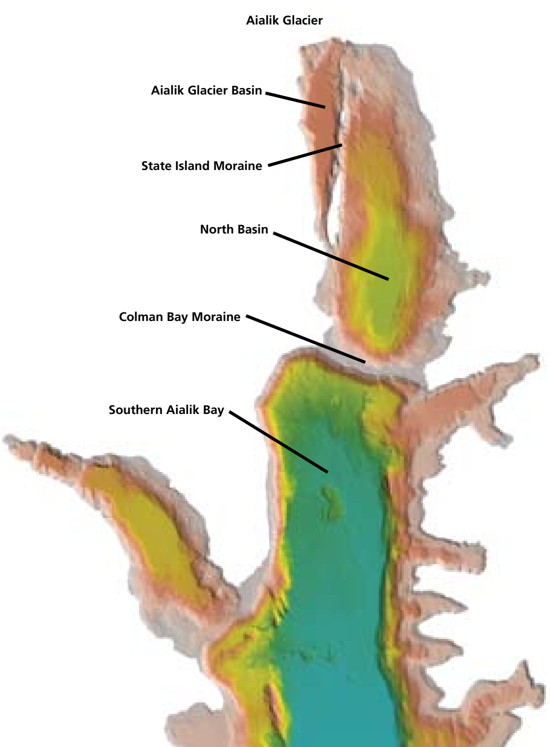
Marine Ecology and Oceanography in Aialik Bay

Figure 1. (Left) Aerial view of upper Aialik Bay, from Aialik Glacier.
USGS photograph by B. Molnia

Figure 2. Bathymetry of upper Aialik Bay, based on data from Office of Coast Survey and National Geophysical Data Center.



By Anne Hoover-Miller and Alexei Pinchuk

Aialik Bay (*Figure 1*) is a tidewater glacial fjord located in the Kenai Fjords National Park. The rugged deep-water fjord was sculpted by Pleistocene glaciers that, during maximum glacial advance, extended far into the Gulf of Alaska. The precipitous high peaks and steep walls of the mountains flanking the fjord descend into frigid 900 feet (270 m) deep subarctic waters. Located in the upper third of the fjord, a prominent subsurface moraine (sill) stretches from Pedersen Lagoon to the north shore of Colman Bay. A natural dam, the moraine abruptly rises more than 670 ft (200 m) to within 18 ft (5.5 m) of the water's surface. A secondary ragged sill, located farther up fjord, extends from Slate Island through Squab Island (*Figure 2*). Each sill acts as a barrier, interrupting the flow of water from the Gulf of Alaska in its own unique manner, creating distinctive environments within each basin. Each of these environments possesses its own individual physical, chemical, and biological properties that provide a platform for equally unique biota.

Perhaps as recently as 1800, Aialik Glacier rested on the north Colman Bay moraine (*Post 1980*). As Aialik Glacier receded, it exposed a 630 ft (190 m) basin east of Slate and Squab Islands. By about 1900, Aialik Glacier receded to near its present location, leaving a relatively shallow basin west of Squab Island that is currently filling with glacial silt.

As glaciers flow down the mountains, the bedrock they flow over is scoured and ground to fine particles commonly known as glacial flour. Outwash from the glacier is heavily laden with glacial flour that markedly decreases the penetration of light into the water to just a few inches (*Carpenter 1983*). When mixed with salt water, glacial flour may "flocculate" and quickly settle to form a sticky grey silt layer on the floor of the fjord. Lower concentrations of silt may remain suspended in surface waters, eventually becoming so diluted as to tint the water a light blue-green.

Post (*1980*) estimated that in Aialik Bay, glacial sediment on the basin west of Slate Island accumulated at 1 ft (0.3 m) annually; east of Slate Island accumulation rates were slower, about 3.5 inches (9 cm) per year. Approximately 70 taxa of marine invertebrates, including polychaetes (worms), mollusks (e.g., clams), and crustaceans (e.g., shrimps, crabs, amphipods) live in silty benthos of upper Aialik Bay. Near the glacier, where sedimentation rates are highest, 23 taxa were found to reside in the sticky mud (*Carpenter 1983*).

Waters entering the mouth of Aialik Bay are transported by the Alaska Coastal Current (ACC) along the coastline from southeastern Alaska to the eastern Aleutian Islands. The current consists of coastal freshwater runoff mixed with marine waters from the Gulf of Alaska. Conductivity-Temperature-Depth (CTD) profiles have been used to identify seasonal and interannual changes in salinity and temperature by depth throughout water column. CTD measurements taken over the last 35 years in lower Resurrection Bay, a fjord immediately to the east and adjacent to Aialik Bay, have provided an extensive time-series that has profiled changes in the ACC immediately before flowing into Aialik Bay (*Royer 2005*, *Weingartner et al. 2005*). CTD profiles have shown that during the winter,

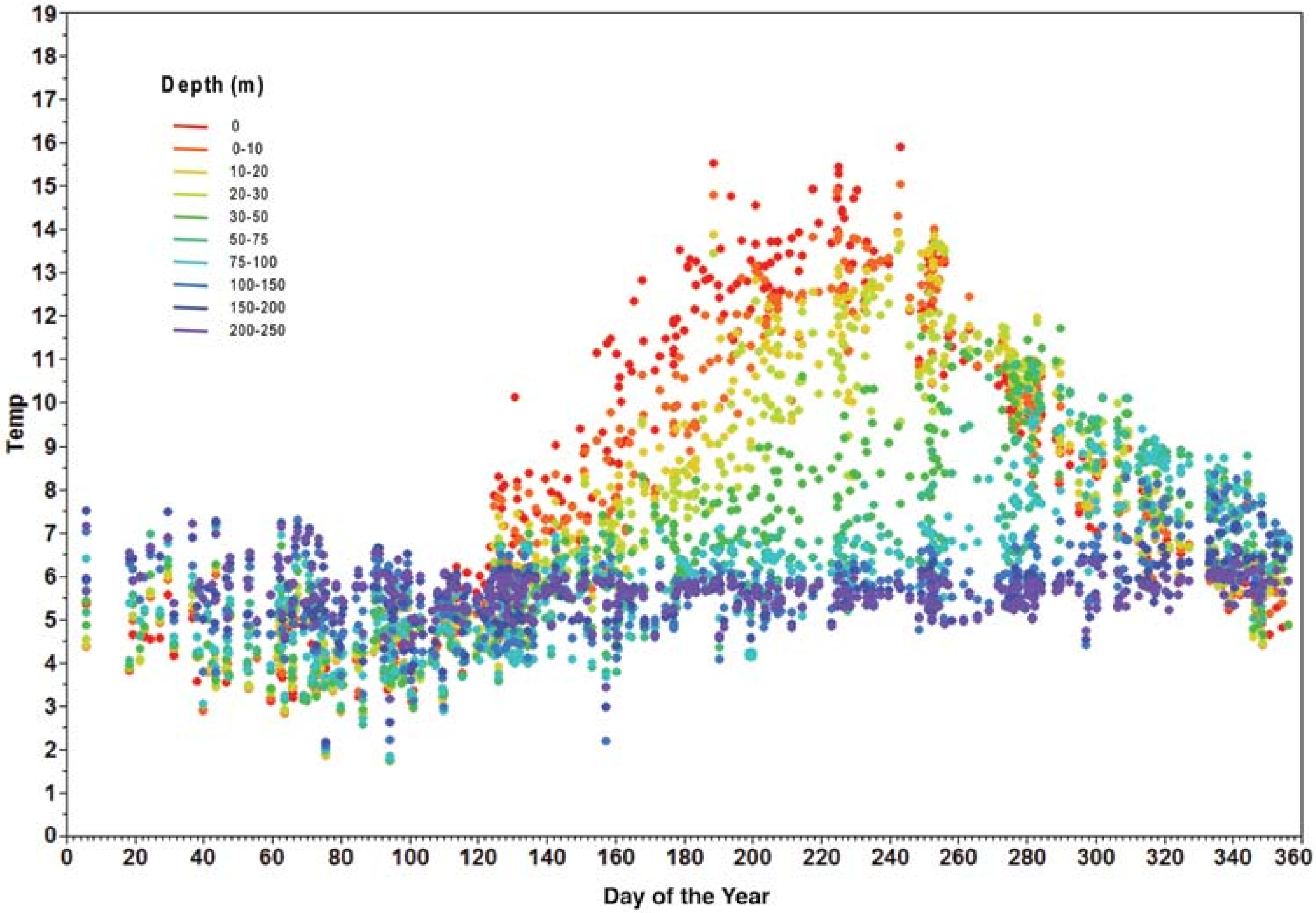


Figure 3. Seasonal changes in temperature by depth, recorded in lower Resurrection Bay at the GAK 1 monitoring station. Based on data from www.ims.uaf.edu/gak1

Figure 4. Location of CTD Sampling Stations in Aialik Bay.

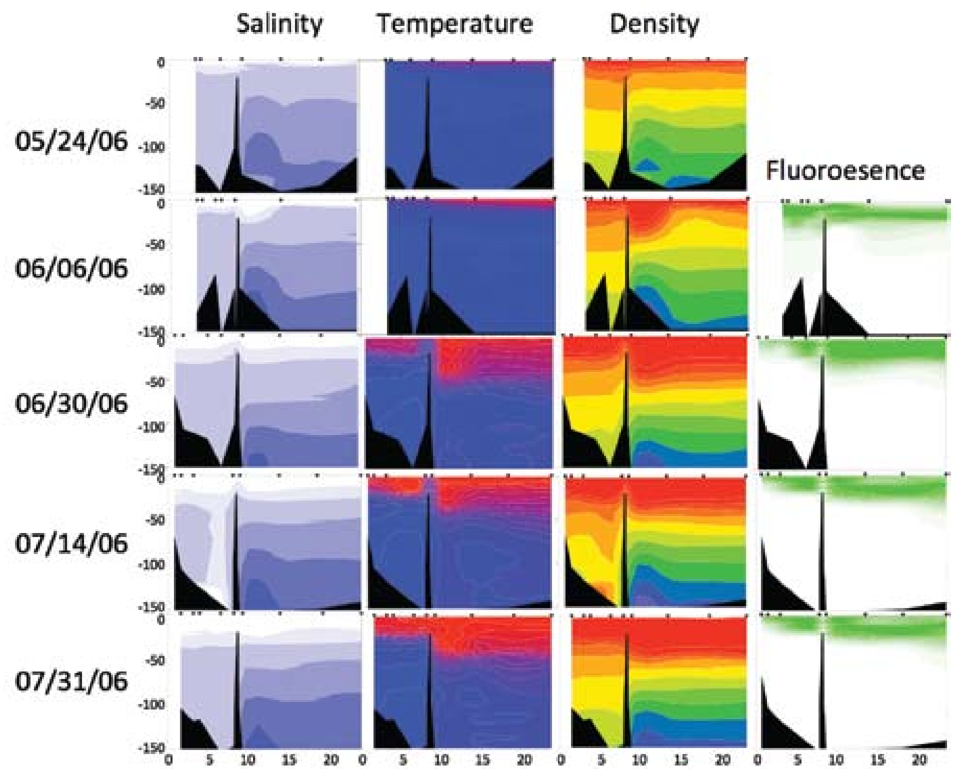
coastal waters are well mixed by storms and show relatively little stratification by depth. Surface waters, exposed to frigid air temperatures, exhibit the lowest temperatures (*Figure 3*). In spring and summer, surface waters freshen and warm from precipitation, melting of snow and glacial ice, and long periods of daylight. Waters stratify across abrupt salinity and temperature gradients, with surface layers of warmer fresher waters forming a productive estuarine surface layer.

Our study investigates seasonal changes in the surface 500 ft (150 m) of the water column of each basin within Aialik Bay. We are interested in better understanding the physical, chemical and biological features associated with tidewater glacial fjords that attracts wildlife such as harbor seals, Kittlitz's murrelets, and foraging black-legged kittiwakes by investigating the following questions: (1) what biological, physical, and chemical characteristics are driven by the presence of tidewater glaciers? (2) What specific attributes sustain species associated with tidewater glaciers? (3) How do those attributes change as glaciers continue to thin and retreat?

Methods

Physical and chemical properties of the water in the top 500 ft (150 m) are measured at eight to 12 stations that extend along the longitudinal axis of Aialik Bay toward Aialik Glacier (*Figure 4*). In 2006, sampling was conducted every two weeks from May 30 - July 31. Sampling included measurements of water conductivity, temperature, chlorophyll-a fluorescence, and dissolved oxygen using a Seabird 19 plus Conductivity-Temperature-Depth (CTD) profiler outfitted with a SB 43 dissolved oxygen sensor and Wet-Labs FLNTURT-220 Flurometer/turbidity sensor. CTD, fluorescence (reflective of chlorophyll-a concentrations from phytoplankton), and dissolved oxygen measurements were averaged every 3.3 ft (1 m) for both downcasts and upcasts, and mathematically extrapolated to profile the sampling trackline.

Plankton were sampled at a subset of stations by dropping a pair of 10 in (26 cm) diameter 150 micron mesh CalVet plankton nets, equipped with mechanical flowmeters, to 300 feet (90 m). The nets were then pulled vertically through the water column using an electric pot puller. Plankton samples were preserved in 5% formalin and stained with Rose Bengal. In the lab, samples were identified and counted using split sampling counting methods (e.g., *Coyle and Pinchuk 2005*).



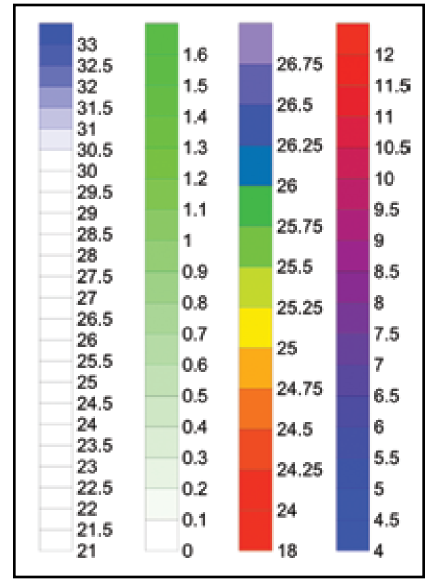


Figure 5. Seasonal changes in salinity, temperature, density and fluorescense by depth, measured from May 24 through July 31, 2006.

Results and Discussion

CTD profiles of Aialik Bay are shown in Figure 5. Below 66 ft (20 m), the bodies of water north and south of the Colman Bay sill differed. The moraine near Coleman Bay, shown in Figure 5 by the black vertical relief reaching nearly to the surface, dramatically impeded the flow of dense, saline, marine waters into the upper bay. The water column north of the sill was distinctly colder, fresher and more uniform than the water column south of the sill, which closely reflected the summer stratification of the Alaska Coastal Current. Surface waters progressively freshened during the summer. South of the sill, surface waters reflected contributions of glacial melt, snowmelt and precipitation from sources east of Aialik Bay; within Aialik Bay, glacial melt, melting ice, and watershed runoff provided additional contributions. Although we saw a progression of increased stratification on both sides of the Colman Bay sill, warmer, fresher waters penetrated to greater depths south of the sill. North of the sill, the warm layer persisted only to about 66 ft (20 m), roughly the depth of water crossing the sill. The shallow moraine near Colman Bay clearly impeded all but surface circulation. During our sampling period, primary productivity, measured by chlorophyll-a fluorescence, was similar on both sides of the moraine and was largely confined to the surface 66-100 ft (20-30 m). Sampling did not include the periods of peak spring or fall plankton blooms, but results indicate that primary productivity persists throughout the summer in both upper and lower Aialik Bay.

During summer months, plankton may be seen swimming in the surface waters. Some species live only a few months, while others live multiple years. Many pass through multiple life stages that provide food for different organisms in the food web. Plankton communities comprise complex food webs, similar to food web structures in terrestrial environments. Like plants, phytoplankton derive their energy from the sun. Zooplankton include grazers (those that eat phytoplankton), carnivores (those that consume grazers and other carnivores), and omnivores (those that eat phytoplankton, grazers, and carnivores). Plankton may be predators and scavengers. As with most marine communities of the North Pacific, zooplankton in Aialik Bay were dominated by several species of copepods —small (0.04-0.08 in/1-2 mm) tear-shaped crustacean with large antennae. Copepods include the primary grazers that transfer energy from phytoplankton to fish, whales, seabirds, and invertebrates, but they also include carnivore and omnivore predators and scavengers.

Vertical plankton tows conducted in Aialik Bay identified differences in the types and distribution of zooplankton within the fjord (*Figures 6 and 7*). Although the tows we conducted were not able to capture all species present, we identified 45 species and taxa groups. Based on numbers counted, two species of copepods, *Pseudocalanus* and *Oithona*, dominated our samples by abundance both north and south of the sill (*Figure 6*). North of the sill, however, the copepods *Oncaea* and *Metridia* were more abundant than they were further south.

The marine environment near tidewater glaciers is challenging for marine organisms. Turbidity from glacial silt reduces penetration of light into the water. The discharge of fresh water causes strong density gradients that, if crossed, are stressful. Habitats near glaciers, however, are more productive than might be expected. Glacial silt has its benefits. Glacial silt may release nutrients and microelements such as iron that help sustain primary productivity. Turbidity and darkness may protect organisms from predators. Rather than migrating to deeper waters during the day to avoid predators, as most plankton do in other locations, zooplankton and shrimp near glaciers tend to remain in mid-waters where they may be better able to forage (*Carpenter 1983*).

Glaciers, however, create serious challenges. Most zooplankton cannot quickly adapt to rapid changes in salinity.

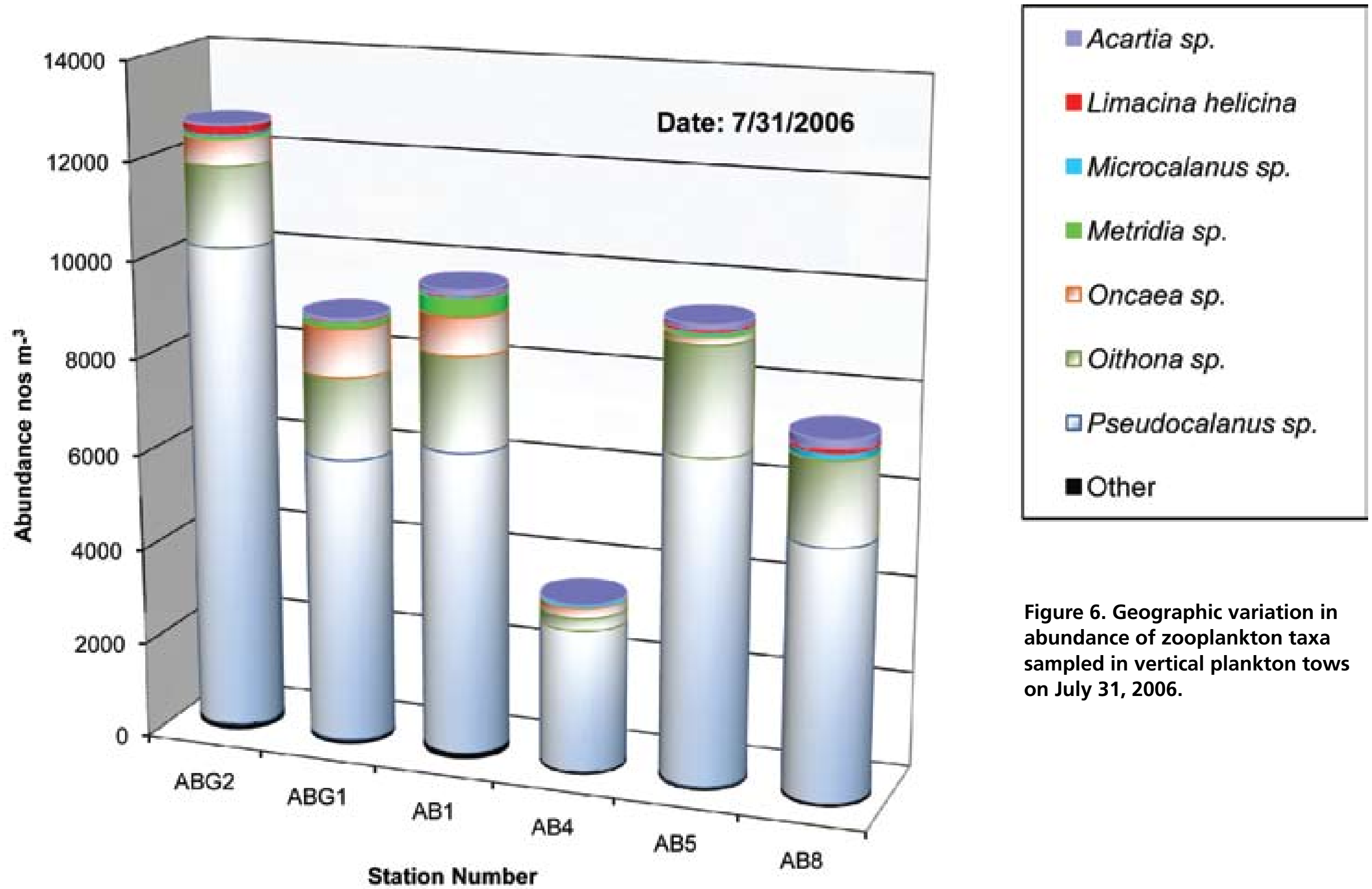


Figure 6. Geographic variation in abundance of zooplankton taxa sampled in vertical plankton tows on July 31, 2006.

Experiments have shown that when exposed to salinities below 9 PSU, copepods die within 15 minutes (*Zajaczkowski and Legezynska 2001*). Practical Salinity Units (PSU) are a measure of salinity based on electrical conductivity. A PSU of about 35 is typical for full-strength seawater. Near the face of the glacier, large quantities of fresh water, released by glacial melt, are ejected in strong outwash currents. Near the Kongsbreen tidal glacier in Svalbard, Zajaczkowski and Legezynska (*2001*) estimated that 15% of the fjords plankton biomass died as a result of osmotic shock from the glacial outwash. With plankton being continuously replenished by circulation of the Alaska Coastal Current, osmotic shock associated with outflow from Aialik Glacier would concentrate dead and impaired plankton in the upper basin near the glacier, providing food for organisms throughout the water column and sea floor. This situation may partially explain why unique assemblages of organisms associate with tidewater glaciers. However, as glaciers recede, the delicate balance of turbidity, chemical, and physical attributes will shift and alter these habitats.

This study will continue to explore seasonal and interannual variability in marine attributes associated with Aialik Glacier. Although little can be done to influence glacial activity, knowledge of how glaciers shape local marine communities will provide insight into ecological changes that may occur with glacial recession. With that knowledge, managers can make informed decisions

Figure 7. Diversity of plankton sampled in Aialik Bay. Sample includes multiple species and lifestages of copepods, shrimp-like euphausiids, spiral-shaped pteropod mollusks, and the bell-shaped hydrozoan jellyfish.

regarding the need and effectiveness of potential mitigation measures for conserving marine communities impacted by climate change.

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REFERENCES

Armstrong, A.K., E.M MacKevett., Jr., and N.J. Silberling. Carpenter, T.C. 1983.
Pandalid shrimps in a tidewater-glacier fjord, Aialik Bay, Alaska. MSc. Thesis. Institute of Marine Science. University of Alaska, Fairbanks.

Coyle K.O., and A.I. Pinchuk. 2005.
Seasonal cross-shelf distribution of major zooplankton taxa on the northern Gulf of Alaska shelf relative to water mass properties, species depth preferences and vertical migration behavior. Deep-Sea Research II-Topical Studies in Oceanography 52 (1-2):217-245.

Post, A. 1980.
Preliminary bathymetry of Aialik Bay and neoglacial changes of Aialik and Pedersen glaciers, Alaska. USGS Open File Report 80-423.

Royer, T.C. 2005.
Hydrographic responses at a coastal site in the northern Gulf of Alaska to seasonal and interannual forcing. Deep-Sea Research II-Topical Studies in Oceanography 52 (1-2):267-288.

Weingartner, T.J., S.L. Danielson, and T.C. Royer. 2005.
Freshwater variability and predictability in the Alaska Coastal Current. Deep-Sea Research Part II-Topical Studies in Oceanography 52 (1-2):169-191

Zajaczkowski, M.J., and J. Legezynska. 2001.
Estimation of zooplankton mortality caused by an Arctic glacier outflow. Oceanologia 43:341-351.