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Fjord Oceanographic Processes in Glacier Bay, Alaska

Oceanography describes one of the most fundamental physical aspects of a marine ecosystem. An understanding of many of the resource and research issues in Glacier Bay will not be possible without understanding the underlying oceanographic processes.

Why study oceanographic processes?

The distributions of organisms are largely dependent upon the physical and biological properties of their habitat. Some marine organisms may be found in waters with a wide range of salinity, temperature, and sediment levels, while others may be restricted to areas with very narrow and specific ranges of these physical properties. The physical attributes of the environment may influence the behavior (such as feeding, mating, or dispersal) or physiology (such as growth rates or metabolic rates) of organisms. For example, in waters near the glaciers, the high sediment levels in the water could decrease the foraging effectiveness of a visual predator such as the harbor seal, while the colder temperatures could slow down the growth rates of fish and crabs.

The circulation patterns of the water are also important components of the oceanographic system of Glacier Bay. Circulation within an estuary (an area where freshwater and saltwater mix) is largely dependent upon the density of different water masses. The density of water is determined by two main properties: salinity and temperature.

The Evasterias *seastar is sensitive to salinity changes and is not found in the upper parts of Glacier Bay.*

As you increase salinity you increase the density of water; as you decrease temperature you increase the density of water. Water masses will come to an equilibrium so that the most dense waters are near the bottom of the water column and the least dense waters are near the top. This property has important implications when we consider how freshwater (less dense) interacts with saltwater (more dense) within the estuarine environment. The depth and bottom topography (bathymetry) can also influence circulation, by potentially restricting or enhancing the movement and mixing of water masses in shallow areas (e.g., sills left by glacial advance). Other forcing mechanisms such as tidal currents and wind can have a large influence on circulation patterns, depending on the region of the estuary.

One important aspect of estuarine circulation is its influence on phytoplankton (microscopic aquatic plants that are the base of the marine food chain). Circulation patterns determine the distribution and abundance of nutrients (e.g., nitrogen, phosphorus, and silica that are vital to the growth of phytoplankton) within surface waters. Other factors that control the productivity of phytoplankton include the depth to which light can penetrate (which can be influenced by the amount of sediment in the water), as well as the presence of a stratified water column. Stratification occurs when there are distinct horizontal layers in the water column, as opposed to a when the water is completely mixed from surface to bottom. If the water column is not stratified and mixing occurs, phytoplankton (as well as nutrients) will be removed from the surface layers and will be delivered to greater depths where there is not enough light available for photosynthesis to occur. Therefore, understanding the oceanographic properties of Glacier Bay provides information on the physical habitats and the circulation patterns within the estuary, which influence the abundance and distribution of phytoplankton and higher-order organisms.

The study described below was conducted to gain a comprehensive description of the spatial and temporal variation in oceanographic patterns of Glacier Bay, an understanding of the potential mechanisms driving these patterns, as well as the implications of oceanographic properties for the biological processes within the Bay.

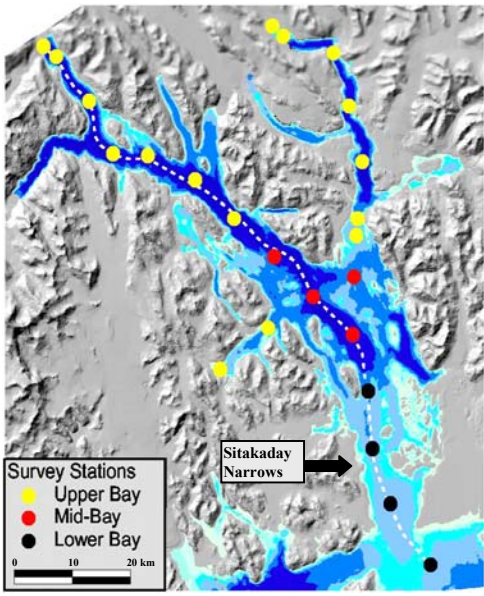

Fig. 1. *Bathymetry of Glacier Bay, AK. Darkest blues are deepest waters (458 m max. depth), and lighter blues are shallower. Circles denote sampling locations. Note the shallow sill at the Bay's mouth and the sill with contraction at Sitakaday Narrows.*

Glacier Bay System

A Fjord is a deep, high-latitude estuary that has been (or is presently being) excavated or modified by land-based ice. Fjords are typically very complex estuarine systems, and Glacier Bay, AK (GLBA) supercedes this complexity for many reasons. GLBA has multiple, very cold tidewater glaciers, which are retreating extremely rapidly (up to 90 m/yr!) and melt year-round. GLBA also has shallow sills backed by deep basins (Fig. 1) and a narrow contraction at the mouth of the Bay (Sitakaday Narrows, Fig. 1). Other factors that add to the system's complexity include: a large amount of runoff, high sedimentation, large tidal range (up to 7.8 m), and strong tidal currents (up to 4.5 m/s).

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Methods

U.S. Geological Survey researchers from the Glacier Bay Field Station conducted oceanographic surveys of 21-24 stations in Glacier Bay 2-8 times annually between 1992 and 2002. CTD (conductivity-temperature-depth) casts were made at each station, taking water measurements every 1 m, from the surface to the bottom. The following parameters were measured: salinity, temperature, depth, optical backscatter (indicator of turbidity-amount of sediment in the water), fluorescence (a proxy for the amount of chlorophyll *a*, and thus phytoplankton abundance), and photosynthetically active radiation (PAR; amount of light available for photosynthesis). To analyze over 1000 casts, we wrote a program for the 3-D and 4-D analysis of oceanographic data within a Geographic Information System (GIS). This extension to ArcView GIS can be used on any oceanographic instrument profile files. Oceanographic Analyst can be found at: http://www.absc.usgs.gov/glba/gistools/

Deploying the CTD instrument in Glacier Bay.

Mixing & Deep Water Renewal

Tidal mixing led to a homogeneous water column (non-stratified) in the Lower Bay of GLBA. Turbulence in this area was due to strong tidal currents, shallow sills, and the contraction at Sitakaday Narrows (Fig. 1). The Mid-Bay area was stratified for much of the year. Despite the shallow entrance sill in GLBA, intrusion of outside (nutrient-rich) waters to intermediate and deep depths (deep water renewal) in the Mid-Bay occurred throughout the year. The Upper Bay exhibited patterns suggestive of weak entrainment (fresh water moving seaward on surface) (Fig. 2).

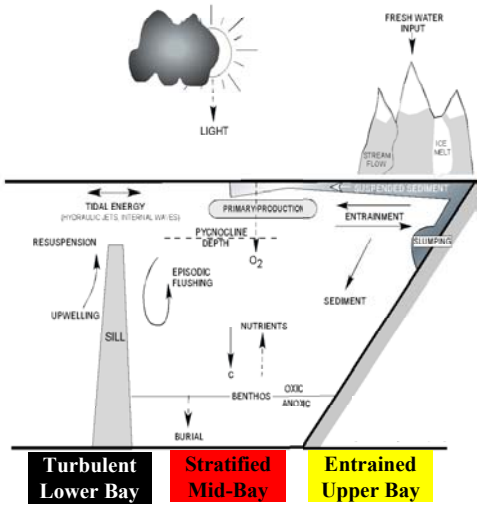

Fig. 2. *Silled Fjord Model: Distinct oceanographic patterns were found in Glacier Bay, and support a 3-part model of silled fjord circulation (modified from Syvitski et al. 1987).*

Phytoplankton Abundance

The central part of GLBA consistently had the highest phytoplankton abundance. In this region, high fluorescence was found only in a narrow band within shallow waters. Our data demonstrate that phytoplankton abundance was sustained from spring to fall, rather than an extreme spring bloom followed by low abundance, which is characteristic of many other regions. Interestingly, high densities of phytoplankton were often found at anomalous depths (where the amount of available light would make photosynthesis impossible) in the Upper Bay near glacial faces.

Role of Sediment

From the CTD data, we found evidence for high sediment levels in the water column throughout Glacier Bay (up to 100 km from glacial sources) for much of the year. Surface sediment levels were highest adjacent to glaciers in both arms, and in the Lower Bay/Sitakaday Narrows region (Fig. 3). There was a significant relationship between turbidity and the amount of light (PAR); PAR penetrated to greater depths farther from glaciers, except in the Lower Bay. Thus, the amount of sediment and light may largely determine the distribution of phytoplankton within Glacier Bay.

Fig. 3. *Landsat TM image of Glacier Bay, AK 5/95. Sediment plumes are evident as light blue/white areas in the water of both arms (near glacial sources) as well as in Sitakaday Narrows and the mouth of Glacier Bay (upwelling of water and re-suspension of sediment from bottom).*

Future Work

The current study provides a general description of the oceanographic system of Glacier Bay. Researchers at the Glacier Bay Field Station are planning to conduct a detailed analysis of annual variation in oceanographic properties within Glacier Bay in an effort to determine how these patterns relate to external oceanographic conditions and climatic variables. This will allow us to better understand the abundance and distribution of animals within Glacier Bay, and to determine whether these patterns are due to local anthropogenic factors or to "natural" fluctuations in the marine environment.

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NATIONAL PARK SERVICE

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