Driving the Marine Ecosystem: Oceanography as a Key Long-term Monitoring Vital Sign at Glacier Bay National Park and Preserve

By Lewis Sharman

Glacier Bay National Park and Preserve is one of the most fundamentally "marine" parks in the national park system. It is certainly one of the largest, with 1,200 miles (1,930 km) of coastline encompassing nearly 600,000 acres of federally protected marine waters, including submerged lands. Virtually everything about the park, even those terrestrial and freshwater ecosystem components centered well inland, has some critical connection to the sea (*Figure 1*). For example, almost every species of bird and mammal in the park – even alpine birds and mountain goats – has been observed foraging in the marine intertidal zone. Similarly, marine materials and energy are well known contributors to terrestrial freshwater and adjacent riparian ecosystems (*Gende et al. 2002*).

Why Oceanography?

In order to fully appreciate how park ecosystems work, and thereby how to protect them, one must understand Glacier Bay itself. A dynamic glacial fjord of considerable physical and biological complexity, the bay is highly productive. This productivity is manifest in the high abundance and diversity of animals and plants throughout the park's marine waters (*Figure 3*). The biota includes all trophic levels, from microscopic phytoplankton primary producers, to apex predators such as killer whales. Members of the marine fauna range from resident sessile invertebrates (e.g., barnacles, sea anemones, sponges) to seasonally migratory vertebrates, many of them large and highly charismatic Glacier Bay "signature species" (e.g., harbor seals, puffins, humpback whales).

Glacier Bay owes its high biological diversity and abundance to the marine production cycle, a phenomenon that is reasonably well understood for glacial fjords (*Syvitski et al. 1987*). The generalized model describes a seasonal pattern of vertically well-mixed waters in winter with high nutrients but low light available for photosynthesis. As air temperature and daylength increase in the spring, freshwater runoff from land to sea increases, enhancing surface stratification and providing light levels sufficient to initiate a "bloom" of phytoplankton. Intermediate levels of vertical mixing by Glacier Bay's large tides continually re-inject nutrients into the sunlit surface waters, perpetuating bloom conditions throughout the summer and into the fall, even as threshold levels of surface water column stability are maintained (*Etherington et al. 2007*). Finally, the system reverts to the winter condition, and biological production diminishes as light levels decline and winds break down vertical stratification as colder temperatures decrease freshwater input from the land.

The fundamental key to creating and maintaining bloom conditions is bringing (and keeping) nutrients and light together. The importance of this very basic ecosystem process cannot be overemphasized, because it powers biological productivity that translates into everything from sea lions to spruce forests. Indeed, it can be argued that the annual sustained spring/summer phytoplankton bloom is the single most significant biological event in the park. At its core, this process is largely mediated by water column dynamics – how water (and the materials, energy, and information contained within it) moves. This is described by oceanography. Consequently, understanding the oceanographic factors (e.g., water temperature, salinity, availability of light for photosynthesis) that ultimately control marine productivity, and thereby influence the entire park, is critical to wise stewardship.

It is not enough simply to describe oceanographic conditions as snapshots in time, because Glacier Bay's picture is continually changing. Not only does the bay experience the substantial seasonal variations described above, it is still responding to a catastrophic retreat of its tidewater glaciers that began some 250 years ago. These changes are reflected in strong gradients in virtually all oceanographic parameters as they vary in proximity to tidewater glacier faces, the heads of turbid outwash fjords, sources of freshwater input, etc., all of which are still changing. Managers today must place these dynamics in the larger context of regional and global climate change, which raises important concerns

Figure 1. Oblique three-dimensional LandSat image of Glacier Bay.

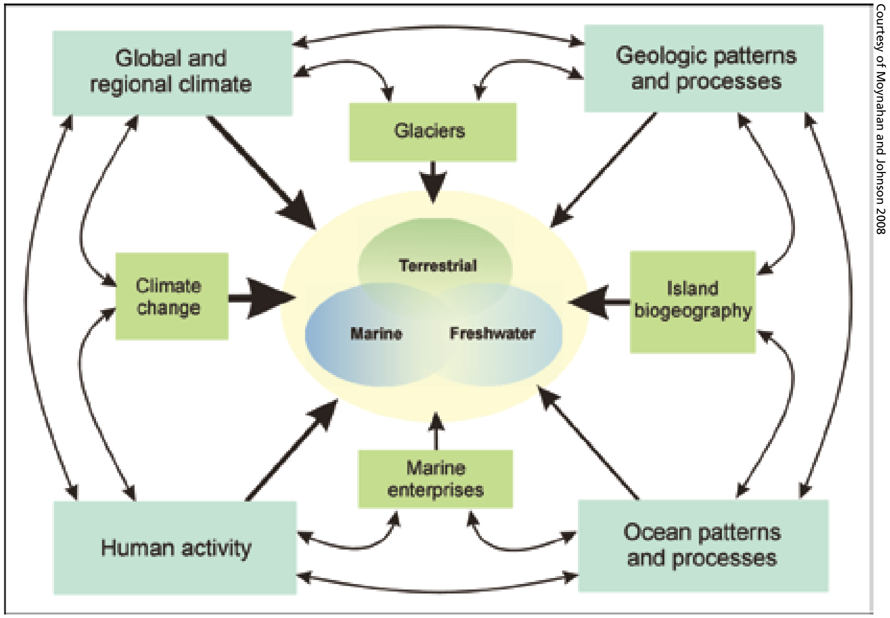

Figure 2. Ocean patterns and processes strongly influence terrestrial and freshwater, as well as marine, ecosystems in Glacier Bay.

such as ocean acidification and sea level rise. It is imperative to monitor the long-term trends in oceanographic parameters, thus the decision by the Southeast Alaska Network (SEAN) to identify Glacier Bay oceanography as a key vital sign. This program is providing an informational context for managers to interpret and respond to long-term changes that are currently and will continue to affect Glacier Bay National Park and Preserve – how we understand it, adapt to it, and protect it.

The Long-term Monitoring Protocol

The objectives of the SEAN oceanographic monitoring program are to document interannual and seasonal variation in physical oceanographic conditions in Glacier Bay. These observations provide a baseline dataset that can be used by researchers to understand spatial and temporal variation in biological productivity, thereby contributing to informed park management.

We collect very accurate and precise measurements of water temperature, conductivity (salinity), light, turbidity, dissolved oxygen, and fluorescence (an index of chlorophyll-a concentration and thus phytoplankton abundance/primary production). These measurements are captured by an array of sensors mounted together in an instrument cluster (*Figure 4*) called a CTD (for Conductivity/Temperature/Depth). A pressure sensor keeps track of depth as the CTD is lowered through the entire water column at a rate on 1 m/second from the surface to just above the bottom. Parameters are measured twice per second, and the data from each "cast" is stored in the CTD and downloaded later. Together these measurements yield a vertical profile of important water column characteristics.

There are 22 standard oceanographic "stations" located mid-channel throughout Glacier Bay (*Figure 5*) where sampling is conducted on a regular schedule. Seven of the stations are sampled monthly, from March through October, to describe seasonal variation during times of the strongest physical structure and highest productivity and dynamism. Twice a year, in July and December/January, we sample all 22 stations to detect annual or longer signals. This design achieves a balance between intensive temporal sampling to resolve seasonal signals, and intensive spatial sampling to resolve annual signals and reveal long-term trends.

Raw data for all parameters are processed and verified following each sampling trip. Data from the previous year are summarized and plotted in an annual winter report that focuses on seasonal patterns. Five-year reports carefully analyze data for annual and longer patterns and trends.

Making the Data Available

The program places a high priority on providing information access. SEAN actively disseminates oceanographic data products, along with the comprehensive detailed protocol, via the SEAN (http://science.nature.nps.gov/im/

NPS photograph

Figure 3. Highly productive kelp forests provide shelter for a wide variety of species within Glacier Bay and adjacent marine waters.

NPS photograph

Figure 4. The CTD ready to be deployed at an oceanographic station.

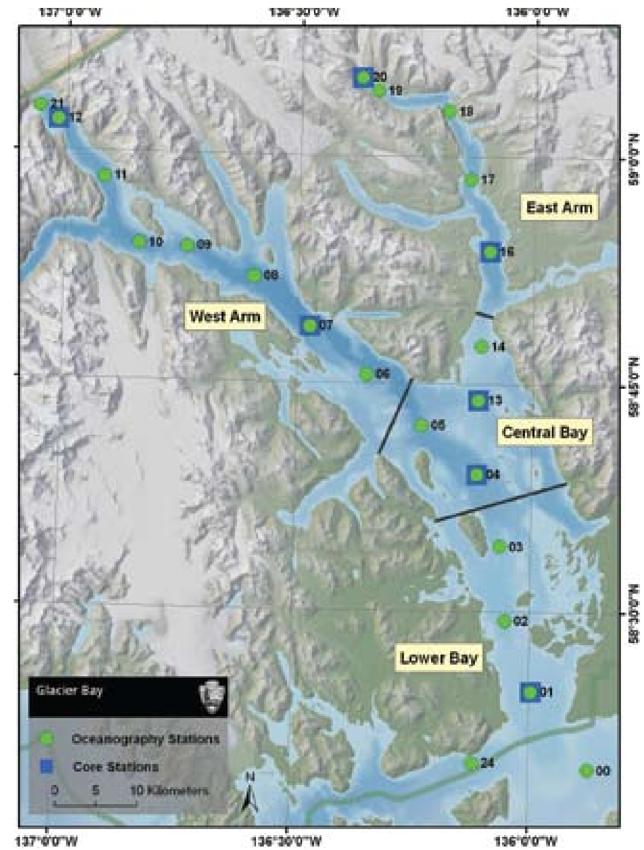

Figure 5. Current oceanographic sampling stations in Glacier Bay. Shaded bathymetry indicates relative water depth (darker means deeper). Station depth ranges from 174 ft (53 m) at Station 00 to 1,427 ft (435 m) at Station 07.

units/sean/OC_Main.aspx) and partner web sites. Subordinate linked pages provide access to formal metadata, references to relevant published and gray literature, etc. Interested parties can also search "Southeast Alaska Network" and access the information via the oceanography page.

Findings So Far

The SEAN is fortunate to be able to sustain a robust oceanographic dataset that was initiated in 1993. Etherington et al. (*2007*) summarized observations from the first ten years (1993-2002). The most interesting results highlighted not only the importance of water column stability to productivity, but that stability is influenced by strong competing forces in Glacier Bay. While high-energy tidal currents at the main entrance enhance vertical mixing in the lower bay, the upper arms are characterized by strong water column stratification that is maintained through much of the year, likely due to high freshwater input. In the central region of the bay where these two processes meet, observed high and sustained chlorophyll-a levels may be due to optimal surface conditions of intermediate stratification, potential nutrient renewal from depth, and decreased suspended sediment levels and thus more light available for photosynthesis (*Figure 6*).

To date we cannot confidently conclude that significant annual changes have occurred since monitoring began. However, we are hopeful that the upcoming summary report (expected in 2010) covering the years 2003 to the present (and adding the previous ten years of data) will be able to determine whether the current comprehensive 16-year dataset is sufficient to detect any long-term temporal changes or trends in measured oceanographic parameters.

The Future

The Glacier Bay long-term oceanographic monitoring program aims to provide data that will inform process studies. For example, important outstanding questions include the source of nutrients to power intense bloom events in the extreme upper arms of fjords. Similarly, accumulating oceanographic data should help managers understand and perhaps even predict patterns of distribution and abundance of forage fishes and the marine vertebrate predators that subsist on them. In direct response to emerging concerns related to climate change, the SEAN is currently collaborating with partners on a proposal to add ocean acidification measures to the existing long-term monitoring protocol. In addition, we hope to geographically expand the program beyond Glacier Bay proper to waters of the park's exposed outer coast.

As described above, ocean dynamics are key to the health of populations and communities across park ecosystems. The SEAN will integrate oceanographic data with those generated from other ongoing vital signs monitoring (e.g., weather/climate, marine contaminants) to improve our understanding of the spatial and temporal dynamics of additional target vital signs (Kittlitz's murrelets, marine predators). In a rapidly changing world, the ultimate goal

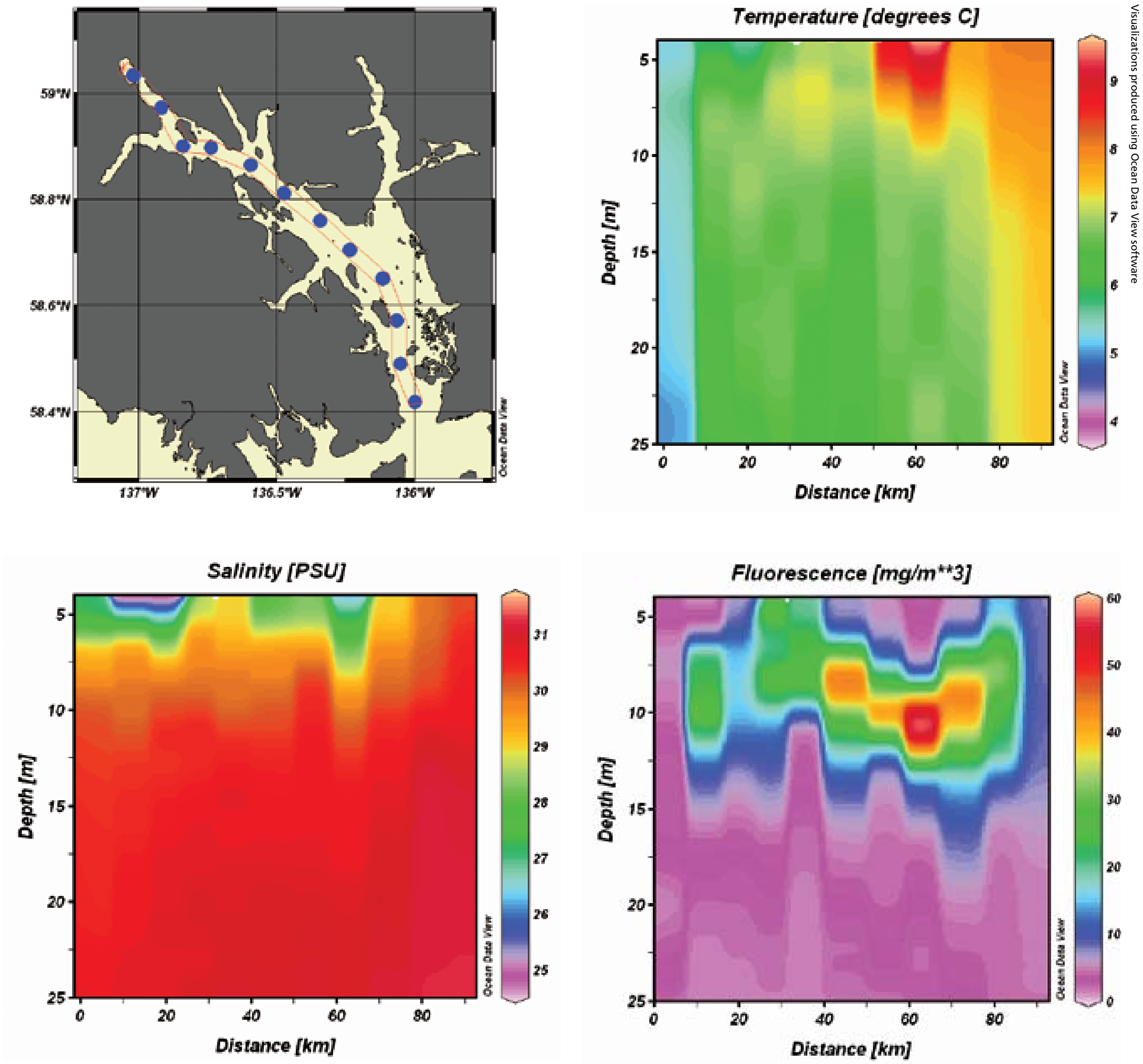

Figure 6 (a-d). Length-of-Bay transect through the West Arm (a), showing spring/summer patterns of water temperature (b) and salinity (c) with depth in the upper 82 ft (25 m). How rapidly these two parameters change with depth correlates positively with degree of water column stratification. Fluorescence (d) is a proxy for phytoplankton abundance and thus amount of primary productivity. Note that an intermediate level of stratification in the central portion of the transect sustains the highest overall level of fluorescence. Data are from monthly surveys March-August 2009.

of the oceanographic monitoring program is to enhance the ability of managers to preserve Glacier Bay's remarkable and increasingly precious resources.

Acknowledgements

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