamics—e.g., wind, precipitation (rain, snow), temperature, solar radiation
- Climate Dynamics—e.g., cyclical change, non-cyclical change (Pacific Decadal Oscillation)
- Sound Dynamics—e.g., propagation of natural (wind, precipitation) and man-made (vessels, aircraft) underwater sounds

Production Processes

- Photosynthesis
- Hydrology
- Nutrients
- Trophic transfer
- Melt water
- Population dynamics
- Recruitment
- Defecation
- Decomposition/Nutrient cycling
- Oceanography
- Mixing

Key Processes, Species and Metrics

The marine ecosystem group recognized three fairly distinct habitats with common and distinctive processes, species, and metrics to be considered in science planning.

Intertidal and Nearshore (20-30 Meters Water Depth) Habitats

Physical

- Water Chemistry
- Temperature
- Salinity
- Icebergs
- Ice freezing
- Ice freezing, pan ice and icebergs
- Solar radiation
- Turbidity (to determine light regime, visual predators, mechanical fouling/clogging)
- Wind

Biological

- Kelps and sea grasses (freshwater and tidal, subtidal, and intertidal)
- Zooplankton
- Exposure (expressed and wave energy)
- Detailed substrate character
- Filter feeders (barnacles, mussels, clams)
- Pan ice (and bergs)
- Snails
- Urchins
- Sea stars (predatory influence)
- Shorebirds (oystercatchers)
- Seabirds (gulls)
- Predatory fishes (rockfish, lingcod, halibut)
- Forage fishes (gunnels, capelin, hooligan, sand lance, juvenile pollock)
- Marine mammals (whales, sea otters, pinnipeds)
- Sea ducks (scoters, Barrows goldeneye)

Transportation Processes

- Passive transport
- Active transport
- Migration
- Currents
- Dispersal
- Patch dynamics
- Atmospheric forcing
- Exotic species introduction
- Behavior

Species Interaction Processes

- Predation
- Fishing
- Grazing
- Facilitation
- Parasitism
- Bioturbation
- Selection
- Succession
- Human subsistence
- Decomposition
- Food chain
- Disease
- Competition
- Mutualism

Human Influence Processes

- Man-made objects
- Contaminants
- Disturbance
- Sound
- Subsistence/removal
- Exotic species introduction
- Habitat change
- Harvest selection

Pelagic Habitat (Water Column Greater than 30 Meters Water Depth)

Physical

- Bathymetry
- Icebergs (harbor seal pupping)
- Wind
- Solar radiation
- Ice face dynamics (vertical mixing and baroclinic flows)
- Temperature
- Salinity
- Turbidity (light levels)
- Hydrography (transportation, productivity)
- Currents
- Water chemistry (contaminants, water quality, nutrients)

Biological

- Forage fishes (food source, lantern fish)
- Phytoplankton (as a standing crop)
- Zooplankton (krill, copepods)
- Seabirds (murrelets, cormorants, kittiwakes, -site specific)
- Marine mammals (whales, seal lions, harbor seals, sea otters)
- Predatory fishes (salmon, halibut, pollock, sleeper sharks)
- Jellyfish
- Puffins (rare bird in the park)
- Water chemistry (contaminants, water quality, nutrients)

Benthic Habitat (Fjord Floor Greater than 30 Meters Water Depth)

Physical

- Replenishment (water cycle in the 3D)
- Substrate (fine- vs. coarse-grained determines species)
- Currents (lower bay different from upper bay and from east and west arms)

Benthic Habitat (Fjord Floor Greater than 30 Meters Water Depth)—Continued

Physical—Continued

- Salinity
- Depth
- Sediment chemistry
- Water chemistry (contaminants, water quality, nutrients)
- Surface-to-benthic coupling (moves detritus, phytoplankton to benthic community)
- Iceberg scouring (disturbance and recolonization)
- Sedimentation rates (controls habitat)
- Bioturbation (substrate)

Biological

- Predatory fish (halibut, lingcod, rockfish, black- and gray cod, sculpins, sharks, rays/skates)
- Soft coral and sponges
- Sea whips
- Horse mussels, scallops (influencing substrate structure)
- Echinoderms (different species depending on location in Bay)
- Shrimp
- Crabs
- Gastropods
- Water chemistry (contaminants, water quality, nutrients)

Key Linkages Among Habitats

- Continuous oceanographic moorings, in various and multiple locations. This would provide information on sediment, temperature, salinity, currents, PAR, chlorophyll, dissolved oxygen, nutrients, sound, and turbidity.
- Continuous real-time weather stations, in various and multiple locations (one within the east and west arm, at a minimum), to gather information on wind speed, precipitation, solar radiation, and temperature.
- Glacier monitoring to understand iceberg production, freshwater and sediment loads into/out of the system and mass balance.

Key Linkages Among Habitats—Continued

- Stream flow discharge monitoring.
- Colonization, as a way to help detect new processes that may not yet exist (design research, monitoring, and inventory programs to detect new things, as well as those that currently exist).
- Gene flow

Integration Across Ecosystems

All groups joined to integrate ideas on the research and monitoring needed to detect and understand change across ecosystems in Glacier Bay. This research, monitoring, and inventory process is the heart of the ISP, which is needed to assist the NPS in identifying resource threats and guiding management decisions.

Three dominant physical processes that link the ecosystems were widely recognized both within and among ecosystems; climate (weather), tectonics and glaciers. Other common linkages include transport and cycling of water, sediment, nutrients, and biota; the presence, abundance and actions of humans, the composition, abundance and distribution of species; and disturbance events, both natural and human induced.

An Integrated Science Framework

Toward developing a generalized approach to understanding and detecting change in Glacier Bay, a list of relevant research topics pertaining to one or more of the ecosystems was developed. Those research topics were then organized and subsequently categorized as Physical, Biological, or Human Processes. Within each of these generalized processes more specific areas of research were identified that bridged each ecosystem:

Physical Processes

- Climate/weather
- Glaciology
- Tectonics
- Hydrology
- Sedimentology
- Chemistry
- Transport of matter, nutrients, and energy

Biological Processes

- Ecosystem and community organization
- Productivity
- Trophic dynamics
- Succession
- Transport of productivity

Human Processes

- Disturbance
- Contaminants
- Removals
- Invasive species

Once the list of key research processes and topics were developed, a list of general questions was formulated in an attempt to capture the important concepts and processes that were widely regarded by the contributing scientists as fundamental to advancing our understanding of the structure and function of Glacier Bay. The questions are framed to be conceptually, organizationally, and taxonomically broad and to embrace those factors that were widely regarded as important in detecting and understanding change within and among the terrestrial, freshwater, and marine ecosystems that comprise Glacier Bay. Clearly, these questions do not provide detail or specific recommendations, but rather they provide a foundation upon which an integrated science plan can be built. Recommendations related to specific metrics or species can be found in the complete workshop report (Glacier Bay NPP, Gustavus AK, electronic link)

Ecosystem Questions

- How do climate change and weather affect physical and biological processes in Glacier Bay?
- What are the consequences of glacial retreat and advance on environments and ecosystems in Glacier Bay?
- How is variation in the transport of matter, nutrients, and energy reflected in variation in productivity in Glacier Bay ecosystems?
- How is variation in biological productivity transferred within and among the marine, freshwater, and terrestrial ecosystems in Glacier Bay?
- What are the human influences that are likely to affect the integrity, stability, beauty, and capacity for self-renewal of Glacier Bay?

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Biologists preparing to conduct surveys for seabirds in Reid Inlet (Reid Glacier in background). (Photograph by Mayumi Arimitsu, U.S. Geological Survey.)