Alaska Park Science

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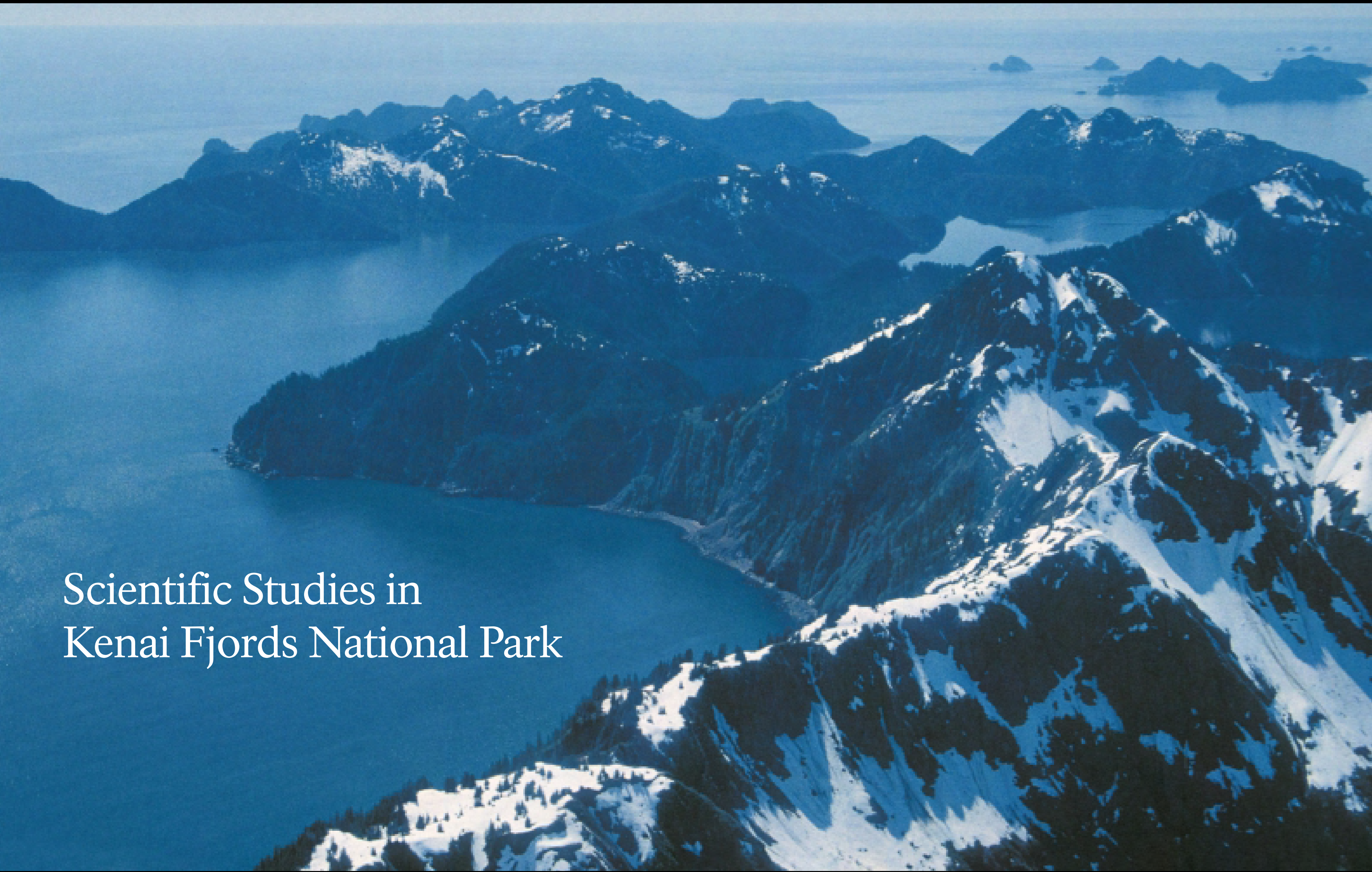

Scientific Studies in
Kenai Fjords National Park

Volume 3, Issue 1

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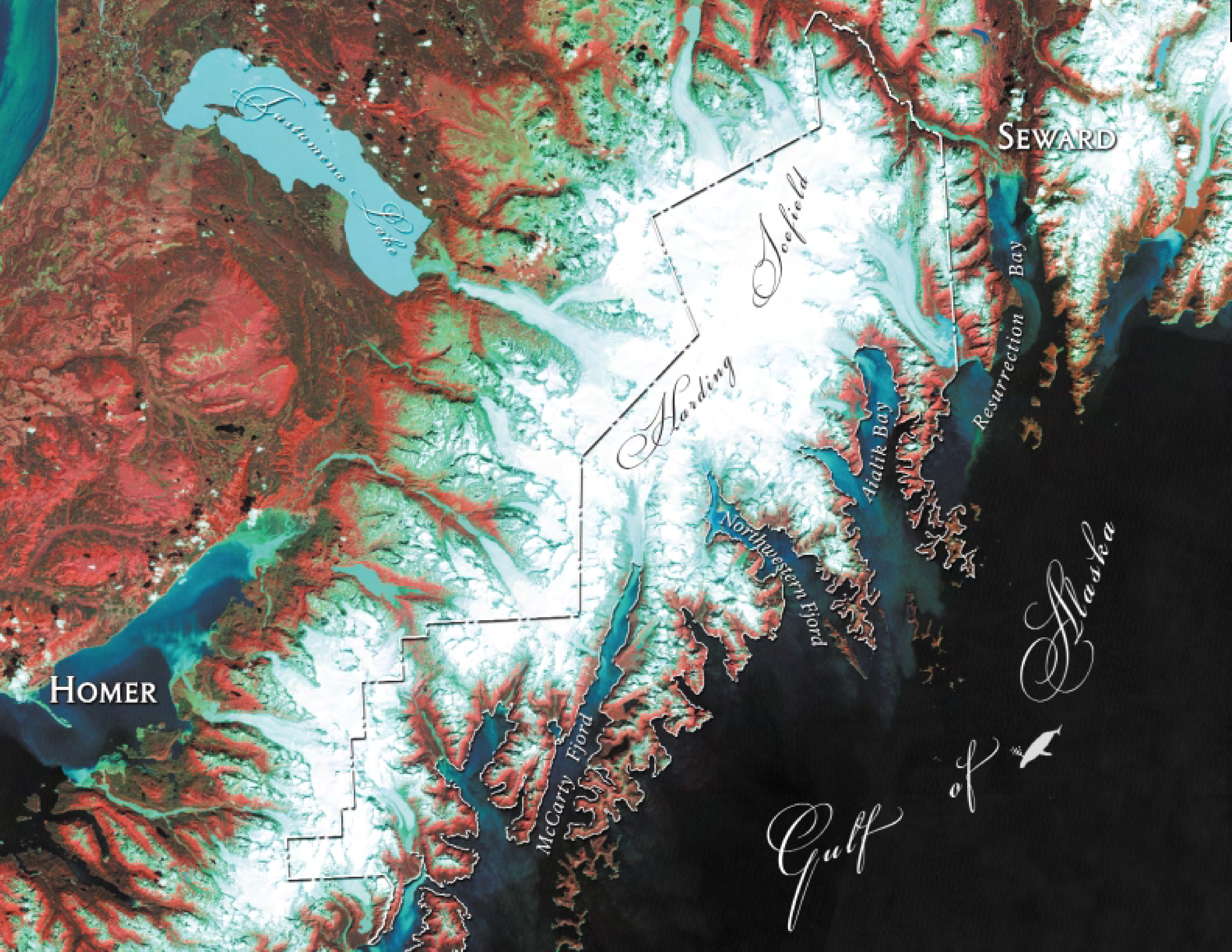

Tustumena Lake
Harding Icefield
Seward
Homer
Resurrection Bay
Aialik Bay
Northwestern Fjord
McCarty Fjord
Gulf of Alaska

Ecological Overview of Kenai Fjords National Park


Photograph ©Page Spencer

Figure 2. Aerial view of the drowned cirques of the Harris Peninsula.

(Left) Figure 1. Landsat TM image of Kenai Fjords region. August 8 and July 26, 2000.

Composited and enhanced by Michael Fleming, USGS. Design by Dave Allen, USFS.

By Page Spencer and Gail V. Irvine

The major drivers of Kenai Fjords ecosystems are tectonics and climate. In this overview, we describe how these forces have contributed to the shaping of the lands and ecosystems of Kenai Fjords.

Physically, the park is comprised of several distinct components, set within a broader ecophysical framework that includes the Kenai Peninsula and coastal marine waters and islands. Squeezed between the Gulf of Alaska and the Kenai Mountains, the coastal zone of the park is a narrow band of exposed headlands and deep fjords. The Harding Icefield caps the Kenai Mountains above the fjords with ice estimated to be 3,000 feet (1,000 m) thick *(Figure 1)*. Although not included in the National Park Service jurisdiction, the park is ecologically linked to the offshore marine ecosystem, and the embedded offshore islands, most of which are part of the Alaska Maritime National Wildlife Refuge, managed by the U.S. Fish and Wildlife Service.

Plate Tectonics

Kenai Fjords National Park rides the exposed edge of the North American plate where the Pacific plate is "diving" beneath the North American plate. As crustal plates have slowly moved northward, they have brought parcels of land (terranes) that were accreted onto the margin of the North American plate in a series of deformed arcuate ridges and basins. These features form the present day Kenai and Chugach Mountains and the Cook Inlet basin. Upper Jurassic and Cretaceous-aged rocks stretch from Kenai Fjords near Gore Point through the Chugach Mountains as far east as Glacier Bay *(Plafker et al. 1994)*.

The park's position on the junction of two crustal plates makes it prone to earthquakes of moderate frequency and intensity, with resulting ocean floor landslides and terrestrial uplift and subsidence. The beautiful circular bays of the Aialik, Harris, and McCarty Peninsulas are drowned cirques of the Chugach Mountains, which were partially submerged by tectonic subsidence during the Holocene *(Hamilton and Nelson 1989) (Figure 2)*. A dozen earthquakes of magnitude 6.0 or greater have occurred in the region during the past century *(Haeusser and Plafker 1995)*. The last great earthquake in southcentral Alaska, before 1964, occurred approximately 800 years ago *(Mann and Crowell 1996)*.

The epicenter of the 1964 Great Alaska Earthquake was 95 miles (150 km) northeast of the town of Seward, and 100-150 miles (150-250 km) from the coast of Kenai Fjords (see article by J. Freymueller, this issue). Land deformation following the earthquake was distributed along a "hinge" line of zero vertical motion that runs offshore of Kenai Fjords. Subsidence occurred to the northwest and uplift to the southeast of this line. Additional coastal erosion was caused by underwater landslides in the fine-grained silts and clays deposited by glacial rivers at the head of Resurrection Bay. Similar landslides (and tsunamis) may have occurred in Beauty Bay and North Arm of the McCarty Fjord at the western

Warming and cooling cycles have resulted in multiple glacial advances and retreats. Unlike many glacial terrains where cooling trends reduce summer melting, bringing on glacial advances, the Kenai Fjords glaciers move forward when warmer weather brings moisture-laden storms to the coast. Air is rapidly forced over the abrupt mountains and drops copious snowfall onto the Harding Icefield.

Photograph ©Page Spencer

Figure 3. "Ghost forest": Sitka spruce killed by saltwater intrusion onto land in Beauty Bay that subsided in the 1964 earthquake.

end of the park. However, most of the fjords have very steep bedrock walls or tidewater glaciers at their heads and lack sediment buildups. Saltwater intrusion and tidal flooding following subsidence have converted freshwater wetlands and spruce forest bands throughout the fjords to tidal marshes and "ghost forests" *(Figure 3)*. Much of Prince William Sound was located on the southeast of the hinge line and experienced uplift, with Montague Island experiencing an extreme elevation rise of 38 feet (12 m) *(Plafker 1969)*.

Climate and Glaciers

In addition to the important influence of plate tectonics, climate has been a recurrent, powerful theme and driver of many changes in Kenai Fjords and its environs. Most obvious, perhaps, is the effect of climate on glaciation. Basic alteration of the weather leads to changes in temperature and precipitation, which affect snow pack formation and glacial movements. It also affects the freshwater contribution into the coastal marine system, which coupled with wind, are primary forcers of the dynamics of the Alaska Coastal Current that flows along the coast.

Pleistocene and Holocene glaciations have shaped the land and ecological processes of the coastline. Warming and cooling cycles have resulted in multiple glacial advances and retreats. Unlike many glacial terrains where cooling trends reduce summer melting, bringing on glacial advances, the Kenai Fjords glaciers move forward when warmer weather brings moisture-laden storms to the coast. Air is rapidly forced over the abrupt mountains and drops copious snowfall onto the Harding Icefield.

There have been at least four major glacial advances in southcentral Alaska during the late Pleistocene and early Holocene eras (25,000 to 9,000 years ago) *(Reger and Pinney 1996)*. These glaciations swept 50-100 miles (80-160 km) beyond the current coastline to the edge of the continental shelf *(Molnia 1986)*. Ice that is more than a mile (1.6km) thick completely covered the Kenai Mountains. Moving ice over a mile deep exerts powerful forces on the terrain beneath it. The ice has carved off all soft and loose material, leaving steep, polished bedrock walls and deep submarine valleys all along the Kenai coast.

More recent glaciations, although impressive in their impacts on the landscape, are mere whimpers in the scheme of glacial cycles. The glaciers reached their last maximum late in the nineteenth century and are currently undergoing a fairly dramatic retreat *(Wiles and Calkin 1994)*. Nearly 40 outlet glaciers flow off the Harding Icefield, seven of which terminate as tidewater glaciers in Aialik, Northwestern, and McCarty Fjords. Approximately 100 years ago, these fjords were filled with glaciers that rested on terminal moraines miles seaward from their current termini (see article by Valentine et al., this issue). McCarty Glacier has retreated 14.5 miles (23 km), and Northwestern and its associated glaciers have retreated more than 9 miles (15 km) since 1909 *(Rice 1987)*.

The Harding Icefield is the largest of four permanent icefields in the Kenai Mountains, covering approximately 700 square miles (1,800 km^2). This flat cap of largely stagnant ice blankets the mountains above 1,650 feet (500 m) *(Wiles 1992)*. Scattered nunataks *(Figure 4)* rise above the icefield to 6,500 feet (2,000 m) on Truuli Peak, the highest point on the Kenai Peninsula. The icefield receives three to four times the precipitation that falls at sea level. Rice (1987) cored the Harding Icefield above Exit Glacier and measured nearly 20 feet (6.3 m) of accumulated snow, equivalent to 11.3 feet (3.5 m) of water for snow-year 1984-85. As the outflow glaciers of the Harding Icefield rapidly retreat, the overall area of the icefield also reduces. However, the icefield seems to be accumulating ice and thickening in its upper reaches.

Climate

Current icefield conditions reflect modern climate. At present, Kenai Fjords has a typical maritime climate, with cool, rainy summers and snowy, storm-driven winters. The occasional calm sunny day is a treat to be savored. Steep mountains rising from sea level to more than 5,000 feet (1,530 m) force moisture-laden storms to rise, where cooling temperatures and reduced moisture-holding capacity cause the clouds to drop massive amounts of snow onto the Harding Icefield.

Lower elevations are the recipients of heavy rains and misty days. Ferocious storms rake the outer coasts, especially the headland cliffs and outer fjords exposed to prevailing southeast storms. North Pacific atmospheric low pressure systems curl counterclockwise right into the Kenai Fjords coast. Rainfall is heaviest in Aialik Bay, ranging from 45-80 inches (100-200 cm) during the summer months, decreasing by 50% along the coast to McCarty Fjord at the west end of the park *(NPS 1999)*. Aialik Bay frequently receives three to four inches (7.5-10 cm) of rainfall in one day, and on August 20, 1993 received a memorable 10.55 inches (27 cm).

Rainfall and glacial melt feed freshwater streams, which on the coast tend to be short and very steep. Waterfalls abound, including an 800-foot (250 m) waterfall above the North Arm of Nuka Bay. Recent deglaciations have opened up new streams and lakes, which are being colonized by salmon. The most recent example of this is Delectable Lake on the east side of McCarty Fjord, which became ice-free within the past 40 years. Although the stream is steep, fast, and very rocky, sockeye, coho, and pink salmon have ascended it to spawn in the lake *(York and Milner 1999)*. Glacial streams, formed of meltwater from grounded and hanging glaciers, also tend to be short, but have a lower gradient than most of the clearwater streams. Sediment loads tend to be higher at the upper ends of fjords, where glacial waters are slow to mix with main Gulf waters *(Figure 1)*. Glaciers such as Bear, Dinglestadt, and Pederson have silty lakes at their terminal faces.

Freshwater discharges into the coastal

Figure 4. Bedrock nunataks on the skyline are surrounded by the Harding Icefield.

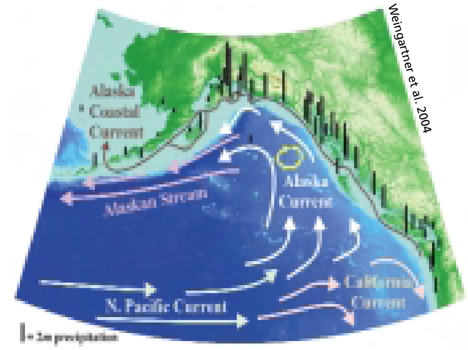


Figure 5. Regional circulation in the Gulf of Alaska with black bars indicating the mean annual precipitation. The Alaska Coastal Current is the dominant coastal current along the Kenai Fjords coast.

Figure 6. Lush intertidal communities composed of marine algae and invertebrates on a rocky island in Kenai Fjords National Park. Note the pattern of vertical zonation expressed as bands of species.

Photograph ©Page Spencer

Figure 7. Sea lions haul out on sloping rocks below a dense (and odiferous) kittiwake colony in Resurrection Bay.

Photograph ©Page Spencer

Figure 8. Vegetation patterns from beach to bedrock, Bulldog Cove. Several lagoons have been formed as beaches are built in front of subsiding valleys. Sitka spruce forests grow around the lower slopes, rapidly giving way to alder, a narrow band of meadow and tundra, and bedrock, snow and ice.

marine waters, along with wind, drive the dynamics of the Alaska Coastal Current *(Weingartner et al. 2004) (Figure 4)*. Although this strong current sweeps along the outer Kenai coast, its range is from British Columbia to the Bering Sea. Consequently, the Alaska Coastal Current functions as both a marine highway for migratory species and a conveyor belt passively transporting plankton, pollutants, and debris along its path. This current binds the offshore oceanic realm to the nearshore, influencing local productivity and climate, and in turn being profoundly affected by broader climate phenomena.

Climate and ocean dynamics in the North Pacific are linked in ways we are just beginning to discern. Variation in climate and biological productivity may occur on many time scales: daily, seasonal, annual, over a few years (e.g., El Niño), decadal (the Pacific Decadal Oscillation), centennial, or millennial *(e.g., Mann et al. 1998)*. The wintertime location and intensity of the Aleutian Low pressure system in the North Pacific appears to be a primary driver of physical systems. Decadal shifts in these conditions are also translated biologically: in the magnitude of salmon runs, abundances of groundfish, shrimp, zooplankton, and fish larvae *(Brodeur et al. 1996, Mantua et al. 1997, Anderson and Piatt 1999, Doyle et al. 2002)*.

Biological Systems

The nearshore marine environment of Kenai Fjords is an area of high productivity, which translates to rich marine ecosystems. In the pelagic portion of the nearshore, plant and animal plankton fuel the food webs of higher consumers, such as fish, seabirds, and marine mammals. Some of this marine productivity is carried into watersheds by salmon, fertilizing terrestrial and freshwater systems with marine nutrients. Attached to the benthos, or bottom habitats, in the nearshore are dense communities of marine invertebrates and plants *(Figure 6)*. These include the more obvious mussels, barnacles, starfish, sea urchins, popweed *(Fucus)*, kelps *(Laminaria and Alaria)*, and hosts of other species.

The nearshore pelagic realm supports many species of fish, including rockfishes, halibut, lingcod, pollock, and char. All five species of Pacific salmon migrate through offshore waters and spawn in Kenai Fjords streams. Forage fish, such as capelin and herring, and several species of shrimp abound. Commercial fishing for salmon and halibut occurs in the fjords.

The Alaska Coastal Current provides a migratory path for humpback, grey, minke, and fin whales in spring and fall. A few humpbacks linger and feed on planktonic crustaceans and small schooling fishes in such places as Resurrection Bay, Harris Bay, and McCarty Pass near Nuka Bay *(Rice 1989)*. A pod of killer whales frequents outer Resurrection Bay. Dall's porpoises are frequently sighted at the mouths of the fjords, usually riding the bow wave of vessels. Harbor seals congregate at the upper ends of Aialik, Northwestern, and McCarty Fjords for pupping and molting on ice calved from tidewater glaciers. The largest sea lion rookeries are on exposed slanted rocks on the Pye and Chiswell Islands *(Figure 7)*. Although much of the pupping and breeding activities take place in the

Maritime Refuge, sea lions use Kenai Fjords rocks as haulouts in smaller numbers. Major feeding and congregation areas for sea otters are the submerged moraines in Aialik, Northwestern, and McCarty fjords, and the sheltered coves and lagoons of Nuka Bay.

The cliffs of the exposed headlands and outer islands are teeming with seabird rookeries. The Chiswell and Pye Islands are nesting grounds for thousands of pelagic seabirds, including tufted and horned puffins, black-legged kittiwakes, murres, pigeon guillemots, and three species of cormorants. Smaller rookeries are found throughout the fjords, especially on the outer headlands and rocky islands inside the fjords. Marbled murrelets nest under glacial rocks *(Rice and Spencer 1991)* and on moss-draped branches of old Sitka spruce along the coast. Their haunting calls before dawn herald their return from a night's fishing at sea. Black oystercatchers scratch shallow nests into gravel beaches just above the tidelines and protect the nests vigorously from beach walkers. Glaucous-winged gulls are aggressively colonizing recently deglaciated islands in the fjords. Bald eagles nest along the coast, averaging 50 active nests per year. And crows cruise the beaches and wind currents with raucous calls.

Vegetation communities of the fjordlands reflect the harsh environment and Holocene glacial and tectonic history. Gravel beaches grade upward to the salt-tolerant community of beach ryegrass, beach pea, and beach greens, with scattered flowering forbs, such as iris and Jacob's ladder. Protected lagoons, like the backs of James and Beauty Bay, provide ample area for rich beds of goose tongue, a favorite spring food for bears. Tufts of grasses and perennial forbs, some richly fertilized and aerated by nesting puffins, grow on exposed rocky cliffs.

Photograph ©Bud Rice

Figure 9. A large mountain goat perches on a granitic rock near the sea. Goats seek shelter from winter storms in the stunted spruce at timberline and feed on dried grasses, forbs, and shrubs on wind-swept ridges.

Alder stands and Sitka spruce forests begin immediately above the storm tide zone *(Figure 8)*. Alder is a rapid invader in disturbed zones, following avalanche tracks from the alpine down to tideline. Scattered grasses and forbs find a foothold under the shrubs. Alder provides nitrogen for recently deglaciated soils, enriching the environment for spruce invasion. Sitka spruce appears to move into de-glaciated terrain within 20 years of ice retreat *(Rice and Spencer 1990)*. Recently developed Sitka spruce stands have uniform-aged trees with a thin moss ground cover, scattered grasses, and shrubs such as salmonberry and *Menziesia*. Older stands, growing through the last glacial maximum, have spruce and hemlock of varying ages, thick moss covering the ground and tree limbs, and alder, salmonberry, and Devil's club in openings. A Sitka spruce cut down in Palisade Lagoon in 1990 was more than 700 years old and seven feet (2.15 m) in diameter. Spruce forest refugia perched high in valleys above the ice limits provide seed sources miles up-valley of the glacial terminus forests. Nunataks within the icefield are largely barren bedrock with prostrate tundra and lichen gardens found cupped in sheltered niches.

Terrestrial mammals have a scattered distribution along the coast. Many species had to survive the glacial era perched on the ice-free peninsulas and valley refugia. Others, such as bears, may have traveled over the Harding Icefield more recently. Both black and brown bears frequent the coast, feeding on tidal offerings, avalanche-borne carcasses, and spring greens until salmon start running each summer. Wolverines are frequently sighted at the heads of the fjords. River otters move along the coast, denning in the forests and fishing in the ocean and lagoons. Porcupines and red squirrels are moving up-fjord with the advancing spruce seedlings. Mountain goats use rocky cliffs along the coast *(Figure 9)*. They are often sighted with their young kids at the ocean's edge, and spend winter storms sheltered in spruce stands at timberline. Moose have made a recent appearance in Nuka Bay, where re-treating glaciers have opened a transit route through the valleys from Kachemak Bay.

Humans have lived along this coast for hundreds of years, moving in and out with the glacial movements and the associated resources *(Crowell and Mann 1998)*. Aboriginal sites have been identified in Northwestern Lagoon, Yalik Bay, Aialik Bay, and McArthur Pass. People have been involved in successive waves of resource extraction along the coast: sea otter harvesting, gold mining, commercial fishing, scattered logging, seal hunting (for bounty), and iceberg "mining" for sale to Japanese bars.

The creation of Kenai Fjords National Park in 1980 by the Alaska National Interest Lands Conservation Act provided the impetus for increased visitation to this wild and spectacular land. Currently, human visitation via day boat trips out of Seward is increasing rapidly. In 1989, two companies ran daily tours during the summer. Now three large companies with approximately 15 vessels make daily trips to Resurrection and Aialik Bays, and Northwestern Lagoon *(Figure 11)*. Additionally, many smaller charters run fishing trips to Resurrection and Aialik Bays. There has also been a rapid proliferation of kayakers who are taken to Aialik Bay or Northwestern Fjord in boats and dropped off for multi-day trips, or are flown from Homer to Nuka Bay. Four public use cabins were built by the NPS: two in Aialik Bay, one in McCarty Fjord, and one in the West Arm of Nuka Bay. These all receive extensive use, especially those in Aialik Bay. Impacts of beach campers on the nearshore meadows, oystercatchers, and black bears are being studied.

Other human activities and potential impacts are difficult to quantify. The 1989 *Exxon Valdez* oil spill and subsequent cleanup activities severely impacted the coast of Kenai Fjords *(Spencer 1990)*. Oil was still on beaches and driftwood in 1996 and documented at a residual oil-monitoring site in 1999 *(Irvine et al. 2002, 2004)*. Oil is likely buried deep in gravel beaches and quiet backwater areas. The chance of another spill of similar magnitude is a function of the trajectories of circumstance and declining North Slope oil production. Oil-laden tankers travel offshore from the Cook Inlet oil field and the Valdez oil terminal. Additionally, the Alaska Coastal Current brings all kinds of marine debris to the outer beaches: drums, plastic of every description, and commercial fishing nets and floats.

Photograph ©Page Spencer

Figure 10. A day boat loaded with eager passengers from Seward visits a sea lion haul out near Aialik Cape. Tour boats are required to maintain minimum distances from marine mammals.

Where Next...

And the really big unknown: global climate change. Warmer ocean currents may bring exotic species to our shores—already a green turtle gone astray was reported in Prince William Sound. Recent investigations using archeological midden materials suggest that climate has strong effects on the productivity patterns and strength of the Alaska Coastal Current *(Irvine et al. 2003)*. Will global warming lead to a strong decrease in the flow rate of the Alaska Coastal Current? How would that affect nearshore productivity? Other studies suggest that global warming is increasing snow precipitation and building the Harding Icefield *(Rice 1987, Wiles 1992)*. Will this lead to continued glacial retreat or advance? Whatever the future shifts in climate, they are sure to have profound effects on the dynamics of the interlocked landscapes and ecosystems in Kenai Fjords National Park.

REFERENCES

Anderson, P.J. and J.F Piatt. 1999. *Community reorganization in the Gulf of Alaska following ocean climate regime shift.* Marine Ecology Progress Series 189:117-123.

Brodeur, R.D., B. Frost, S.R. Hare, R.C. Francis, and W.J. Ingraham, Jr. 1996. *Interannual variations in zooplankton biomass in the Gulf of Alaska and covariations with California Current zooplankton biomass.* CalCOFI Rept. 37: 81-99.

Crowell, A.L. and D.H. Mann. 1998. *Archaeology and Coastal Dynamics of Kenai Fjords National Park, Alaska.* Research/Resources Management Report ARRCR/CRR-98/34. DOI-NPS. Anchorage, Alaska.

Doyle, M.J., K.L. Mier, M.S. Busby, and R.D. Brodeur. 2002. *Regional variation in springtime ichthyoplankton assemblages in the northeast Pacific Ocean.* Progress in Oceanography 53 (2-4): 247-281.

Hamilton, T.D. and S.W. Nelson. 1989. *Introduction, Guide to the Geology of the Resurrection Bay-Eastern Kenai Fjords Area.* Alaska Geological Society, Anchorage, Alaska. 1-4.

Haeusser, P.J. and G. Plafker. 1995. *Earthquakes in Alaska.* USGS Open file report 95-624. 1 map. (http://quake.wr.usgs.gov/prepare/alaska/).

Irvine, G.V., S.J. Carpenter, D.H. Mann, and J.M. Schaaf. 2003. *A 6,300-year old window into the past: Retrospective analysis of nearshore marine communities based on analysis of archeological material and isotopic analysis.* Draft Final Report, Project 03656, submitted to Exxon Valdez Oil Spill Trustee Council Restoration Program, Anchorage, Alaska.

Irvine, G.V., D.H. Mann, and J.W. Short. 2002. *Residual oiling of armored beaches and mussel beds in the Gulf of Alaska.* Final Report, Restoration Project 00459, submitted to the Exxon Valdez Oil Spill Trustee Council Restoration Program, Anchorage, Alaska.

Irvine, G.V., D.H. Mann, and J.W. Short. 2004. *Persistence of ten-year old Exxon Valdez oil on Gulf of Alaska beaches: the importance of boulder armoring.* Marine Pollution Bulletin. In press.

Mann, D.H. and A.L. Crowell. 1996. *A large earthquake occurring 700 to 800 years ago in Aialik Bay, southern coastal Alaska.* Canadian Journal of Earth Sciences 33: 117-126.

Mann, D., A.L. Crowell, T.D. Hamilton, and B.P. Finney. 1998. *Holocene geologic and climatic history around the Gulf of Alaska.* Arctic Anthropology 35(1): 112-131.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. *A Pacific interdecadal climate oscillation with impacts on salmon production.* Bulletin of the American Meteorological Society 78:1069-1079.

Molnia, B.F. 1986. *Glacial History of the Northeastern Gulf of Alaska – A Synthesis.* In Glaciation in Alaska, the Geologic Record, edited by T.D. Hamilton, K.M. Reed and R.M. Thorson. The Alaska Geological Society, Anchorage, Alaska. 219-235.

National Park Service. 1999. *Weather Observation Data Set 1990-1998, Aialik and Nuka Bays, Kenai Fjords National Park.* Digital files.

Plafker, G. 1969. *Tectonics of the March 27, 1964, Alaska earthquake.* U.S. Geological Survey Professional Paper 543-1.

Plafker, G., J.C. Moore, and G.R. Winkler. 1994. *Geology of the southern Alaska margin.* In The Geology of Alaska, edited by G. Plafker and H.C.Berg. The Geological Society of America. Boulder, CO. 153-204.

Reger, R.D. and D.S. Pinney. 1996. *Late Wisconsin Glaciation of the Cook Inlet Region with Emphasis on the Kenai Lowland and Implications for Early Peopling.* In Adventures through Time: Readings in the Anthropology of Cook Inlet, Alaska, edited by N.Y. Davis. and W.E. Davis. Cook Inlet Historical Society. Anchorage, Alaska. 13-35.

Rice, W.D. 1987. *Changes in the Harding Icefield, Kenai Peninsula, Alaska.* MS Professional Paper, University of Alaska, Fairbanks.

Rice, W.D. 1989. *Sensitive Wildlife Habitat.* NPS files. 1:250,000. 1 map.

Rice, W.D. and P. Spencer. 1990. *Tree cores of Sitka spruce along the temporal sequence of Northwestern Glacier.* Unpublished data collected in 1990.

Rice, W.D. and P. Spencer. 1991. *Discovery of Marbled Murrelet Nest.* Alaska Bird Conference, Anchorage, Alaska.

Spencer, P. 1990. *White Silk & Black Tar.* Bergamot Books, Minneapolis, Minnesota.

Weingartner, T.J., S.L. Danielson, and T.C. Royer. 2004. *Freshwater variability and predictability in the Alaska Coastal Current.* Deep Sea Research, Special Issue on the Northeast Pacific GLOBEC Program. In press.

Wiles, G.C. 1992. *Holocene glacial fluctuations in the southern Kenai Mountains, Alaska.* Ph.D. dissertation, University of New York at Buffalo.

Wiles, G.C. and P.E. Calkin. 1994. *Late Holocene, high resolution glacial chronologies and climate, Kenai Mountains, Alaska.* Geological Society of America Bulletin 106: 281-303.

York, G. and A. Milner. 1999. *Colonization and Community Development of Salmonids and Benthic Macroinvertebrates in a New Stream within Kenai Fjords National Park, Alaska.* Final Report to the NPS, Cooperative Agreement No. CA 9700-2-9021. ENRI, University of Alaska. Anchorage, Alaska.

Physical Science in Kenai Fjords

Harding Icefield's Clues to Climate Change

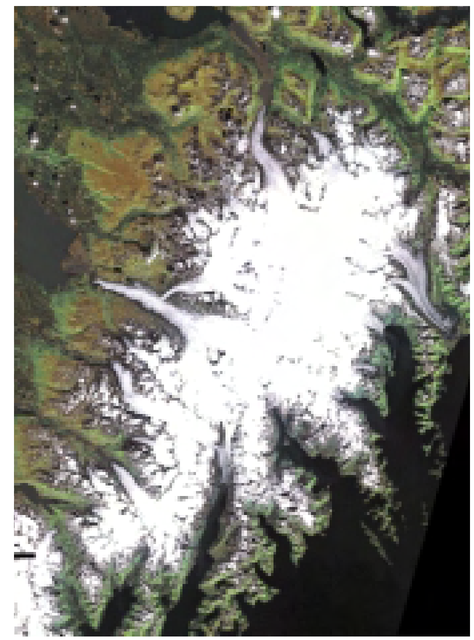
by Virginia Valentine, Keith Echelmeyer, Susan Campbell, Sandra Zirnheld

Visitors to Kenai Fjords National Park can watch icebergs calve from the towering ice face of Aialik Glacier, view Exit Glacier's diminishing profile from the trail, or take a scenic flight over the Harding Icefield where all the glaciers in the park originate. The park encompasses about half of Harding Icefield's 700 square miles of ice *(Figure 1)*, including numerous small glaciers and 20 large glaciers. Since glaciers are good indicators of what happens when temperature and precipitation change, glaciologists are interested in studying their behavior and the mechanisms that drive them. Since the early 1990s, scientists from the Geophysical Institute of the University of Alaska Fairbanks (UAF) have measured changes in the thickness and length of more than 100 glaciers in Alaska and western Canada, including 13 of the largest glaciers on Harding Icefield. Their results indicate that almost all of these glaciers are thinning and are also retreating. Their challenge is to figure out how these changes are related to what is commonly referred to as "global warming," what scientists prefer to call "climate change."

Anatomy of a Glacier

Glaciers are flowing rivers of ice that begin high in the mountains where more snow falls than melts (the accumulation zone). This accumulating snow is compressed into ice, which then flows downhill like a gigantic frozen river *(Figure 2)*. The ice flows to lower elevations, where it is warmer and melting occurs (the ablation zone). If changes occur in the temperature and/or the amount of snowfall, then the size and thickness of a glacier change.

Glaciers range in size from small cirque glaciers, to medium-sized valley glaciers, to huge Rhode Island-sized behemoths. Cirque



Landsat TM 7 satellite imagery of Harding Icefield, August 9, 2000.

(Left) Figure 1. An icefield is a great expanse of very thick glacier ice, with individual glaciers draining ice down adjacent valleys. Mountains buried beneath the ice sometimes emerge as isolated peaks, called nunataks, as seen here behind the plane.

Photograph ©Geophysical Institute

Crevasses on the lower McCarty Glacier. Animal tracks enter from the lower left corner, cross the crevasse field, and exit from the upper right corner. You can imagine how some prehistoric animals became entrapped in glaciers. The wolverine who made these tracks escaped such a fate—this time.

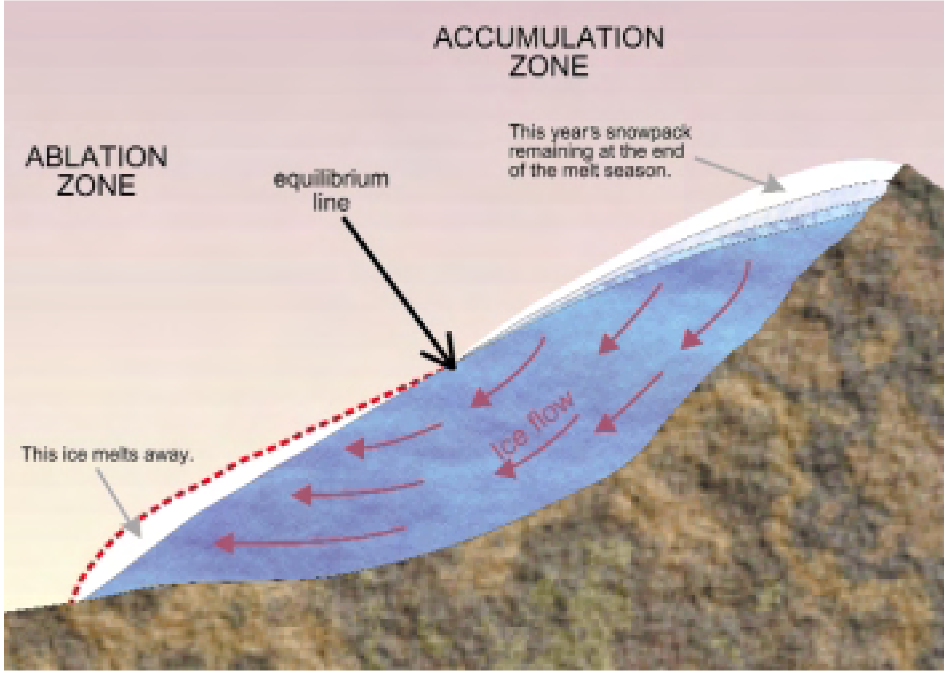


Figure 2. Anatomy of a Glacier. At the end of the melt season, there is still snow left high on the glacier (in the accumulation zone). The equilibrium line is the divide between the accumulation and melting (ablation) zones. As each year's snowpack is buried, the snow is compressed into ice, which begins to flow downhill. Ice that melts on the lower end of the glacier tends to be replaced by ice flowing from above.

glaciers fill bowl-shaped hollows and are typically a half mile wide and long. There are many cirque glaciers in Kenai Fjords National Park, but most of them are unnamed because they are so small. Valley glaciers are what most people picture when they think of glaciers. All of the glaciers that drain the Harding Icefield are valley glaciers. Examples of typical, medium-sized valley glaciers in the icefield are Skilak and McCarty. They are each about 15 miles (24 km) long and two miles (3 km) wide. On the far end of the spectrum are the largest glaciers in Alaska, Malaspina and Bering in Wrangell-St. Elias National Park and Preserve. These glaciers are up to 100 miles (160 km) long and 50 miles (80 km) wide.

Two basic categories of valley glaciers emanate from Harding Icefield: terrestrial and tidewater. Of Harding's 20 large glaciers, 13 are terrestrial glaciers, such as Exit and Little Dinglestadt *(Figure 3),* and are entirely on land. There are seven large tidewater glaciers, including Aialik *(Figure 3)* and McCarty. They start on land and flow to the ocean, but do not float; instead the terminus (the lowest end) rests on the sea floor. Bear Glacier was once a tidewater glacier, but its terminus has retreated onto land, making it a terrestrial glacier now.

Glacier Changes

Terrestrial and tidewater glaciers respond differently to climate change. Terrestrial glaciers become thinner if less snow falls or if temperatures rise, causing more melting. Evidence of such thinning are trimlines, which resemble bathtub rings, high on valley walls where a glacier once scraped the surrounding mountainsides. Visitors can see these trimlines on Tustumena and Skilak Glaciers on the western side of Harding Icefield *(Figure 4)*. Terrestrial glaciers become thicker if snowfall increases and/or temperatures decrease and prevent melting.

The thickening or thinning of a terrestrial glacier can happen relatively quickly—in a year or two. It takes more time for the length of a glacier to show a measurable change, and so terminus advance or retreat is not a sensitive indicator of recent climate change. Glaciers do not thin or thicken evenly over their whole length *(Figure 5a)*. Small changes tend to occur at the highest elevations (in the accumulation zone), while the surface can change by several feet per year near the terminus (in the ablation zone). Usually when glaciers are thinning drastically at their terminus, they are also retreating. For example, Exit Glacier retreated about one quarter of a mile from 1950-1994. In the same time period, the glacier thinned by 300 feet (90 m) near its terminus, but less than a foot at higher elevations. This distribution of thickness change led to an average glacier-wide rate of thinning of seven inches per year.

Tidewater glaciers have a mind of their own. In contrast to terrestrial glaciers, they advance slowly, maintaining a submarine shoal at their terminus. If the terminus moves back from the shoal, calving increases in the deeper water behind the shoal and the glacier retreats quickly. Northwestern Glacier is a good example of a retreating tidewater glacier in the park.

Measuring Glacier Changes

Even 100 years ago, people noticed that many glaciers around the world seemed to be shrinking. Scientists at UAF set out to determine whether this was true by building a laser altimetry system to measure thickness changes of glaciers throughout Alaska and western Canada *(Echelmeyer et al. 1996)*. This system is designed to fit in the back of a Piper PA-12, a two-passenger airplane nimble enough to navigate the steep, narrow terrain of small valley glaciers.

The altimetry system consists of a highly accurate Global Positioning System (GPS) receiver, a laser, and a gyroscope *(Figure 6)*. The GPS records the position of the plane every second as it flies down a glacier, the laser continually measures the distance between the plane and the glacier surface, and the gyroscope measures the direction in which the laser is pointing. Combining data from these instruments, elevation profiles of the surface of the glacier are created that are accurate to within a few inches.

These surface profiles are used to calculate long-term changes in glacier thickness by comparing them with U.S. Geological Survey (USGS) topographic maps made 50 years ago. Even after taking into account the inaccuracies of the old maps, the glaciolo-

Photograph ©Geophysical Institute

Photograph ©Geophysical Institute

Figure 3. There are two types of glaciers, those that terminate on land, and those that terminate in the water. The Little Dinglestadt Glacier (Left) is an example of a land-terminating or terrestrial glacier. Aialik Glacier (Right) is an example of a water-terminating or tidewater glacier. Tidewater glaciers do not float on the ocean surface, but rather rest on the sea floor.

Photograph ©Geophysical Institute

Figure 4: The arrow points to trimlines of the Tustumena Glacier, which indicate areas that were scraped by the glacier when it was much thicker than it is today. Trimlines are often evidence of the dramatic thinning and/or retreat of a glacier.

gists have found that most glaciers have thinned hundreds of feet in the last five decades (up to eight ft/yr). The researchers have also followed the same flight lines after ten years. By comparing data from these repeated flights they are able to obtain short-term measures of glacier change that are much more accurate. In this ten-year period, they have seen substantial increases in the rate of thinning, up to 15 feet/year (2.7 m/yr), on many glaciers in Alaska and western Canada *(Figure 5b) (Arendt et al. 2002)*.

Changes on the Harding Icefield

UAF researchers have flown altimetry profiles over 13 of the major glaciers in the Harding Icefield and have compared the profiles to USGS topographic maps *(Figure 7)*. From the 1950s to the early 1990s, they found that, on average, most glaciers flowing from the Harding Icefield were thinning *(Figure 5b) (Adalgeirsdottir et al. 1998)*. For example, Bear, Tustumena, and Northwestern Glaciers thinned about 2.5 feet/year (0.75 m/yr) in this long-term period. Northeastern Glacier was the big loser, with an average thinning of more than 7 feet/year (2.1 m/yr)! Two of the tidewater glaciers in the park did not thin: Aialik Glacier remained about the same, and McCarty Glacier actually thickened.

Data from the last ten years show that Harding Icefield glaciers continue to thin. Curiously, although these glaciers are still losing ice, they do not show the accelerated thinning rates measured elsewhere in Alaska and western Canada *(Figure 5b)*. Aialik Glacier is now thinning, while McCarty Glacier continues to thicken and advance. In the future, more of the tidewater glaciers in the park may become terrestrial like Bear Glacier.

Relevance to Sea Level Changes

Currently, global sea level is rising at a rate of 1.3 inches (3.25 cm) per decade *(Houghton et al. 2001)*. The largest component (~87%) of this current rise is due to the increasing temperature of the oceans, which causes the water to expand, filling the ocean basins to a higher level. Scientists estimate that the melting of glaciers around the world (excluding Greenland and Antarctica) makes the next largest contribution. In particular, glaciers in Alaska and western Canada account for ~9% of the measured sea level rise in the last 50 years. This amount is far out of proportion relative to the area these glaciers cover. Although Greenland ice is thinning *(Krabill et al. 2000)*, and although Greenland and Antarctica contain vast amounts of glacier ice, on a per-area basis these regions are not currently contributing to sea level rise as much as Alaska and western Canada.

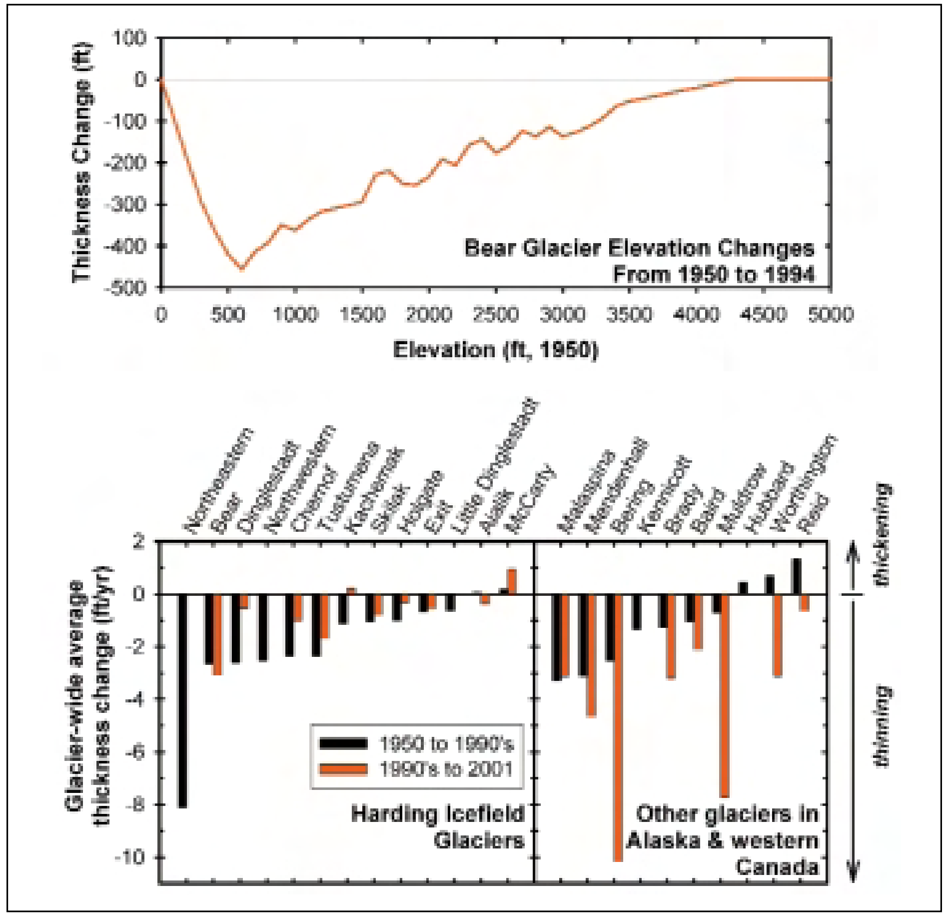


Figure 5a: (Top) Glacier Thickness Changes.
Ice thickness does not change uniformly over an entire glacier. Changes are small in the higher elevations, but often dramatic in the lower, warmer elevations where melting occurs. Bear Glacier exhibits the typical pattern of thickness change with elevation.

Figure 5b. (Bottom) Thickness changes (ft/yr) for the two time periods: 1950s-1990s and 1990s-2001. During the earlier time period, Harding Icefield glaciers thinned like glaciers elsewhere, but do not show the accelerated thinning during the recent period that is seen in other areas throughout Alaska and western Canada. Wrangell-St.Elias NP: Malaspina, Bering, Hubbard, and Kennicott glaciers. Glacier Bay NP: Brady and Reid glaciers. Denali NP: Muldrow Glacier. Tongass National Forest: Mendenhall Glacier. Valdez: Worthington Glacier. SE Alaska: Baird.

Conclusions

Most of the glaciers in Kenai Fjords National Park are losing ice and becoming thinner, the same as other glaciers in Alaska and western Canada. Scientists believe that the loss of ice is due to increased temperatures and/or decreased snowfall, and that this glacier melting is contributing to sea level rise. The questions surrounding climate change are complex. The research being done on arctic glaciers continues, as scientists try to understand what glaciers are telling us about climate change.

Visitors to Kenai Fjords National Park can look forward to viewing the grandeur of some of Alaska's most beautiful glaciers for decades to come, but, as the years go by, the view will be changing.

Acknowledgments

The authors wish to acknowledge Anthony Arendt for his helpful comments and contributions to the creation of the figures. Research conducted in Kenai Fjords National Park was funded by the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, and the National Science Foundation-Office of Polar Programs.

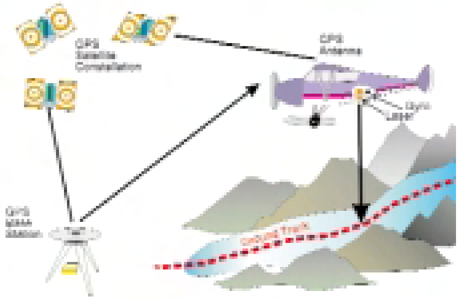


Figure 6. An airborne laser altimetry system allows Keith Echelmeyerís team to measure the elevation of the ice surface along a track down a glacier. These elevations can then be compared to map elevations dating from the 1950s, or to previously flown altimetry profiles, to determine the amount of thinning or thickening of a glacier during the intervening time period.

REFERENCES

Adalgeirsdottir, G., K. Echelmeyer, and W. Harrison. 1998. *Elevation and Volume Changes on the Harding Icefield, Alaska.* Journal of Glaciology, 44(148): 570-582.

Arendt, A., K. Echelmeyer, W. Harrison, C. Lingle, and V. Valentine. 2002. *Rapid Wastage of Alaska Glaciers and Their Contribution to Rising Sea Level.* Science, 297(5580): 382-386.

Echelmeyer, K., W.D. Harrison, C.F. Larsen, J. Sapiano, J. E. Mitchell, L. DeMallie, B. Rabus, G. Adalgeirsdottir, and L. Sombardier. 1996. *Airborne Surface Profiling of Glaciers: A Case Study in Alaska.* Journal of Glaciology, 42(142): 538-547.

Houghton, J., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, and D. Xiaosu (ed.). 2001. *Climate Change 2001: The Scientific Basis.*
Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK.

Krabill, W., W. Abdalati, E. Frederick, S. Manizade, C. Martin, J. Sonntag, R. Swift, R. Thomas, W. Wright, and J. Yungel. 2000. *Greenland Ice Sheet: High-Elevation Balance and Peripheral Thinning.* Science, 289(5478): 428-430.

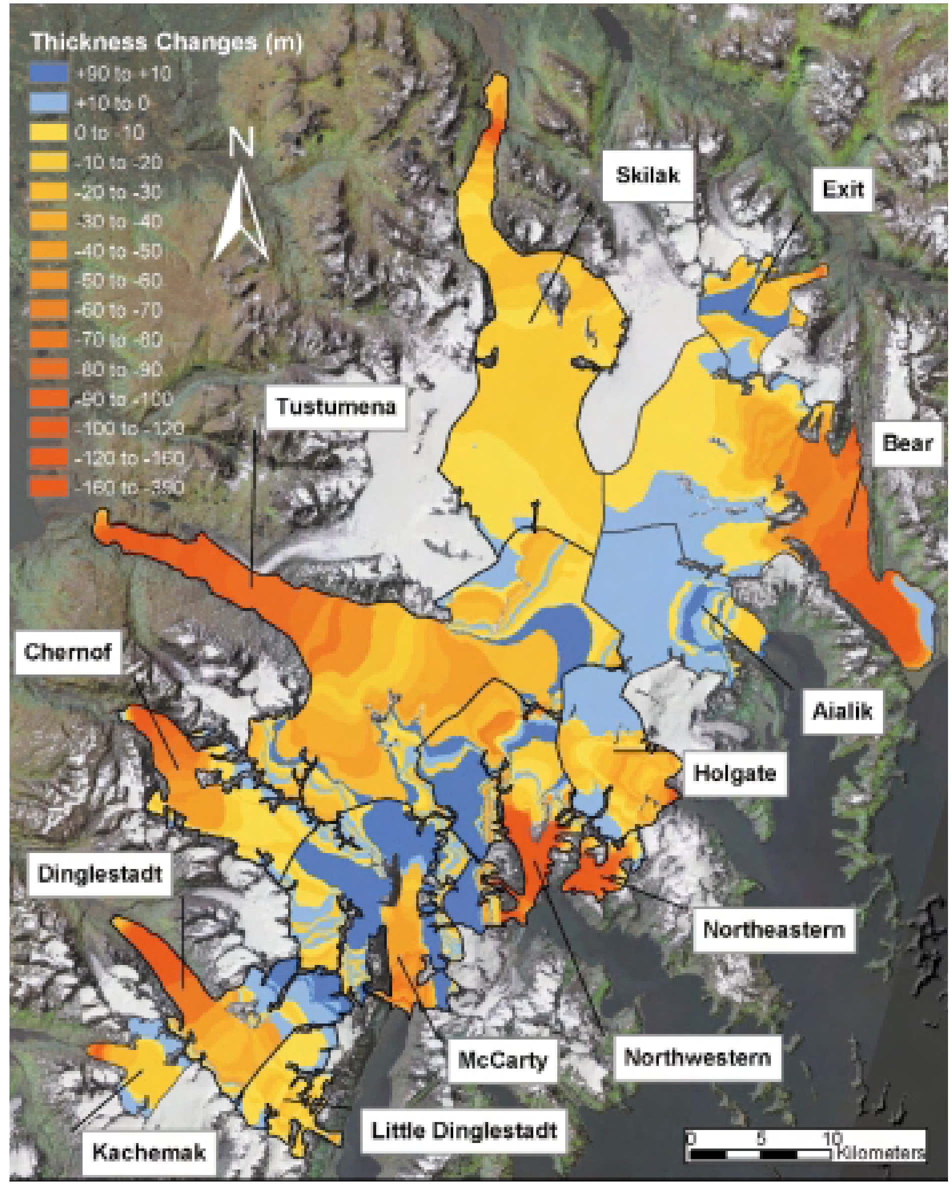


Figure 7. Harding Icefield glaciers monitored by researchers from the University of Alaska Fairbanks, Geophysical Institute. Glacier basins are outlined in black. Thickness changes from the 1950s to the 1990s are indicated by color, with blue indicating areas of thickening, yellow indicating areas of moderate thinning, and red indicating areas of dramatic thinning.

Photograph ©Sigrún Hreinsdóttir

Photo 1. Researcher placing the portable GPS recorder.

Lingering Mysteries of the 1964 Earthquake

By Dr. Jeffrey T. Freymueller

Early in the evening of March 27, 1964 (5:36 p.m. local time), the ground began to shake across all of southern Alaska. The 1964 Great Alaska Earthquake, magnitude 9.2, was the second largest earthquake ever recorded within the roughly 100 years of the instrumental record, topped only by the 1960 (magnitude 9.5) Chile earthquake. During the five minutes of the earthquake, about 500 miles (800 km) of the Pacific tectonic plate slipped as much as 70-100 feet (20-30 m) beneath North America. Buildings and oil tanks collapsed; roads, railroads, and bridges were destroyed; and the collapse of several segments of seaside bluffs destroyed numerous homes and businesses in Anchorage. In Seward, now the administrative home of Kenai Fjords National Park, the worst was soon to come. A deadly tsunami, or seismic sea wave, was triggered by the sudden uplift of the seafloor, and it destroyed the waterfront as it surged into Seward and other coastal communities. The tsunami also propagated across the Pacific Ocean, causing deaths in Hawaii and California. A total of 131 people died, 115 in Alaska.

Earthquakes are a sudden slippage of rocks past each other on a fault, or break in the earth. The 1964 earthquake occurred on a fault that separates the Pacific tectonic plate from the North American plate *(Figure 1)*. The Pacific plate moves north-northwest at a rate of about 2.2 inches (5.6 cm) per year relative to North America. At the southern coast of Alaska, the Pacific plate pushes beneath North America, thrusting down to the north at an angle of only a few degrees, before eventually diving down deep into the earth. Large earthquakes occur on this fault because the two sides of the shallow part of the fault are usually locked together by friction, which keeps them from slipping past each other. But the Pacific plate never stops moving, and eventually enough force builds up to break the frictional contact. When this happens, in seconds to minutes the Pacific plate slips deeper beneath North America.

Earthquakes, the Buildup of Stress, and Deformation of the Earth

Imagine pushing a refrigerator or other heavy object across a carpeted floor—at first it will be stuck in place, but if enough force is applied, the friction can be overcome, and the object will suddenly lurch forward before it stops again. If there is a stiff spring between you and the fridge, as you push forward, the spring compresses, storing elastic energy in it. Eventually the force of the spring added to your pushing will overcome friction, and the fridge will

One especially intriguing feature of the earthquake is that the amount of slip on the fault was highly variable. … Is this dramatic change reflected somehow in the present tectonic loading that is building up to the next earthquake?

slide forward. As the Pacific plate tries to push beneath North America, it compresses both itself and the North American plate, until the elastic energy stored in the crust by this compression is released in a sudden slippage on the fault.

Using ultra-precise Global Positioning System (GPS) surveying instruments *(Photos 1 and 2)*, we can measure the small motions of the earth's crust. The GPS receivers are small, easily portable, and require little power, all important factors for research in remote places like Aialik Bay. Portable GPS receivers are set up for a couple of days over a survey marker set into the ground, recording data from the GPS satellites. We use that data to determine the position of the survey marker, which is precise to several millimeters in three dimensions. An added benefit to this type of research is the low impact: researchers can obtain useful data without leaving a trace on the land (except for inconspicuous survey markers).

By repeating such surveys over a few years, we can measure the horizontal motion of the survey points, to a precision of about one-tenth of an inch (1-2 mm) per year. For example, the entire city of Seward is moving steadily to the north-northwest at a rate of 1.5 inches (35 mm) per year relative to the North American plate *(Figure 2)*. It will continue moving northward until the next big earthquake, when it will suddenly spring southward again as it did in 1964.

The fortieth anniversary of this incredible event is now upon us, so it is consigned to the distant past for most people. But several mysteries about the earthquake and its effects linger, and they are the subject of ongoing research. One especially intriguing feature of the earthquake is that the amount of slip on the fault was highly variable. Beneath Prince William Sound and the eastern Kenai Peninsula, the Pacific plate slipped an average of 60-100 feet (20-30 m) beneath North America. Beneath Kodiak Island, the Pacific plate slipped an average of 30-50 feet (10-15 m) beneath North America. But in between these two areas of high slip, the amount of slip was much lower, perhaps as little as 15 feet (5 m) or less. Why such a dramatic variation, and what does it mean for earthquake processes in general? Is this dramatic change reflected somehow in the present tectonic loading that is building up to the next earthquake?

Stuck or Not Stuck

It has been known for a long time that some subduction zones (places like southern Alaska where one plate thrusts beneath another) generate many, very large earthquakes, while others rarely generate any. One factor that affects the number and size of large earthquakes is the rate of plate motion. In general, a fast-moving plate will generate either more earthquakes or bigger ones as it subducts, compared to a slow-moving plate. This happens because over time the faster moving plate has to slip a greater distance. But the worldwide differences in rates of plate motion are not nearly large enough to explain the global variation in earthquake occurrence at subduction zones. There must also be variations in the amount of the plate interface that is stuck by friction.

The subduction zones that almost never have significant earthquakes seem to have a plate interface that slips slowly but steadily all the time, rather than being stuck most of the time and slipping only in earthquakes. These faults are somehow more slippery than usual, and they behave differently. The famous San Andreas Fault in California has a long section that shows this same kind of creep, and as far as we know never generates large earthquakes.

In regard to the low slip zone in the 1964 earthquake, questions remain. It could represent a "creeping section" that is unable to slip much in an earthquake because it constantly relieves stress by steady creep.

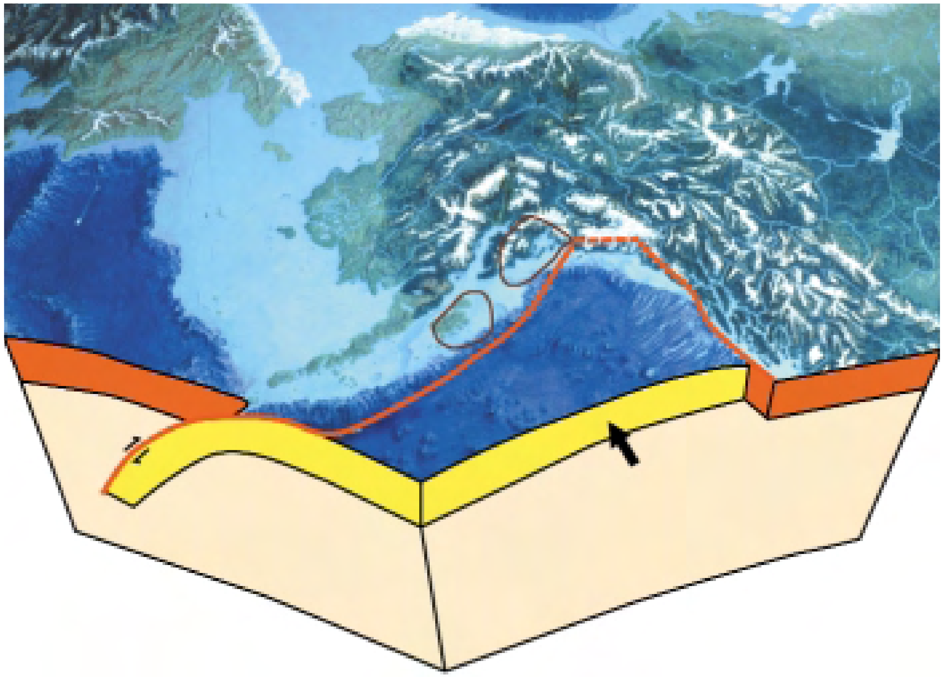


Figure 1. Cutaway view of the Pacific plate subducting, or thrusting beneath North America. The Pacific plate moves north-northwest at a rate of about 2.2 inches (about 5.6 cm) per year. The red lines mark the boundaries between the Pacific and North American plates. The two dark lines outline the regions of high slip in the 1964 Alaska earthquake.

Photograph ©Sigrún Hreinsdóttir

Photo 2. Researchers and equipment, which are small and easily portable.

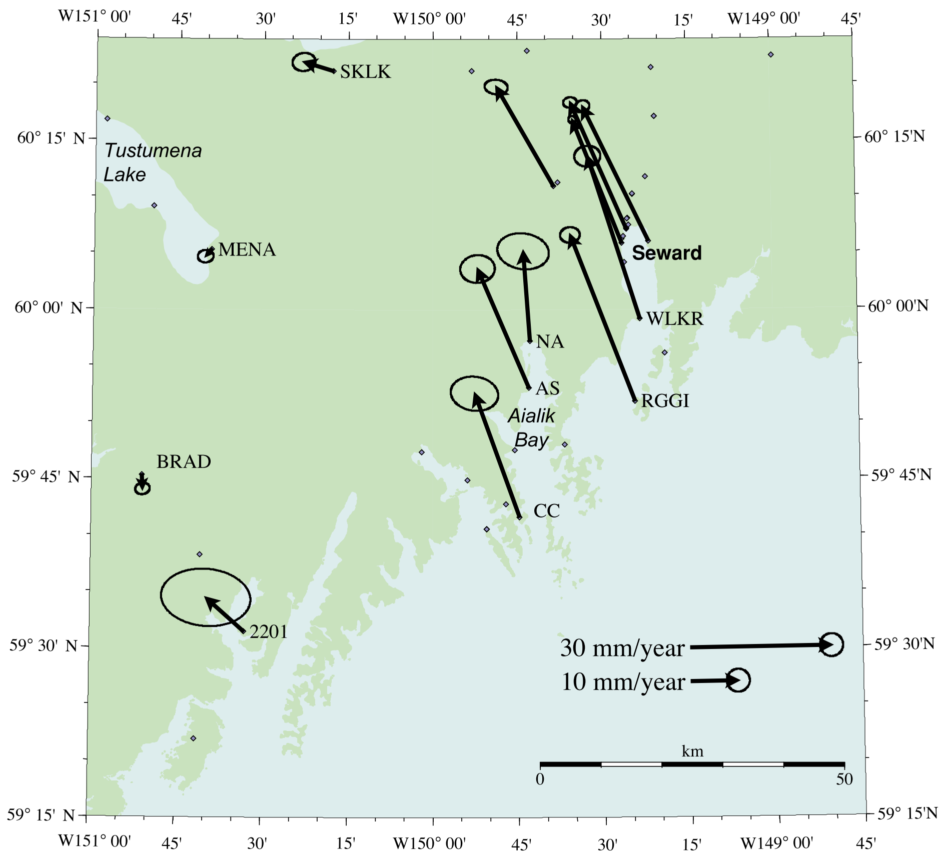


Figure 2. Velocities of sites in and around Kenai Fjords National Park, relative to North America. The northwestward motion results from the increasing compression of the North American plate. Comparing sites at similar distances from the coast reveals a substantial change across this region. For example, the site CC moves more slowly than RGGI, and the site 2201 more slowly than site AS or any of the sites in Seward.

Or, it may be no different from the regions to either side. In the latter case, the lack of slip in 1964 could be explained if there had been an earthquake in that section a century or two ago, relieving most of the stress there. The historical record in Alaska is short, so it is difficult to rule this out. Answering why there was a low slip zone is important not only for understanding how faults behave, but also for evaluating the earthquake hazards faced by cities like Homer, Seward, and Kodiak.

Fortunately, we can tell the difference between these two cases using motions derived from GPS data. In the first scenario, with the creeping fault, we expect to see little to no contraction in North America, because stress is neither building up nor compressing the western Kenai Peninsula. In the second case, we would expect to see significant contraction, the same as in Prince William Sound. The GPS data clearly point to the first explanation *(Figure 2)*. The contraction we would see from a locked fault is either much slower than we observe in Prince William Sound, or not there at all. This leads us to infer that most of or all of the plate interface beneath the western Kenai Peninsula is creeping steadily, and it will not slip much in future great earthquakes.

Although we are confident that the low slip zone is a "creeping section", the exact length and width of the zone is unknown. There may be patches within the zone that are locked. The eastern boundary is also unclear. We know from prior work that the edge of the large slip zone lies near Seward, probably a bit to the west. In short, this boundary lies right beneath Kenai Fjords National Park.

In 2001 we began making measurements at several sites along the Pacific coast of the Kenai Peninsula, including sites within the park. In June 2002, UAF graduate student Sigrún Hreinsdóttir and Lissy Hennig, a summer intern from the Technical University of Dresden, Germany, surveyed sites in Aialik Bay with the assistance of Park Rangers Janette Chiron and Brandon Hallock. Despite generally bad weather and a huge storm that blew one instrument partially into the ocean (fortunately it was repairable), they successfully repeated surveys done in 2000 by a National Ocean and Atmospheric Administration team that was making an updated bathymetric map of the region.

The contraction we would see from a locked fault is either much slower than we observe in Prince William Sound, or not there at all. This leads us to infer that most of or all of the plate interface beneath the western Kenai Peninsula is creeping steadily, and it will not slip much in future great earthquakes.

Most of our sites in the park have been surveyed at least twice, and they document a significant westward reduction in the amount of contraction of the North American plate *(Figure 2)*.

Our work continues, and we aim to answer the questions raised about the boundaries of the low slip zone and if there are locked segments within it. We are working to identify the location of the edge of the large locked patch and to make an estimate of the distance over which the interface changes behavior from fully locked to fully creeping. This is the first step in understanding what causes this change in behavior of the fault. A greater understanding of earthquakes, and an improved ability to forecast (or possibly someday predict) them, may be impossible until we have a better understanding of the physical properties and mechanics of fault behavior. Studies like this are steps toward that eventual goal, as we hope to learn what happens deep within the earth as tectonic forces build slowly toward the next great earthquake in southcentral Alaska.

Wandering Rocks in Kenai Fjords National Park

Figure 1. Deployment by helicopter for paleontological inventory in Kenai Fjords National Park. Petrof Glacier in background.

By Anthony R. Fiorillo, Peter Armato, and Russell Kucinski

In 2003, we marked the fourth year of the Southwest Alaska Inventory and Monitoring Network paleontological inventory. Each field season provided many surprises including the discovery of a dinosaur trackway in Aniakchak National Monument and Preserve, previously undescribed floral assemblages in Katmai National Park and Preserve, and in 2003, the location and description of a shallow-water marine reef assemblage in Kenai Fjords National Park. *While clinging precariously to a narrow perch, high on a steep valley wall, overlooking Petrof Glacier, I was comforted by the secure feel of solid rock beneath my feet (Fiorillo, video excerpt)*. Though these rock outcrops feel firmly rooted now, their presence in Kenai Fjords is the result of a journey that began in Central Asia approximately 280 million years ago. However, this is a story best told by the fossils contained within the rocks themselves.

Last summer, the investigation of the paleontological resources of the national parks in the Alaska Region included Kenai Fjords National Park *(Figure 1)*. Though most people associate the park with the vast Harding Icefield and the spectacular assemblage of glaciers flowing from the icefield, the park also contains a fascinating and unique paleontological story.

The rocks located through much of southcentral Alaska belong to the McHugh Complex, named for exposures along McHugh Creek just south of Anchorage. These rocks range in age from Permian (286-248 million years ago) to Cretaceous (145-65 million years ago). The McHugh complex is part of the larger Chugach Terrane and consists largely of metamor-

Figure 2. McHugh Complex exposed near Exit Glacier. Note the alternating bands of sedimentary rock.

National Park Service (NPS) and Dallas museum of Natural History (DMNH) photograph

Figure 3. Exposure of Permian limestone containing fossil fauna. Petrof Glacier in background.

phosed siltstones, sandstones, and conglomerates, as well as various igneous rocks. Igneous rocks form when molten rock cools and solidifies (crystallizes) *(Figure 3)*. One additional minor component within the complex is limestone, a sedimentary rock consisting mainly of calcium carbonate *(Figure 4)*. It is within these isolated blocks of limestone that the most interesting paleontological story of Kenai Fjords National Park is recorded.

Entombed in the twisted and churned limestone blocks is a diverse suite of fossils. Some, called fusilinids, are very large one-celled animals shaped roughly like grains of wheat *(Figure 4)*. Calvin Stevens of San Jose State University and colleagues reported 12 different fusilinids from this limestone. They also mentioned several types of single-celled organisms called foraminifera, and one alga. Dwight Bradley of the U.S. Geological Survey, Alaska and colleagues identified conodonts, tiny jaw-like structures the size of a grain of sand.

The most common fossil that we found was a generally flat, platy animal, which occurred in layers within the limestone matrix *(Figure 5)*. Though at this point in the study it is not possible to rule out bryozoans, a primitive colonial animal, the animals we found may be related to sponges. There are other animals that occur in layers and are closely related to sponges. These sponge-like animals are abundant throughout much of the limestone outcrops.

In much lesser abundance were broken remains of crinoids, lily-like marine animals that blanketed floors of ancient shallow seas. There were also very rare occurrences of broken mollusk shells. Together, these animals represent a type of ancient reef complex, one that was present in a warm, shallow, tropical ocean. An additional surprise contained in the fossil reef complex was the presence of a highly altered hydrocarbon, presumably naturally occurring oil residue *(Figure 5)*.

A preliminary analysis suggests the ancient assemblage of organisms is Permian in age and formed a thriving reef community that lived long before any dinosaurs walked the earth. The type of animals found in the rocks of Kenai Fjords National Park are most like those found in similarly aged rocks in Asia rather than any in northwestern North America. Given this, it appears that this small slice of Alaska was indeed mobile *(Figure 6)* and wandered from Asia, an unsettling thought when one is clinging to such rocks believed to be deeply rooted in the mountainous terrain of Kenai Fjords.

NPS and DMNH photograph

Figure 4. Close up of limestone showing remains of fusilinids in cross-section. They are the circular outlines on the dark gray limestone.

NPS and DMNH photograph

Figure 5. Close up of Permian limestone showing the platy fossils tentatively identified as the remains of sponge-like animals. The dark material is the highly altered hydrocarbon residue.

NPS and DMNH photograph

Figure 6. Small, isolated block of limestone, approximately the size of a basketball. This rock was torn off the main limestone boulder and incorporated into the surrounding rock as this section of Alaska moved from Asia to its current position.

REFERENCES

Bradley, D.C., T.M. Kusky, P.J. Haeussler, S.M. Karl, and D.T. Donley. 1999. *Geologic map of the Seldovia Quadrangle, south-central Alaska.* United States Geological Survey, Open-File Report OF 99-18.

Clark, S.H.B. 1972. *The McHugh Complex of south-central Alaska.* United States Geological Survey, Bulletin 1372-D.

Stevens, C.H., V.I. Davydov, and D. Bradley. 1997. *Permian Tethyan Fusilinina from the Kenai Peninsula, Alaska.* Journal of Paleontology, v. 71, pp. 985-994.

Biological Science in Kenai Fjords

Photograph courtesy of Alaska SeaLife Center

Live Feed Video Monitoring of Harbor Seals

**By Anne Hoover-Miller,
Shannon Atkinson, and Peter Armato**

Only a century ago, the Kenai Fjords were in the grip of the Little Ice Age, the most recent widespread glacial advance in the North Pacific. Glacial encroachments into the fjords created unique and dynamic habitats abutting the faces of tidewater glaciers. Those habitats continue to be renowned for concentrations of harbor seals, sea otters, Kittlitz's murrelets, and shrimp.

Harbor seals, the common seal of beaches, mudflats, and rocky shores throughout the North Pacific, are distinguished for living within diverse coastal environments *(Figure 1)*. Throughout their range, their populations have shown resilience despite the encroachment of humans and shoreline development. Recent warming trends, however, have set in motion new ecological events that, in the Gulf of Alaska, are affecting some haulout substrates. Although an icon of ecological adaptability, harbor seals in the Kenai Fjords are facing challenges that radically affect their survival.

Twenty-six years ago an abrupt climatic shift in the western Gulf of Alaska was postulated to have precipitated a major reorganization of the marine community structure *(Anderson and Piatt 1999)*. Shrimp-dominated communities, prevalent during the early and mid-1970s, were replaced by cods and flatfish. Simultaneously, population sizes of many seabird and marine mammal populations plummeted. Numbers of harbor seals decreased by as much as 90% in some areas *(Pitcher 1990)*. Although the changes in numbers of seals have been

(Left) Figure 1. Harbor seal on glacial ice in upper Aialik Bay.

(Opposite page) Dr. Shannon Atkinson and Anne Hoover-Miller at the Aialik Glacier video camera site in Kenai Fjords National Park.

Photograph courtesy of Alaska SeaLife Center

Photograph courtesy of Alaska SeaLife Center

Figure 3. Powered by solar panels and wind-driven generators, three camera stations transmit signals between upper Aialik Bay and the Alaska SeaLife Center.

attributed to many factors, including the climate-regime shift and subsequent nutritional stress, the actual mechanisms resulting in lower numbers of seals remains a mystery.

Despite the cold and protected features of glacial ice habitats, harbor seals in Kenai Fjords National Park did not escape environmental factors affecting other Gulf of Alaska seal populations. In 1980 more than 1,600 seals, including 350 pups hauled out on the ice near Aialik Glacier *(Hoover 1983) (Figure 5)*. By 1989, only 269 seals, including 92 pups were counted *(Hoover-Miller 1989)*. During the next decade numbers of seals remained low, with fewer than 300 seals and about 40 pups counted each year *(Tetreau 1998)*. Although numbers of seals in offshore waters near Kodiak Island have been increasing since 1993 at a rate of 6.6% per year *(Small et al. 2003)*, those in Aialik Bay have not *(Figure 2)*.

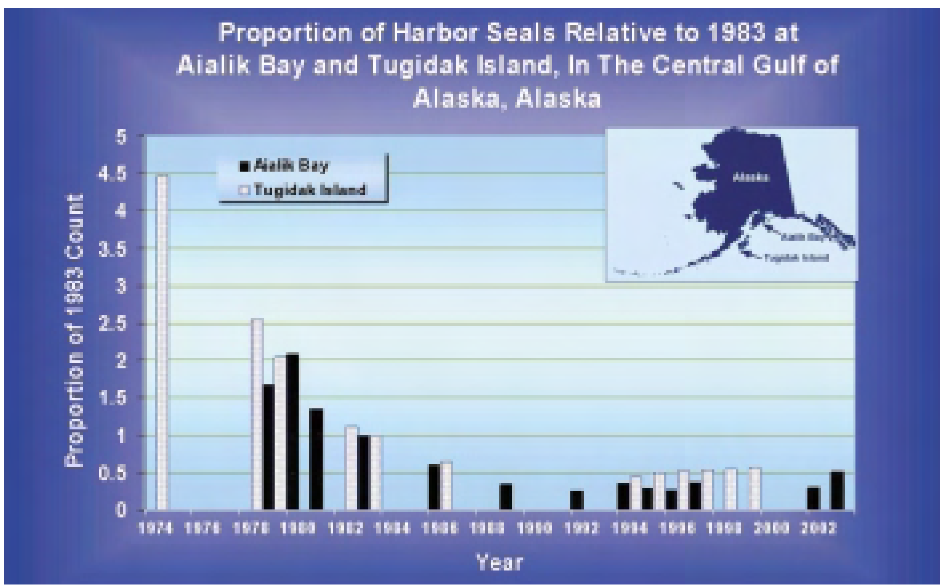
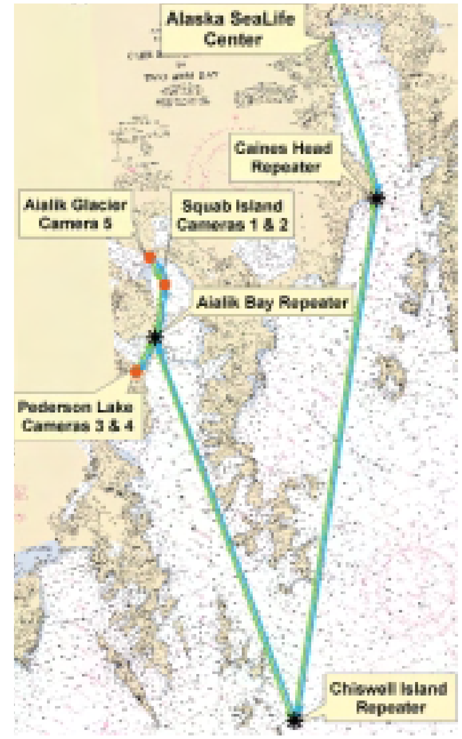


Figure 2. Relative rates of population decline of harbor seals at two locations in the Gulf of Alaska: Tugidak Island, near Kodiak Island, and in Aialik Bay, in Kenai Fjords National Park.

In 2002, the Alaska SeaLife Center (ASLC), in partnership with the National Park Service through the Ocean Alaska Science and Learning Center (OASLC), initiated a study of harbor seals in Aialik Bay using remotely-controlled video cameras to observe seals floating on the glacial ice. Video cameras, developed by SeeMore Wildlife Inc., have been placed at three locations for observing seals at Pedersen and Aialik Glaciers *(Figure 3)*. Powered by solar panels and wind-driven generators, the system consists of three camera stations assisted by three repeaters needed to transmit the signals 100 km between upper Aialik Bay and the Alaska SeaLife Center. The cameras with 25x optical zoom are controlled by personnel at the ASLC, and video signals are received and recorded on time-lapse video tape. Video images are used for documenting harbor seal population dynamics, haulout behavior, and interactions between vessels and seals.



Map of cameras and repeaters used for harbor seal study.

Harbor seals on ice

Newborn young of harbor seals are exceptionally precotial. Unlike most seals and sea lions, whose young may not enter the water until a month or two old, harbor seal pups shed their wooly lanugo coat before they are born and begin swimming within an hour of birth. Pups and their mothers typically are inseparable prior to weaning. This mobile strategy allows harbor seals to use haulouts that may be available only during limited tidal stages and weather conditions; it also permits lactating seals to forage, and aids pups in developing swimming and foraging skills.

In contrast to waters surrounding land haulouts typically used by harbor seals, waters within tidewater glacial fjords are especially cold (37-39ºF / 3-4ºC in spring), steeped with ice, and are strongly influenced by silt-laden fresh water discharged by both the glaciers and drainage from the steep watersheds surrounding the fjords *(Gay and Armato 1998)*. The first plunge of newborn pups in ice-infested waters is an energetic challenge, but the ability to swim soon after birth is critical. Glacial ice is always on the move and melting ice often becomes unstable and may roll or break apart within hours. Although ice is replenished by the glacier's calving, seals often must swim more than a dozen kilometers just to compensate for the day's drift.

Ice availability also is affected by weather conditions. In 1979, strong northwesterly winds blew for four days during peak pupping. With the exception of a few seals observed using rocks and islands as haulout sites, the remainder of the seals apparently stayed in the water. Calls of swimming pups were heard throughout the upper bay. Pup mortality appeared high that year with frequent sightings of pups without their mothers and low numbers of mother-pup pairs *(Hoover 1983)*.

Glacial Lakes

Glacial lakes are specialized glacial ice habitats also used by harbor seals. Unlike the tidewater glacial ice habitats of fjords, where ice movements are unconstrained, glacial lakes lie at the bases of glaciers, but are separated from marine systems by stream outflows. Salinity levels within the lakes are regulated by the reach of tides with some lakes being estuarine while

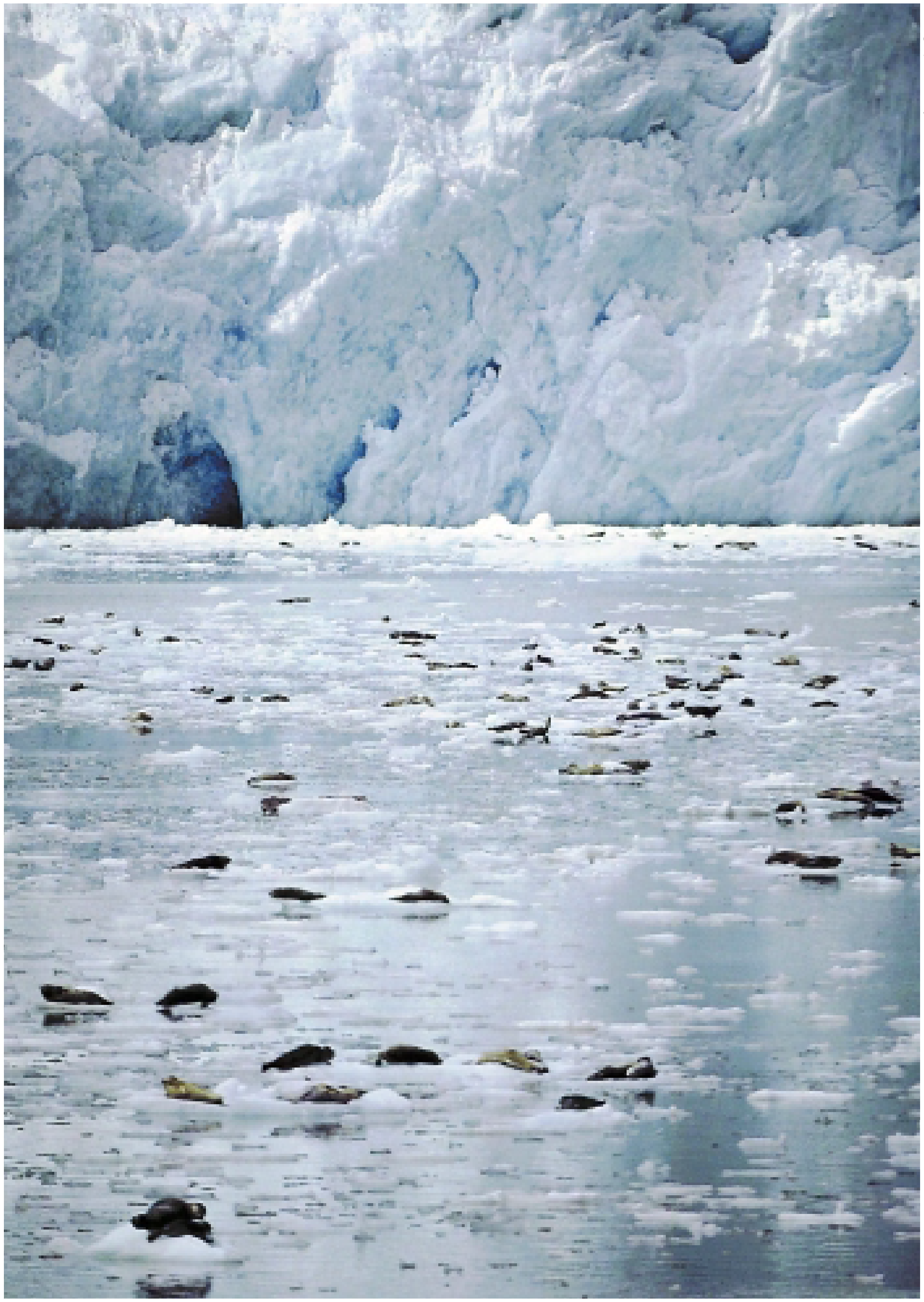
Vessel congestion at wildlife viewing areas and associated disturbances of marine mammals precipitated local tour vessel operators to establish voluntarily vessel operating guidelines. Marine mammal viewing guidelines were developed and adopted in 2000-2001 to minimize the impact of tour vessel operations on wildlife and enhance viewing opportunities for multiple vessels throughout the day

Photograph courtesy of Alaska SeaLife Center

Figure 4. Tours to tidewater glaciers in Kenai Fjords National Park provide visitors with opportunities to view actively calving glaciers and wildlife associated with tidewater glaciers.

Photograph courtesy of Alaska SeaLife Center

View of Aialik Glacier.



Photograph courtesy of Alaska SeaLife Center

Figure 5. Harbor seals were abundant on glacial calved ice during the early 1980s.

others may be free of marine influence. Stream entrances, usually cut through moraine deposits, restrict tidal flows into the lake as well as the drift of ice out of the lake. These lakes have only recently been recognized as an important habitat for harbor seals.

The lake abutting Pedersen Glacier, currently provides haulout habitat for approximately 200 harbor seals. Unlike Aialik Glacier, which is used by pupping and molting seals, Pedersen Lake is used primarily in mid-summer and fall by molting seals. The trapped ice within the lake provides a more reliable habitat for seals to haul out on, but infrequent glacial activity results in low rates of ice replenishment.

Cameras installed at Pedersen Lake provide a glimpse into the life of seals in a remote, secluded environment. Movements of seals in and out of the estuarine lake are restricted to higher tidal stages when water levels are sufficiently high for them to swim the shallow stream. Once in the lake, the seals are trapped until the tides release them.

Vessel Disturbance

With the establishment of Kenai Fjords National Park in 1980, a new environmental change was set in motion. Once a location visited by a few commercial fishermen and the occasional recreational boater, upper Aialik Bay has now become a primary destination for park visitors. Currently more than 75,000 people travel by vessel, ranging in size from 100-foot tour-vessels to small kayaks, to visit glacial haulouts in Aialik Bay and neighboring Northwestern Fjord. Aboard the vessels, visitors have the opportunity to view calving tidewater glaciers and observe seals, sea otters, and other wildlife resting on the floating ice *(Figure 4)*.

Once a location visited by a few commercial fishermen and the occasional recreational boater, upper Aialik Bay has now become a primary destination for park visitors. Currently more than 75,000 people travel by vessel, ranging in size from 100-foot tour-vessels to small kayaks, to visit glacial haulouts in Aialik Bay and neighboring Northwestern Fjord.

Baseline studies in 1979 and 1980 documented low vessel traffic, usually only one to two vessels per day in the upper bay. Few of those vessels entered the ice or interacted with the seals. By 1996, multiple vessels visited glacial face sites on a daily basis. In 1996, the NPS observed seals during a 12-day period at two fjords within the park. Twenty-eight vessels entered ice affected areas. Of those, 13 vessels (46%) caused major disturbances, where at least 20 seals abandoned the ice, and a total of 16 vessels (57%) caused at least one seal to enter the water *(Tetreau 1996)*.

Vessel congestion at wildlife viewing areas and associated disturbances of marine mammals precipitated local tour vessel operators to establish voluntarily vessel operating guidelines. Marine mammal viewing guidelines were developed and adopted in 2000-

2001 to minimize the impact of tour vessel operations on wildlife and enhance viewing opportunities for multiple vessels throughout the day.

During 2002, researchers at the ASLC observed 64 interactions between vessels and harbor seals. Of those interactions, 58% resulted in no seals entering the water, 30% resulted in fewer than six seals entering the water, and 5% caused interactions where more than 20 seals entered the water. Observations taken the following year documented 89 interactions between vessels and harbor seals. Of those, 82% caused no seals to enter the water, 10% caused fewer than six seals to enter the water, and 8% caused at least 20 seals to enter the water. The decreased frequency of disturbances appears to be primarily the result of improved vessel operating practices adopted by local commercial vessel operators. Continued reduction of incidences causing seals to enter the water in 2003 coincided with more conservative vessel operations in conjunction with a greater awareness of the cameras and the ongoing study.

Currently, harbor seals are facing strong selective pressures to adapt to rapidly changing environmental conditions. Many seals have not coped well; however, ongoing studies will aid researchers in identifying environmental parameters critical for seals. With this information, management practices that mitigate adverse effects from anthropogenic activities within the fjords can be developed, and continued monitoring will enhance our understanding of how successfully seals are adjusting.

More information on this research and the harbor seals of the Kenai Fjords can be found at http://www.alaskasealife.org/site/research/science_programs/harborseals

Photograph ©Bob Hoover

View of upper Aialik Bay.

REFERENCES

Anderson, P.J. and J.F Piatt. 1999.
Community reorganization in the Gulf of Alaska following ocean climate regime shift.
Marine Ecology Program Series 189:117-123.

Gay, S.M. III and P.J. Armato. 1998.
Hydrography of McCarty Fjord, Northwestern Fjord and Aialik Bay, Kenai Fjords National Park, Alaska. Report from pilot study submitted to Kenai Fjords National Park.

Hoover, A.A. 1983.
Behavior and ecology of harbor seals (Phoca vitulina richardsi) inhabiting glacial ice in Aialik Bay, Alaska.
M.Sc. Thesis. University of Alaska, Fairbanks.

Hoover-Miller, A.A. 1989.
Impact assessment of the T/V Exxon Valdez oil spill on glaucous-winged gulls in the Kenai Fjords National Park, 1989.
Report to the National Park Service, Seward, Alaska.

Hoover-Miller, A.A. 1994.
Harbor seals (Phoca vitulina): Biology and Management in Alaska. Report to the Marine Mammal Commission. Contract Number T75134749. Washington, D.C.

Pitcher, K.W. 1990.
Major decline in number of harbor seals, Phoca vitulina richardsi, on Tugidak Island, Gulf of Alaska.
Marine Mammal Science 6:121-134.

Small, R.J., G.W. Pendleton, and K.W. Pitcher. 2003.
Trends in abundance of Alaska Harbor seals, 1983-2001.
Marine Mammal Science 19(2):344-362.

Tetreau, M. 1998.
Harbor seal decline studied in Kenai Fjords National Park.
Park Science 18(1):4.

Black oystercatcher.

Monitoring Nesting Success of the Black Oystercatcher

By Michael Tetreau

The black oystercatcher *(Haematopus bachmani)* is a shore bird that is entirely dependent on rocky intertidal shorelines along the Pacific coast of North America to make its living. As ground nesters with semi-precocial young, black oystercatcher productivity may be negatively affected by human disturbance *(Nysewander 1977, Andres and Falxa 1995)*. In Kenai Fjords National Park, increasing use of the shoreline by visitors, primarily sea kayakers and pleasure boaters, has raised concerns. In 1999 the park initiated a study to examine factors influencing the productivity of black oystercatchers in the park, with fieldwork expected to continue through 2005. The results of this project will provide a valuable tool for managers of similar coastal environments to address increasing levels of human activity.

The study area consists of Aialik Bay, Northwestern Fjord, the east shore of Harris Bay, and the southwest shore of Resurrection Bay ñ approximately 150 miles (240 km) of shoreline in total. Initial boat-based surveys of oystercatcher habitat are conducted each year in early May to provide an overview of possible nesting sites in the study area. The location of each breeding pair and all other oystercatcher sightings are mapped using global positioning systems (GPS) and aerial photographs. Following the initial survey, all nests and potential nesting areas where oystercatchers had been observed are revisited every three to seven days. Once a nest is found, its status is monitored until it fails or the chicks are fledged.

Beginning in 2003, additional methods were incorporated into the study that include periodic floating of the eggs to determine their developmental stage and banding adults and chicks with both permanent metal bands and temporary colored bands for identification. When the birds are captured for banding, morphological measurements are taken, and a small blood sample is collected for sex determination and genetic analysis. In addition to data collected on the birds themselves, environmental conditions throughout the study area and the amount of human activity at campsites are monitored, and surveys of potential predators (e.g., ravens, gulls, and otters) are conducted in camping and non-camping areas.

Approximately 40 to 50 nests are monitored each year. Nesting success and overall productivity was very low through 2002, with less than 25% of the nests being successful in any year. Preliminary data from 2003 indicates that nesting success was significantly higher than in previous years, with approximately 50% of the nests hatching at least one egg. The reasons for this increase are unknown.

Thus far, the only significant pattern observed is that nests located on islets and islands have significantly greater hatching success than those found on the mainland. This may be due to the greater accessibility of mainland nests to mammalian predators such as bear, mink, and wolverine. Additionally, human activity associated with camping may attract predators to nests and thus indirectly cause nest failures by increasing levels of predation. Potential predators such as ravens and bears may be attracted to campsites for food, thus increasing predator densities and the potential for predation of nearby nests. Conversely, other predators such as wolverines may avoid humans thus reducing the likelihood of predation.

Few studies, however, have examined the interaction of humans and predators and their effects on productivity. Data analyzed to date from this study do not indicate a significant difference in nesting success between camping and non-camping areas, only that nests on islets and islands have greater hatching success than those on the mainland; however, two more years remain in the study.

REFERENCES

Andres, B.A. and G.A. Falxa. 1995. *Black Oystercatcher (Haematopus bachmani) in The Birds of North America* No. 155, edited by A. Poole and F. Gill. The Academy of Natural Sciences, Philadelphia, and the American Ornithologists' Union, Washington, D.C.

Nysewander, D.R. 1977. *Reproductive success of the Black Oystercatcher in Washington State.* M.S. Thesis, University Washington, Seattle.

Figure 1. Scanning electron micrograph of an adult ice worm. Arrow indicates the head; arrowhead identifies the clitellum. Scale bar = 0.5 mm.

The Ice Worm's Secret

By Daniel H. Shain

While many Alaskans and most tourists find ice worms *(Mesenchytraeus solifugus)* an intriguing part of Alaska folklore, cultivated by Robert Service's tales of the Yukon, ice worms do in fact exist. ...Their bellies were a bilious blue, their eyes a bulbous red... *(Service 2004)*. In fact, they do not have bilious blue bellies and bulbous red eyes; rather, they have a non-discrete appearance resembling a small earthworm *(Figure 1)* and keep a low profile on temperate Alaska glaciers.

Their unique adaptations permit ice worms to thrive in this extreme habitat (~32°F / 0°C, the freezing point of water), where life stops in almost all other animals *(Belehradek 1935)*. Remarkably, ice worms go about their business, crawling, feeding, and other worm activities at speeds essentially the same as their soil-dwelling relatives. Earthworms generally survive between 50 - 68°F / 10 - 20°C. An appreciation for this adaptation can be gained in several ways: by putting an earthworm in a refrigerator in which it no longer moves and eventually dies; or, skinny-dipping in a glacial run-off stream makes the point much more dramatically.

A fundamental challenge for ice worms is generating sufficient levels of energy to sustain life, which becomes increasingly difficult as temperatures fall and molecular motion slows. As an analogy, it is more difficult to start your car at low temperatures, and the engine runs inefficiently when cold. While automobiles use gasoline as an energy source, the currency of energy in biology is a molecule called adenosine triphosphate (ATP). Just as gasoline provides the energy to move your car, ATP provides the energy for driving most biological processes — growth, metabolism, movement. Because additional energy is needed for maintaining biochemical reactions at low temperatures, we hypothesized that ATP levels in ice worms would be relatively higher than those in other organisms.

Not only was this true, but a perplexing observation was made. Ice worms increased their cellular ATP levels as temperatures fell *(Figure 2)*, a response opposite to all temperate organisms examined — algae, bacteria, plant, worm, and yeast *(Napolitano et al. 2003)*. In other words, ice worms appear to produce more energy as temperatures become colder, even as low as 21°F / -6°C where ice worms begin to freeze. From an energetic standpoint, this is quite difficult to explain since most processes such as metabolism and respiration slow down with temperature, including energy production in "normal" organisms. What then is the ice worm's secret? The answer, of course, remains unknown. It seems likely that ATP accumulation in ice worms results from unequal changes in ATP production versus consumption at low temperatures. Thus, both processes decrease with temperature as required by thermodynamic laws, but energy consumption decreases at a faster rate than energy production, generating a net increase in ATP. Not a bad trick for a worm confined to poetry books by most. More than likely, the ice worm has a few more tricks up its clitellum, a sleeve-like structure around the midbody of most worms *(see Figure 1)*.

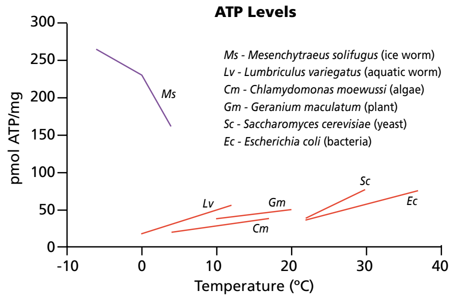


Figure 2. Energetic differences between ice worms and temperate organisms. Ice worms display elevated ATP levels that increase as temperatures fall, while temperate species have elevated ATP levels as temperatures rise.

REFERENCES

Belehradek, J. 1935. *Temperature and Living Matter.* Gebruder, Borntraeger, Berlin.

Napolitano, M.J., R.O. Nagele, and D.H. Shain. 2003. *The ice worm, Mesenchytraeus solifugus, elevates adenylate levels at low physiological temperature.* Comparative Biochemistry and Physiology Part A (137):227-235.

Service, Robert W. *The Ballad of the Ice-Worm Cocktail, from Bar-room Ballads.* http://www.explorenorth.com/library/service/bl-service.htm.

Cultural Science in Kenai Fjords

Smithsonian Institution photographs

(Above) Historic villages of the outer Kenai Coast with Alutiiq place names.

Smithsonian Institution photograph

Yup'ik student Michelle George, of the University of Alaska Fairbanks, excavating the floor of a 700 year-old house at the Cove Site in 2002.

(Left) Artifacts from the Early Contact Village Site, about A.D. 1790 - 1810.

Top, left to right: lead trade ring, wrought iron nail, Russian one-half kopeck coin dated 1748, large bone harpoon head for sea mammals, small bone harpoon head with slate blade (possibly a toy).

Bottom, left to right: two slate arrow blades, three barbed slate lance blades, bone fishhook. The two parts of the hook would have been lashed together with sinew.

Connecting with the Past — The Kenai Fjords Oral History and Archeology Project

By Aron L. Crowell

Most visitors perceive the Pacific coast of the Kenai Peninsula as a spectacular but empty wilderness, devoid of human history. Glaciers rumble down steep valleys to the sea, and sheer cliffs line the long fjords. The ocean waters teem with otters, whales, seals, and birds; but no echo of a human presence seems to linger in the quiet coastal forests.

History, oral tradition, and archeology tell a different story. Eighteenth century Russian, British, and Spanish explorers encountered Alutiiq (Sugpiaq) people who lived along the Pacific shore of the Kenai Peninsula, and Russian fur companies recruited hunters there for the sea otter trade *(Cook and Norris 1998)*. Alutiiq villages and seasonal camps once dotted the coast between Prince William Sound and Cook Inlet, including several within the bounds of Kenai Fjords National Park. The indigenous population dwindled during the nineteenth century and shifted westward, eventually settling at Nanwalek, Port Graham, and Seldovia. Elders in these Cook Inlet villages still remember stories that their parents and grandparents told about life, travel, and subsistence hunting on the outer coast, from Qugyugtulik (Dogfish Bay) to Prince William Sound *(ADF&G et al. 2000; Stanek 1985, 1999)*.

Today the three villages are active partners in the Kenai Fjords Oral History and Archaeology Project, a Smithsonian Institution program of research and education that seeks to bring the past alive for both current Alutiiq generations and visitors to the park. A team of archeologists, students, and village residents is working at sites that are remembered in oral tradition, as well as older locations where ancestral Alutiit lived hundreds of years ago. The project was organized by the Arctic Studies Center (ASC), a special program for northern cultural and scientific studies that is part of the Department of Anthropology at the Smithsonian's National Museum of Natural History.

Anchorage Museum of History and Art photograph

Alutiiq kayaks near Port Dick on the outer Kenai coast. Engraved from a watercolor by Henry Humphries, artist with the George Vancouver expedition, 1794.

Cooperating institutions include the Ocean Alaska Science and Learning Center (OASLC), tribal governments, Alaska Native corporations, the Pratt Museum in Homer, and the University of Alaska (Anchorage and Fairbanks campuses). University students and interns from village high schools are assisting scientists in the field and joining in the rediscovery of ancestral life ways. Several dozen Alutiiq Elders have recorded oral histories for the project, and others have helped to interpret archeological discoveries during site visits and community presentations.

Archeology and History on the Outer Kenai Coast

The outer Kenai coast lies in the very heart of the Alutiiq cultural area, which extends to the Alaska Peninsula, Cook Inlet, the Kodiak archipelago, and Prince William Sound. While work on the Kenai coast is just beginning, archeologists have explored these surrounding areas for decades *(Clark 1984; De Laguna 1934, 1956; Knecht 1995; Steffian 2001)*. Studies show that Alutiiq people and their cultural predecessors have lived along the Gulf of Alaska for at least 7,500 years, and possibly for as long as 10,000 years. They developed sophisticated watercraft, fishing methods, and hunting technologies. Classical Alutiiq society was populous, complex, and possessed of unique styles of art, dress, and spiritual celebration *(Crowell et al. 2001)*.

Although nearly invisible to the untrained eye, traces of Alutiiq settlements have been discovered all along the outer Kenai coast. More than 30 indigenous archeological sites have been identified in Kenai Fjords National Park and on adjacent Nuka Island, ranging in age from A.D. 250 to the early twentieth century *(Betts et al. 1991; Crowell and Mann 1996, 1998; McMahan and Holmes 1987)*. These include summer hunting camps, winter villages, log cabins, and even groves of old spruce and hemlock trees that bear scars from Alutiiq bark harvesting centuries ago.

Archeological *middens*—trash disposal areas—contain charcoal, fire-shattered rock from cooking fires and steam baths, broken tools, and the discarded remains of shellfish, fish, birds, and mammals. Inside the collapsed remains of earthen-walled houses (called *ciqluat* in Alutiiq or by the Russian-Siberian term *barabara*) is more evidence of everyday activities. There are cooking hearths, *uluat* (ulu knives) for preparing food and skins, stone debris from the manufacture of arrow and harpoon points, beads from garments and jewelry, and stone lamps that gave light from burning seal oil.

Scientific archeology is a painstaking effort. Each layer of the soil must be removed slowly, with sharp-eyed attention to the bones and artifacts it contains. The excavated dirt is then water-screened through fine mesh to ensure that small items such as tiny glass trade beads do not escape unnoticed. Excavators map each layer, artifact, and architectural feature on a three-dimensional grid, allowing the site and its contents to be rebuilt later in computer-virtual form. Bones and artifacts are bagged and labeled for identification and analysis. Hundreds of pages of bug and mud-smeared notes accumulate in the course of many weeks of work. Archeologists never dig more than a small part of any site, leaving most untouched as a resource for future study.

Alutiiq Elders from Nanwalek and Port Graham who visited excavations at the Cove Site (A.D. 1000-1300) recognized many features of the houses there because they matched oral tradition. Nick Tanape, Sr. remarked that a slab-lined pit in the center of the floor was like the kind his father and other hunters used for steaming seal and bear meat between layers of seaweed. He suggested that fragments of burned bone found near the hearth were evidence of *pinahsuhtut* "they are hunting for good weather," a traditional practice of tossing bones in the fire to chase away storms. Examining a complete lance point, *uluaq* knife, and other tools left in the house by the dwelling's last occupants, Elders said that it had always been the custom to leave stores of food, firewood, and tools inside *barabaras* so that weather-besieged travelers on the outer coast could find comfort and shelter there.

Pratt Museum photograph

Nick Tanape, Sr. of Nanwalek (right) discusses archeological finds at the Cove Site (A.D. 1000 - 1300) with Project Director Aron Crowell. In the 1930s, Mr. Tanape's father traveled to Aialik Bay from Nanwalek by skin-covered kayak for winter trapping and spring seal hunting.

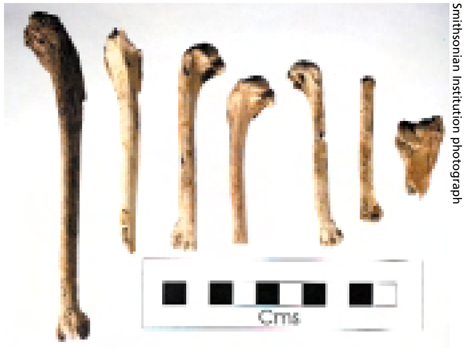
At the Early Contact Site in Aialik Bay, excavated in 2003, the archeological team found evidence of contacts between Alutiiq residents and Russian fur traders. During the late 1790s and first decade of the 1800s, the Russian-American Company on Kodiak Island assembled Alutiiq kayak fleets for sea otter hunting. Each April, the largest of these fleets would travel east from Kodiak toward Sitka, passing the Kenai coast and picking up additional hunters along the way *(Davydov 1977, Gideon 1989)*. Some men were recruited to hunt birds (probably puffins or murres) for parkas *"on the islands near Voskresensk [Resurrection] Bay"(Davydov 1977),* an apparent reference to seabird colonies in the Chiswell Islands or on Renard, Rugged, Hive, and Cheval Islands in Resurrection Bay.

National Park Service photograph

Natalie Kvasnikoff of Nanwalek, interviewed at an 1880s village site in Aialik Bay, shares traditional knowledge about life on the outer coast.

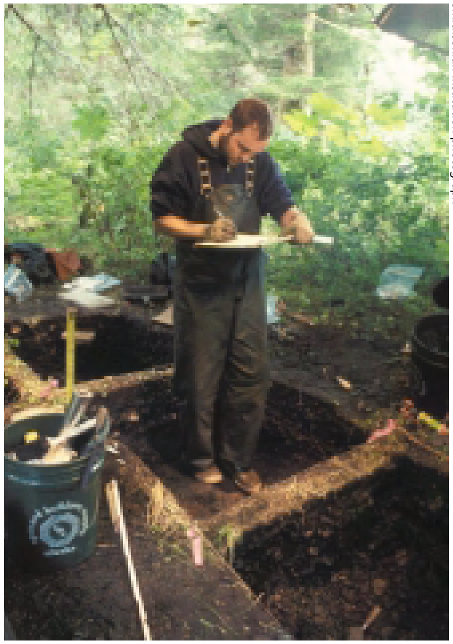
The Early Contact Village in Aialik Bay, which consists of a midden mound and nearby cluster of small house depressions, may be one of the settlements that supplied men for the annual sea otter and bird hunts. The midden and house floors contain hundreds of trade beads in colors and varieties that the Russians brought during this period, as well as a hand-forged iron knife, iron nails, small pieces of window glass (one made into a scraper), a trade ring made of lead, and a 1748 Russian coin. Traditional stone and bone tools, such as slate lance blades and harpoon heads, are present. No imported ceramic cups or plates—common in Alaska Native sites after the 1830s—were found. Based on comparison of these artifacts with those found at other Russian period sites *(Crowell 1997; Knecht and Jordan 1985; Bundy et al. 2003),* we suggest that the Early Contact Village was occupied for several years during the period A.D. 1790 - 1810. Puffin and murre bones are unusually abundant at the site, suggesting use of the birds for parkas as well as food. Sea otter bones are rare. These animals, common in Aialik Bay today, may have been locally depleted as a result of the Russian commercial harvest by the time the Early Contact Site was occupied.

The site offers clues to the nature of Russian-Native interactions on the Kenai coast. On Kodiak Island, Alutiiq men and women were forced to work for the Russian-American Company and usually received only parkas and other locally made goods in payment. Glass beads, tobacco, and other imported trade items were dispensed very sparingly. The relative abundance of glass beads and other



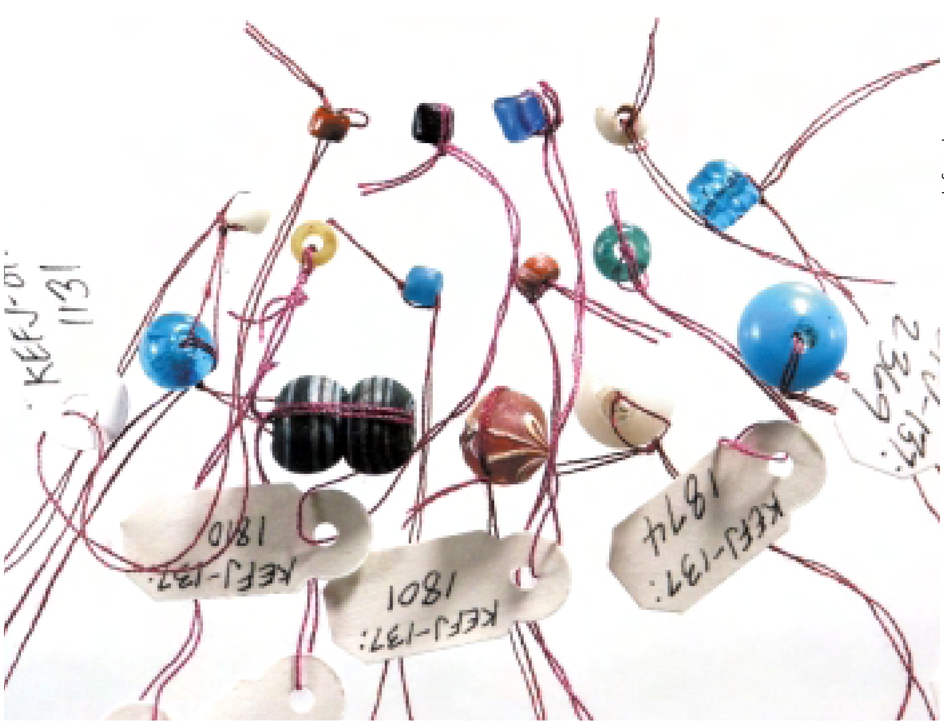
Smithsonian Institution photograph

Bird bones from the Early Contact Village Site. Site residents hunted a wide variety of species. All are humerus (upper wing) bones. Left to right: red-throated loon, pelagic cormorant, murre, eider or scoter, puffin, rhinoceros auklet, and common loon. Puffins and murres are the most common bird species in the midden. Identifications by David Yesner, University of Alaska Anchorage.



Smithsonian Institution photograph

Jim Whitney, of the University of Alaska Museum in Fairbanks, records artifacts at the Cove Site in 2002.



Smithsonian Institution photograph

Glass trade beads from the Early Contact Village Site. The beads were made in China and Europe and imported by Russian fur traders.

imported artifacts at the Early Contact Site may indicate that Alutiiq villagers on the Kenai coast were not subject to direct and forceful Russian control, and were therefore able to demand more in payment for their furs and labor. An abundance of animal bones at the village site also suggests that it was well supplied with food, as opposed to Kodiak Island villages that were reduced to starvation under the demands of the Russian labor system *(Davydov 1977, Gideon 1989)*.

People in a Dynamic Environment

Some of the most interesting questions for current research concern Alutiiq responses to dramatic changes in the landscape, climate, and ecology of the outer Kenai coast. In 1993, geologist Daniel H. Mann (University of Alaska Fairbanks) discovered old tree stumps buried beneath beach gravel on the west side of Aialik Bay, evidence of a massive earthquake that shook southcentral Alaska in about A.D. 1170 *(Mann and Crowell 1996)*. The temblor caused the shoreline of Kenai Fjords National Park to drop about two meters, just as another great Alaska earthquake did in 1964.

The A.D. 1170 earthquake would have been disastrous for human residents. There are few level places to build villages along the outer Kenai coast, except low-lying spits and beaches. Settlements in such locations would have been flooded by the sudden downward movement of the land, or swept by tidal waves. A thick lens of beach gravel that intrudes between cultural levels at the Cove Site is probably direct evidence of this event. The upper cultural level at this site, which dates to slightly later than the earthquake, shows that people returned after the land had risen again, as it does between major quakes. Nonetheless, the cumulative trend of earth movements on the outer Kenai coast is downward. The narrow, ragged peninsulas of Kenai Fjords National Park consist of mountain ridges that are slowly sinking into the sea. This geological history (see article by J. Freymueller, this issue) explains why sites from the first 8,000 years of Alutiiq history have not been found on the outer coast. Such sites, if not erased by wave action, probably lie deeply buried in beach gravels or underwater off the coast.

Alutiiq residents also had to adapt to

Smithsonian Institution photograph

Yup'ik student Michelle George, of the University of Alaska Fairbanks, holds a long stone lance blade made of slate, from House 8 at the Cove Site.

Tlingit oral histories from southeast Alaska tell of advancing glaciers that overran living villages. …One large Alutiiq settlement in Northwestern Lagoon almost suffered this fate, although the ice stopped about 218 yards (200 m) away.

the chilly temperatures of the Little Ice Age (LIA), a global cooling period between A.D. 1250 and 1900. Glaciers in Aialik Bay, Northwestern Fjord, McCarty Fjord, and other locations grew substantially during the LIA. Tlingit oral histories from southeast Alaska tell of advancing glaciers that overran living villages *(De Laguna 1972)*. One large Alutiiq settlement in Northwestern Lagoon almost suffered this fate, although the ice stopped about 218 yards (200 m) away *(Crowell and Mann 1998)*.

Colder water temperatures during the Little Ice Age may have had a greater direct impact on Alutiiq residents than advancing glaciers. Recent studies have demonstrated the profound impact of cyclical changes in North Pacific water temperatures, including correlated shifts in the abundance of key subsistence species, such as salmon, seals, and sea lions *(Finney et al. 2002, Francis et al. 1997)*. Well-preserved bones of sea mammals, fish, and birds at the Early Contact Site may hold important clues to differences between the LIA and present conditions. For example, some species of fish were much larger two centuries ago, including Pacific cod that weighed as much as 50 pounds *(Yarborough 1998)*.

Archeological mollusks, such as Nuttall's cockle and the Pacific Littleneck clam, are also substantially larger than modern specimens from Aialik Bay. David Yesner, an archeologist at the University of Alaska Anchorage, is working with the Arctic Studies Center to identify and interpret patterning in the many thousands of bones that were recovered from the Early Contact Site in 2003. We also plan to analyze oxygen, carbon, and nitrogen isotopes in bones and bivalve shells to document trends in water temperature and ocean productivity during the LIA.

Project Outreach and Education

In addition to its scientific and historical results, the Kenai Fjords Oral History and Archaeology Project has been fertile ground for public outreach and education. Internships sponsored by the Pratt Museum have enabled seven high school students from Homer, Nanwalek, and Port Graham to join scientists in the field for two to six weeks of intensive learning. On-site field schools and lab work have engaged graduate and undergraduate students from the University of Alaska, University of California (Berkeley), and Dartmouth College. The Pratt Museum, Arctic Studies Center, tribal councils, and village residents joined in the production of two educational videos about the project. The Pratt's ***Bringing Back the Stories*** will become part of its new exhibition ***Kachemak Bay: An Exploration of People and Place***, which opens in the summer of 2004. The Arctic Studies Center's ***Archaeology and Memory: Ancestral Alutiiq Villages on the Outer Kenai Coast, Alaska*** is shown at the Kenai Fjords National Park visitor center.

The Ocean Alaska Science and Learning Center developed its own 40-minute audiovisual program about the project that is presented daily to summer visitors by interpretive staff at the Alaska SeaLife Center. The program emphasizes how scientific archeology and traditional knowledge can be combined, and features video clips of archeologists in the field and of Alutiiq participants discussing their thoughts about what has been found. The audience is left with a keen awareness of the power of archeology to help define cultural identity and to create strong connections between present and past.

In addition, the OASLC developed a hands-on outreach program aimed at middle and high school students that provides a lesson in archeological stratigraphy and allows students to draw conclusions about a fictional site based on artifacts found there, much as archeologists do. The program highlights the importance of protecting archeological sites so that future generations can learn from them.

In the summer of 2003, National Native News aired a radio feature about the project that was broadcast by more than 50 stations nationwide. The British Broadcasting Company featured the Kenai Fjords work in its *Heritage* radio series in 2002. Several local newspaper articles have also contributed to public awareness of the rich history and cultural resources of Kenai Fjords National Park.

Acknowledgments

The Kenai Fjords Oral History and Archaeology Project has been supported by grants and assistance from the Ocean Alaska Science and Learning Center, with special thanks to OASLC Director Peter Armato and Education Coordinator Jim Pfeiffenberger. Our sincere appreciation to the Seldovia Village Tribe, Nanwalek Village Council, and Port Graham Village Council as well as Elders and village residents for supporting this collaborative program of discovery. Kenai Fjords National Park Superintendent Anne Castellina and staff—including Mike Tetreau, Vic Aderholt, Kirk Desermia, and Ida Murdock—have provided superlative logistical and administrative assistance. The Alaska Humanities Forum funded project planning and village consultations. Gale Parsons, Curator of Education at the Pratt Museum, played a key role in coordinating community relations and the high school intern program. Betsy Webb and Wendy Erd at the Pratt Museum generously shared video interviews from the villages. Thanks to Nick Tanape, Sr., Herman Moonin, Jr., and Lillian Elvsaas for their knowledge and participation; to archeologist and field coordinator Mark Luttrell; to Jeff Leer (Alaska Native Language Center) and Ron Stanek (Alaska Department of Fish and Game) for sharing research results; to hard

Smithsonian Institution photograph

Early Contact Village archaeology crew, 2003. Excavators are surrounded by walls of midden that are left standing so that layers of the deposit can be drawn.
From left to right across front: Forest Kvasnikoff (Port Graham), Katrina Dupree (Seward), Rita Eagle (University of Alaska Anchorage), Connie Hedrick (Seward), Binh Tam Ha (University of California, Berkeley). Left to right across back: Derek Shaw (University of California, California, Berkeley) and Mark Luttrell (Seward).

coordinator Mark Luttrell; to Jeff Leer (Alaska Native Language Center) and Ron Stanek (Alaska Department of Fish and Game) for sharing research results; to hard working 2002 and 2003 field crews and lab assistants including Dan Anahonak, Dylan Anderson, Sperry Ash, Katrina Dupree, Rita Eagle, Michelle George, Binh Tam Ha, Connie Hedrick, Stacey Hetrick, Travis Hines, Tim Johnson, Forest Kvasnikoff, Robert McMullen, Brie Miles-Brache, Cora Moonin, Bill Parker, Derek Shaw, Zachary Strong, Nicole Tozzi, and Jim Whitney; and to colleagues Dan Mann, Tom Hamilton, David Yesner, Bill and Karen Workman, and Maribeth Murray.

REFERENCES

Alaska Department of Fish and Game, Native Village of Nanwalek, and Native Village of Port Graham. 2000. *Project Jukebox Oral History CD-ROM, Nanwalek/Port Graham.* Oral History Program, University of Alaska, Fairbanks.

Betts, Robert C., Christopher B. Wooley, Charles M, Mobely, and Aron Crowell. 1991. *Site Protection and Oil Spill Treatment at SEL-188, An Archaeological Site in Kenai Fjords National Park, Alaska.* Exxon Shipping Company and Exxon USA, Anchorage.

Bundy, Barbara, Allen P. McCartney, and Douglas Veltre. 2003. *Glass Trade Beads from Reese Bay, Unalaska Island: Spatial and Temporal Patterns.* Arctic Anthropology 40(1):29-47.

Clark, Donald W. 1984. *Prehistory of the Pacific Eskimo Region.* In Arctic, edited by D. Damas, pp. 136-148. Handbook of North American Indians, Vol. 5, W.C. Sturtevant, general editor. Smithsonian Institution, Washington, D.C.

Cook, Linda and Frank Norris. 1998. *A Stern and Rockbound Coast. Kenai Fjords National Park Historic Resource Study.* National Park Service, Alaska Support Office, Anchorage.

Crowell, Aron L. 1997. *Archaeology and the Capitalist World System: A Study from Russian America.* Plenum Press, New York.

Crowell, Aron L. and Daniel H. Mann. 1996. *Sea Level Dynamics, Glaciers, and Archaeology along the Central Gulf of Alaska Coast.* Arctic Anthropology 33(2):16-37.

Crowell, A.L. and D.H. Mann. 1998. *Archaeology and Coastal Dynamics of Kenai Fjords National Park, Gulf of Alaska.* National Park Service, Anchorage.

Crowell, Aron L., Amy F. Steffian, and Gordon L. Pullar (ed.). 2001. *Looking Both Ways: Heritage and Identity of the Alutiiq People.* University of Alaska Press, Fairbanks.

Davydov, G.I. 1977. *Two Voyages to Russian America, 1802-1807.* Translated by Colin Bearne. Edited by Richard A. Pierce. The Limestone Press, Kingston, Ontario.

De Laguna, Frederica. 1934. *The Archaeology of Cook Inlet, Alaska.* University of Pennsylvania Museum, Philadelphia. Reprinted in 1975 by the Alaska Historical Society, Anchorage.

De Laguna, Frederica. 1956. *Chugach Prehistory: The Archaeology of Prince William Sound, Alaska.* University of Washington Publications in Anthropology, Vol. 13. University of Washington, Seattle.

De Laguna, Frederica. 1972. *Under Mount Saint Elias: The History and Culture of the Yakutat Tlingit.* Smithsonian Institution, Washington, D.C.

Finney, B.P., I. Gregory-Eaves, M.S.V. Douglas, and J.P. Smol. 2002. *Fisheries Productivity in the Northeastern Pacific Ocean over the Past 2000 Years.* Nature 416:729-733.

Francis, R.C., S.R. Hare, A.B. Hollowed, and W.S. Wooster. 1997. *Effects of Interdecadal Climate Variability on the Oceanic Ecosystems of the NE Pacific.* Fisheries Oceanography 7(1):1-21.

Gideon. 1989. *The Round the World Voyage of Hieromonk Gideon 1803-1809.* Translated, with an introduction and notes, by Lydia T. Black. Edited by Richard A. Pierce. The Limestone Press, Kingston, Ontario.

Knecht, Richard A. 1995. *The Late Prehistory of the Alutiiq People: Culture Change in the Kodiak Archipelago from 1200 - 1750 A.D.* Unpublished Ph.D. dissertation, Bryn Mawr College.

Knecht, Richard H. and Richard H. Jordan. 1985. *Nunakakhnak: An Historic Period Koniag Village in Karluk, Kodiak Island, Alaska.* Arctic Anthropology 22(2):17-35

Mann, Daniel H. and Aron L. Crowell. 1998. *A Large Earthquake Occurring 700 - 800 Years Ago in Aialik Bay, Southern Coastal Alaska.* Canadian Journal of Earth Sciences 33:117-126.

McMahan, J. D. and C. E. Holmes. 1987. *Report of Archaeological and Historical Investigations at Nuka Island and the Adjacent Kenai Peninsula, Gulf of Alaska.* Office of History and Archaeology Report No. 5. Alaska Department of Natural Resources, Anchorage.

Stanek, Ronald. 1985. *Patterns of Wild Resource Use in English Bay and Port Graham, Alaska.* Department of Fish and Game, Division of Subsistence Technical Paper No. 104. Anchorage.

Stanek, Ronald. 1999. *Ethnographic Overview and Assessment for Nanwalek and Port Graham.* Division of Subsistence, Alaska Department of Fish and Game, Anchorage.

Steffian, Amy F. 2001. *Cúmilalhet — "Our Ancestors". In Looking Both Ways: Heritage and Identity of the Alutiiq People,* edited by Aron L. Crowell, Amy F. Steffian, and Gordon L. Pullar, pp. 99-135. University of Alaska Press, Fairbanks.

Yarborough, Linda. 1998. *Appendix: Faunal Analysis, Kenai Fjords Archaeological Survey.* In Archaeology and Coastal Dynamics of Kenai Fjords National Park, Gulf of Alaska, by Aron L. Crowell and Daniel H. Mann, pp. A1-A38. National Park Service, Anchorage.

Photograph courtesy of the Seward Museum

Frank with Captain of *Manning,* Chirikof Island, 1913. This is one of the few photos of Franklin G. Lowell, probably taken during a visit with his daughter Eva and grandson Frank Revell, Jr. on Chirikof Island, shortly after Katmai volcano erupted in 1912.

The Lowell Family and Alaska's Fur Trade Industry: Seward, Alaska

By Sandy Brue

Life on the Outer Coast

To appreciate the natural wonders of the remote landscape of Kenai Fjords National Park, one must understand the people who visited and lived along its rockbound coast. Explorers of Alaska waters in the early historic period, chiefly Russians (although British, American, French and Spanish ships were recorded as early as 1725), were not the first humans to eke a living from this wilderness.

Thousands of years before the first European explorers arrived, Alaska Native people traveled regularly from the Aleutian Islands to southeast Alaska in skin boats. The glaciated fjords, from Resurrection Bay on the east coast of the park, around the Kenai Peninsula south to Kachemak Bay, were home to the Unergkurmiut (see article by A. Crowell, this issue).

Before their first contact with Europeans between 1750 and 1780, Alutiiq people derived most of their livelihood from the sea. In the spring, people collected shellfish and watched for sea mammals, birds, and fish to return. Summer was a time for hard work: hunting sea mammals, collecting sea bird eggs, fishing for salmon, and picking berries. Fall was a time of preparation: hunting ducks and caribou, and storing food for winter use. Winter provided an opportunity for trapping and social gathering.

Women prepared bird, fox, otter, and ground squirrel skins and stitched them into loose fitting garments. They dried fish and gathered foodstuffs. Women worked with delicate gut skin to provide waterproof jackets and bags. They created waterproof stitches for boat covers made from seal and sea lion skins. In addition, they wove and made baskets used for cooking, drinking, and eating vessels, from spruce roots, beach grass, and baleen. Baskets were used for food storage, collecting, backpacks, and cradling babies. By the time the Russians began the fur trade in Resurrection Bay, the Russian-American Company had already been a colonial presence in the Aleutian Islands for decades. Sea otter fur pelts were "soft gold," valuable for trade to the market in Asia. The Russians were unskilled in sea otter hunting, so they forced Native men, who were accustomed to life on the water in lightweight *baidarkas* (kayaks), to hunt the elusive mammals.

While the Russians depended greatly upon the Native men's hunting skills, it was the constant supply of food, clothing, baskets, and footgear produced by Native women that enabled the fur traders and Native hunters to survive. Historians have given but a passing glance to Native women's role in the fur trade industry. Without the support they provided, however, the fur trade industry could not have prospered.

American Fur Traders Arrive in Alaska

After the United States purchased Alaska in 1867, the Alaska Commercial Company (ACC) and the North American Commercial Company (NAC) continued the fur trade from the same stores and warehouses the Russian-American Company had used. Like other New England men of his time, Franklin G. Lowell of Maine arrived in Alaska about 1870 to begin working in the fur trade.

Frank Lowell was a distant relative of the

Photograph courtesy of the Seward Museum

After Frank left, Mary and the children raised vegetables in this garden, trapped, and fished. A monthly steamer brought them supplies, carried away their furs, and brought mail.

Photograph courtesy of the Seward Museum

famous Massachusetts Lowell family. His father died before he was five, and young Frank grew up on the rugged coast of Maine, in a family who made their living on the sea. The fjord-like bays of Lincoln County, Maine, where Frank learned to fish and sail, resembled the coast line of Kenai Peninsula.

Young Frank inherited his seamanship from both sides of his family, preparing him for a lifetime of work in Alaska waters. His maternal grandfather, Captain Robert P. Manson, Sr., earned a reputation as a free spirit in 1809 when he piloted merchant brigs through United States fortifications, defying the federal government's embargo with France and Great Britain. Frank's aunt, Eliza Lowell, married Captain Samuel Snow, a merchant sailor who established a shipping line between San Francisco, Seattle, and Alaska. In fact, Captain Snow's company often carried supplies for the Alaska Commercial Company.

Frank was apprenticed to his maternal uncle, R.P. Manson, a ship builder, at age 11. When he was 15, Frank left Maine and made his way to Alaska. He sailed around Cape Horn with an older relative—an uncle or cousin—and arrived in Sitka, a common entry point to Alaska at the time.

By 1875, after becoming an accomplished entrepreneur, Frank had moved west, to the Kenai and Alaska Peninsulas. In the Kenai Peninsula area, Frank sold salted salmon to the Alaska Commercial Company from the shores of Resurrection Bay, maintained trading stations in Nuka and Aialik Bays, employed Native hunting parties, and sold furs to both the ACC and the North American Commercial Company. Eventually, Frank became an agent for the ACC at Wrangell Station on the Alaska Peninsula in 1889. In Kodiak, he worked on the 1890 census.

Photograph courtesy of the Seward Museum

The Lowell family cabin, as it sat at the head of Resurrection Bay, circa 1902.

During these years, Frank had children with three Alaska Native women from the communities where he worked. From interviews historian Mary J. Barry conducted with Frank's daughter, Eva Lowell Revell Simons, we learn that after Frank's arrival in Sitka he fathered a son with a Native woman. Whether this was his son William who accompanied him to Resurrection Bay (Russian Orthodox Church records in Seward list the boy as Vasilii F. Lovel, born in 1870) or another child is unknown.

Sometime before 1871, when their oldest daughter Anna was born, Frank met Mary Forgal from English Bay, an Alutiiq village now known as Nanwalek. Mary would have been about 16 when she married Frank. Little is known of her earlier years. Since there was a Russian Orthodox funeral when Mary died in Seward in 1906, she probably belonged to that church;

however, research has yet to find her listed in any Orthodox parish records. There are no records of Frank and Mary's marriage, which produced eight or nine children. In 1883 or 1884, the couple, their children, and several Natives from English Bay (perhaps Mary's relatives) settled on the shores of Resurrection Bay at the present site of Seward, Alaska.

It is understandable that Frank Lowell needed a Native wife and partner. Union with a Native woman gained Frank a firm alliance with local Native families and cemented his trading ties. Native women's skills made them valuable wives: they knew how to trap small game, gather edibles, and prepare skins and footwear. The women also provided a link between the white traders and Native men. Frank Lowell's story illustrates the continued dependence of European fur traders on the Native community—a story that began with Russian occupation in the eighteenth century.

During the years of the Russian Colony, Resurrection Bay represented only one of many locations along the route between two points of commerce, Sitka and Kodiak. Census records for 1890 show that ACC trading stations dotted the southwestern coast of Alaska and continued into the interior along the Yukon River. Fur exports from Alaska were sent exclusively to Portland, Oregon and San Francisco. Resurrection Bay, at the time the Lowells moved there, was an isolated outpost on the outer fringe of the fur trade industry.

Frank and Mary Lowell's decision in 1884 to move from English Bay, the center of the fur trade, to settle on Resurrection Bay was probably influenced by several

Photograph courtesy of the Seward Museum

An early photograph of Seward, Alaska

local events. In 1883, an influenza epidemic swept through the Kenai Peninsula, taking hundreds of lives in the villages of Ninilchik, Seldovia, and English Bay. This tragedy occurred the same year that Mt. Augustine, a volcano across Cook Inlet from English Bay, erupted and covered the villages with ash. A tidal wave flooded English Bay. Thus, in addition to the incentive to start a new fur trading post, the Lowells may have wished to leave English Bay behind.

The ACC influenced their white and Native employees and families to move and resettle among fur trading posts. The company built chapels and stores in population centers such as Kodiak to attract hunters and fur traders to these communities. By 1889, the sea otter catch was declining; the few animals found in the outer fjords were disappearing from years of overhunting. As the fur trade industry began to collapse, the ACC focused its business interests in the area around Kodiak Island, outposts along the Yukon River, and the eastern coast of the Alaska Peninsula. Frank Lowell was forced to take a post as general agent of the Wrangell Station on the Alaska Peninsula in order to remain employed by the ACC. According to Frank's daughter Eva, her mother Mary refused to leave Resurrection Bay with Frank. Mary and her children stayed in Seward, and Frank moved to the Alaska Peninsula.

Frank was the ACC agent at Wrangell Station for several years, even after the declining company stopped paying him a salary or expenses. In August 1895 Frank married Akilina Koshon, a Native woman from the Alaska Peninsula. By the turn of the century, although Frank was still employed by the ACC, the Wrangell Station was deeply in debt. His letters from those years reveal that he closed the station, sold

Photograph courtesy of the Seward Museum

Frank Junior, Ida, and Harry Revell, 1913.
This photo of Frank and Eva Revell's children was probably taken about the time of their mother's marriage to Andy Simons.

the warehouse to "the church" (probably the Russian Orthodox Church), and moved to Kodiak Island. A contract with the ACC found with Frank's letters shows he worked on a fox farm for the company on South Semidi Island from June 1903 until about 1907. When Akilina died about 1910, Frank placed his two daughters, Anna and Emma, in the Russian Orthodox orphanage founded by Father Herman near Kodiak. Census records for that year, however, also show that his two boys, age three and five, were

Photograph courtesy of the Seward Museum

Eva Lowell Revell Simons on wedding day, September 1903. In September 1903 Eva Lowell married Harry E. Revell. They later divorced and she remarried Andy Simons, about 1913.

with him on Chirikof Island. In his declining years, Frank, still working for the ACC, was caretaker on Chirikof Island in the Kodiak Archipelago.

Meanwhile, 1906 and 1907 were years of tragedy for Mary Lowell and for Frank's children who had stayed in Resurrection Bay when he left. Mary Lowell died in May 1906 from pleurisy; and Frank's oldest son, William, lost his Aleut wife and eleven-year-old daughter to disease. In the spring of 1908, Frank's daughter Eva wrote to him that the past summer, when the schooner *Dora* carried William's surviving children to the Kodiak Baptist Orphanage, was the worst she had seen. Thus, when Frank sent his daughters by Akilina to the Herman Orphanage in Kodiak, some of his grandchildren were living nearby in the Baptist Orphanage.

What became of the Lowells? The trail grows cold after Eva Lowell Revell Simon's death. Her children, Harry E. Revell and Frank Revell, moved to Oregon and Washington. The Resurrection Bay Historical Society has letters from Eva's son Frank, written in 1976 when he was in his seventies, recounting a trip to visit his grandfather

In the archives of the Kodiak Baptist Orphanage, a single file card records the date William Lowell left his children there. Dated July 1907, it shows several payments he made for their care.

Photo courtesy of USGS archives in Denver, Colorado

Frank and Mary Lowell's story is not unusual. There were thousands of European fur traders who depended upon Native women, as companions, wives, mothers of their children, and unofficial members of the work force. The wives of Alaska Commercial Company boat captains in this photo probably shared in the daily work of transporting hunters and furs.

Frank Lowell in 1913. His letter of June 29, 1976 recalls that his mother passed down to him a watch that belonged to Frank Lowell, his grandfather. Today, this watch resides in the Lowell exhibit of the Seward Museum. There are letters written in the 1970s from Rita Lowell Johnson, Eva's only daughter, living in Oregon, crippled with arthritis and wheelchair-bound, keeping in touch with old friends still living in Seward. In one letter Rita describes her mother and Andy Simon's home, which Rita had inherited, sliding into Kenai Lake during the 1964 earthquake.

In the archives of the Kodiak Baptist Orphanage, a single file card records the date William Lowell left his children there. Dated July 1907, it shows several payments he made for their care. Most records from the orphanage were lost in a 1925 fire, but in the few remaining copies of newsletters sent back east to sponsoring churches, there are hints about the lives of the Lowell children. William's daughter Eva died before the census of 1910, and Alexandra died from tuberculosis in 1912. Young Frank disappears from the records, but in 1921 John's name appears in the newsletters as a young man coming of age and ready to leave the Kodiak Baptist Orphanage after residing there for 14 years.

In April 1911, William Lowell married Elena Berestov. They had one child, Mamie, before Elena died in 1913. In September 1916 Mamie joined her half-brothers living in the Baptist Orphanage. The only record of little Mamie found in the orphanage archives is a photo of her, standing with her sewing class, proudly holding up a newly stitched white apron.

To date no Herman Orphanage records have been found of Frank's children while they lived there. Church archives and other records may yet tell us about Mary's heritage. Her voice, like the voices of Native women who married white fur traders, is silent on the subject.

There is no doubt that in Alaska the very survival of fur traders depended upon the skills and companionship of Native women like Mary Lowell. A glance at the clothing worn by U.S. Geological Survey (USGS) surveyors in the late 1890s, with their fur coats, leggings, and moccasins, tells of survival in a harsh wilderness made possible by the work of Native women. Photos taken by USGS surveyor Mendenhall in 1898 show the Native wives of the crew of the ACC schooner *Olga* assisting with the crew work. White traders married local Native women who worked alongside them and provided companionship. They were unofficial members of the workforce.

The Lowells may be gone, but their story lives on at Kenai Fjords National Park on Resurrection Bay, where Frank maintained his hunting and trading business. Several geographical places in Seward such as Lowell Point, Lowell Canyon, Mount Eva, and Mount Alice (named for Eva's sister) are all within sight of the original Lowell homestead on the shore of Resurrection Bay. Interwoven with the history of the Alutiiq people, the Russian colony, and the Alaska Commercial Company, the Lowells' story documents the human side and the personal experiences of the people who hunted and traded furs in Alaska.

Photograph courtesy of the Seward Museum

Eva on front porch of the family cabin, Resurrection Bay, 1902. Eva Lowell, youngest daughter of Frank and Mary Lowell lived with her mother and two younger brothers in the family cabin until her marriage in 1903 to Harry Revell. She was always proud of her father's connection to the Massachusetts/Maine Lowells, as evidenced in the caption written on the bottom of this photo.

REFERENCES

Alaska Commercial Company Records.
Archives, University of Alaska Archives,
Elmer E. Rasmuson Library, Fairbanks. 1868-1911.

Barry, Mary J. 1986.
Seward, Alaska: A History of the Gateway City.
Volume I: Prehistory to 1914. Anchorage: MJP Barry.

Barry, Mary J. 1995.
Seward, Alaska: A History of the Gateway City.
Volume III: 1924-1993. Growth, Tragedy, Recovery, Adaptation. Anchorage: MJP Barry.

Cook, Linda and Frank Norris. 1998.
A Stern and Rock-Bound Coast: Kenai Fjords National Park Historic Resource Study.
Anchorage, AK: NPS Alaska Support Office.

Crowell, A.L., A.F. Steffian, and G.L. Pullar, ed. 2001.
Looking Both Ways: Heritage and Identity of the Alutiiq People. Fairbanks: University of Alaska Press.

Langdon, Steven J. 2002.
"Aleuts," in The Native People of Alaska.
Fourth edition, edited by Edward Bovy.
Anchorage, AK: Greatland Graphics.

Looking Both Ways, Museum Exhibit. 2003.
Women at Work and Cycle of Life.
Alutiiq Museum and Archaeological Repository, Kodiak, AK.

Lowell, Delmar R. 1899.
The Historic Genealogy of the Lowells of America, From 1639 to1899.
Rutland, VT: The Tuttle Company Printers.

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Smithsonian Institution photograph

Dan Anahonak (Nanwalek) and Forest Kvasnikoff (Port Graham) at the Early Contact Village Site, Aialik Bay, 2003. **See story page 33.**