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Assessment of Coastal Water Resources and Watershed Conditions

Kenai Fjords National Park

Natural Resource Report NPS/NRPC/WRD/NRR—2010/192




ON THE COVER
Top left: Bear Glacier; top right: Holgate Glacier; bottom left: Nature center at Exit Glacier area; bottom right: Aialik Cape. Photographs by S. Nagorski.

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Executive Summary

This assessment of coastal water resources and watershed conditions in Kenai Fjords National Park (KEFJ) is provided in response to the National Park Service (NPS) Natural Resource Challenge, initially funded by the U.S. Congress in 2003 to assess the environmental conditions of NPS units. KEFJ is part of the Southwest Alaska Network (SWAN), which also includes the Alagnak Wild River (ALAG), Aniakchak National Monument and Preserve (ANIA), Katmai National Park and Preserve (KATM), and Lake Clark National Park and Preserve (LACL). The SWAN units are currently implementing a Vital Signs Monitoring Program, part of the NPS Inventory and Monitoring (I&M) Program, in which baseline inventories and long-term monitoring are being designed and conducted.

Physical, Oceanographic, and Climatic Setting

The 271,132 hectare (669,983 acre) Kenai Fjords National Park (KEFJ) is located along the southeastern side of the Kenai Peninsula in southcentral Alaska. Accessible by road only to the Exit Glacier, approximately 15 km (9 mi) from the town of Seward, the snow- and ice-dominated park is largely seen and accessed from the coast via tour boats and kayaks. The coastline is characterized by extensive fjords, numerous offshore islands and sea stacks, and abundant marine wildlife. The park lies along an active continental margin, making it highly prone to earthquakes, sudden sea level changes, and resulting tsunamis. KEFJ includes a large portion of the Harding Icefield, which covers large portions of the eastern slope of Kenai Mountains and is the second largest icefield entirely within U.S. borders. Coastal streams terminate in bays, fjords, and lagoons that deeply indent the southwest to northeast-trending coastal boundary of the Kenai Peninsula. Most of the watersheds are at least partially of glacial origin, and some include substantial lakes. The offshore islands, sea stacks, and rock spires (including Chiswell, Harbor, and Pye island group) are part of the Alaska Maritime National Wildlife Refuge and not under the jurisdiction of the National Park Service. Additionally, Alaska Native corporations Port Graham Corporation and English Bay Corporation hold title to approximately 49,000 ha (122,000 acres) of Native-owned land, which is mostly along the coast. The State of Alaska owns approximately 7,700 ha (19,000 acres) of land within KEFJ.

KEFJ has a maritime climate characterized by frequent cloudiness and precipitation, strong winds, and relatively mild temperatures. Annual precipitation increases dramatically toward the interior of KEFJ and can exceed 380 cm (150 in) in the Harding Icefield. There are a number of weather stations in and around KEFJ, and the SWAN I&M Program now has remote automated weather stations (RAWS) at two sites within KEFJ—McArthur Pass and Harding Icefield.

Hydrologic Information

Most streams in KEFJ are unnamed, short (<5 km), and either carry glacier runoff or drain small, rugged coastal watersheds that rim the fjords and bays. Watersheds extend from sea level to greater than 1,500 m (~5,000 ft) in elevation on the Harding Icefield. Exit Creek is the main water body targeted for long-term monitoring by the SWAN. Several U.S. Geological Survey (USGS) gages have historically been operational on streams whose watersheds are at least partially contained within KEFJ (on the Nuka and Resurrection rivers), and currently only river stage is continuously recorded (by the National Weather Service River Forecast Office) at two sites: on Exit Creek (in KEFJ) and the Resurrection River (outside the NPS boundaries). Exit Creek is being developed for seasonal streamflow gaging under the I&M Program. Several dozen small lakes dot the coastal landscape of KEFJ, but there are no major lakes such as those in LACL and KATM. No known studies have been conducted on the physical or chemical attributes of these lakes. No groundwater resources in KEFJ have been inventoried or described except for an isolated survey of groundwater conditions in the Exit Creek glacier area.

The majority of glaciers in KEFJ are part of the Harding Icefield, which is about 80 km long and 50 km wide and contains glaciers that cover approximately 1800 km^2 (695 mi^2). Most of the glaciers in KEFJ have been retreating since the end of the Little Ice Age (~250 yrs ago) and continue to retreat today. Early glaciological studies estimated a 5% decrease in glacial ice coverage for the Harding Icefield between the early 1950s and mid-1980s, and an average retreat rate of 27 m/yr during the 20th century for six land-terminating glaciers on the west flank of the Harding Icefield. The SWAN I&M Program has identified glacier extent as an important vital sign to monitor and is using satellite imagery (primarily Landsat) to monitor changes in glacial coverage. Data indicate that glacial area within the boundaries of KEFJ decreased by 21.7 km^2 (8.4 mi^2) or 1.6% between 1986–2000 and that nunataks on the Harding Icefield have shown a 30% increase in mean increase in area between the 1950s and 2005. Current monitoring efforts include repeat center line laser altimetry surveys conducted in 1994, 2002, and 2007 that provide information about rates of glacier elevation and volume change. Kenai Fjords National Park is also cataloging repeat photographs that document changes in glacier extent and is measuring the surface velocity of the ice at the terminus as well as the terminus position of Exit Glacier. In 2009, KEFJ initiated mass-balance monitoring on Exit Glacier, and two other glaciers are planned.

Biological Resources

The NPS I&M Program's inventories completed in 2001 listed 660 vascular plant species (136 confirmed as present), 40 fish species (30 confirmed as present), 210 bird species (188 confirmed as present), and 54 mammal species (42 confirmed as present) as occurring in KEFJ. Several of the marine mammal species, including Steller sea lions and harbors seals that haul out in and near the park, have experienced precipitous population declines. Diverse and numerous species of marine fishes occur off the KEFJ coast. Coastal KEFJ hosts abundant seabird populations that include tufted and horned puffins, black-legged kittiwakes, glaucous-winged gulls, common murres, Kittlitz's murrelets (a candidate species for listing as threatened), and many others. The National Park Service cooperates with the Alaska Maritime National Wildlife Refuge in surveying bird colonies along the Kenai Peninsula coast. Marine nearshore vital signs monitoring by the SWAN I&M Program include marine water chemistry, kelp and eelgrass, marine intertidal invertebrates, marine birds, black oystercatcher, and sea otters.

The SWAN I&M Program's freshwater fishes inventory process confirmed the presence of 13 freshwater fish species within KEFJ, although other studies identified an additional 11 species with ranges that included KEFJ. The I&M Program predicted (but did not confirm) another 29 species considered tidepool or estuarine. Information on aquatic invertebrates is limited to Delusion Creek, where taxa were largely represented by chironomids, mayflies, and stoneflies. Studies in the Delusion Creek and Lake system included measurements of zooplankton densities and chlorophyll-a concentrations. The biological development of this stream-lake system in response to glacial retreat followed the same general patterns as observed in watersheds in Glacier Bay National Park and Preserve.

Upland areas have been inventoried and described according to ecological systems, landcover classes, and plant associations. In recently deglaciated watersheds or those with actively retreating glaciers, a predictable sequence of vegetative succession occurs along age gradients of newly exposed soils, as described for the outwash plain formed in front on the retreating Exit Glacier. As part of the I&M Program, vegetation composition and structure are being monitored in the SWAN using Landsat TM/ETM+ satellite images, orthorectified aerial photos and high-resolution IKONOS imagery, as well as ground-based monitoring.

A mammal inventory conducted throughout the SWAN in 2003–2004 provided confirmation of many species in KEFJ, from cinereus and montane shrews to mountain goats and moose, as well as recording of four new species. A summer landbird inventory detected 101 species of birds, including 62 species of landbirds—most commonly hermit thrush, orange-crowned warbler, and Wilson's warbler. The Nuka and Resurrection river corridors are particularly important habitats for regional landbirds.

Water Quality Assessment

Water, sediment, and biologic quality in marine waters was surveyed in 2002 by the State of Alaska as part of the nationwide Environmental Monitoring and Assessment Program, which showed that water and sediment quality conditions in the Gulf of Alaska region were very high. Pedersen Lagoon and Quicksand Lagoon were surveyed by SWAN staff in 2003/2004. Water quality specifically in KEFJ fjords and lagoons was studied in 2007 by the USGS and again showed healthy conditions. Spatial variations in temperature, salinity, turbidity, chlorophyll-a, and nutrients were evaluated in terms of distance from glacial sources.

Vital signs monitored by the SWAN I&M Program were chosen based on ecological significance and relevance to SWAN resource management issues. Those that are directly related to the marine nearshore include marine water chemistry, kelp and eelgrass, marine intertidal invertebrates, marine birds and mammals, black oystercatchers, bald eagles, and sea otters. Vital signs related to freshwater resources include surface water hydrology, freshwater chemistry, and landscape processes. Results of an NPS water quality review found no 303(d) impaired waters present within KEFJ, and concluded that although water quality collection has been sporadic, conditions appear to be generally good with low nutrient levels and little evidence of anthropogenic impacts. For future long-term monitoring of water quality, SWAN streams and lakes were categorized into three tiers by using a ranking procedure that considered access, level of use/management issues, and ecological and spatial cover. In KEFJ, Exit Creek/Resurrection River was identified as Tier 1 (targeted for annual monitoring), and the Nuka River and Delusion Lake were designated as Tier 2 (targeted for sampling every 2–5 years).

Very few water quality data exist for streams within KEFJ. The largest source of information is an inventory of 62 sites in streams, lakes, and lagoons that was conducted in the summers of 2003 and 2004 by the National Park Service. Parameters measured were temperature, pH, conductivity, specific conductance, dissolved oxygen, and turbidity, and results showed very high water quality throughout the surveyed area. Other sources of information include historical USGS sampling of the Nuka and Resurrection rivers and Exit Creek, a study on macroinvertebrates and salmonids in three lake systems on the McCarty Peninsula, a hydrologic and biologic survey of the uppermost reach of the Nuka River, and some unpublished geochemical reconnaissance work in the historic mining areas of the Nuka River region.

Generally, all water quality and biologic investigations showed the streams to be within normal ranges for glacial streams. The only exception was in the historic mining area, where an anomalously high arsenic reading was found downstream of the Little Creek Prospect. Follow-up reconnaissance of the area led to the remediation of the mine tailings site in 1998. Information on the water quality of lakes is limited to studies of Delight and Desire lakes by several different researchers, and a single-event survey of eight lakes and ponds in the Harris Bay and Two Arm Bay lakes area for basic parameters (temperature, dissolved oxygen, pH, and turbidity).

Threats to Coastal Resources

The release of petroleum poses a great environmental threat, whether as catastrophic spills or from chronic discharges. In addition to physical impacts of large spills, the toxicity of many of the individual compounds contained in petroleum is significant, and even small releases can kill or damage organisms. Swift currents and large tidal ranges can quickly transport released petroleum great distances and over wide coastal zones, as evidenced by the *Exxon Valdez* Oil Spill (EVOS) in 1989. As a result of EVOS, oil affected approximately 20 mi (32 km) of coast within KEFJ. Future oil spills similar in scale to that of EVOS continue to be possible in the region. Potential source areas include the Valdez Marine Terminal (Prince William Sound); Drift River Marine Terminal (Cook Inlet); Nikiski Oil Terminal and Refinery (Cook Inlet); and 17 gas and seven oil producing fields within Cook Inlet. Several more oil and gas sales are currently proposed for development over the next 5 years in the Cook Inlet region. Not only are these activities subject to inevitable human error, but they are located along an extremely active volcanic and seismic area.

The ShoreZone mapping program computed an "Oil Residence Index" (ORI) along coastal KEFJ that was developed from data on wave exposure levels and substrate types. Geographic Response Strategies (GRS) and Potential Places of Refuge (PPORs) are in place for certain areas of KEFJ. The identification of these PPORs should reduce the response time and regional environmental damage in the event of a spill from a distressed vessel, but it is also likely that the PPOR used in such an event will experience a disproportionately large amount of impact.

Visitor tour boats and cruise ships travel in the immediate vicinity of KEFJ, and fishing vessels of all sizes are abundant in the Gulf of Alaska in general. No analyses of marine vessel impacts have been conducted for the KEFJ coast, but marine vessels have the potential to degrade water quality by the accidental release of petroleum products, the release of wastewater or other discharges, or by resuspension of sediments. The effects to water quality along coastal KEFJ are most likely temporary and limited to the immediate area of vessel traffic.

Global atmospheric pollutants such as mercury (Hg) and persistent organic pollutants (POPs) may enter KEFJ by atmospheric deposition and via transport and deposition by spawning salmon that accumulate these toxins in the marine environment. These contaminants biomagnify up trophic levels, and Hg has shown significant concentration increases over the last few decades. Several studies in southern coastal Alaska (focusing on sea bird eggs, lake sediments, and streambed sediment) indicate the region is being affected by these contaminants and deserves further evaluation and monitoring. The recently published results of the Western Airborne Contaminants Assessment Project, which were based on samples from three NPS units in Alaska, showed that contaminants were found in all park units studied. Very low concentrations of most current-use chemicals were found; however, the occurrence of historic-use compounds in Alaska matching levels found in the lower 48 states further suggests that Alaska is being affected by atmospheric transport from global sources. Contaminant monitoring has begun in the SWAN, although most of the effort is focused in LACL and KATM. The only Mercury Deposition Network stations in Alaska are in Kodiak (operated by the State of Alaska since 2007) and in Bartlett Cove (in GLBA; operation by the National Park Service beginning in 2009); these sites will be instrumental for tracking Hg levels in southern Alaska.

Climate change is increasingly being recognized as an important natural resource issue for national parks in Alaska. Climate warming is amplified at higher latitudes, and Alaska's climate has warmed by approximately 2.2 ºC (4º F) since the 1950s and is projected to rise an additional 2.8–10 ºC (5–18 ºF) by 2100. The environment and water resources of KEFJ are highly susceptible to climate change in large part because more than half of KEFJ is covered by glacial ice and permanent snowfields, the volume and extent of which are diminished by climate warming. Recent research on the Lower Kenai Peninsula has shown that water temperatures in salmon streams in this area regularly exceed 13˚C, which is the State of Alaska standard for egg and fry incubation. The Harding Icefield, much of which is contained in KEFJ, has been shrinking and thinning at a rate of approximately 0.61 ± 0.12 m/yr (2.00 ± 0.39 ft/yr) since the 1950s. Glacial runoff strongly influences the physical and biological characteristics of streams within and around KEFJ; thus changing glacial coverage has important implications for aquatic ecosystems (both freshwater and marine) in KEFJ. In the near term, it is likely that increased runoff associated with glacial wastage will lead to the creation of new streams and lakes and alter the sediment, streamflow, and temperature regimes in surrounding streams. Climate warming also has the potential to affect the occurrence of lakes and ponds within KEFJ based on recent research from the Seward and Kenai peninsulas that has demonstrated a substantial landscape-level reduction in surface water area as well as the number of closed-basin ponds. However, within KEFJ the formation of new lakes associated with continued glacier recession may offset any loss of lakes associated with permafrost degradation.

Unlike the other SWAN units, KEFJ does not contain any active volcanoes, although regional eruptions outside of KEFJ can impact park resources. Earthquakes have been a powerful force of geomorphologic and ecologic change along the Kenai coast. The largest modern earthquake occurred in 1964, when the largest earthquake in North America occurred in the northern Prince William Sound and caused land around the Kenai Mountains to drop more than 2 m (6.6 ft), in turn causing geomorphological and vegetative changes along the KEFJ coast. In the three decades following the 1964 earthquake, the KEFJ coastline has been uplifted up to 40 cm, as determined from GPS measurements and water level recorders. Current uplift rates currently outpace the rise of global sea-level, which is approximately 1.8 mm/yr. In 2004, the USGS created a map of the coastal change potential of the KEFJ shoreline to future sea-level changes and concluded that overall, areas in KEFJ most susceptible to sea-level changes are tidewater glaciers and outer coast shorelines of unconsolidated sediment.

Visitor use of KEFJ has increased nearly twenty-fold since 1982 and is concentrated in the Exit Glacier area. Glacier and wildlife cruises are becoming an increasingly popular way of exploring the coastline, with numerous tour boats departing from Seward daily during the summer. The vast majority of visitors to the park do not overnight, although the campground and public use cabins are in high demand. Winter snowmobiling at the Exit Glacier area is growing in popularity as well. Potential impacts from visitor use include wildlife disturbance and displacement; damage to soil and vegetation; spreading of exotic/invasive species; fuel spills from motorized vehicle/airplane use; noise pollution from visitors and motorized vehicles; air pollution from watercraft and snowmobiles; stress imposed on marine mammals targeted for close viewing by tour boats and kayakers; damage of nesting sites along beaches; and human-bear interactions. One potentially vulnerable species, the black oystercatcher, nests on beaches; however, its nesting success was not affected by recreational usage.

The vast majority of all backcountry camping occurs at about 30 sites in Aialik Bay and Northwestern Lagoon. Monitoring of the impacts of camping on cultural and natural resources in the park is currently being developed, although surveys to date have identified fire rings, charred wood, cut stumps, root exposure, vegetation trampling, trash, human waste, soil erosion, campsite proliferation, increased human-wildlife interactions, and social trails as some of the impacts by camping activity in these heavily-used sites. The Harding Icefield Trail (HIT) at Exit Glacier has been receiving increasingly heavy use during the summer months. For the past several summers, KEFJ staff has been regularly flagging the trail to help prevent visitors from hiking off the trail and causing vegetative damage and erosion.

In 2008, the only lodge within KEFJ was constructed on 10 acres of Native-owned (Port Graham Corporation, PGC) land along the eastern shore of Pedersen Lagoon. The Kenai Fjords Glacier Lodge, operated by Alaska Wildland Adventures, includes approximately 800 ha (2,000 acres) of land surrounding the development that will be known as the Pedersen Lagoon Wildlife Sanctuary. The development, maintenance, and operation of this lodge will undoubtedly provide some level of disturbance to birds and marine and terrestrial wildlife in this biologically rich area that contains the highest species diversity along the KEFJ coast.

Several mining sites are located in the Historic Mining District of Nuka Bay. Mining claims at the Goyne (or Waterfield) prospect remain administratively active. Surveys of water quality conditions in the area found detectable, and in some cases high, concentrations of metals. Mine tailings were removed from the Beauty Bay site in 1998, and other remedial actions were suggested and then retracted at the Sonny Fox Mine along Babcock Creek. A 2007 mine site condition assessment report, which assessed the mines as cultural resources, categorized two of six surveyed sites to be in good condition (Alaska Hills Cabin and Alaska Hills Mill &Mine); three to be in fair condition (Glass & Heifner Mine, Rosness Larson Mine Site, and Sonny Fox Mine); and one site (Nuka Bay Mine) to be of unknown condition due to snow cover at the time of the assessment. No further remediation of mining contaminants is currently planned. Two mine openings were closed at the Nuka Bay Mine in 2008. Six mine openings are planned for closure in 2010. The Surprise Bay No.1 is the only remaining active federal mining claim in the District

The hydrologic setting of the Exit Glacier area (including the KEFJ nature center and trails) and the road leading to it has proven to be complex in terms of flood prevention and abatement. The primary source of flooding to the Exit Glacier area is a tributary stream to Exit Creek that easily floods during the fall months when rainstorms are large and frequent. The foundation of the nature center could be compromised following prolonged exposure to flow. The six channel crossings present between the nature center and the end of the nature trail were identified as being undersized for even small (two-year) flood events. Another unintended consequence to these diversions is deprivation of flow to an adjacent wetland area, potentially producing deleterious effects on the wetland floral community. In addition to the flooding in the nature center area, flooding also occurs along the portion of the Exit Glacier access road that crosses floodplain and wetland environments supported by both the Resurrection River and Exit Creek as well as at the maintenance facility on Old Exit Road.

Water rights have been an issue in the uppermost section of the Nuka River. Concern for NPS resources stems from the partial diversion of flow from this upper reach of the Nuka River toward the Bradley Lake Hydroelectric Project. However, by 2003 and as the Nuka Glacier has retreated, its outflow was greatly shifted toward Bradley Lake, leaving the upper ~1 km of the Nuka River dry during portions of the year. It was not clear if this change was entirely natural or if it was intensified by the diversion structures. The National Park Service directed a habitat assessment and biological inventory of the area, and currently there is little concern that the natural hydrologic changes threaten the biological integrity of the Nuka River.

Exotic plants are a management concern to the National Park Service because they can hybridize with native flora, can outcompete resident species for limited resources, and can change the structure and function of ecosystems through alterations of biogeochemical and geophysical processes. KEFJ has been following the Alaska Region’s Exotic Plant Management Team protocol to try to eradicate exotic plant populations, which typically are concentrated along roads and trails and at campsites and other places used by visitors. The main area of infestation by exotic plants in KEFJ is along the Exit Glacier road and parking lot.

The continued northward migration of escaped farmed Atlantic salmon and other non-native migrating species pose threats to indigenous salmon and trout and their stream communities. The increase in visitor use along the coast may result in the import of exotic species to the area in the near future. Concerns also include spruce beetle infestations and potential arrival of the avian influenza (H5N1) virus in Alaska. Chytridiomycosis, a waterborne infectious disease contributing to severe amphibian declines globally, has been detected in southcentral and southeast Alaska. Wood frog populations are not known to occur currently within KEFJ, but it remains unclear as to whether chytrid fungus could have impacted populations historically.

Our condition assessment of water resources-related indicators and current/potential stressors of aquatic resources in Kenai Fjords National Park is summarized in the table below.

Indicator	Freshwater	Intertidal, Bays, Estuaries & Salt Marshes	Coastal waters
Water Quality			
Nutrients/ Eutrophication	OK	OK	OK
Contaminants	OK	OK	OK
Hypoxia	OK	OK	OK
Temperature	OK	OK	OK
Turbidity (non-glacial)	OK	OK	OK
Pathogens	OK	OK	OK
Habitat Disruption			
Climate change	EP	EP	EP
Oil spills	NA	EP	EP
Aquatic/marine invasive species	PP	PP	PP
Exotic plant species	EP	PP	NA
Insect outbreaks and disease	EP	PP	NA
Coastal development	PP	PP	NA
Water quantity/ withdrawals	OK	NA	NA
Natural geologic hazards	IP	IP	IP
Natural coastal uplift and erosion	OK	IP	OK
Historic mine sites	EP	PP	OK
Logging in private inholdings	OK	OK	OK
Flooding	EP	NA	NA

Indicator	Freshwater	Intertidal, Bays, Estuaries & Salt Marshes	Coastal waters
Recreational usage			
Coastal tour boats and kayaks	PP	PP	PP
Backcountry camping, hiking	PP	PP	NA
Other Indicators			
Harmful algal blooms	NA	OK	OK

Definitions: EP= existing problem, IP= Intermittent Problem, PP = potential problem, OK= no detectable problem, shaded =limited data, NA= not applicable.

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Commonly Used Abbreviations

AC – Alaska Current
ACC – Alaska Coastal Current
ADEC – Alaska Department of Environmental Conservation
ADFG – Alaska Department of Fish and Game
ADNR – Alaska Department of Natural Resources
ALAG – Alagnak Wild River
AMNWR - Alaska Maritime National Wildlife Refuge
ANIA – Aniakchak National Monument & Preserve
ANILCA – Alaska National Interest Land Conservation Act
AVO – Alaska Volcano Observatory
AWA – Alaska Wildland Adventures
BLHP—Bradley Lake Hydroelectric Project
CWA – Clean Water Act
DENA – Denali National Park & Preserve
DNR – Department of Natural Resources
EMAP – Environmental Monitoring and Assessment Program (U.S. EPA)
ENSO – El Niño Southern Oscillation
EPA – U.S. Environmental Protection Agency
EVOS – *Exxon Valdez* Oil Spill
GAAR – Gates of the Arctic National Park & Preserve
GEM – Gulf Ecosystem Monitoring (*Exxon Valdez* Oil Spill Trustee Council)
GLBA – Glacier Bay National Park & Preserve
GRS – Geographic Response Strategies
HAB – Harmful Algal Bloom
HIT – Harding Icefield Trail
I&M – Inventory and Monitoring Program
KATM – Katmai National Park and Preserve (National Park Service Designation)
KEFJ – Kenai Fjords National Park (National Park Service Designation)
LACL – Lake Clark National Park and Preserve (National Park Service Designation)
LIA – Little Ice Age
LTEMP – Long Term Environmental Monitoring Program
MDN – Mercury Deposition Network
NADP – National Atmospheric Deposition Program
NOAA – National Oceanic and Atmospheric Administration (U.S. Department of Commerce)
NOAT – Noatak National Preserve
NPS – National Park Service (U.S. Department of Interior)
NS&T – National Status and Trends (NOAA)
NWI – National Wetlands Inventory (of the U.S. Fish and Wildlife Service)
NWS RFO - National Weather Service River Forecast Office
ORI – Oil Residence Index
PAHs – Polycyclic aromatic hydrocarbons
PCBs – Polychlorinated biphenyls
PDO – Pacific Decadal Oscillation
PGC – Port Graham Corporation

POPs – Persistent Organic Pollutants
PPOR – Potential Places of Refuge
PSP – Paralytic Shellfish Poisoning
SRTM – Shuttle Radar Topography Mission
SQG – Sediment Quality Guidelines
SWAN – Southwest Alaska Network
UAS – University of Alaska Southeast
USDA – U.S. Department of Agriculture
USFWS – U.S. Fish and Wildlife Service (U.S. Department of Interior)
USGS – U.S. Geological Survey (U.S. Department of Interior)
WACAP – Western Airborne Contaminants Assessment Project

1. Purpose and Scope

This assessment of coastal water resources and watershed conditions in Kenai Fjords National Park (KEFJ) in southwest Alaska is provided in response to the National Park Service (NPS) Natural Resource Challenge, initially funded by the U.S. Congress in 2003 to assess the environmental conditions of NPS units. Of particular interest are the threats posed by point source and non-point source pollutants, nutrient enrichment, coastal development and tourism, resource extractive uses, and the spread of exotic species. The Watershed Assessment Program has been tasked with synthesizing existing data, formulating recommendations, and guiding management actions to reduce factors that currently stress, or threaten to stress, the health of NPS watershed resources.

This report provides a synopsis of existing knowledge about KEFJ watersheds, all of which are coastal and drain into the Gulf of Alaska. KEFJ is part of the Southwest Alaska Network (SWAN), which also includes the Alagnak Wild River (ALAG), Aniakchak National Monument and Preserve (ANIA), Lake Clark National Park and Preserve (LACL), and Katmai National Park and Preserve (KATM). These park units are currently implementing their Vital Signs Monitoring Plan, in which baseline inventories and long-term monitoring protocols and plans are being developed for climatic, biological, physical, hydrochemical, and other parameters that are considered to be “vital signs,” or key indicators, of ecological and physical conditions within the park units. The list of vital signs selected for the network is presented in Appendix A of this report. Many products of the ongoing SWAN I&M Program are relevant to this Watershed Assessment effort. Information, bibliographies, and other resources regarding the SWAN I&M Program are found at http://science.nature.nps.gov/im/units/swan/.

2. Park Description and History

2.1. Setting

2.1.1. Geographic Setting

Kenai Fjords National Park is located 209 road km (130 mi) south of Anchorage along the southeastern side of the Kenai Peninsula in southcentral Alaska (Figure 1). This 271,132-ha (669,983 acres) park is bordered to the north by the Chugach National Forest, to the southeast by the Gulf of Alaska, to the south by the Kachemak Bay State Wilderness Park, and to the northwest by the Kenai National Wildlife Refuge. The town of Seward, home to the park’s headquarters, is located 5 km (3 mi) east from the park boundaries. Accessible by road only to the Exit Glacier, approximately 15 km (9 mi) from Seward, the snow- and ice- dominated park is largely seen and accessed from the coast via tour boats and kayaks. Protruding through the massive Harding Icefield as nunataks, the mile-high Kenai Mountains form the spine of the park along its north and western border. Glaciers emanating from the icefield carve deep U-shaped valleys into partially metamorphosed muddy sandstones and shales (with intrusions of granite and granodiorite) that dominate the underlying bedrock (Beikman 1980). The coastline is characterized by deep and extensive fjords, numerous offshore islands and sea stacks, and abundant marine wildlife. The park lies along the convergent plate boundary between the Pacific and North American plates, making it highly prone to earthquakes, sudden sea level changes, and resulting tsunamis (Mann et al. 1998).

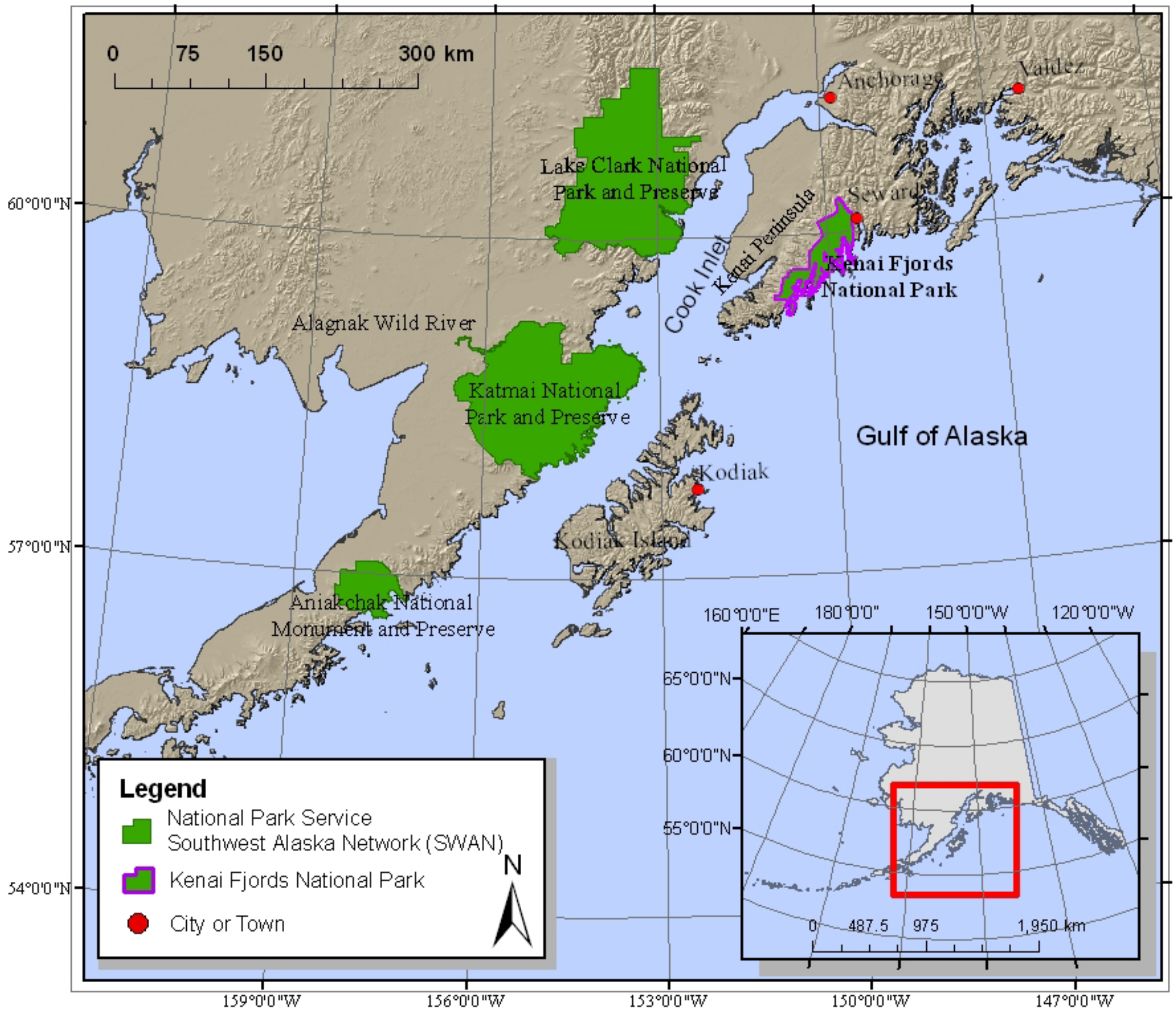


Figure 1. Location of Kenai Fjords National Park and other SWAN NPS units in Alaska.

The most striking physical feature within KEFJ is the Harding Icefield, which covers large portions of the eastern slope of Kenai Mountains and an area of 483 km² (300 mi²), not counting the glaciers that emanate from it. Half of the Harding Icefield is within KEFJ, which also includes a portion of the Grewingk-Yalik Glacier Complex located west of Nuka Bay. The Harding Icefield is one of the four major ice caps in the United States and one of the largest icefields entirely within U.S. borders (Cook and Norris, 1998). The Harding Icefield is a remnant of the expansive ice sheets that covered southcentral Alaska during the Pleistocene glaciations. The icefield has seen periods of glacial advances throughout the Holocene, most recently during the Little Ice Age (AD 1200 to 1900) (Mann 1998, Wiles et al. 1995).

The coastal boundary of KEFJ extends along the mean high tide line from the southern end of the Bear Glacier moraine in lower Resurrection Bay to just south of Yalik Point in Nuka Bay. The coastline includes the main glacial fjords of Aialik Bay, Harris Bay, and Northwestern Fjord, Two Arm Bay, McCarty Fjord, and West and North arms of Nuka Bay (Figure 2). Coastal streams terminate in bays, fjords, and lagoons that deeply indent the southwest to northeast-trending coastal boundary of the Kenai Peninsula. Most of the watersheds are at least partially of glacial origin, and some include substantial lakes. All watersheds in KEFJ drain into the Gulf of Alaska and are therefore included in this coastal watershed assessment report.

The coastline is made up of an intricate system of fjords, drowned cirques, offshore islands, sea stacks, and rock spires comprised of Cretaceous sedimentary rocks as well as Holocene granite and granodiorite (Tande and Michaelson, 2001). Uncommon protected areas hold depositional features such as sand and gravel floodplains, beaches, river deltas, tidal flats and salt marsh systems (Tande and Michaelson 2001). The offshore islands, sea stacks, and rock spires (including Chiswell, Harbor, and Pye Island group) are part of the Alaska Maritime National Wildlife Refuge (AMNWR) and not under the jurisdiction of the National Park Service. Additionally, Alaska Native corporations Port Graham Corporation (PGC) and English Bay Village corporation (EBVC) hold title to the majority of approximately 49,000 ha (122,000 acres) of Native-owned land, which is mostly along the coast (Figure 3). The State of Alaska owns approximately 7,700 ha (19,000 acres) of land within KEFJ (Figure 3).

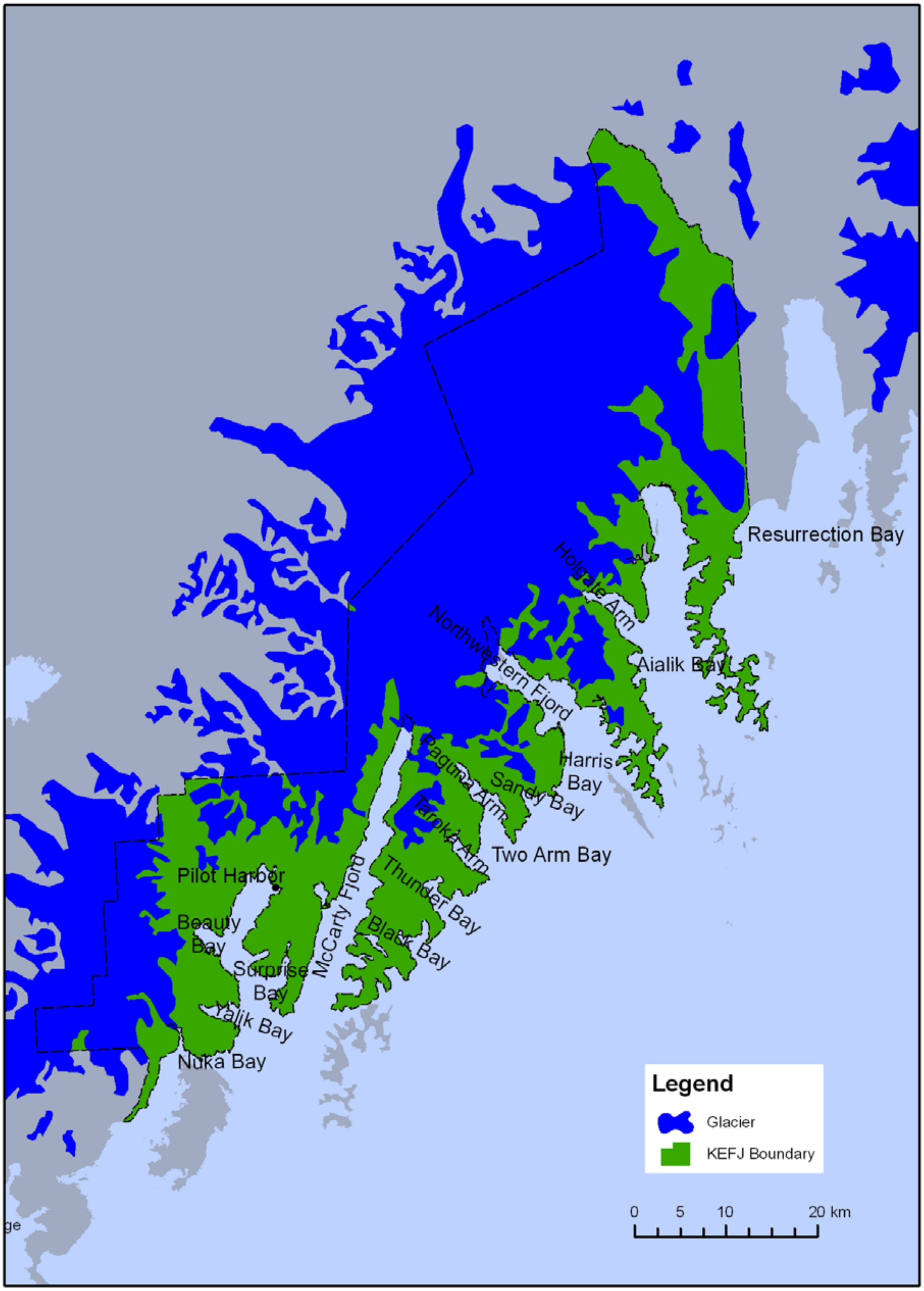


Figure 2. Bays and fjords along the KEFJ coastline.

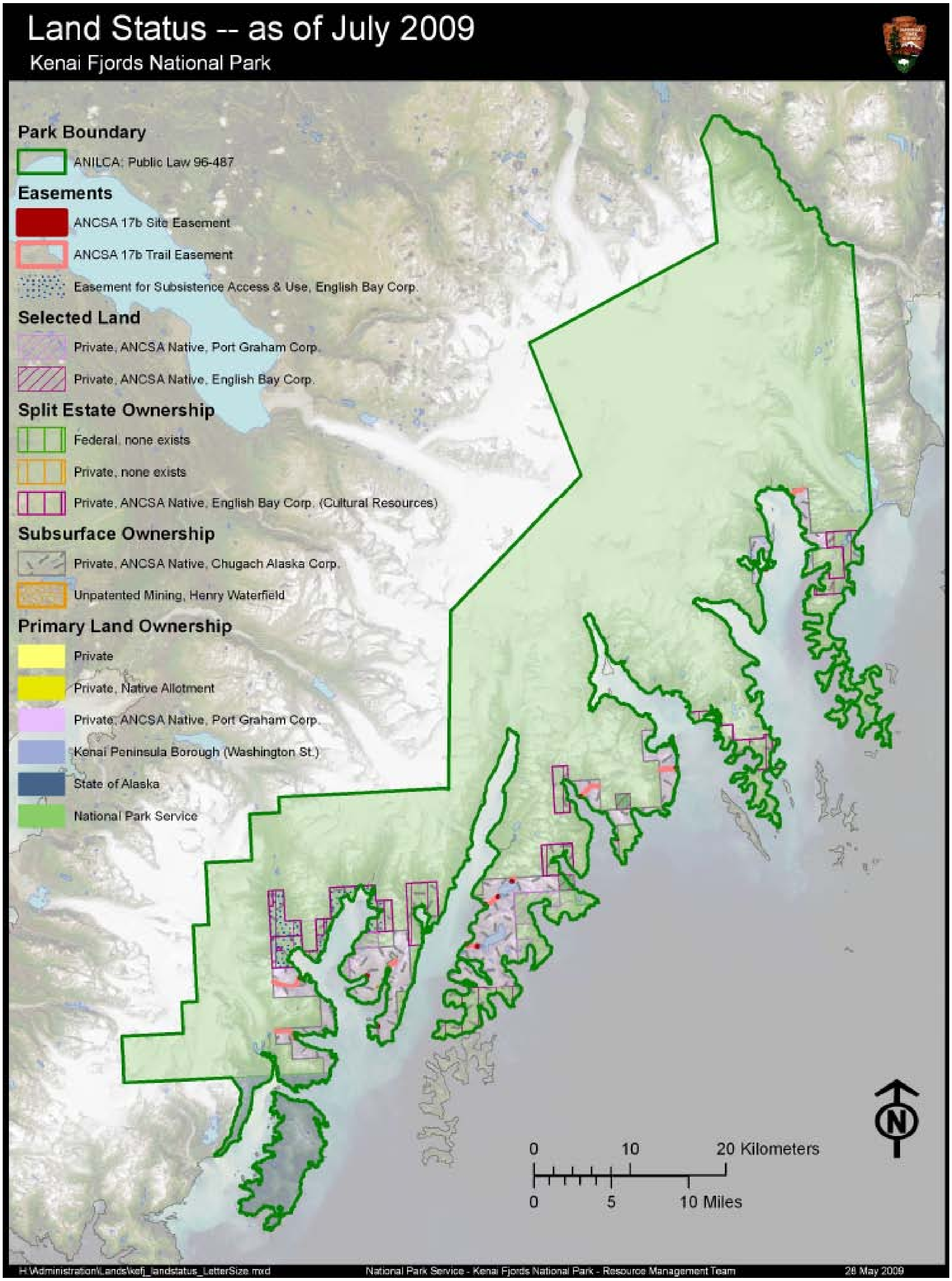


Figure 3. Land status map of KEFJ. Map by Fritz Klasner, National Park Service, 2009.

2.1.2. Human Utilization

The earliest inhabitants of the Kenai Peninsula outer coast were one of the easternmost groups of the Pacific Eskimos, who may have migrated from Kodiak Island or the Alaska Peninsula (Cook and Norris 1998). There is almost no archeological information prior to approximately 800 years ago, and this absence is likely due to the obscuration of sites as a result of tectonic subsidence during a major earthquake about AD 1170 (Crowell and Mann 1996). Archaeological investigations have resulted in little consensus over which subgroups of the Eskimos inhabited the coastal region of the Kenai Peninsula, where Native inhabitants are known as the Alutiiq Chugach. Archeological studies have shown conflicting evidence for habitation by the Chugach, Unixkugmiut, and Unegkurmiut peoples along the Kenai coast. Archaeological investigations in the region also suggest that the coastal peoples lived with little cultural exchange for approximately 500 years prior to European contact.

At the time of Russian contact in about 1780, there were an estimated 600 inhabitants of the southern Kenai Peninsula, of which an unknown number were from the coastal region (Oswalt 1967). There were an unknown number of villages along the coast, but the village of Yalik is the only one within KEFJ boundaries (located in Yalik Bay) to survive by name into historic times, being mentioned in a Russian census in 1880 (Cook and Norris 1998). With the arrival of Russians to the Kenai Peninsula came tremendous suffering from disease, hostilities, forced labor, and relocation that destroyed the structure of Native communities, and their populations plummeted (Cook and Norris 1998). However, hunters and trappers continued to use the coast for many decades thereafter, until the 1940s. An extensive history of European and American hunting (particularly of marine mammals), trapping, hunting, gold mining, fishing, and early tourism along the Kenai coast is provided in Cook and Norris (1998).

Attention by federal and state governments given to the Kenai Peninsula’s coastal fjord region before the 1960s was limited to a handful of U.S. Geological Survey (USGS), Bureau of Mines, and U.S. Coast and Geodetic Survey, and Fish and Wildlife Survey investigations (Cook and Norris 1998). Then in 1968, the Alaska Field Office of the National Park Service evaluated the Harding and Sargent Icefields and unsuccessfully recommended them for inclusion in the National Natural Landmarks program. In the 1970s, much of the present KEFJ area was recommended to be made a national recreation area with mixed land use provisions. However, in 1971, passage of the Alaska Native Claims Settlement Act put specific land designations on hold until the 1980 passage of the Alaska National Interest Lands Conservation Act (ANILCA), which designated KEFJ as a National Park (KEFJ became a national monument in 1978). The park’s mandate was “to maintain unimpaired the scenic and environmental integrity of the Harding Icefield, its outflowing glaciers, and coastal fjords and islands in their natural state; and to protect seals, sea lions, other marine mammals, and marine and other birds and to maintain their hauling and breeding areas in their natural state, free of human activity which is disruptive to their natural processes.”

2.2. Hydrologic Information

2.2.1. Oceanographic Setting

The coast of KEFJ is characterized by a series of fjords and offshore islands along the edge of the Gulf of Alaska. Fjords are deep, high-latitude estuaries that have been or are presently excavated by land-based ice (Syvitski et al. 1987). Seismic surveys of the continental shelf off the KEFJ coast indicate that bathymetric variations are the result of erosion, tectonism, and proglacial deposition (von Huene 1966). Within fjords, water is often highly stratified along density gradients resulting from strong temperature and salinity gradients. Little is known specifically about the oceanography of the coastal waters bordering KEFJ, but information from a nearby fjord, Resurrection Bay, provides insight. Recurring seasonal cycles drive flushing and renewal of the deep basin water in Resurrection Bay with water from the Gulf of Alaska during the summer months (Royer 1975). As upwelling occurs in the Gulf of Alaska onto the continental shelf, dense water rushes into Resurrection Bay, renewing the deep water there. This deep-water renewal begins in April–May and continues with multiple replacements through September–October (Heggie and Burrell 1981). During the winter, between renewal periods, Resurrection Bay basin is well stratified, with low dissolved oxygen in deep waters (Burrell 1983). Arimitsu et al. (2008) took measurements of currents and tidal discharge within two KEFJ fjords. Measurements along cross sections in Aialik and Northwestern fjords showed low current velocities at the faces of the glaciers, high velocities over submerged moraines, stratification from freshwater input, and occasionally high tidal discharges (maxima occurred on 8/15/07 and were 12,300 m^3/s and 10,100 m^3/s in Aialik and Northwestern fjords, respectively). Complex flow patterns in the fjords were efficient at inducing mixing of sediment-laden freshwater with waters from the Gulf of Alaska.

The Gulf of Alaska is bordered by the Alaska Peninsula to the northwest and the Canadian mainland at Queen Charlotte Sound to the southeast (Figure 4). Dominant habitats include continental shelf, slope, and abyssal plain. The continental shelf area of the Gulf of Alaska represents more than 12% of the continental shelf holdings of the United States (Hood and Zimmerman 1986). The width of the continental shelf ranges from 5 km in the southeast to nearly 200 km around Kodiak Island (Weingartner 2005). Abyssal depths (>7,000 m) occur in the northwest portion of the Gulf of Alaska within the Aleutian Trench. Fjords, convoluted shorelines, underwater canyons and ridges, and multiple islands create a mosaic of geological features that contribute to a complex oceanographic domain. Offshore circulation is dominated by a cyclonic subarctic gyre. The sluggish, easterly-flowing North Pacific Current bifurcates near 52° N and becomes the Alaska Current (AC) northward (Figure 4) and the California Current southward. The Alaska Coastal Current (ACC), inshore of the AC, is a low-salinity, cyclonic (counter-clockwise), fast-moving (13–133 cm/s) current driven by winds and density gradients established through freshwater input (Hood and Zimmerman 1986). Precipitation within the Gulf of Alaska ranges from 2 to 6 m per annum (Weingartner et al. 2005). The region is affected by intense winter storms that frequently become trapped or stalled by the surrounding rugged coastal topography (Royer 1998; Wilson and Overland 1986). Persistent cyclonic winds, coupled with onshore surface Ekman transport (movement of surface waters from the wind and Coriolis effect), promote downwelling favorable conditions for much of the Gulf of Alaska; however, episodic and local upwelling may be generated by eddies or other local geography. Despite predominant downwelling, the Gulf of Alaska is a productive ecosystem. Nutrients are supplied from small-scale upwelling, eddies, shear, Ekman transport, resuspension of shelf sediments, and river discharge (Stabeno et al. 2004). Eddies are frequently generated off the British Columbia coast (Crawford et al. 2002) and in Southeast Alaska near Sitka and propagate through the Gulf of Alaska along the ACC. Eddies in the Gulf of Alaska range from 10 to 50 km and normally persist for one to four weeks (Bograd et al., 1994). The arrival of eddies to the shore may increase larval recruitment via entrainment of fish and shellfish larvae within water conditions favorable to survival (Incze et al. 1989, Schumacher et al. 1993), whereas the generation of eddies may decrease larval recruitment via advection (Sinclair and Crawford 2005).

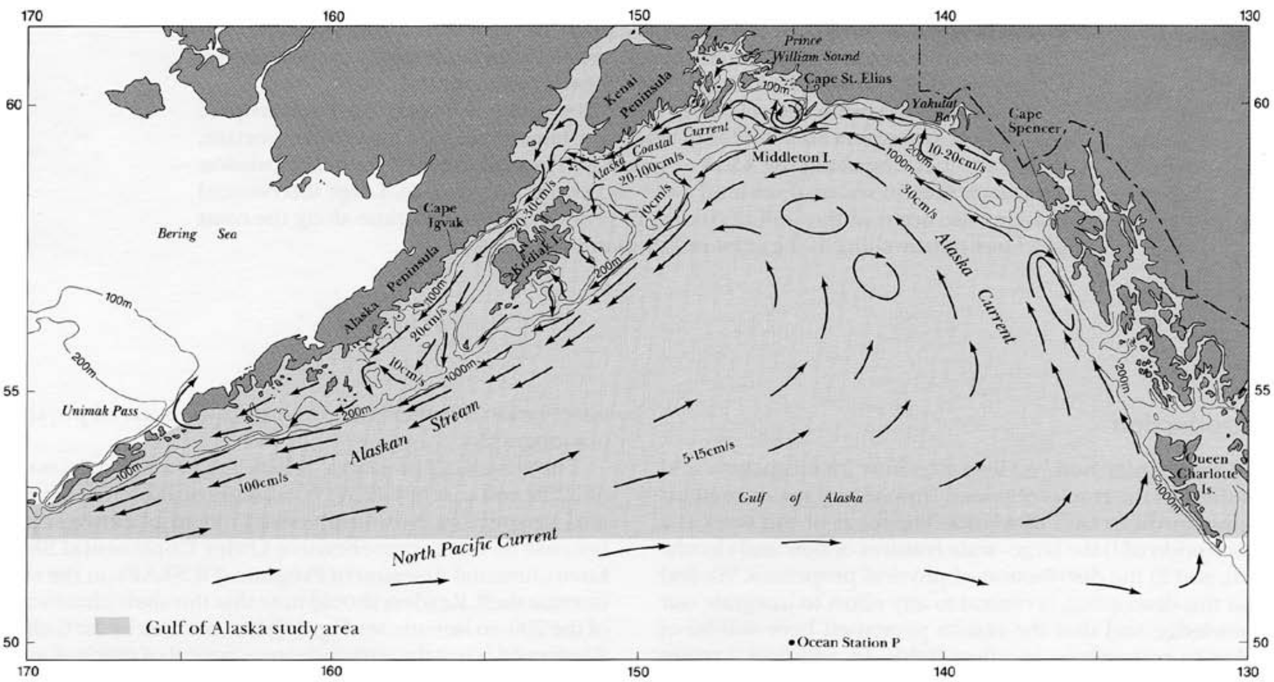


Figure 4. Predominant currents in the Gulf of Alaska (Reed & Schumacher 1986).

The Gulf of Alaska is meteorologically active and dominated by a persistently located area of low pressure known as the Aleutian Low (Mundy and Olsson 2005). Winter storms, characterized by low sea-level pressures, can routinely produce >15 m waves and gale-strength winds (Wilson and Overland 1986). The Aleutian Low oscillates in strength and location throughout the year but maintains its influence on the regional climate (Wilson and Overland 1986, Mundy and Olsson 2005). The Pacific Decadal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO) are global-scale atmospheric and oceanic conditions that influence climate, weather events, circulation, and, ultimately, the biology of the Gulf of Alaska. The time scale of the PDO and ENSO are quite distinct; the PDO describes variability on interdecadal time scales, while the ENSO describes variability on intradecadal time scales. The sea surface temperature anomalies arising from the PDO are smaller magnitude but geographically larger than those occurring during ENSO (Weingartner 2007). The PDO is characterized by descriptive weather indices that track anomalies of sea surface temperature, wind stress, and sea level atmospheric pressure (Hare et al. 1999). During the warm (or positive) phase of the PDO, sea surface temperatures are above normal in the Gulf of Alaska, with the opposite pattern during the cold phase (Mantua et al. 1997). ENSO has its largest effects in the equatorial Pacific. During an ENSO warming event, sea levels rise, upwelling shuts off, and water temperatures in the equatorial Pacific near Peru may rise as much as 5.4° C. During a cool phase (La Niña), cooler surface waters (< 20° C) extend offshore of Peru and intensify upwelling currents in that region. These effects alter global atmospheric circulation and propagate to the Gulf of Alaska, with maximal ENSO signals in the Gulf of Alaska in fall and winter (Weingartner 2007).

2.2.2. Climatic Setting

KEFJ has a maritime climate characterized by frequent cloudiness and precipitation, strong winds, and relatively mild temperatures. Low pressure systems that form in the western Aleutians region frequently move into the Gulf of Alaska where they can become stationary and intensify. This pattern produces strong southeasterly circulation of moist, maritime air into the coastal mountains within KEFJ (Bailey 1977) and results in a strong orographic precipitation gradient within KEFJ. Annual precipitation increases dramatically toward the interior of KEFJ and can exceed 380 cm (150 in) in the Harding Icefield, based on PRISM models and KEFJ snowpit data (C. Lindsay, NPS, written communication, 2009) (Figure 5). A National Weather Service station in Seward at sea level on the eastern border of KEFJ has climate data available back to 1949. The mean annual temperature in Seward is 4.4°C (40° F) with a range of -3.7 to 13.4°C (Figure 6). Annual precipitation at Seward is 173 cm (68.1 in) and peaks during fall at 25 cm (10 in) per month during September and October (Figure 6). Annual snowfall averages 211 cm (83.1 in) with an average of 25–50 cm (10–20 in) per month between December and March. Snow on the ground typically averages less than 25 cm (10 in) in depth and persists from November through April.

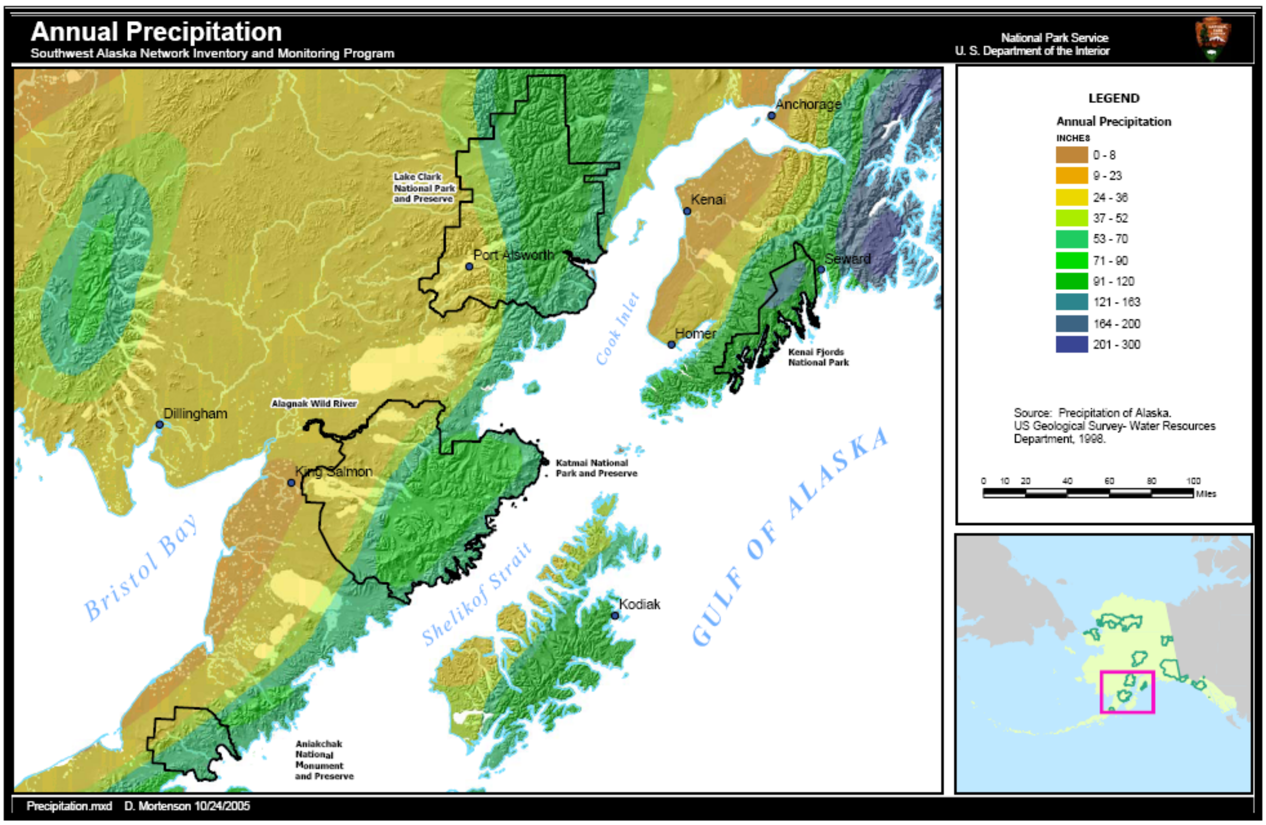


Figure 5. Annual precipitation for SWAN units, as compiled by the National Park Service. Taken from http://science.nature.nps.gov/im/units/swan/index.cfm?theme=climate.

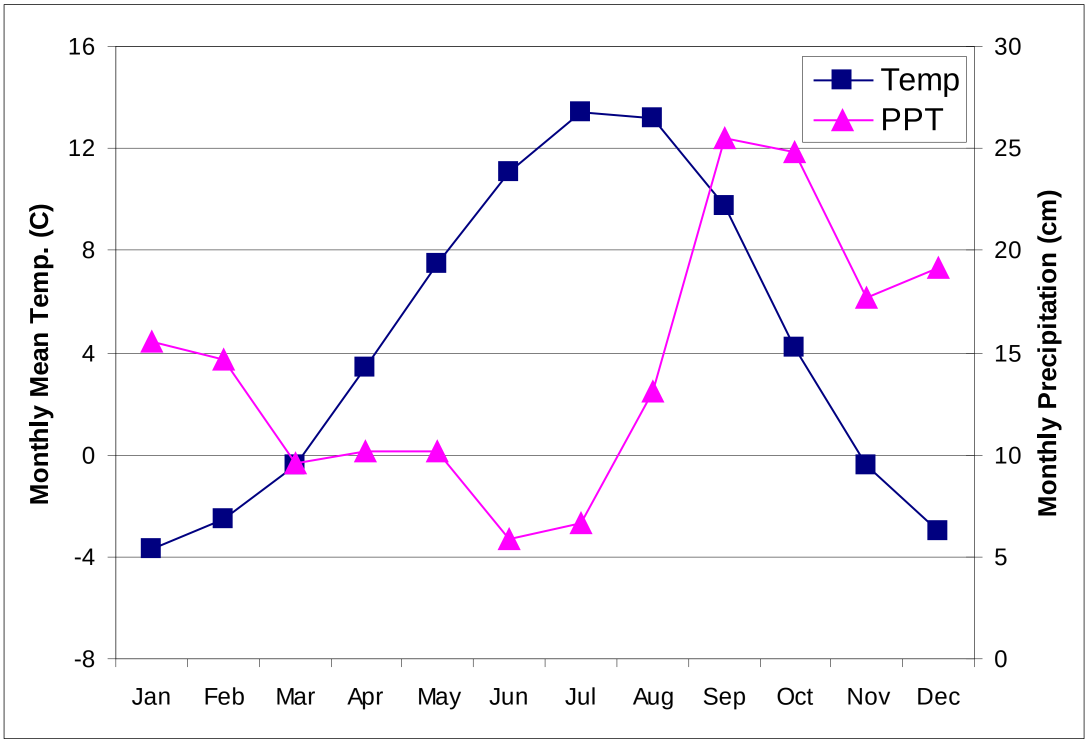


Figure 6. Mean monthly temperature and monthly precipitation in Seward (1949–2005). Data from the Western Regional Climate Center (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?aksewa).

There are a number of weather stations in and around KEFJ, and the SWAN I&M Program now has remote automated weather stations (RAWS) at two sites within KEFJ—McArthur Pass and Harding Icefield (Figure 7). The RAWS sites are fully automated, solar-powered stations that record temperature, wind speed and direction, precipitation, snow depth, relative humidity, and solar radiation on an hourly basis. The data for these sites are archived by the Western Regional Climate Center. The McArthur Pass site is located in the southern region of KEFJ at 400 m (1,300 ft) elevation and has been in operation since June 2008 (http://www.raws.dri.edu/cgi-bin/rawMAIN.pl?akAMCA) (Figure 7).

The Harding Icefield site is located on a nunatak in the northeast portion of the icefield at 1,280 m (4,200 ft) elevation and has been in operation since July 2004 (http://www.raws.dri.edu/cgi-bin/rawMAIN.pl?akAHAR) (Figure 7). Data from the Harding Icefield site characterize the extreme climate of the icefield with peak monthly wind gusts that typically exceed 22 m/s (50 mph) and average daily low temperatures of less than -12°C (10°F) during winter months. The highest wind speed measured at the site is 52 m/s (117 mph) and the lowest recorded temperature is -29.5°C (-21.1°F).

Current and historic data from weather stations in an around KEFJ including Exit Glacier, Nuka Glacier, Seward Airport, and Harding Icefield are summarized in Lindsay and Klasner (2009).

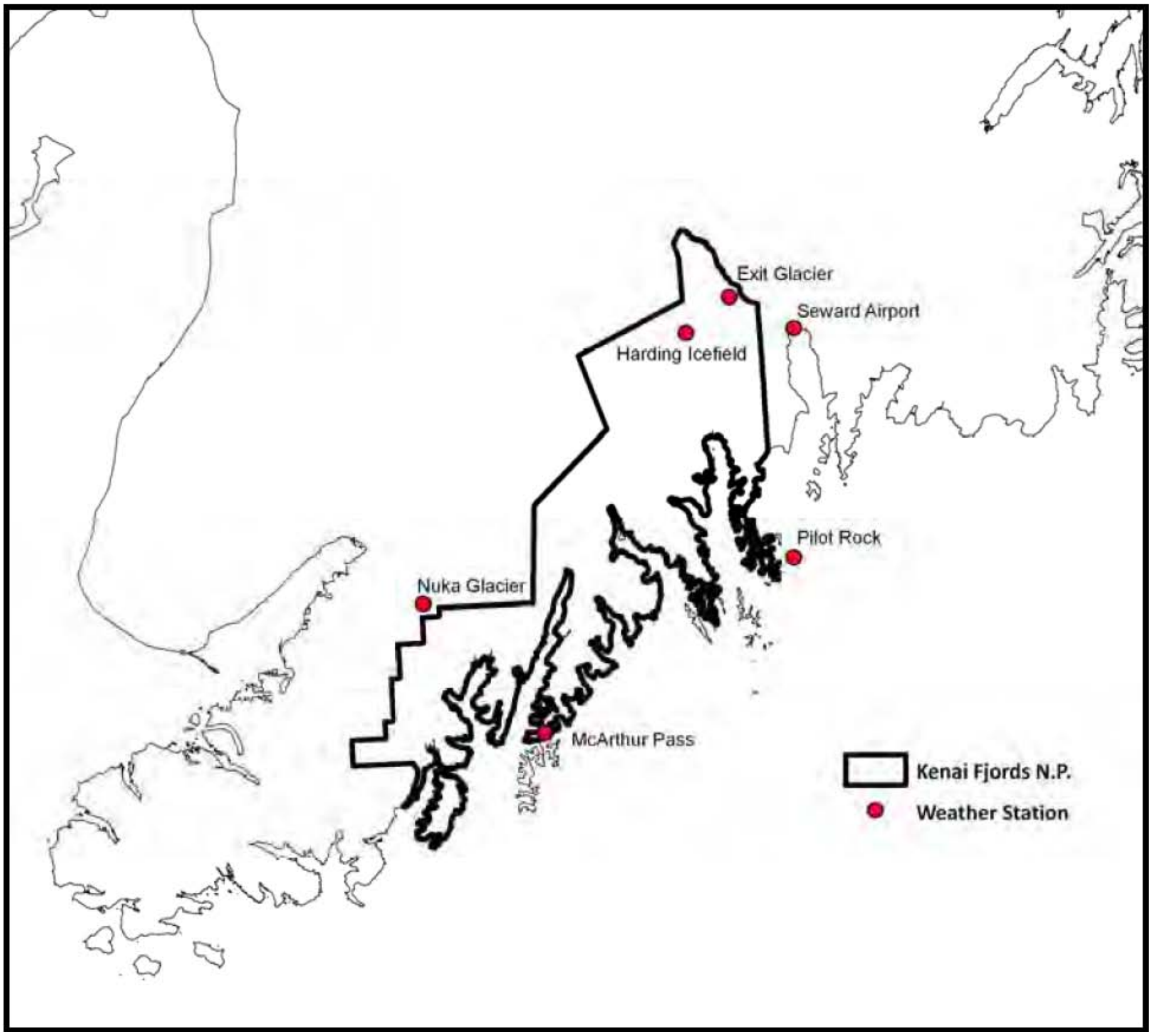


Figure 7. Map of weather stations in and adjacent to KEFJ. The McArthur Pass site began collecting data in June 2008 (Lindsay and Klasner 2009).

2.2.3. Streams and Streamflow

Most streams in KEFJ are unnamed, short (<5 km), and either carry glacier runoff or drain small coastal rugged watersheds that rim the fjords and bays. Watersheds extend from sea level to greater than 1,500 m (~5,000 ft) in elevation on the Harding Icefield. Hydrologic unit codes for watersheds within KEFJ are shown in Figure 8.

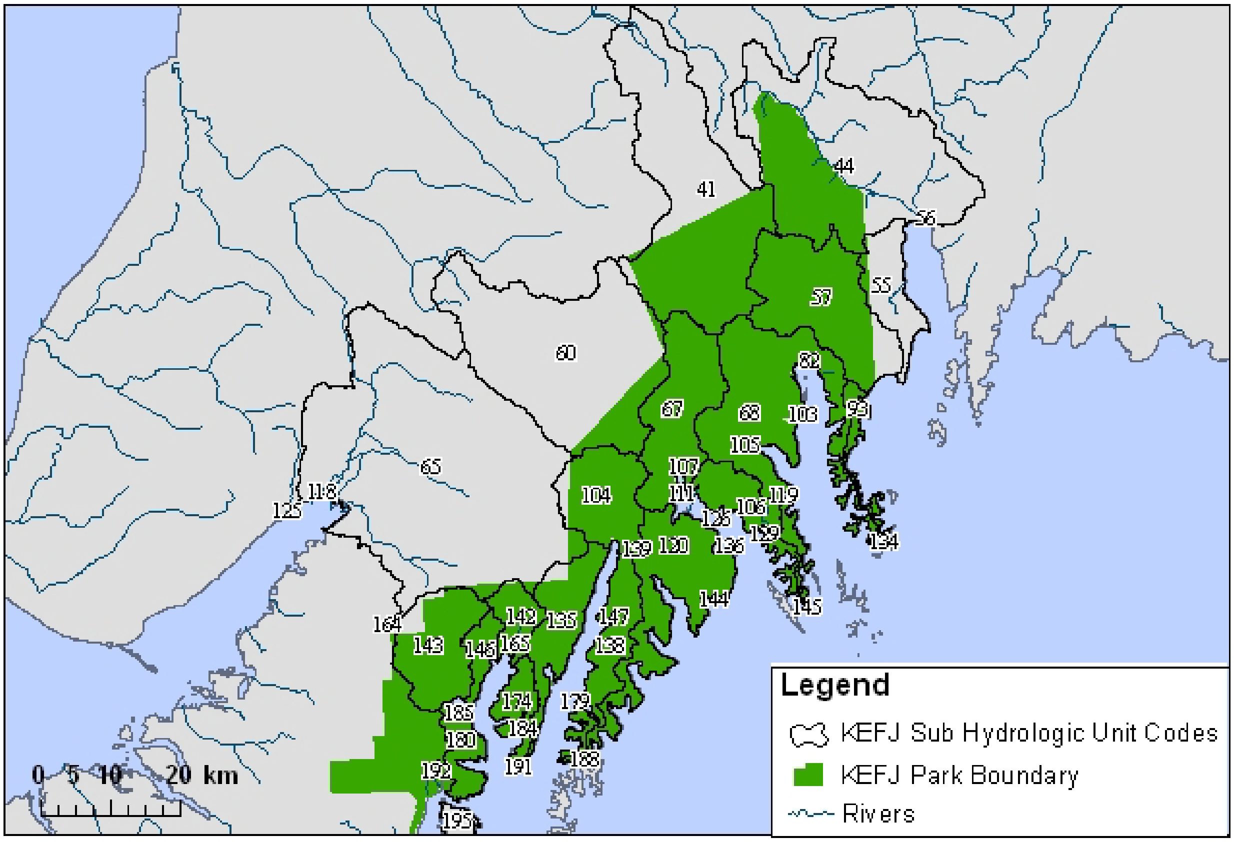


Figure 8. Watersheds fully or partially within KEFJ, as identified by hydrologic unit codes.

The majority of streams are fed by meltwater from glaciers and snowfields, although there are a number of small, low-elevation watersheds along the coast where streamflow is derived primarily from rainfall and intermittent snowmelt. The named KEFJ streams include (from north to south): Resurrection River (with tributaries: Exit, Moose, Placer, Cottonwood, Redman, and Paradise Creeks); Lowell, Spruce, and Tonsina creeks along western Resurrection Bay; Delusion Creek (and lakes, draining into McCarty Fjord); Babcock Creek (draining into Surprise Bay); and the Nuka River and adjacent Ferrum Creek (Figure 9). Exit Creek, which is the main water body targeted for long-term monitoring by SWAN, flows from the terminus of Exit Glacier (on the northeast end of the Harding Icefield, near the visitor center and Seward) for 3.2 km (2.0 mi) to the confluence with the Resurrection River (Figure 10).

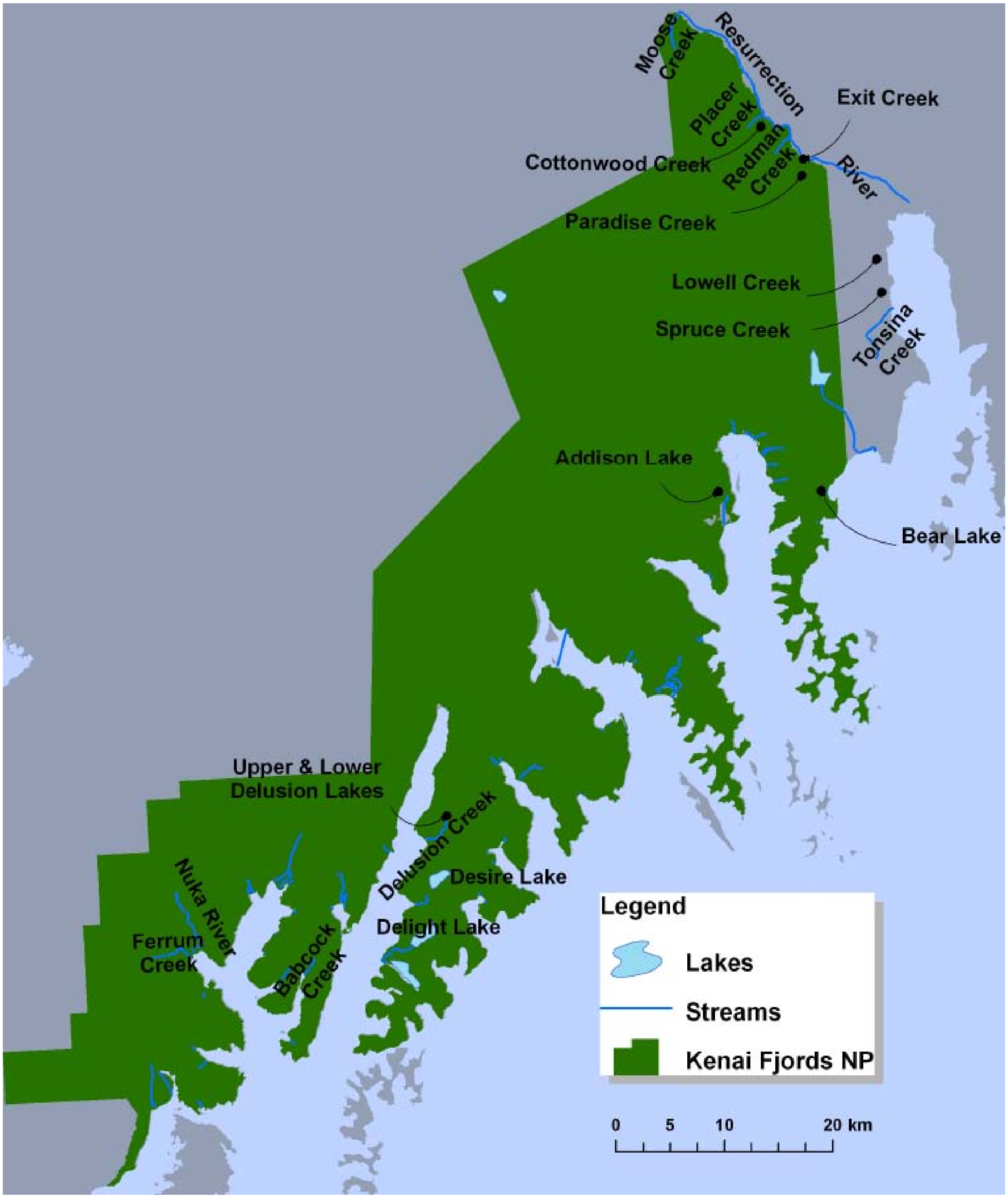


Figure 9. Streams and lakes in KEFJ.

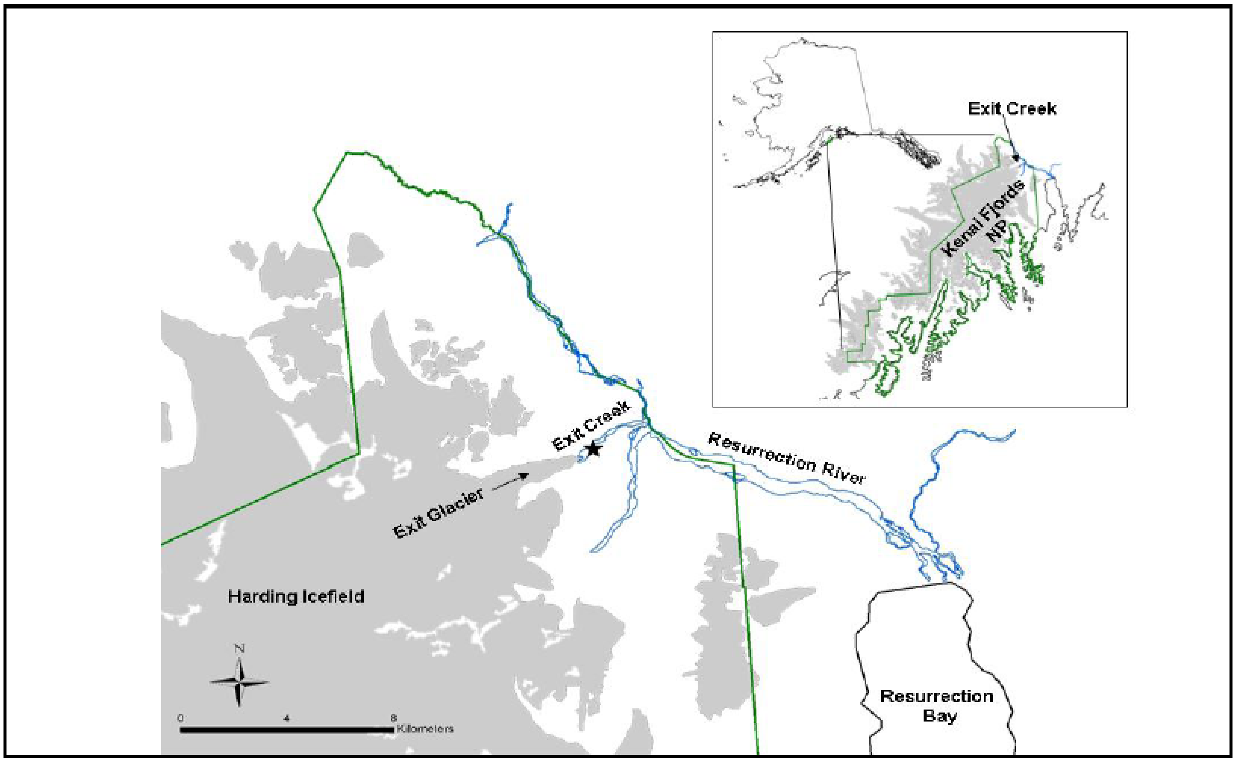


Figure 10. Location of Exit Creek and Resurrection River in KEFJ. The star denotes the Exit Creek monitoring location, and grey areas represent glacial ice cover. From Shearer and Moore (2009).

Several USGS gages have historically been operational on streams whose watersheds lie at least partially within KEFJ boundaries, although the gages themselves have not been within the park: three on the Nuka River and two on the Resurrection River. Several reports provide limited data on streamflow in other KEFJ streams. For example, a recent water quality inventory of KEFJ stated that discharge measurements were taken in most of the streams sampled, but no discharge data are provided in the final report (Bennett 2005). Also, a study of salmonid and macroinvertebrate colonization of Delusion Creek, a newly formed stream in McCarty Fjord, included discharge measurements. Discharge measured 2.4–17.3 m^3/s (84–610 cfs) between 8/3/92 and 9/1/92, and 4.8–18.0 m^3/s (168–636 cfs) between 6/5/93 and 7/27/93 (York and Milner 1999). The steepness of the watershed and the intensity of rainfall events indicated that the upper watershed lakes did little to buffer flow variations in Delusion Creek (York and Milner 1999).

One of the USGS gages on the Nuka River (site number 15238650; "Nuka River nr Homer") reports only two discharge measurements: 0.13 m^3/s (4.7 cfs) on 3/12/1960 and 0.13 m^3/s (14 cfs) on 1/7/1961. However USGS site 15238648 ("Upper Nuka River nr park boundary nr Homer AK"; operated in conjunction with the Alaska Energy Authority) has a 25-year record of continuous streamflow measurements (beginning on 09/01/1984 and continuing to the present). The lower site (USGS Station 15238653; "Nuka River nr Tidewater nr Homer") has continuous discharge for thirteen months, from 9/1/1984 to 9/30/1985 (Figure 11). The streamflow pattern for this single study year clearly shows the large contribution of glacial meltwater to the stream during the summer months, when streamflow was two to three orders of magnitude greater than during the winter months. Short-term spikes in flow from rainstorm events are apparent throughout the water year.

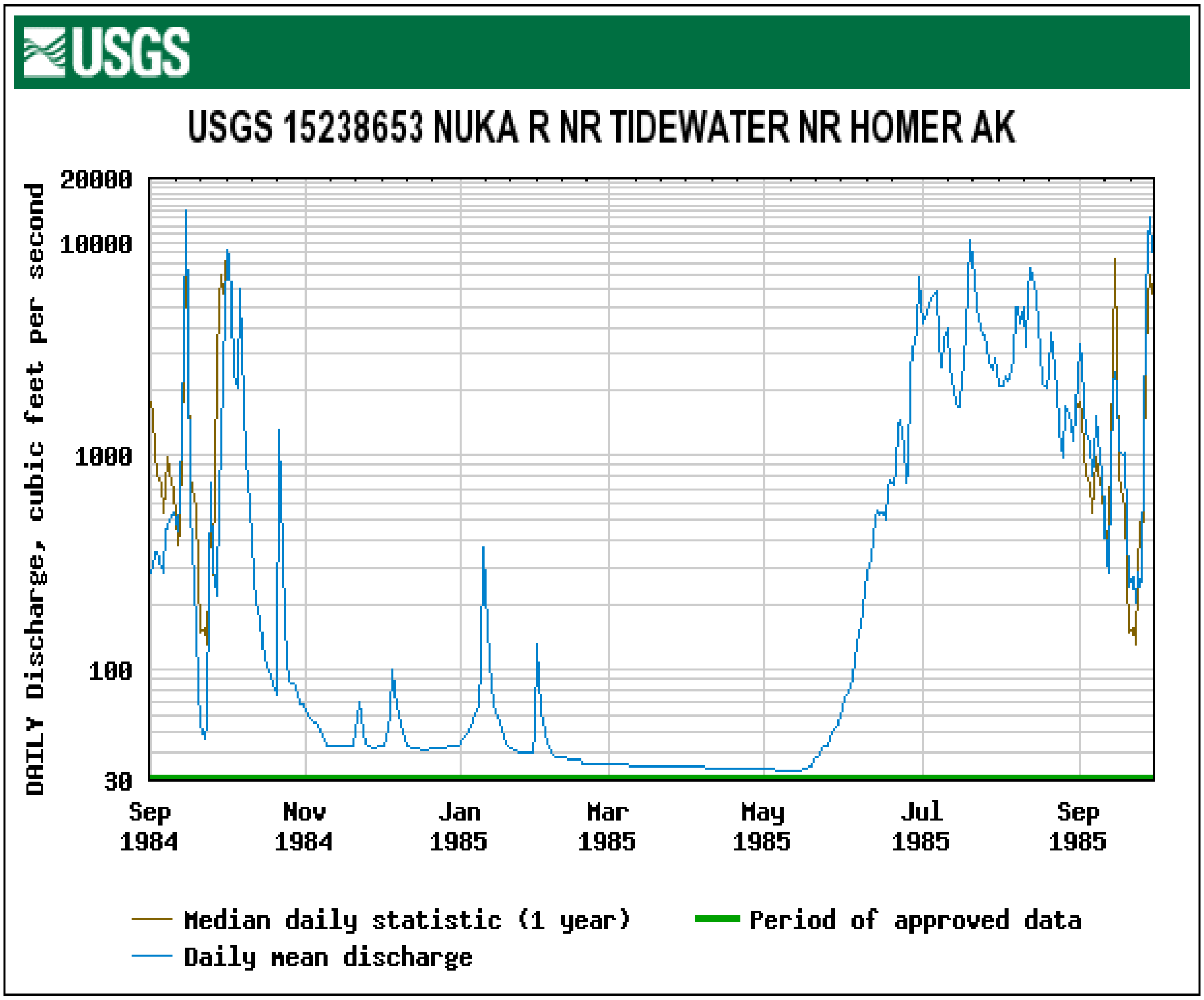


Figure 11. Streamflow data for the USGS gaging station on the Nuka River, for the entirety of its record (September 1984–September 1985). Data from USGS (http://nwis.waterdata.usgs.gov/ak/nwis/uv/?site_no=15238653).

The other two historical USGS gaging stations were on the Resurrection River. The one in the upper watershed (USGS station1523767500, "Resurrection R at Exit Glacier C nr Seward") reports only 11 field measurements; one was from June 1993, but the other 10 all were taken between August and October 1986 (Table 1). Therefore, no seasonal or time-series trends are discernable from the site. However, the lower Resurrection River was gaged continuously from 10/1/01964 to 6/30/1968 (USGS station 15237700, "Resurrection R at Seward AK"). These four years of gage data show a classic glacier-influenced streamflow trend characterized by a sharp and sustained increase in discharge during the summer months when glacial meltwater contributions dominate, and low flows in the winter and early spring, when groundwater sustains relatively low levels of streamflow that are punctuated by short term spikes from rainfall events (Figure 12).

Table 1. Streamflow measurements reported for the Resurrection River above Exit Glacier Creek. Data from http://alaska.usgs.gov/science/water/index.php

Date	Streamflow (cfs)	Streamflow (m3 s-1)
6/23/1993	1420	40.21
10/14/1986	2620	74.19
10/8/1986	345	9.77
9/30/1986	319	9.03
9/24/1986	526	14.89
9/19/1986	783	22.17
9/12/1986	816	23.11
9/5/1986	764	21.63
8/29/1986	1890	53.52
8/21/1986	670	18.97
8/15/1986	736	20.84

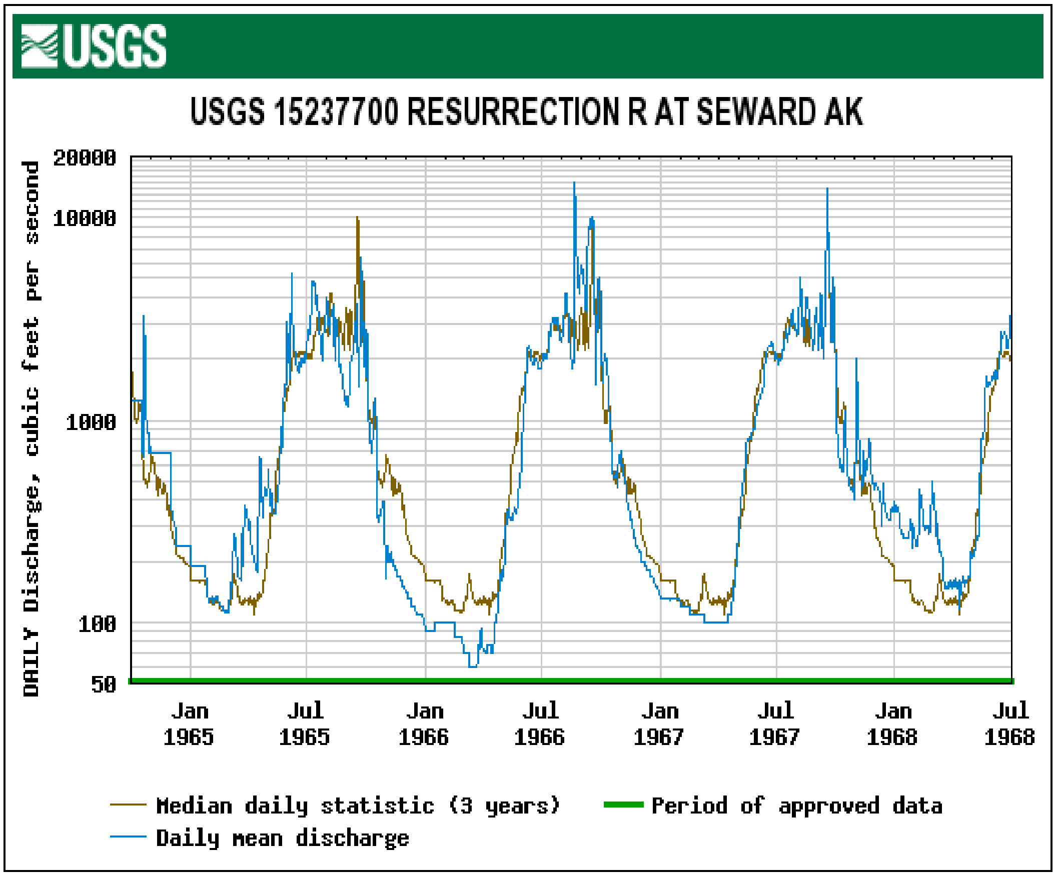


Figure 12. Streamflow data for the Resurrection River at Seward. (USGS stream gage 15237700) for the period of record: 10/1/01964– 6/30/1968. Data from USGS (http://nwis.waterdata.usgs.gov/ak/nwis/uv/?site_no=15237700).

Although there are no longer any continuously gaged rivers in KEFJ, stage level is recorded at both the Resurrection River and Exit Creek by the National Weather Service River Forecast Office (NWS RFO). Hourly stage data for the Resurrection River (at Exit Glacier Bridge) is at available at http://aprfc.arh.noaa.gov/ahps2/hydrograph.php?wfo=pafc&gage=resa2, and daily summer stage is available for Exit Creek (near the visitor center) at http://aprfc.arh.noaa.gov/ahps2/hydrograph.php?wfo=pafc&gage=exta2. This monitoring effort provides stage data, which are converted to estimated discharge, and rates flood risk (Table 2). Flooding of the Resurrection River onto the Exit Glacier Road has occurred many times in the recent past and is a visitor access concern for the Park (Table 2). Resurrection River stage is also monitored by the National Weather Service River Forecast Office (NWS RFO) at a site lower in the watershed, at the Seward Highway Bridge.

Table 2. Flood categories and historical crests for the Resurrection River at Exit Glacier Bridge. Data from the National Weather Service River Forecast Office.

Flood category	***Stage (ft)***	***Stage (m)***
Major flood stage	20.00	6.10
Moderate flood stage	18.50	5.64
Flood stage	17.50	5.33
Action stage	16.00	4.88
Historical crests		
10/9/2006	19.85	6.05
9/20/1995	19.36	5.90
10/23/2002	18.50	5.64
9/9/1995	17.90	5.46
10/1/2003	16.32	4.97
9/14/2002	16.20	4.94
10/3/2004	15.86	4.83
9/15/2006	15.67	4.78
9/14/2008	15.37	4.68
12/16/2005	15.05	4.59
6/17/2004	13.94	4.25
6/11/2007	10.80	3.29

Flood forecasts are not available for the Exit Creek site. This site had been monitored only once per day, and only during the summer months, when the Exit Glacier visitor center was open. However, in 2008, the National Park Service placed a water level pressure transducer at the site to record hourly stage readings, and, in 2009, the National Park Service resurveyed the channel cross-section and started to work on rebuilding the stage-discharge rating (Jeff Shearer, NPS, written communication, 2009). Exit Creek is slated to be gaged regularly as part of the NPS I&M Program.

2.2.4. Lakes and Ponds
Several dozen small lakes dot the coastal landscape of KEFJ, but there are no major lakes such as those in LACL and KATM. The largest lakes (all <5 km^2 [2 mi^2]) are on the east side of the East Arm of Nuka Bay: Upper and Lower Delusion Lakes, Desire Lake, and Delight Lake. Addison Lake (draining into Pederson Lagoon) and Bear Glacier Lake (an estuarine lagoon connected to Resurrection Bay) are the only other lakes in the park bearing official names (Figure 9). No known studies have been conducted on the physical or chemical attributes of these lakes; however, bathymetric maps made by the Alaska Department of Fish and Game in 1981 are available for Delight and Desire Lakes (Mortenson et al. 2005). The maximum depth of Delight and Desire Lakes are shown as 40 m and 27 m, respectively.

2.2.5 Groundwater
No groundwater resources in KEFJ have been inventoried or described except for an isolated survey of groundwater conditions in the Exit Creek glacier area (Sloan 1985). This study identified three principal geologic units in the area as bedrock, glacial till, and fluvial sand and gravel, and it reported that an ample supply of groundwater at a depth of <15 m (50 ft) was available for visitor services.

Despite the lack of groundwater surveys throughout KEFJ, some general features of groundwater systems in glaciated environments likely pertain to the park. Glacial outwash deposits in general are characterized by broad, extensive groundwater systems that are well connected through highly conductive sands and gravels. In contrast, till deposits and lenses of fine-grained clays may produce perched aquifers and regions of low hydraulic conductivity (Stephenson et al. 1988). Groundwater flow in the steep, high, mountainous areas of KEFJ is likely limited to relatively shallow soil zones and fraction flow through faults and fissures in the bedrock. Through wetland areas, groundwater is abundant, and the water table intersects the land surface. Wetlands, lakes, ponds, and streams are likely closely connected by groundwater in such areas. Considering the rapid retreat of most glaciers within KEFJ and the uncovering of new stream valleys, it is also likely that the dimensions of groundwater reservoirs are expanding and shifting in sync with the changes in surface hydrology. Storage and routing of meltwater through floodplain aquifers likely result in significant contributions of flow to the streams. During periods of low precipitation and during times of subfreezing temperatures, groundwater flow into streams may sustain thawed channel conditions, thereby creating refuges for fish and other biological resources that require above-freezing temperatures.

2.2.6. Snow, Ice, and Glaciers

There are more than 20 named glaciers that are totally or partially within KEFJ, including a number of tidewater glaciers that deliver ice to bays and lagoons within the park (Figure 13). The majority of glaciers within KEFJ are part of the Harding Icefield. In total, Harding Icefield is about 80 km long and 50 km wide and contains glaciers that cover approximately 1,800 km^2 (695 mi^2; Hall et al. 2005; VanLooy et al. 2006). About half of the Harding Icefield lies within the boundaries of KEFJ and glacial ice, icefields, snowfields, and late-lying snow, cover approximately 56% of the total area of KEFJ (Boggs et al. 2008) (Figure 13). There have been repeated glacial advances from the Harding Icefield during the late Holocene. The most significant late Holocene advance occurred during the Little Ice Age (LIA), which lasted from approximately AD 1200 to 1900 (Mann 1998, Wiles and Calkin 1990). Glaciers in KEFJ varied in the timing of their LIA maxima by as much as 250 years. For example, the Aialik and Holgate glaciers reached maxima and begin retreating by the late 1600s, whereas the McCarthy and Northwestern glaciers reached maxima closer to AD 1900 (Mann 1998). Most of the glaciers in KEFJ have been retreating since the end of the Little Ice Age (~250 yrs ago) and have continued to retreat in recent decades (Figure 14). The effects of climate change on glaciers in KEFJ are discussed in more depth in Section 4.2. Unlike the other units within SWAN that exclusively contain glaciers with grounded termini, KEFJ contains a mixture of grounded and tidewater glaciers. The major tidewater glaciers along the eastern side of the park include the Aialik, Bear, Holgate, Northwestern, and McCarty glaciers. The largest glaciers in KEFJ drain the Harding Icefield in the northeastern portion of the park. The largest glacier contained entirely within KEFJ is Bear Glacier, which extends more than 30 km (19 mi) from the center of the Harding Icefield to Resurrection Bay (Figure 13). Despite the widespread occurrence of glacial ice, KEFJ is free of permafrost because of the mild, maritime climate. Maps of permafrost extent in Alaska are available through the University of Alaska Fairbanks Geophysical Institute at: http://nrm.salrm.uaf.edu/%7Edverbyla/bnz_synthesis_CD/chapter3/statewide_permafrost_distribution.jpg.

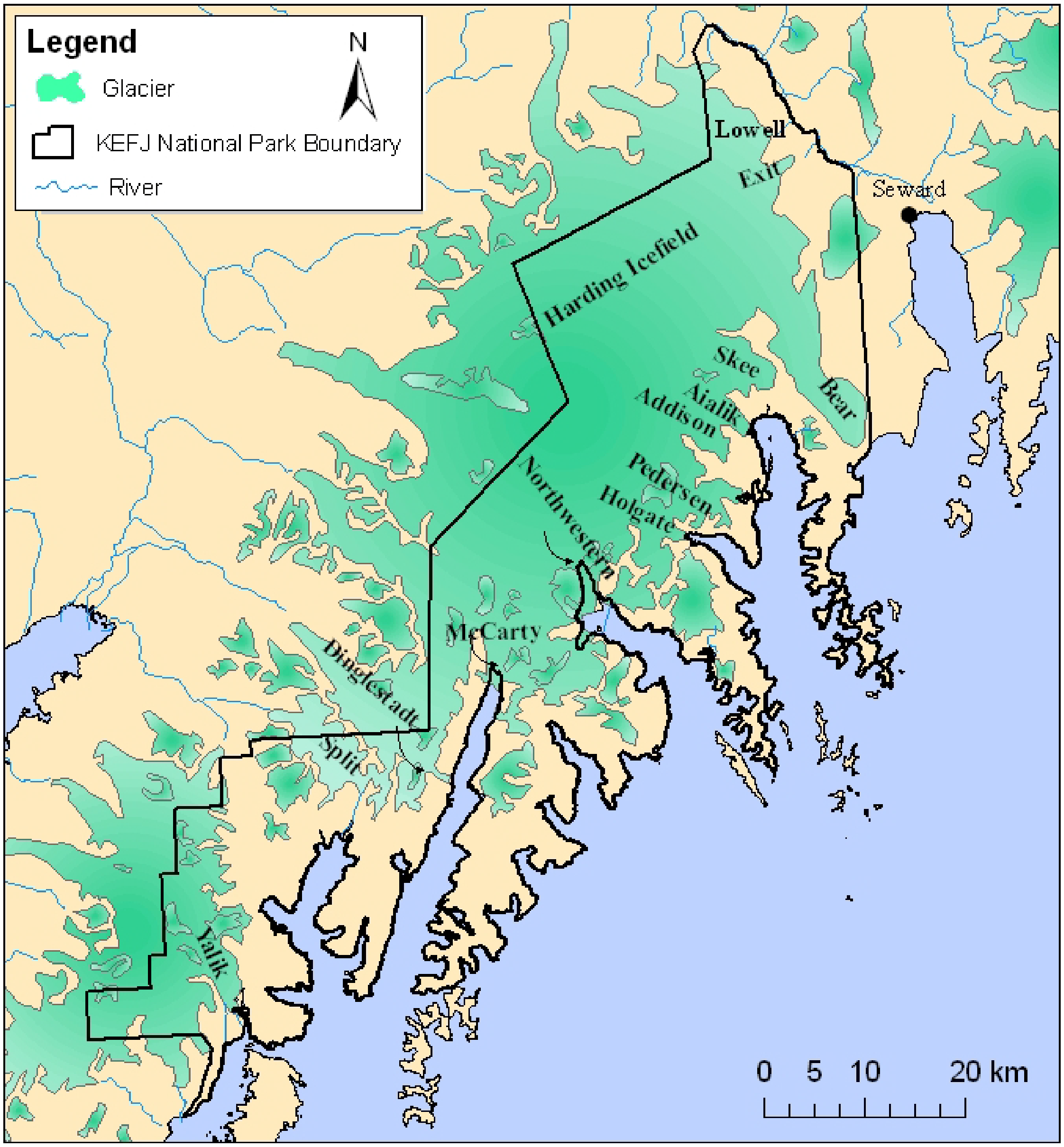


Figure 13. The Harding Icefield and major glaciers in KEFJ.

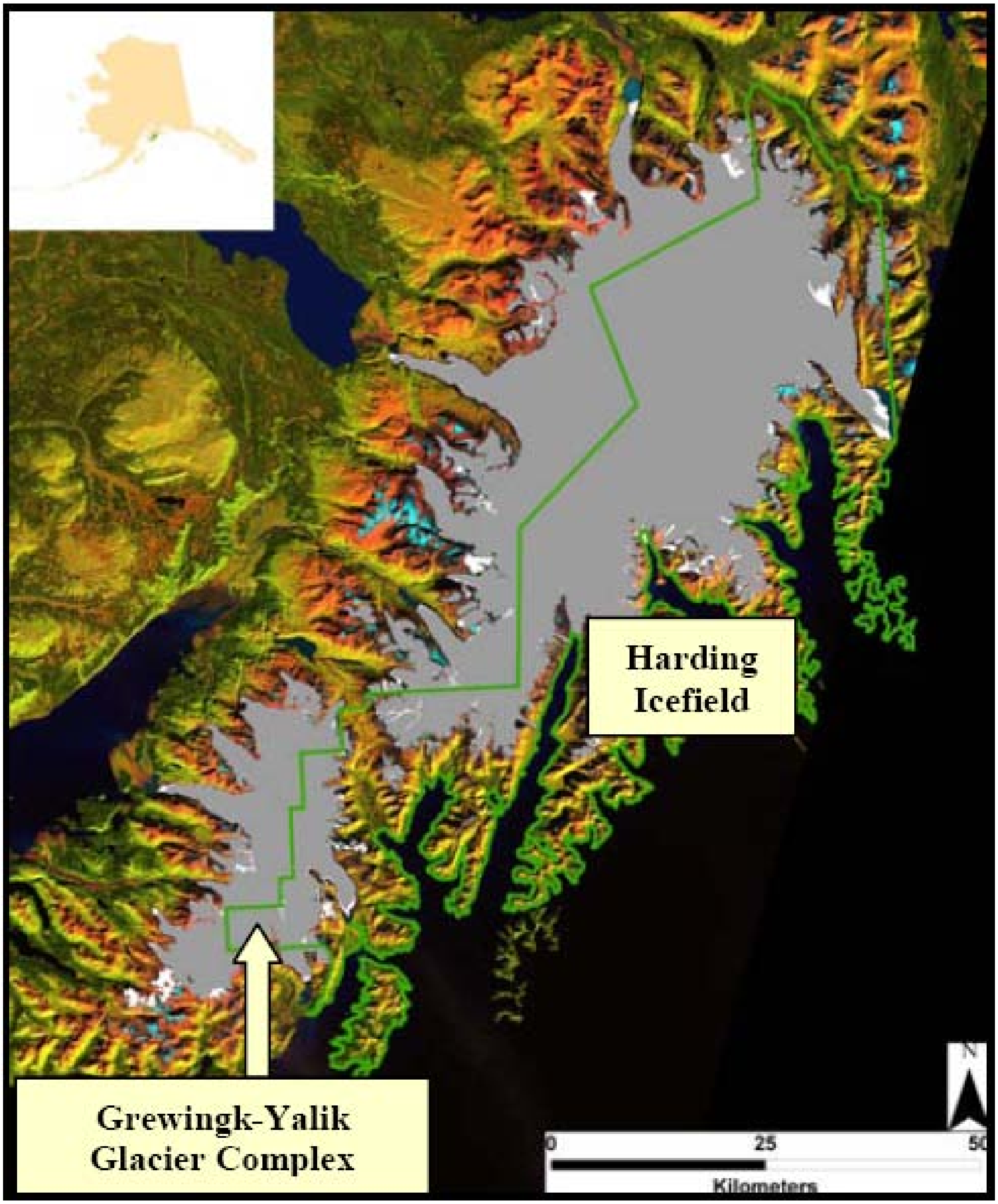


Figure 14. Change in areal extent of glacier in the Harding Icefield and Grewingk-Yalik Glacier Complex for the period 1986 (shown in white) to 2000 (shown in grey) (Giffen et al. 2009)

Glaciers within KEFJ have profound effects on the landscape, including erosion and deposition that produce moraines and eskers as well as pro-glacial lakes. Additionally, meltwater flowing from glaciers creates broad outwash zones and braided stream channels such as those seen in the Nuka and Resurrection rivers. Runoff from glaciers produces extremely high yields of water and sediment in pro-glacial rivers and streams (Lawson 1993). The hydrologic system of a glacier determines the rate at which the glacier transmits and discharges freshwater. In addition, glacial hydrology can control the occurrence of outburst floods and rates of glacier sliding and surging, both of which are enhanced by the presence of meltwater at the glacier base.

The hydrology of glaciers is relatively complex and not well understood. Meltwater channels can develop on the glacier surface (supraglacial) and beneath the glacier (subglacial), as well as within the glacier (englacial). Recent research suggests that the hydrologic system of temperate glaciers like those found in KEFJ is dominated by networks of fractures within the glacier ice that convey water at relatively slow speeds (Fountain et al. 2005). These fractures are regenerated seasonally and are the primary conduit through which water moves from the surface of a glacier to the glacier bed.

Early glaciological studies including native observations of glacial landscapes and early European explorations in KEFJ are reviewed in Rice (1987). This study also estimated a 5% decrease in glacial ice coverage for the Harding Icefield between the early 1950s and mid-1980s and reported results from an early ice coring project on the icefield. The late-Holocene glacial history of KEFJ has been examined using a combination of radiocarbon dating of ice-marginal trees and measurements of lichen diameters (Wiles and Calkin 1990). Results from this study indicated that glacial retreat rates averaged 27 m/yr during the 20th century for six land-terminating glaciers on the west flank of the Harding Icefield. Similar analyses on iceberg-calving glaciers on the east side of KEFJ reported that fjord depth, sediment supply, and fjord geometry are strong controls on glacier stability in tidewater glaciers (Wiles et al. 1995). As a result, these periods of advance in tidewater glaciers within KEFJ may not be well correlated with climate. For example, the Aialik and Holgate glaciers were climatically insensitive during the Little Ice Age and remained that way until at least the mid-1990s (Wiles et al. 1995).

During the 1990s, there were a number of studies that evaluated changes in glacier elevation and volume on the Harding Icefield (Adalgeirsdottir et al. 1998, Echelmeyer et al. 1996, Sapiano et al. 1998). These studies used airborne surface elevation profiling to evaluate changes in the volume of Harding Icefield glaciers since the 1950s when the original USGS topographic maps were surveyed. Recent investigations into glacier extent within KEFJ have used satellite images to track changes in glacial coverage for the Kenai Peninsula. Hall et al. (2005) used Landsat images to create GIS shapefiles to estimate glacier area and terminus changes for the period 1973–2002. Additionally, classification of 1986 and 2002 Landsat scenes for the Harding Icefield and Grewingk-Yalik Glacier Complex found that there was a 3.7% or 78 km^2 (30 mi^2) decrease in ice extent during this period (Hall et al. 2005). The SWAN I&M Program has identified glacier extent as an important vital sign to monitor and is using satellite imagery (primarily Landsat) to monitor changes in glacial coverage in SWAN parks. Glacier monitoring on the Harding Icefield in and around KEFJ is ongoing in collaboration with Dr. Dorothy Hall from the NASA Goddard Space Flight Center. Currently, glacier extent data for Harding Icefield and Grewingk-Yalik Glacier Complex for 1986 and 2000 (Table 3) are available through the SWAN website. These data indicate that glacial area within the boundaries of KEFJ decreased by 21.7 km^2 (8.4 mi^2) or 1.6% between 1986 and 2000. Coincident with the decrease in glacial area, an analysis of aerial imagery indicates that nunataks on the Harding Icefield have shown a 30% increase in area during the period between the 1950s and 2005 (Miller et al. 2006). In addition to glacial extent, the laser altimetry group at the University of Alaska Fairbanks has an ongoing program to monitor changes in the volume of Alaskan glaciers. Current monitoring efforts, including repeat center line laser altimetry surveys conducted in 1994, 2002, and 2007, cover a number of KEFJ glaciers including the Bear, Aialik, Holgate, and Exit glaciers. These laser altimetry surveys provide information about rates of glacier elevation change and volume change between survey dates (Figure 15).

Table 3. Summary of the extent of the Harding Icefield, the Grewingk-Yalik Glacier Complex and surrounding glaciers as measured using Landsat data (in sq km) (Giffen et al. 2009)

	1986 (sq km)	**2000 (sq km)**	**1986 to 2000 Change in Glacier Cover (sq km)**	**% Change**
Harding Icefield main body**	1828.41	1786.38	-42.03	-2.3%
Harding Icefield and surrounding glaciers	1935.03	1902.79	-32.24	-1.7%
Grewingk-Yalik Glacier Complex main body	423.37	411.69	-11.68	-2.8%
Grewingk-Yalik Glacier Complex and surrounding glaciers	444.81	424.32	-20.50	-4.6%
Harding Icefield and Grewingk-Yalik Glacier Complex and surrounding glaciers	2379.84	2327.11	-52.73	-2.2%
Glacier Ice within park boundary	1388.20	1366.52	-21.68	-1.6%

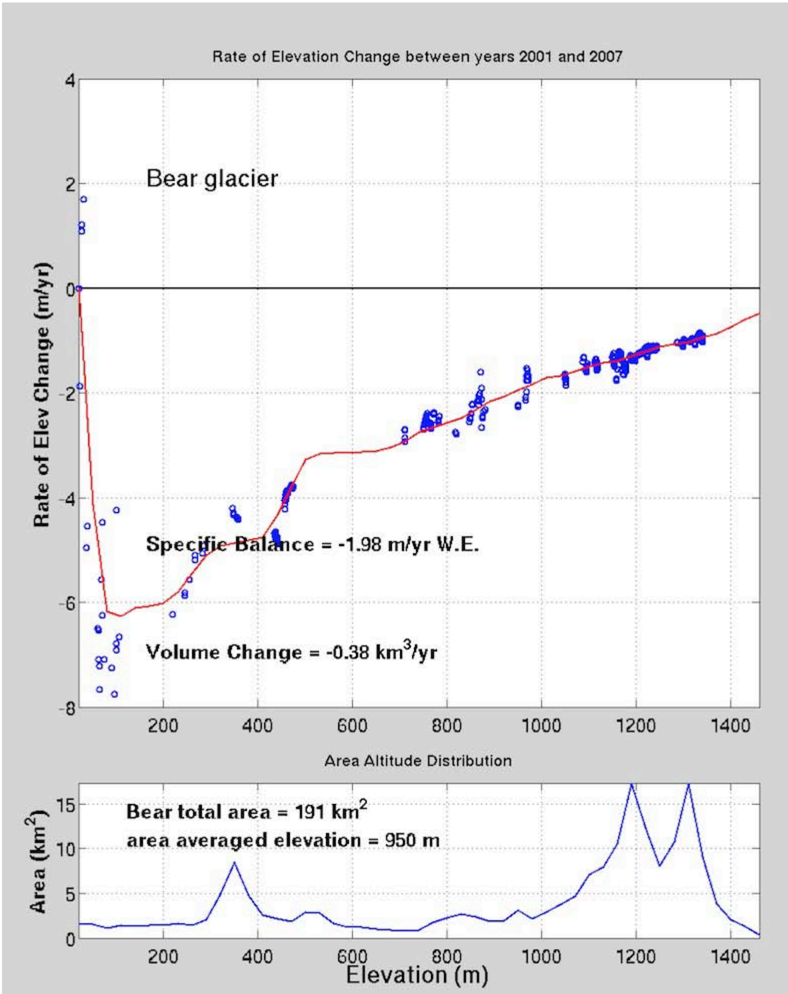


Figure 15. Rate of elevation change (m/yr) and volume change for the Bear glacier between 2001 and 2007. Data are derived from laser altimetry surveys done by the University of Alaska Fairbanks Laser Altimetry Group and are available at http://gps.alaska.edu/chris/images/Mass%20Balance%20Curves/index2.html

In addition to mapping efforts, the SWAN I&M Program is cataloging repeat photographs that document changes in glacier extent within KEFJ. In 2004, Phillips and Molnia (2004) also re-established 40 photo stations in and around KEFJ from the 1909 glacier survey done by the USGS (Phillips and Molnia 2004). The 2004 photographs duplicate the field of view from the 1909 survey photos and document dramatic changes in glacier thickness and extent as well as landcover. The repeat photographs have been used to create short time-lapse videos for seven glaciers within KEFJ and are available through the Ocean Alaska Science and Learning Center at: http://www.oceanalaska.org/research/rptglacier-video.htm. Aerial photography is also being used to monitor the terminus of the Exit Glacier in the eastern portion of KEFJ. Aerial photographs taken regularly during fall since 2004 are being used to calculate the annual change in terminus position (Klasner 2008b). The surface velocity of the ice at the terminus of the Exit Glacier is also being monitored using a radio transmitter in conjunction with a differential GPS. Results from this study ongoing since 1995 indicate that ice flow rate averaged 25 cm/day (10 in/day) and 93 m/yr (306 ft/yr) during 1995–2007 (Klasner 2008a). Glacier terminus position is also irregularly monitored at Exit Glacier (Fritz Klasner, NPS Seward, written communication, 2009). In 2009, KEFJ initiated mass-balance monitoring on Exit Glacier, and two other glaciers are planned (Fritz Klasner, NPS Seward, written communication, 2009).

None of the glaciers within KEFJ have ongoing, field-based mass balance programs; however, the Wolverine Glacier, which is located on the Kenai Peninsula approximately 40 km (25 mi) northeast of KEFJ, has been designated as one of three USGS Benchmark Glaciers and has continuous annual mass balance records dating to 1966 (http://ak.water.usgs.gov/glaciology). The Wolverine Glacier mass balance record is a useful indicator of likely mass balance trends within KEFJ because it is at a similar latitude and elevation range compared to glaciers within KEFJ.

2.3. Biological Resources

The National Park Service is active in extensive inventory and monitoring efforts at KEFJ and other units. The SWAN I&M Program currently includes the most extensive effort to describe, catalog, and assess the condition of biological resources in KEFJ (see http://science.nature.nps.gov/im/units/swan/index.cfm/.) As part of the NPS I&M Program, species lists have been compiled for vascular plants, fish, birds, and mammals within each of the SWAN units (Lenz et al. 2002). The data compilation completed in 2001 listed 660 vascular plant species (136 confirmed as present), 40 fish species (30 confirmed as present), 210 bird species (188 confirmed as present), and 54 mammal species (42 confirmed as present) as occurring in KEFJ (Lenz et al. 2002). A bibliography of the sources of information used to develop these lists is available through the I&M Program (Lenz et al. 2001). The full species lists are provided by the National Park Service (NPS 2004a, b, c) and online at the NPSpecies webpage (http://science.nature.nps.gov/im/apps/npspp/).

2.3.1. Marine Biological Resources

Estuarine and marine regions of KEFJ are primarily outside the jurisdiction of the National Park Service. Only those regions above the high tide zone are managed by the National Park Service.

Marine mammals: Marine mammals are well represented in KEFJ. The NPS species list for KEFJ includes northern fur seals (C*allorhinus ursinus*), Steller sea lions *(Eumetopias jubatus),* harbor seals *(Phoca vitulina),* minke whales (*Balaenoptera acutorostrata),* sei whales (*Balaenoptera borealis),* fin whales (*Balaenoptera physalus)*, humpback whales (*Magaptera movaeangliae)*, Pacific white-sided dophins (*Lagenorhynchus obliquidens),* killer whales (*Orcinus orca)*, grey whales (*Eschrichtius robustus),* sea otters (*Enhydra lutris*), and Dall's porpoises *(Phocoenoides dalli)* (NPS 2004b). In a 2002 survey from Cape Resurrection to Gore Point, six humpback whales, two Pacific white-sided dolphins, one harbor porpoise and four Dall's porpoise were observed (Van Pelt and Piatt 2003). Historical accounts of marine mammals in the vicinity of KEFJ indicate that their abundances may have been higher than they are today, and declines have been documented in Steller sea lions and harbor seals.

Sea otters: Sea otters are not evenly distributed in the KEFJ region; rather they are found in discrete locations. Historically, sea otters were most abundant in Harris Bay, with 90 observed (~1.3 sea otters/observed mile), and second most abundant in McCarthy Fjord, with 63 observed (~1.2 sea otters/observed mile) by Vequist (1990). In a 2002 survey from Cape Resurrection to

Gore Point, 144 sea otters were observed; Harris Bay was the only location with aggregations of more than 10 sea otters (Van Pelt and Piatt 2003). In a more recent and thorough survey in June 2007, the estimated sea otter population size in KEFJ was 1,511 with an average density of 1.02 otters/km^2 (Figure 16). Sea otter carcass surveys in 2007 revealed one carcass, although limited haul-out areas in KEFJ make it difficult to implement the otter carcass survey protocol there (NPS 2009a).

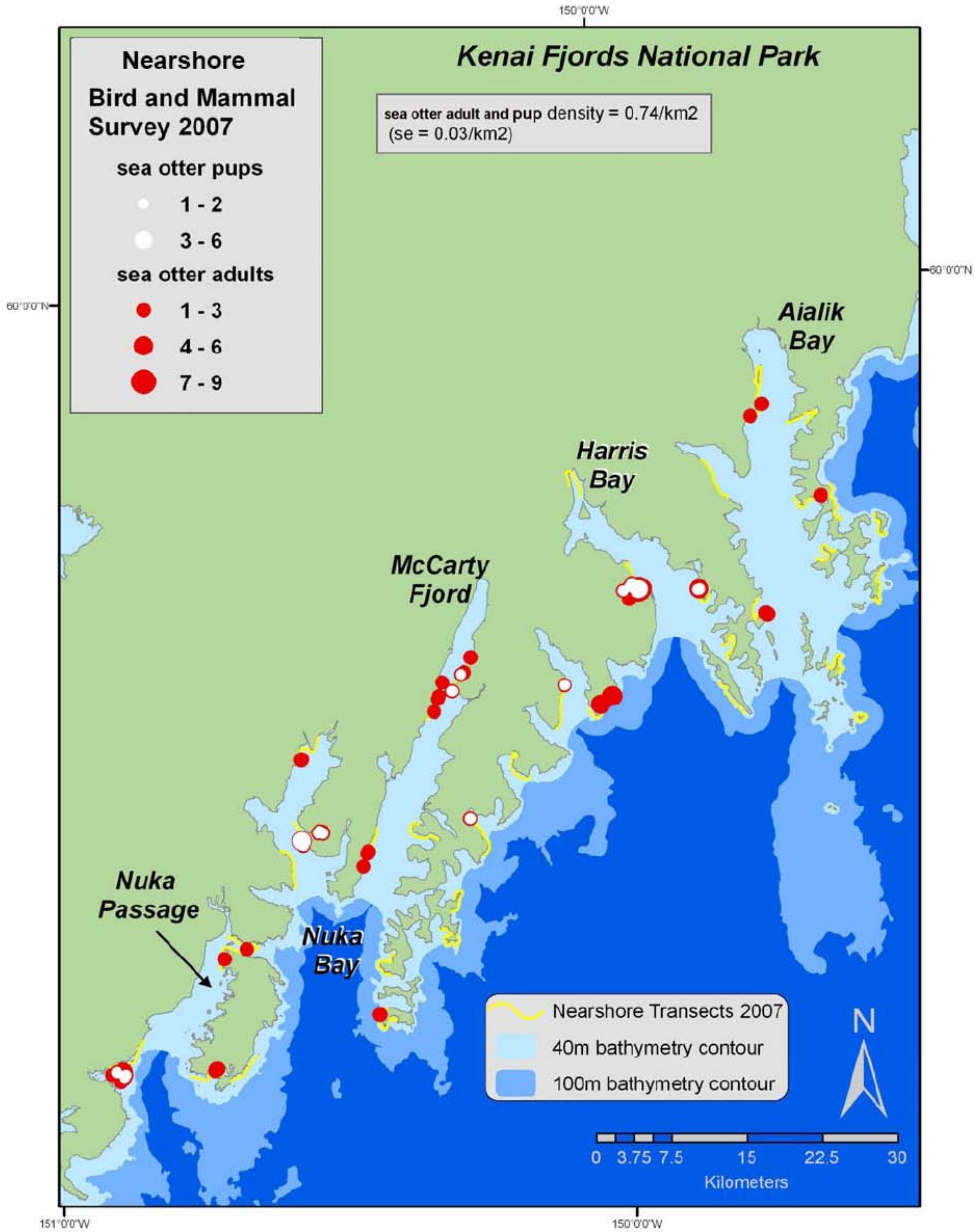


Figure 16. Distribution and abundance of sea otters in 2007 from the SWAN nearshore monitoring program (Bodkin et al. 2008).

Harbor seals: The National Marine Fisheries Service (NMFS) recently modified harbor seal survey methods. Previously (1996–2007) harbor seals in each of five different regions of Alaska were surveyed every five years (National Marine Fisheries Service et al. 2003). Under this survey protocol, harbor seals in the Gulf of Alaska were surveyed by NMFS in 2006 and would not be resurveyed until 2011. Under a revised survey protocol using new technology, low-elevation photos are taken to survey harbor seals. An estimated seventy percent of the harbor seals in Alaska were photographed in 2008 and will be surveyed annually (National Marine Fisheries Service 2009). The SWAN nearshore monitoring program conducts nearshore marine bird and mammal surveys in KEFJ on an annual basis (Coletti et al. 2009). The 2007 SWAN survey estimated harbor seal density in KEFJ as $5.4/km^2$ (se=1.6) (Figure 17), (Bodkin et al. 2008). The Alaska Sealife Center has conducted harbor seal studies in the vicinity of KEFJ. Harbor seals in Aialik Bay have undergone a drastic decline (Hoover-Miller 2004) (Figure 18), similar to that observed in other locations within the Gulf of Alaska (Mathews and Pendleton 2006). Numbers of seals in Aialik Bay declined more than 85% between 1980 and 1989. From 1989 to 2003, numbers of seals remained low but relatively stable. A harbor seal video monitoring program (Figure 19) was established in 2002 to observe harbor seals in their native habitat. These remotely controlled cameras observe harbor seals in the wild without potential for human influence on their behavior (Figure 20). These cameras are also thought to have reduced vessel interactions with harbor seals, with a decline in the number of vessel interactions resulting in large numbers (>20) of seals entering the water in the years after camera installation (Hoover-Miller 2004).

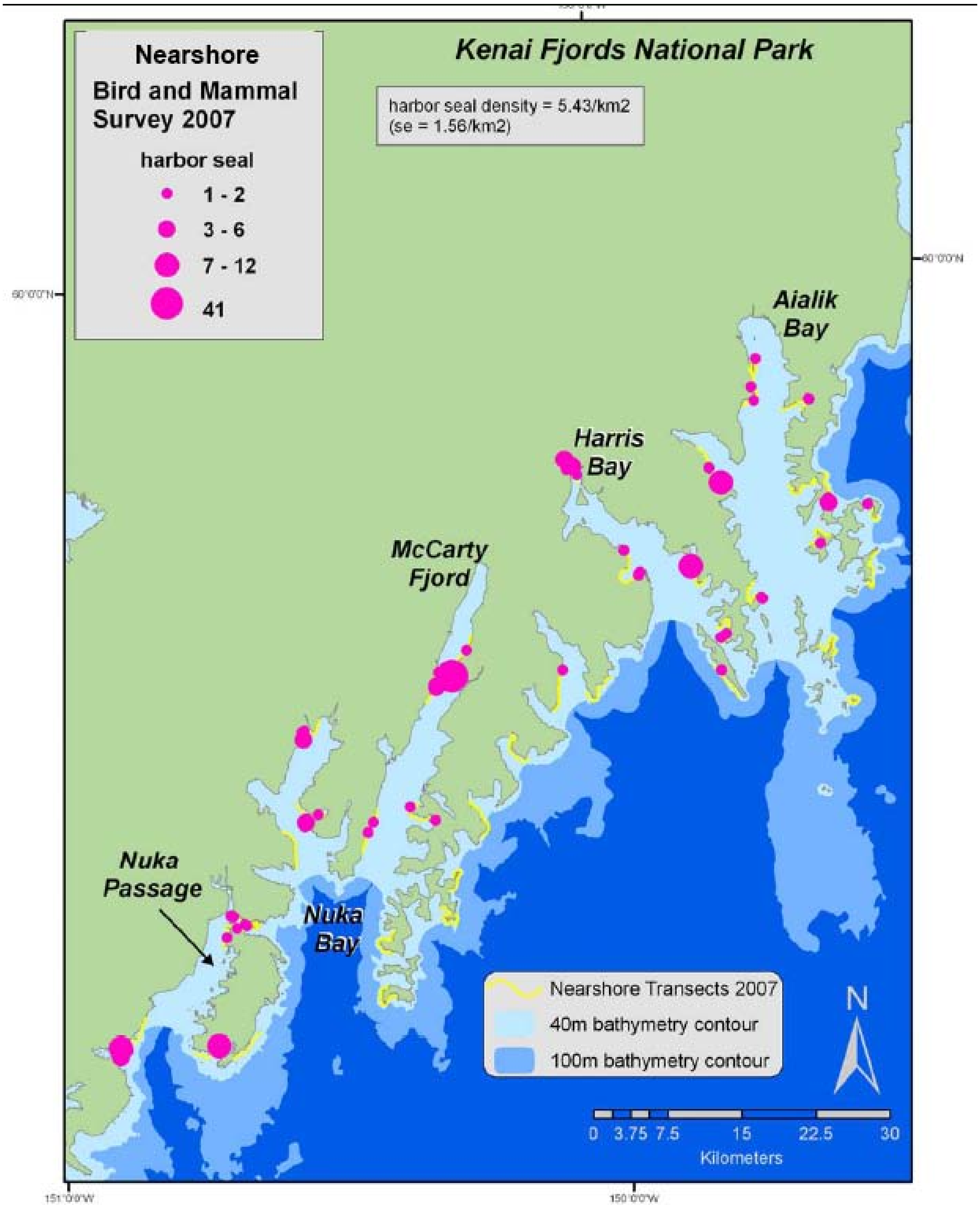


Figure 17. Distribution and abundance of harbor seals in 2007 from the SWAN nearshore monitoring program (Bodkin et al. 2008).

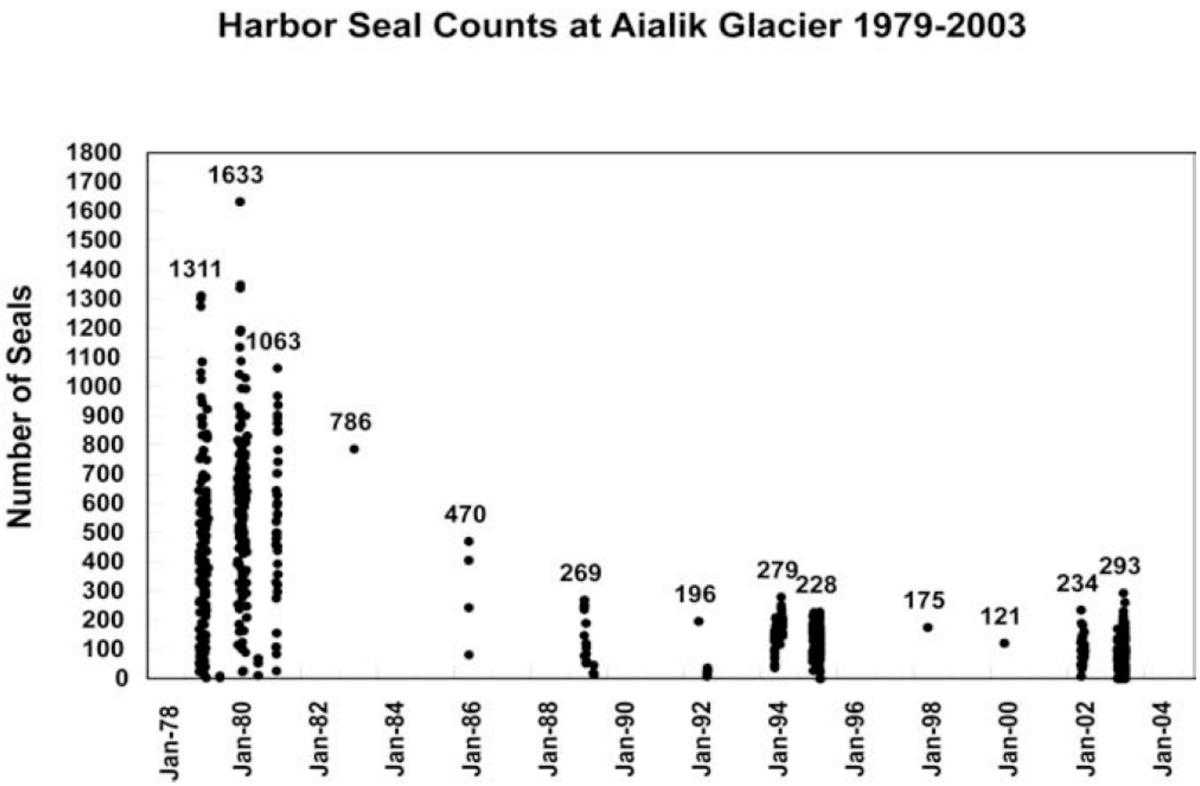


Figure 18. Numbers of harbor seals, including pups, counted near Aialik Glacier from 1979 to 2003 (Hoover-Miller 2004)

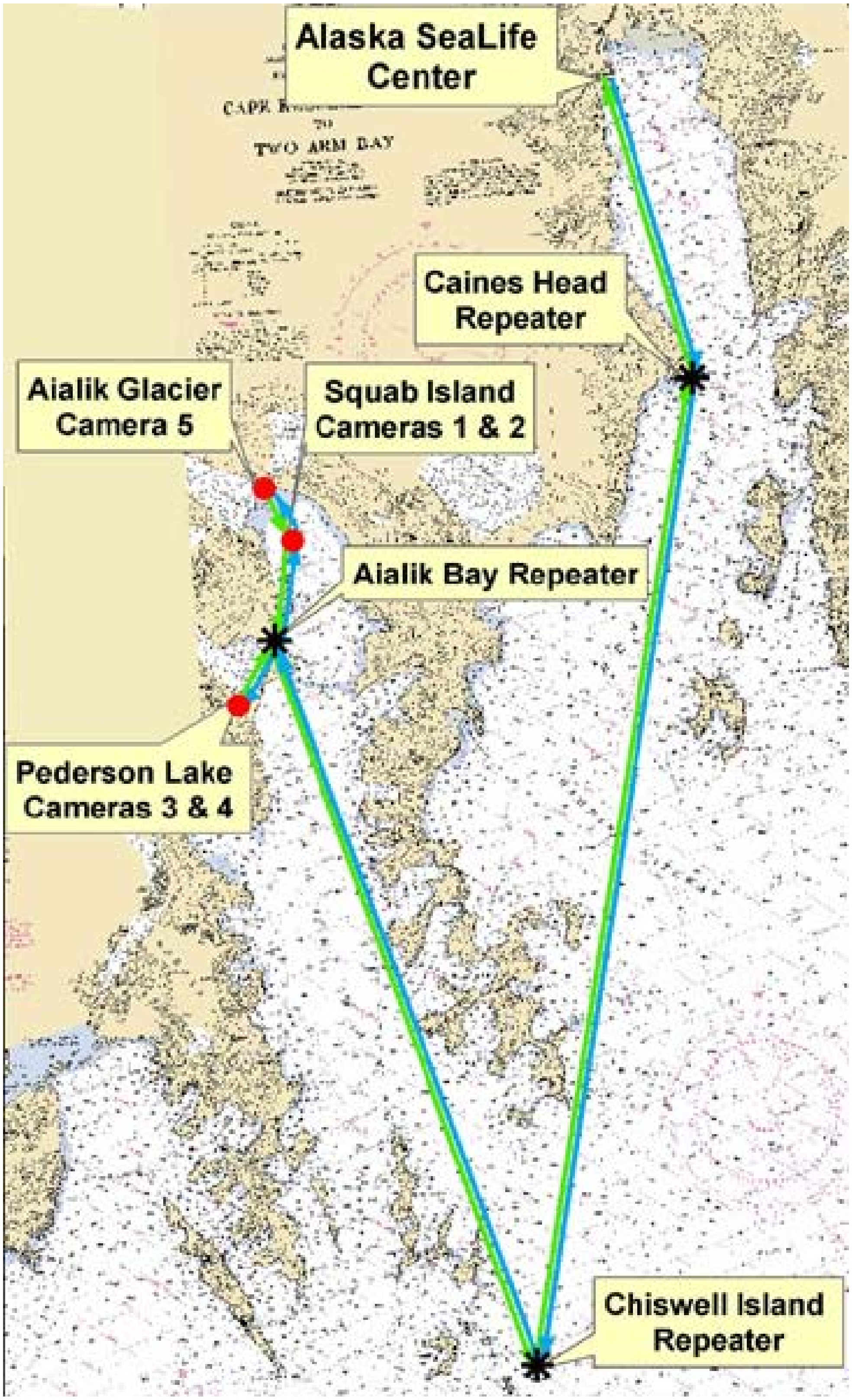


Figure 19. Five remote cameras observe harbor seals and relay images to the Alaska Sea Life Center. http://www.oceanalaska.org/research/sealrvm-images.htm

Figure 20. One of the remote cameras located on Squab Island near the face of Aialik Glacier relays live video of harbor seals adjacent to the glacier. http://www.oceanalaska.org/research/sealrvm-images.htm

Steller sea lions: The U.S. western stock of Steller sea lions (*Eumetopias jubatus*) located westward of Cape Suckling, 144º W, and including the KEFJ region, is federally listed as endangered due to declining populations throughout the western Gulf of Alaska and Bering Sea regions (Sease and Loughlin 1997). Critical habitat for Steller sea lions exists offshore of KEFJ around Chiswell Islands, Seal Rocks and Pye Islands (Figure 21, 50 CFR 226.202 available at http://www.fakr.noaa.gov/protectedresources/stellers/habitat.htm). Sea lions appear to be declining in the vicinity of KEFJ. Vequist (1990) observed a 66% decline from 1976 to 1986 (from 3,700 to 1,258 sea lions) and a 41% decline in pups (from 400 to 237) at the Outer Island rookery. A video monitoring system at the Chiswell Islands rookery (outside the park boundary) has been used to observe sea lion pupping success and predation by killer whales (Maniscalco et al. 2002, Maniscalco et al. 2007). During the NPS SWAN nearshore monitoring program survey in 2007, sea lions had the highest density of marine mammals at 7.7/km^2 (se=3.7) (Bodkin et al. 2008).

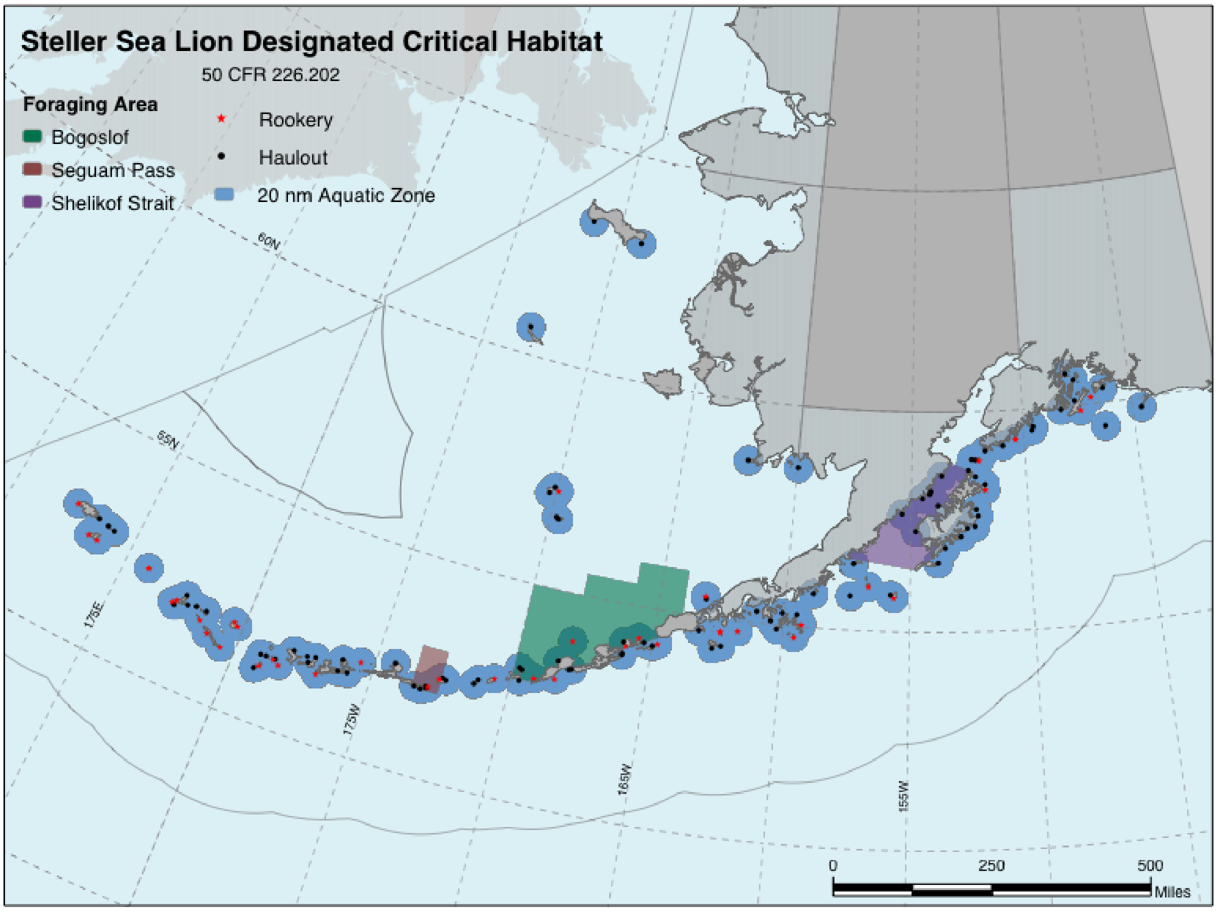


Figure 21. Critical habitat for Steller sea lions. Fishing is restricted in the blue zone (20 nm Aquatic Zone) around rookeries and haulouts. http://www.fakr.noaa.gov/protectedresources/stellers/habitat.htm

Marine fishes: An NPS fish inventory lists the following species as occurring in KEFJ: Pacific herring *(Clupea pallasii)*, longnose sucker *(Catostomus catostomus)*, saffron cod *(Eleginus gracilis)*, Pacific cod *(Gadus macrocephalus)*, Pacific tomcod *(Microgadus proximus)*, Alaska pollock *(Theragra chalcogramma)*, burbot *(Lota lota)*, Alaskan stickleback *(Gasterosteus aculeatus)*, salmon shark *Lamna ditropis)*, eulachon *(Thaleichthys pacificus)*, Alaskan ronquil *(Bathymster caeruleofasciatus)*, blackbelly eelpout *(Lycodopsis pacifica)*, Pacific lamprey *(Lampetra tridentata)*, arrowtooth flounder *(Atheresthes stomias)*, rex sole *(Glyptocephalus zachirus)*, flathead sole *(Hippoglossoides elassodon)*, Pacific halibut *(Hippoglossus stenolepis)*, English sole *(Parophrys vetulus)*, starry flounder *(Platichthys stellatus)*, curlfin sole *(Pleuronichthys decurrens)*, longnose skate *(Raja rhina)*, sablefish *(Anoplopoma fimbria)*, whitespotted greenling *(Hexagrammos stelleri)*, yelloweye rockfish *(Sebastes ruber)*, and piked dogfish *(Squalus acanthias)* (NPS 2004a). A more recent survey conducted by the USGS in 2007 listed additional species occurring in the nearshore and pelagic environments adjacent to KEFJ, as listed in Table 4 and Table 5 (Arimitsu et al. 2008).

Table 4. Nearshore fish species, relative abundance, and size (fork length, mm) collected with a beach seine in KEFJ during 2007. Species are arranged in order of relative abundance. Taken from table 5 in Arimitsu et al. 2008.

Common Name	Scientific Name	Total Catch (# fish)	Size Range	Average ± SD (mm)
Pacific sand lance	*Ammodytes hexapterus*	1686	32 - 156	92 ± 35
Pacific herring	*Clupea pallasii*	152	30 - 143	97 ± 21
Chum salmon	*Oncorhynchus keta*	96	39 - 69	56 ± 9
Pacific cod	*Gadus macrocephalus*	86	50 - 95	64 ± 8
Sockeye salmon	*Oncorhynchus nerka*	46	59 - 104	84 ± 12
Surf smelt	*Hypomesus pretiosus*	32	37 - 114	61 ± 20
Sculpin (Myox.)	*Myoxocephalus* sp.	21	12 - 20	17 ± 2
Pink salmon	*Oncorhynchus gorbuscha*	4	32 - 35	34 ± 1
Great sculpin	*Myoxocephalus polyacanthocephalus*	4	46 - 159	78 ± 54
Buffalo sculpin	*Enophrys bison*	3	45 - 119	78 ± 33
Dolly varden	*Salvelinus malma*	3	150 - 202	184 ± 26
Sculpin	Cottidae (family)	2	12 - 15	14 ± 2
Sharpnose sculpin	*Clinocottus acuticeps*	2	17 - 27	22 ± 7
Capelin (spent female)	*Mallotus villosus*	1	105	105
Threespine stickleback	*Gasterosteus aculeatus*	1	29	29
Greenling	*Hexagrammos* sp.	1	28	28
Rock greenling	*Hexagrammos lagocephalus*	1	140	140
White-spotted greenling	*Hexagrammos stelleri*	1	82	82
Padded sculpin	*Artedius fenestralis*	1	34	34
Daubed shanny	*Lumpenus maculatus*	1	61	61
Crescent gunnel	*Pholis laeta*	1	39	39
Yellowfin sole	*Pleuronectes asper*	1	45	45

Table 5. Pelagic fish species, size (fork length, mm) and frequency of occurrence (FOC) at Isaacs-Kidd midwater trawl stations in KEFJ in 2007. Species are arranged in order of decreasing frequency of occurrence. From Arimitsu et al. (2008).

Common Name	Scientific Name	Size Range	Average (±SD)	FO
Saffron cod	*Eleginus gracilis*	12-51	31 ± 9.8	0.81
Walleye pollock	*Theragra chalcogramma*	17-41	25 ± 4.5	0.62
Spinyhead sculpin	*Dasycottus setiger*	12-25	14 ± 3.2	0.57
Poacher	Agonidae (family)	8-20	16± 3.5	0.48
Gadid	Gadidae (Family)	12-32	22 ± 5.2	0.43
Flathead sole	*Hippoglossoides elassodon*	12-25	20 ± 3.1	0.33
Larval flatfish	Pleuronectidae (Family)	12-24	19 ± 3.5	0.29
Larval prickleback	Sticheaidae (Family)	21-63	41 ± 15.5	0.29
Snailfish	Liparidae (family)	13-19	15 ± 2.2	0.24
Soft sculpin	*Psychrolutes sigalutes*	12-54	34 ± 19.0	0.19
Prowfish	*Zaprora silenus*	26-36	31 ± 4.8	0.19
Pacific sand lance	*Ammodytes hexapterus*	23-43	30 ± 7.9	0.19
Butter sole	*Isopsetta isolepis*	18-25	21 ± 2.4	0.19
Daubed shanny	*Leptoclinus maculatus*	28-45	37 ± 6.9	0.14
Snake prickleback	*Lumpenus sagitta*	22-67	45 ± 17.1	0.14
Rockfish	*Sebastes* spp.	11-19	14 ± 3.2	0.10
Crested sculpin	*Blepsias bilobus*	21-27	24 ± 2.2	0.10
Lepidopsetta sp.	*Lepidopsetta* spp.	13-22	16 ± 4.9	0.10
Northern rock sole	*Lepidopsetta polyxystra*	15-21	18 ± 2.4	0.10
Northern smoothtongue	*Leuroglossus schmidti*	27	27	0.05
Larval smelt	Osmeridae (Family)	26	26	0.05
Eulachon	*Thaleichthys pacificus*	26	26	0.05
Pacific cod	*Gadus macrocephalus*	33-36	35 ± 2.1	0.05
Sturgeon poacher	*Podothecus accipenserinus*	20	20	0.05
Northern ronquil	*Ronquilus jordani*	30	30	0.05
Pacific sandfish	*Trichodon trichodon*	57	57	0.05
Sand sole	*Psettichthys melanosticus*	13-21	16 ± 3.6	0.05

This 2007 survey (Arimitsu et al. 2008) found that fish biomass (measured by acoustic backscatter) as well as primary productivity were higher in glacial areas of Northwestern Lagoon than in glacial areas of Aialik Bay. Although no significant difference in zooplankton abundance was found between or within fjords, euphausiid density in trawls was negatively associated with distance to tidewater glaciers (Arimitsu et al. 2008). The study also found that capelin likely spawn in Pederson Lagoon, where high densities of marine birds congregate during the summer. Beach seine sampling found a numerical dominance of Pacific sand lance *(Ammodytes hexapterus)* and Pacific herring (*Clupea pallasii)* in nearshore areas. Trawl surveys found saffron cod (*Eleginus gracilis*), walleye Pollock (*Theragra chalcogramma*), and spinyhead sculpin (*Dasycottus setiger*) were the most abundant species (Arimitsu et al. 2008).

Marine birds: Seventy-one shorebird species—one-third of the known shorebird species in the world—occur along coastal Alaska (Andres and Gill 2000). Coastal KEFJ hosts abundant seabird populations. Marine birds are one of the vital signs designated by the SWAN nearshore monitoring program, and as a result, summer and winter seabird surveys were conducted along

KEFJ in 2007 and 2008 (Bodkin et al. 2008, Coletti and Bodkin 2009). Objectives of the surveys included characterization of species composition, density, and distribution for over-wintering sea ducks prior to their migration to breeding grounds, and further studies are planned as part of the long-term monitoring protocol. Distribution maps of the most common marine bird species are presented from this SWAN nearshore monitoring program (Figures 22–31).

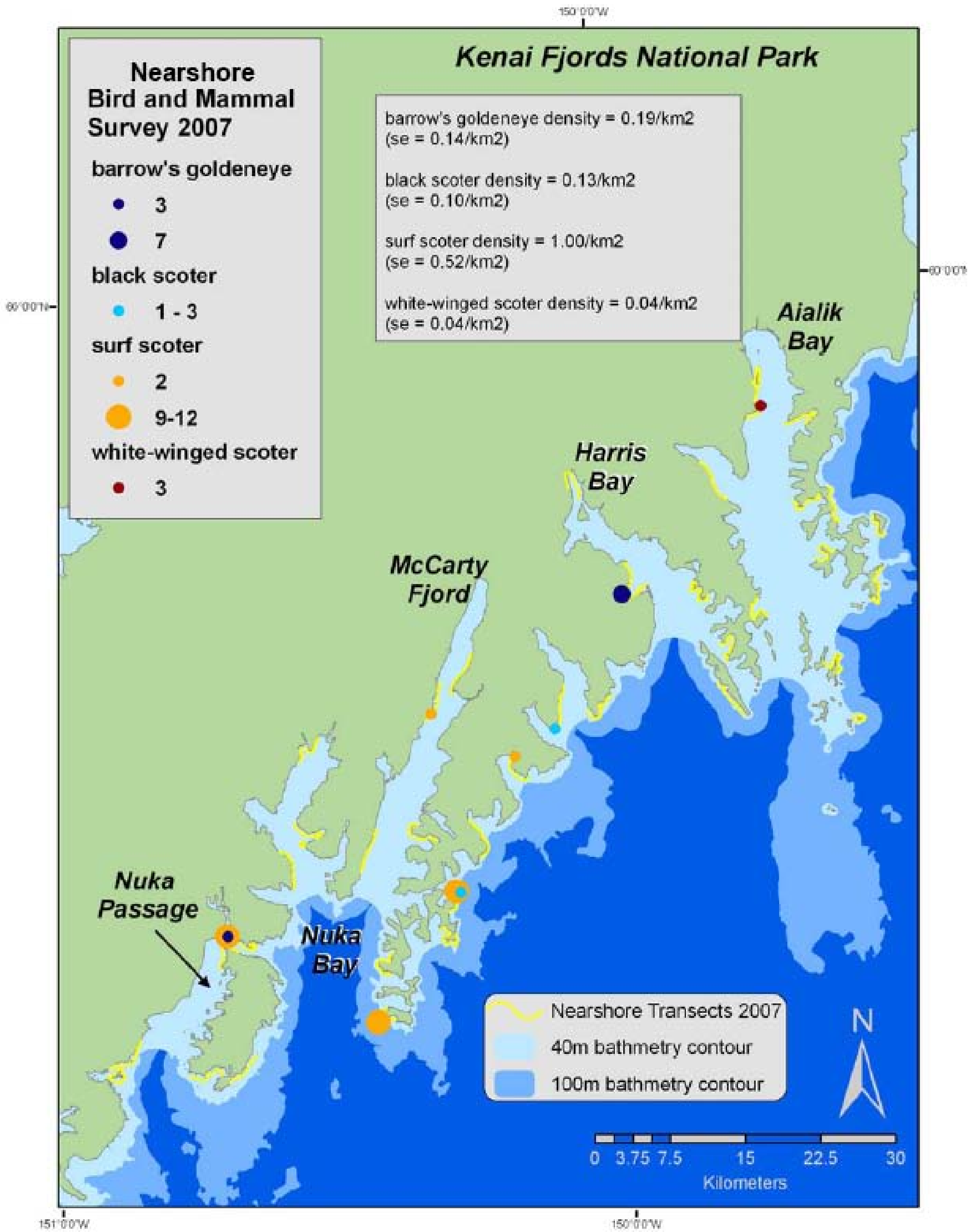


Figure 22. Distribution, abundance, and density of Barrow's goldeneye, black, surf, and white-winged scoters in June 2007 (Bodkin et al. 2008).

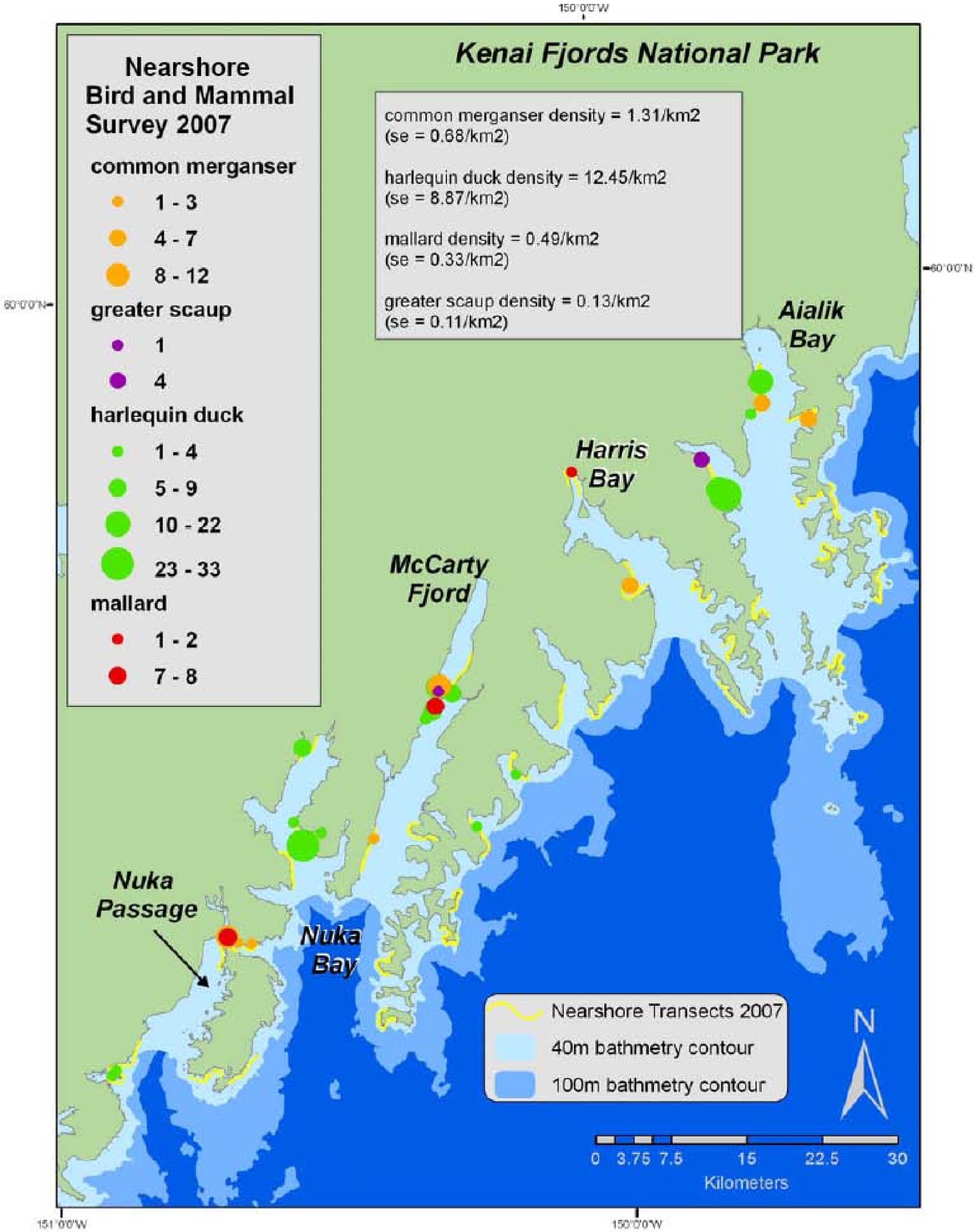


Figure 23. Distribution, abundance, and density of common merganser, greater scaup, harlequin duck, and mallard in June 2007 (Bodkin et al. 2008).

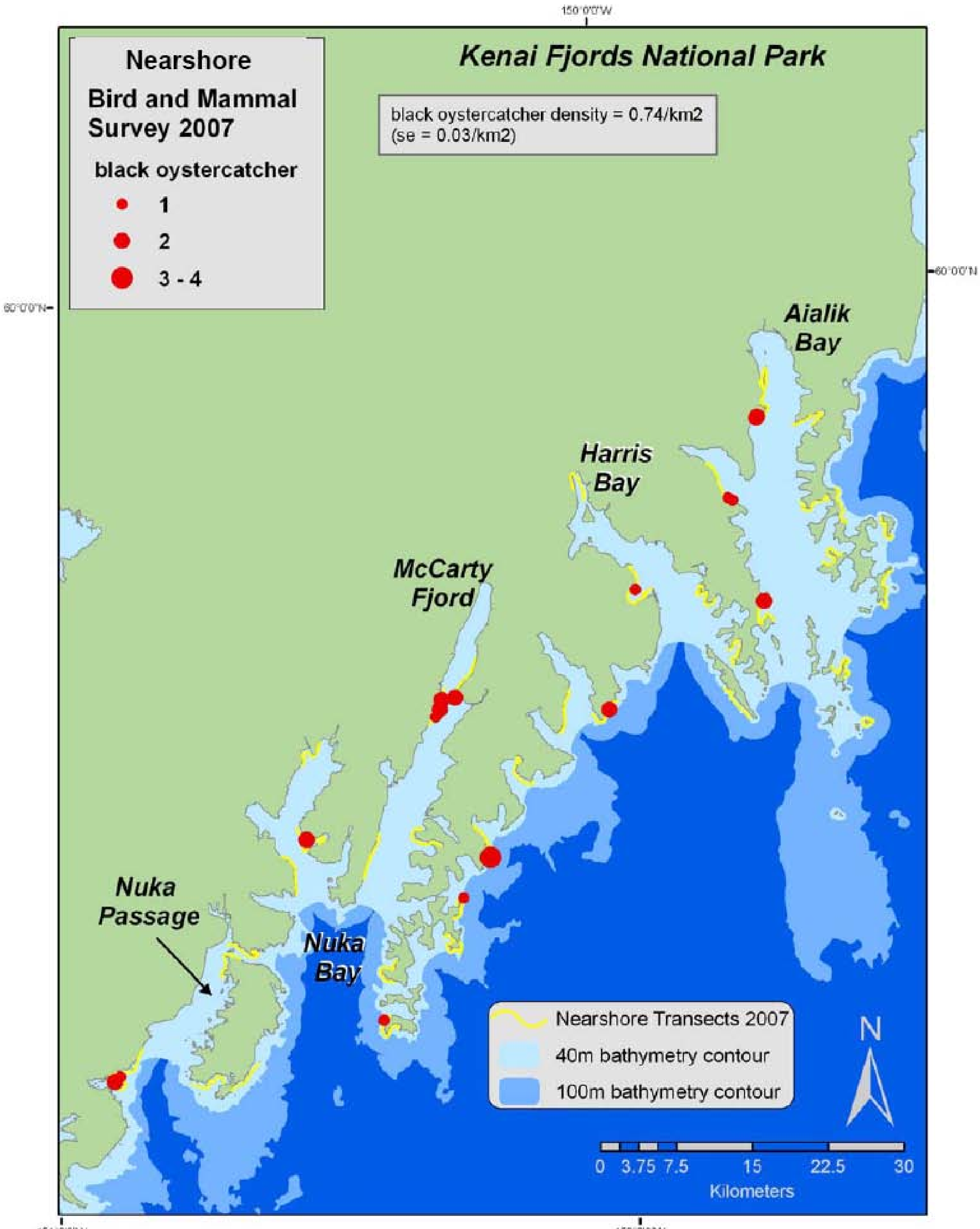


Figure 24. Distribution, abundance, and density of black oystercatchers in June 2007 (Bodkin et al. 2008).

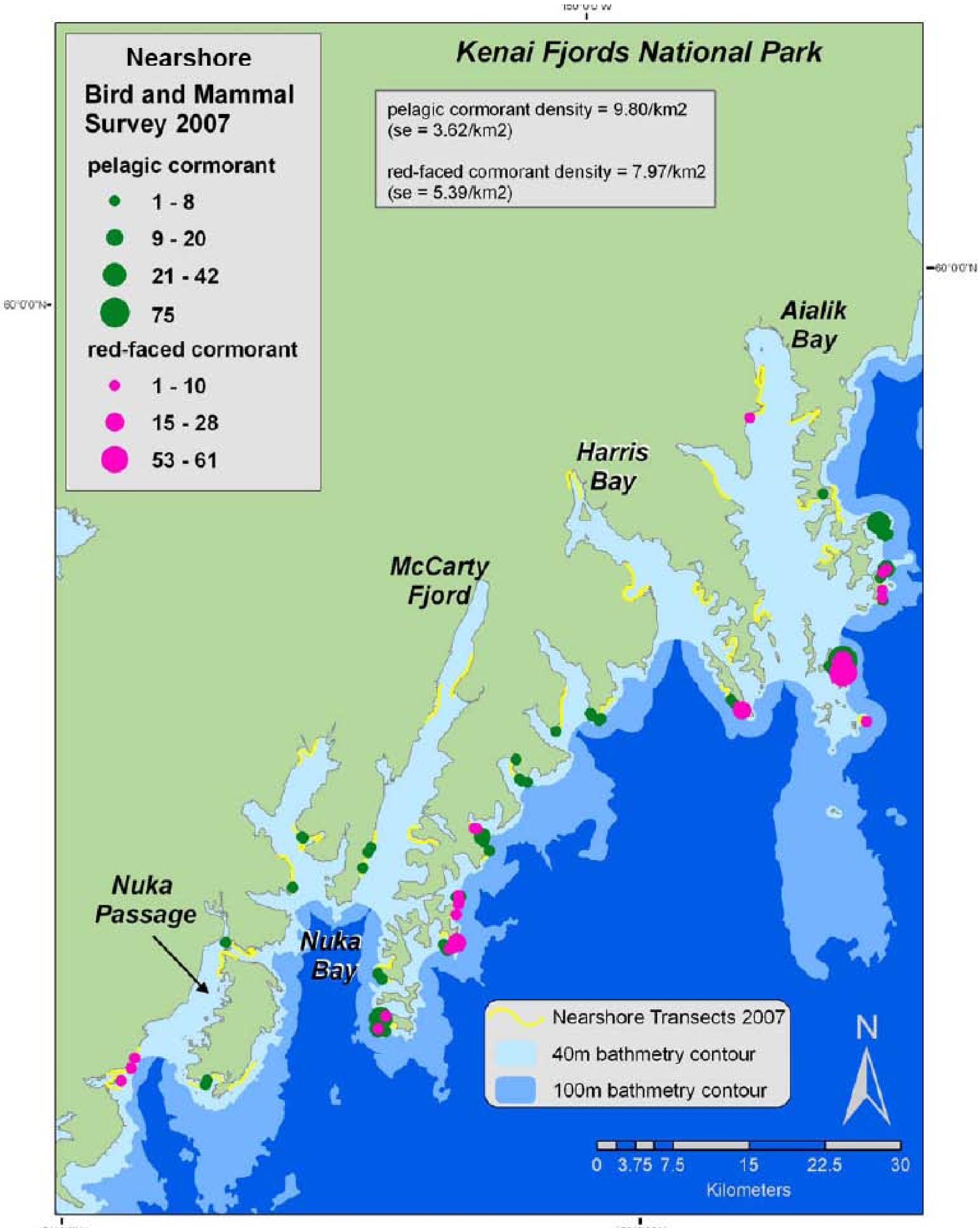


Figure 25. Distribution, abundance, and density of pelagic and red-faced cormorants in June 2007 (Bodkin et al. 2008).

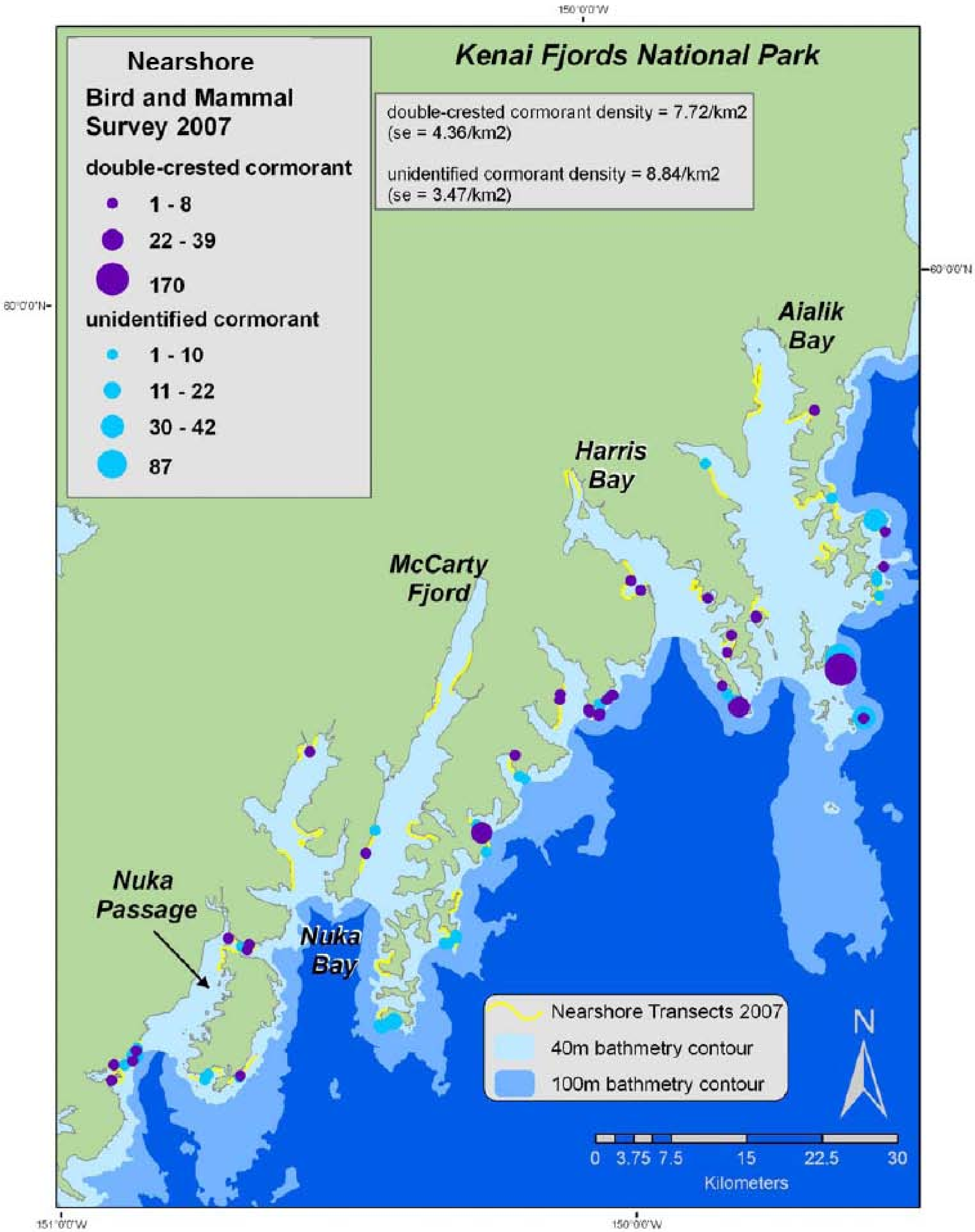


Figure 26. Distribution, abundance, and density of double-crested and unidentified cormorants in June 2007 (Bodkin et al. 2008).

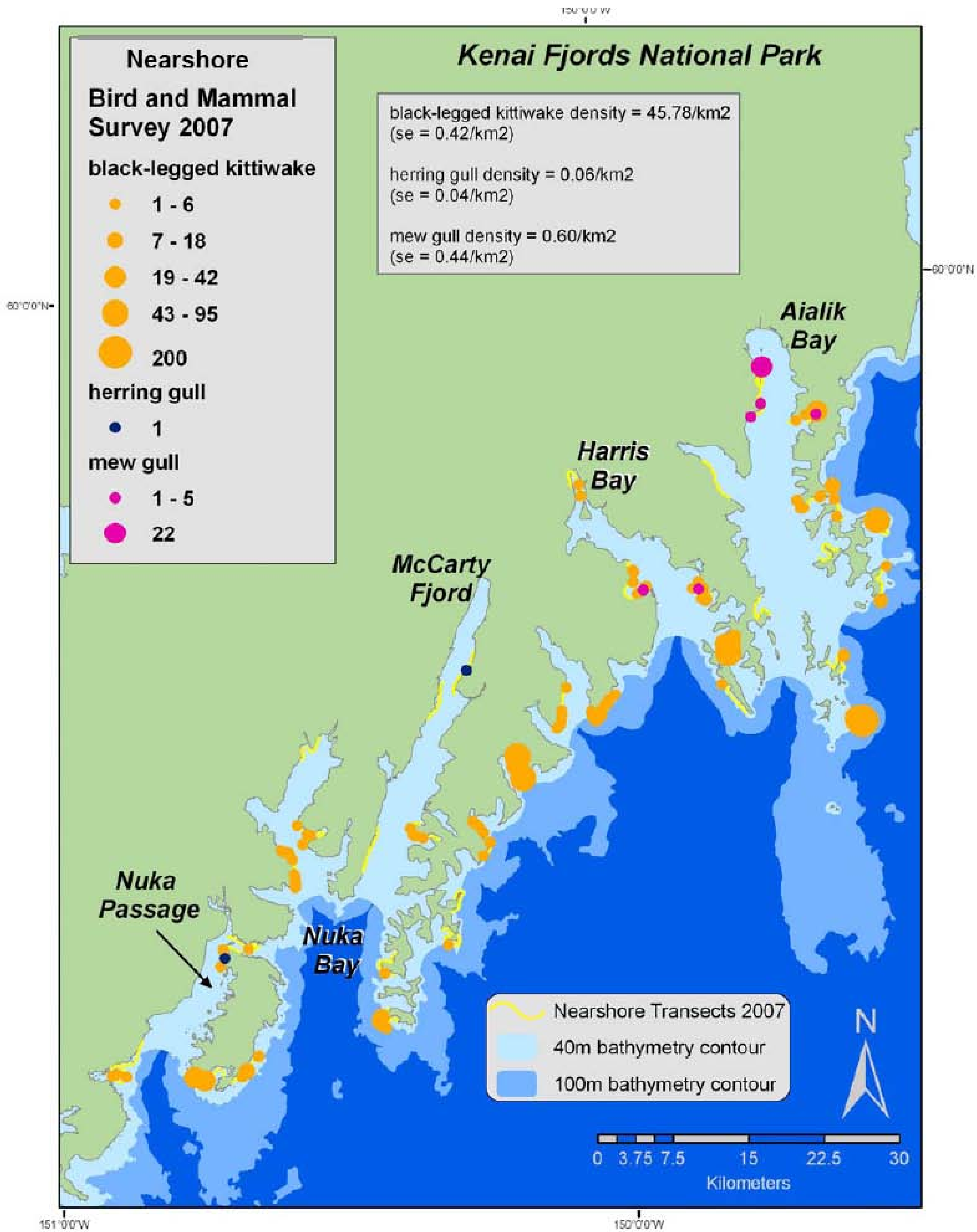


Figure 27. Distribution, abundance, and density of black-legged kittiwakes, herring and mew gulls in June 2007 (Bodkin et al. 2008).

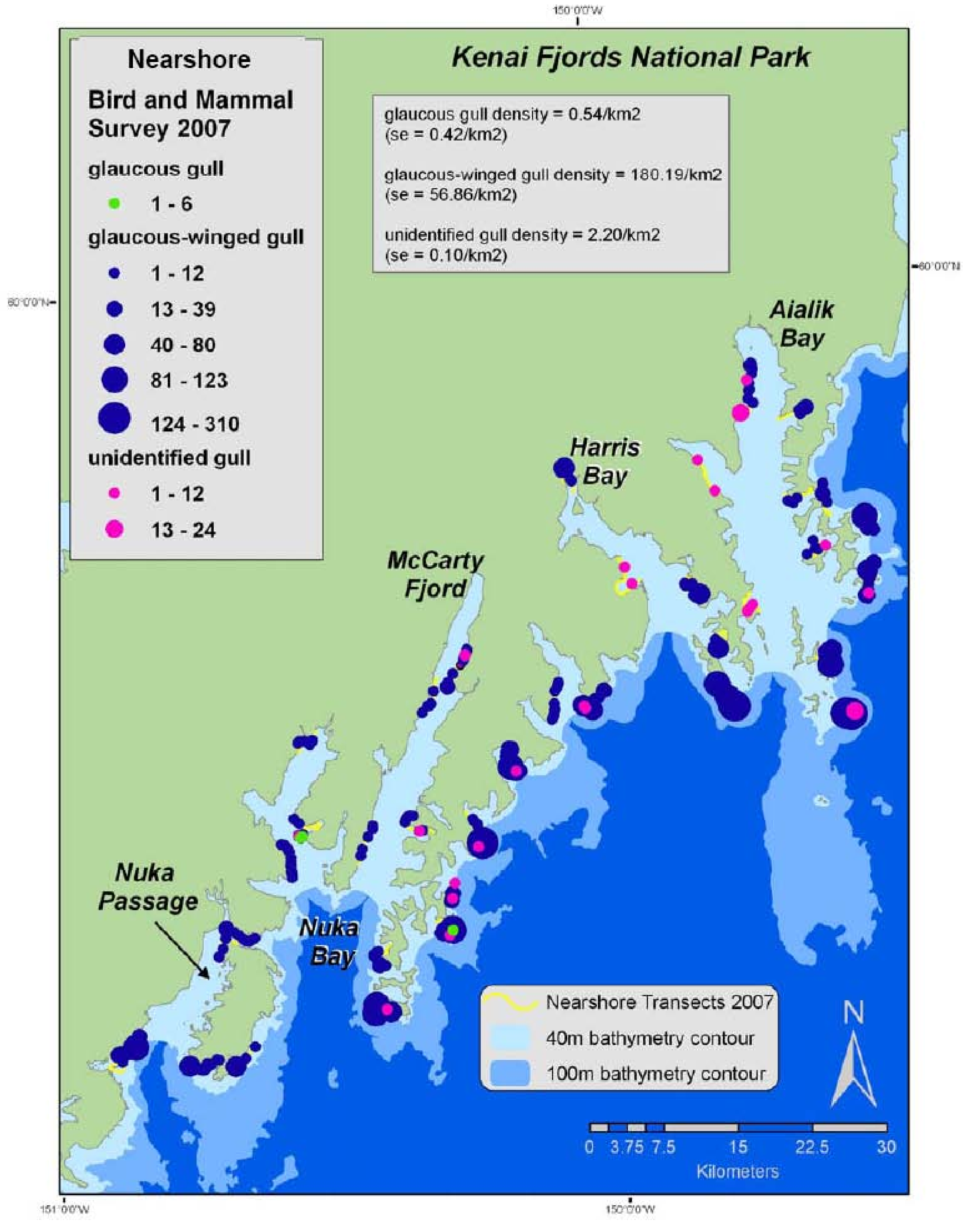


Figure 28. Distribution, abundance, and density of glaucous, glaucous-winged and unidentified gulls in June 2007 (Bodkin et al. 2008).

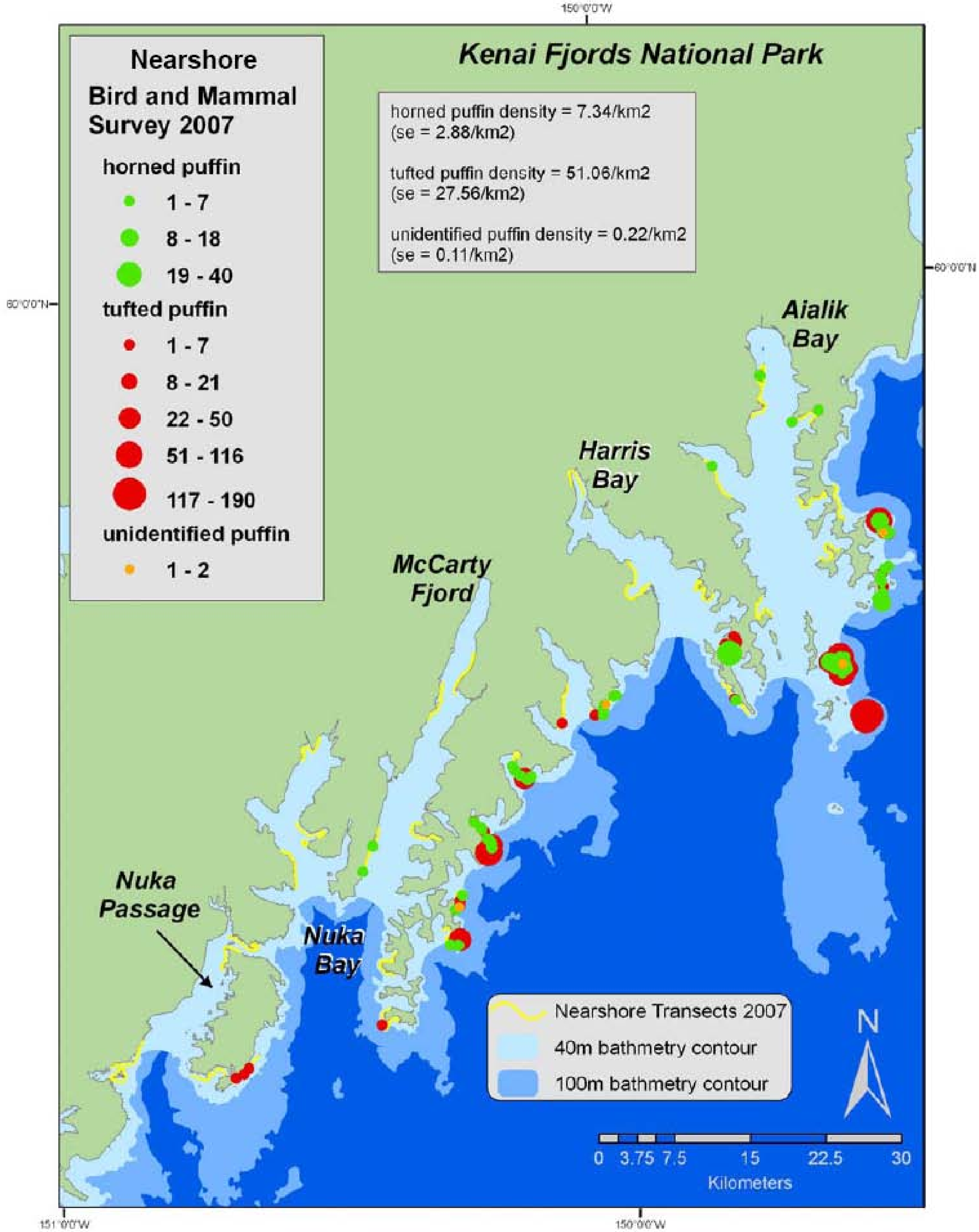


Figure 29. Distribution, abundance, and density of horned, tufted, and unidentified puffins in June 2007 (Bodkin et al. 2008).

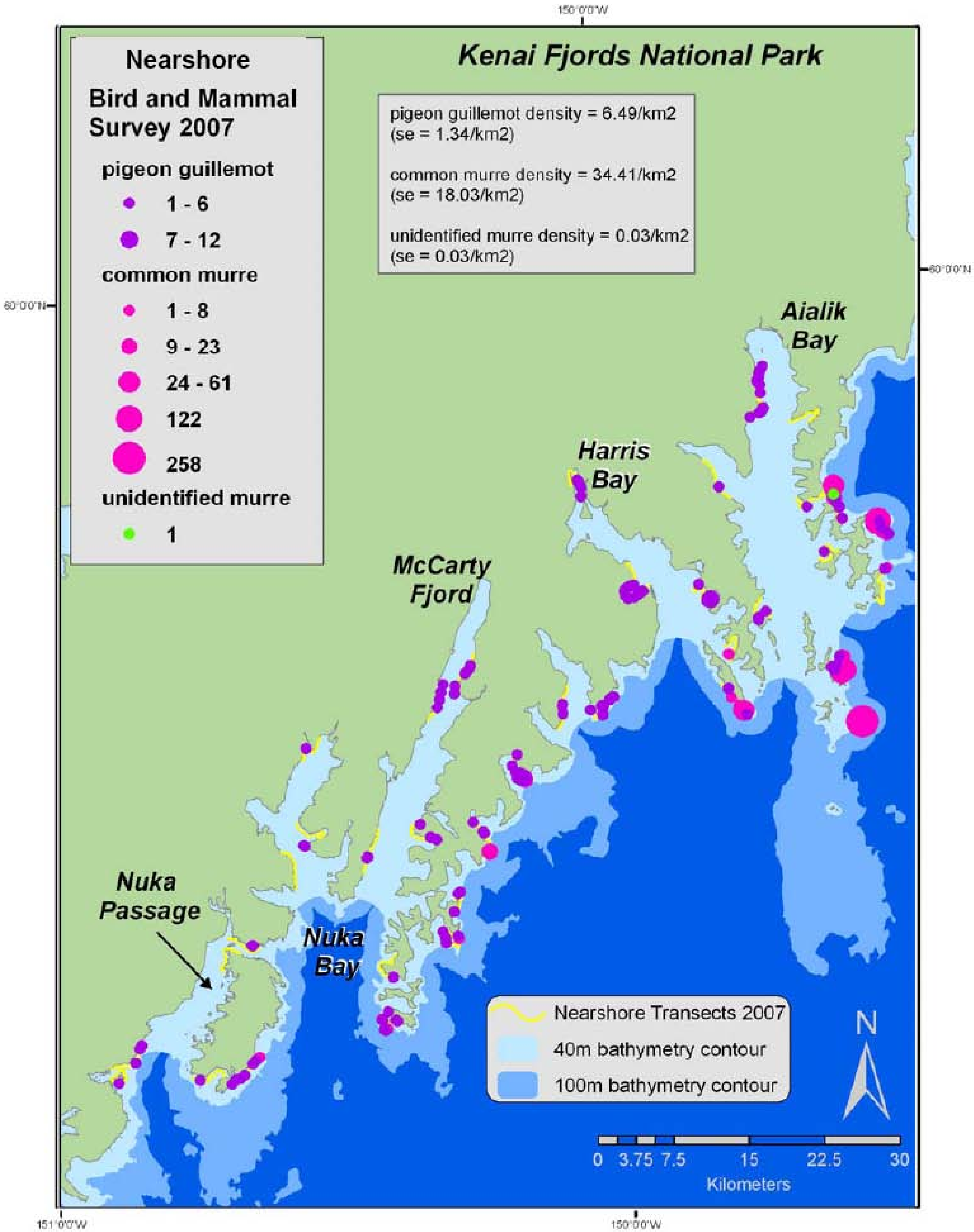


Figure 30. Distribution, abundance, and density of pigeon guillemots, common murres, and an unidentified murre in June 2007 (Bodkin et al. 2008).

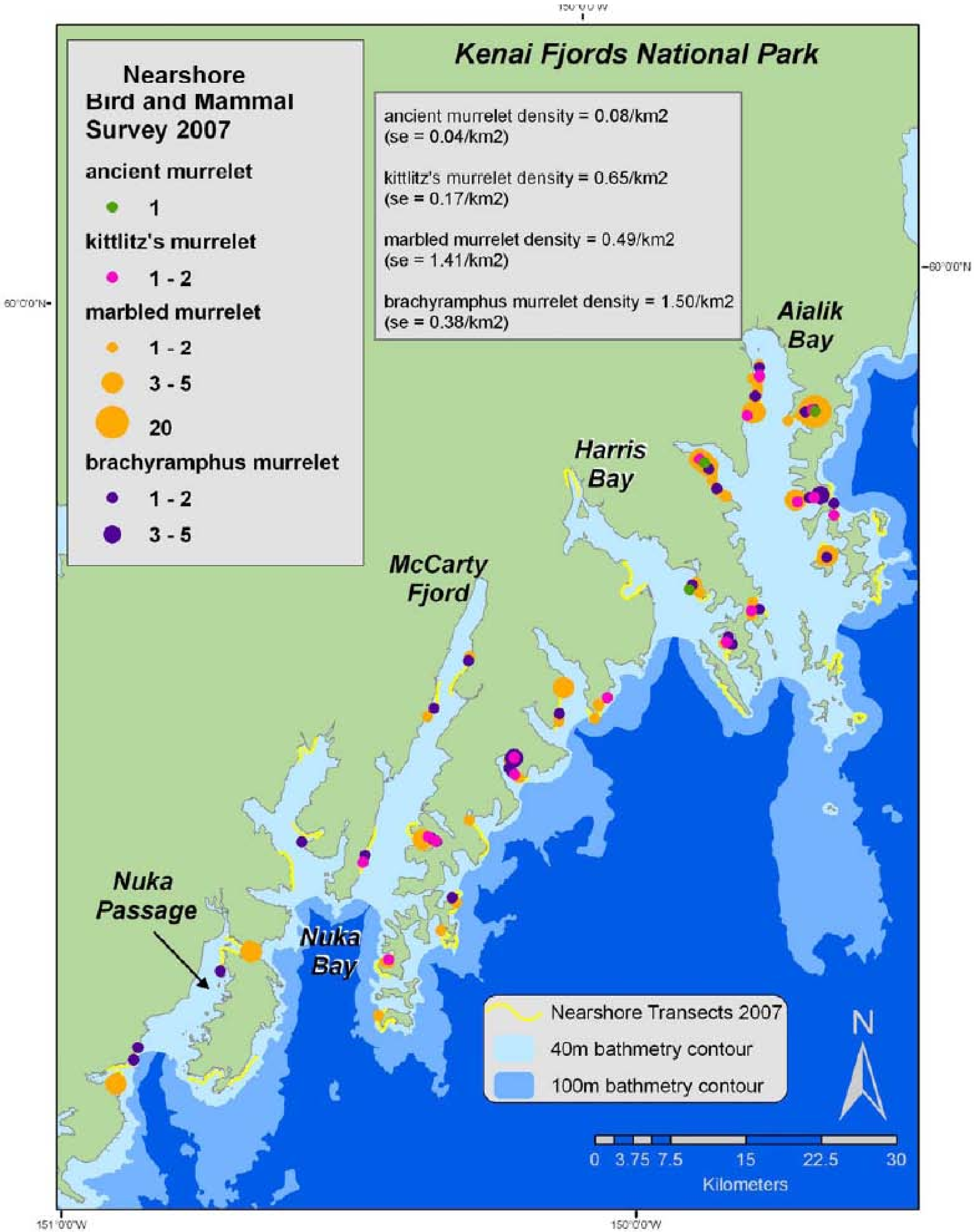


Figure 31. Distribution, abundance, and density of ancient, Kittlitz's, marbled, and brachyramphus murrelets in June 2007 (Bodkin et al. 2008).

Older studies include a marine bird and mammal survey conducted between 19 June and 14 July 1976 along almost 970 km (600 mi) of southern Kenai Peninsula and offshore Islands (Point Adam to Cape Resurrection), which counted a total of 174,000 seabirds of 30 species (Bailey 1977). An estimated half of the breeding pairs were tufted puffins (*Lunda cirrhata*); black-legged kittiwakes *(Rissa tridactyla)*, glaucous-winged gulls *(Larus glaucoscons)*, common murres *(Mergus merganser)*, and horned puffins *(Fratercula corniculata)* were the next most common nesting species. Abundance and diversity was highest in the Chiswell Islands, home to 42% of the total birds recorded in the survey. In 2007, the National Park Service (in conjunction with the Alaska Maritime National Wildlife Refuge, or AMNWR) resurveyed 14 of the seabird colonies visited by Bailey (1977) (Hahr 2008b) (Figure 32). The three-day survey in July 2007 found that the relative abundance of colony counts of all species except glaucous-winged gulls appears to have declined. Generally, the most abundant species were the same in the re-survey as in 1976, but red-faced cormorants *(Plalacrocorax urile)* and arctic terns (*Sterna paradisaea)* were not seen in the 2007 survey. Nonetheless, NPS staff observed nesting red-faced cormorants nesting on the Chiswell Islands in the summer of 2009 (Bill Thompson, NPS Seward, written communication, 2009). However, double-crested cormorants (*Phalacrocorax auritus*) were observed at seven colonies in 2007 but were not found in 1976. KEFJ and the AMNWR plan to continue cooperatively surveying seabirds along the Kenai Peninsula coast (Hahr, 2008b).

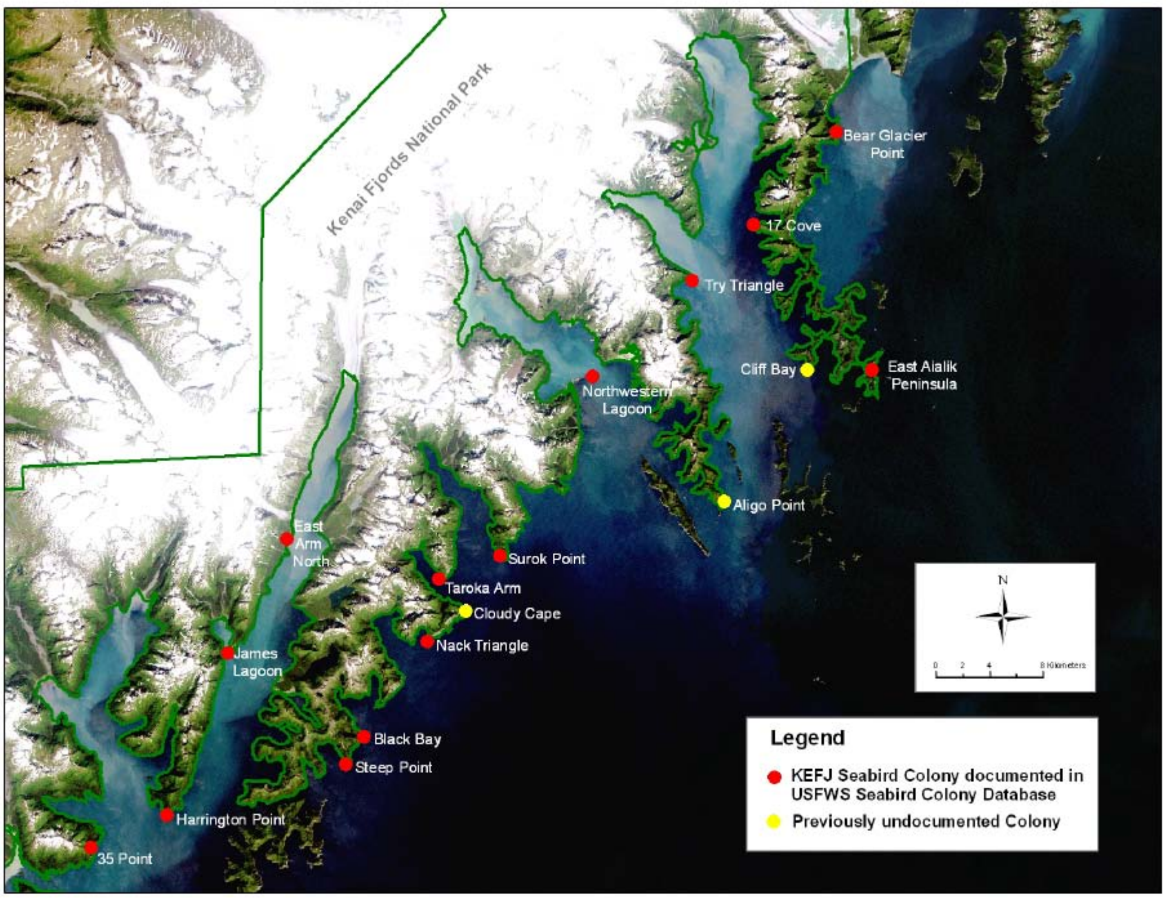


Figure 32. Seabird breeding colony locations along the KEFJ coast. From Hahr (2008b).

Additional surveys of seabirds were conducted in 1989 in response to the *Exxon Valdez* Oil Spill, including a survey of most of the KEFJ coast (Vequist and Nishimoto 1989) as well as a survey focused on the Chiswell and Pye Islands (and specifically on black-legged kittiwakes and common murres) (Nysewander 1989). Another study investigated the deaths of approximately 11,000 pigeon guillemots (*Uria aalge*) along the south coast of the Kenai Peninsula (Piatt and Van Pelt 1997). The cause of death was inconclusive, but the researchers surmised that starvation (potentially due to conditions made responsible by the prolonged 1990–1995 El Nino-Southern Oscillation event) may have been the cause.

The Kittlitz's murrelet (*Brachyramphus brevitostris,* Alcidae), a candidate for threatened species listing, has received special attention in KEFJ. This species was particularly heavily impacted by the EVOS (van Vleit and McAllister. 1994). One study on Kittlitz's murrelets along the southern Kenai coast (including KEFJ) estimated a population decline of 83% since 1976 (Van Pelt and Piatt 2003). This study also listed data on abundance and distribution of other seabird species encountered in the July 2002 murrelet survey (see Van Pelt and Piatt 2003 for details). A more recent study in 2007 estimated that there were 346 Kittlitz's murrelets and 3,229 marbled murrelets in the KEFJ nearshore waters in mid-summer 2007 (Arimitsu et al. 2008). Kittlitz's murrelets were found to occur only in the upper ends of glacial fjords (Arimitsu et al. 2008). Nesting habitats of marbled murrelets *(Brachyramphus marmoratus)* in KEFJ and elsewhere in southcentral Alaska have been found to be tied to low-elevation locations near the heads of bays with extensive forest cover and large, old-growth trees (Kuletz et al. 1995), although the 2007 survey (a broad-scale distribution and abundance study of murrelets and other species that used a systematic sampling design along the coast) found them to be widely distributed along glacial areas (Arimitsu et al. 2008).

Chlorophyll-a and Zooplankton: A 2007 survey of seabirds along the KEFJ coast included oceanographic measurements and sampling (Arimitsu et al. 2008). Chlorophyll-*a* was higher at distal stations (south of submerged glacial moraines) compared with glacial stations (north of submerged glacial moraines) in early June but not significantly different in late July/early August, and it was higher in glacial areas of Northwestern Fjord than in Aialik Bay. Zooplankton samples were dominated by small copepods such as *Pseudocalanus* spp., *Oithona similis,* and *Acartia longiremis* (Table 6), and there generally was no pattern of copepod abundance by species in glacial and distal areas, except for *Eucalanus bungii,* which was more abundant at distal stations (Arimitsu et al. 2008).

Table 6. The 25 most frequently occurring species of zooplankton sampled in 2007 by Arimitsu et al (2008). FO= frequency of occurrence. Table excerpted from Arimitsu et al (2008).

Taxon	Species	Mean CPUE	SD	FO
Copepod	*Pseudocalanus* spp.	25741.64	15582.57	1.00
Copepod	*Oithona similis*	6363.39	274.79	1.00
Copepod	*Acartia longiremis*	2728.71	2597.47	1.00
Copepod	*Calanus marshallae*	161.26	187.96	1.00
Chaetognath	*Sagitta elegans*	69.82	67.26	1.00
Gastropod	*Limacina helicina*	22.48	241.12	1.00
Gastropod	Gastropod larvae	233.66	488.64	0.96
Larvacean	*Oikopleura* sp.	14.83	97.84	0.96
Copepod	*Metridia pacifica*	128.27	125.35	0.92
Copepod	*Centropages abdominalis*	81.33	8.55	0.88
Copepod	*Eucalanus bungii*	25.94	27.75	0.79
Decapod	Hippolytidae zoea	3.38	3.97	0.75
Bivalve	Bivalvia	135.22	277.17	0.71
Euphausiid	Euphausiid (nauplii-juvenile)	8.19	12.94	0.71
Copepod	*Neocalanus flemingeri*	4.25	5.14	0.71
Decapod	Paguridae zoea	2.52	2.86	0.71
	Evadnae	286.52	147.25	0.58
	Bougainvilla sp	0.34	0.47	0.50
Copepod	*Neocalanus plumchrus*	1.72	2.54	0.46
Copepod	Copepoda nauplii	251.86	685.72	0.42
Decapod	Pisinae zoea	1.23	2.14	0.42
Decapod	Brachyrhancha zoea	2.78	6.29	0.29
Decapod	Pinnotheridae zoea	0.47	1.22	0.29
	Oncea	36.29	89.55	0.25
Cnidarian	*Aglantha digitale*	0.28	0.62	0.25

Marine intertidal resources

Intertidal mapping: ShoreZone is a coastal mapping project that provides a comprehensive and recent source of information on the KEFJ nearshore environments, descriptive overviews of coastal habitat, and classifications of physical and biological attributes. The purpose of the project is to provide a tool for oil spill response and not to serve as a mechanism for quantifying coastal resources. ShoreZone aerially surveyed intertidal and shallow subtidal areas during extremely low tides in the summer in order to identify shoreline morphology, substrate, wave exposure, and biota of intertidal and nearshore habitats. This multi-agency-funded mapping effort is accessible online through a database with interactive GIS layers, digital maps, aerial images and video of the KEFJ coastline. At the Gulf of Alaska Imagery website (http://mapping.fakr.noaa.gov/Website/ShoreZone/viewer.htm), users can generate maps of habitat and substrate types (Figure 33), as well as those of many other coastal ecological and geological features (e.g., salt marsh vegetation [Figure 34], sea grasses [Figure 35], or canopy kelps [Figure 36]) by turning on various layers available through the internet browser. Additional information on the ShoreZone mapping program for coastal Alaska is available at http://www.coastalaska.net.

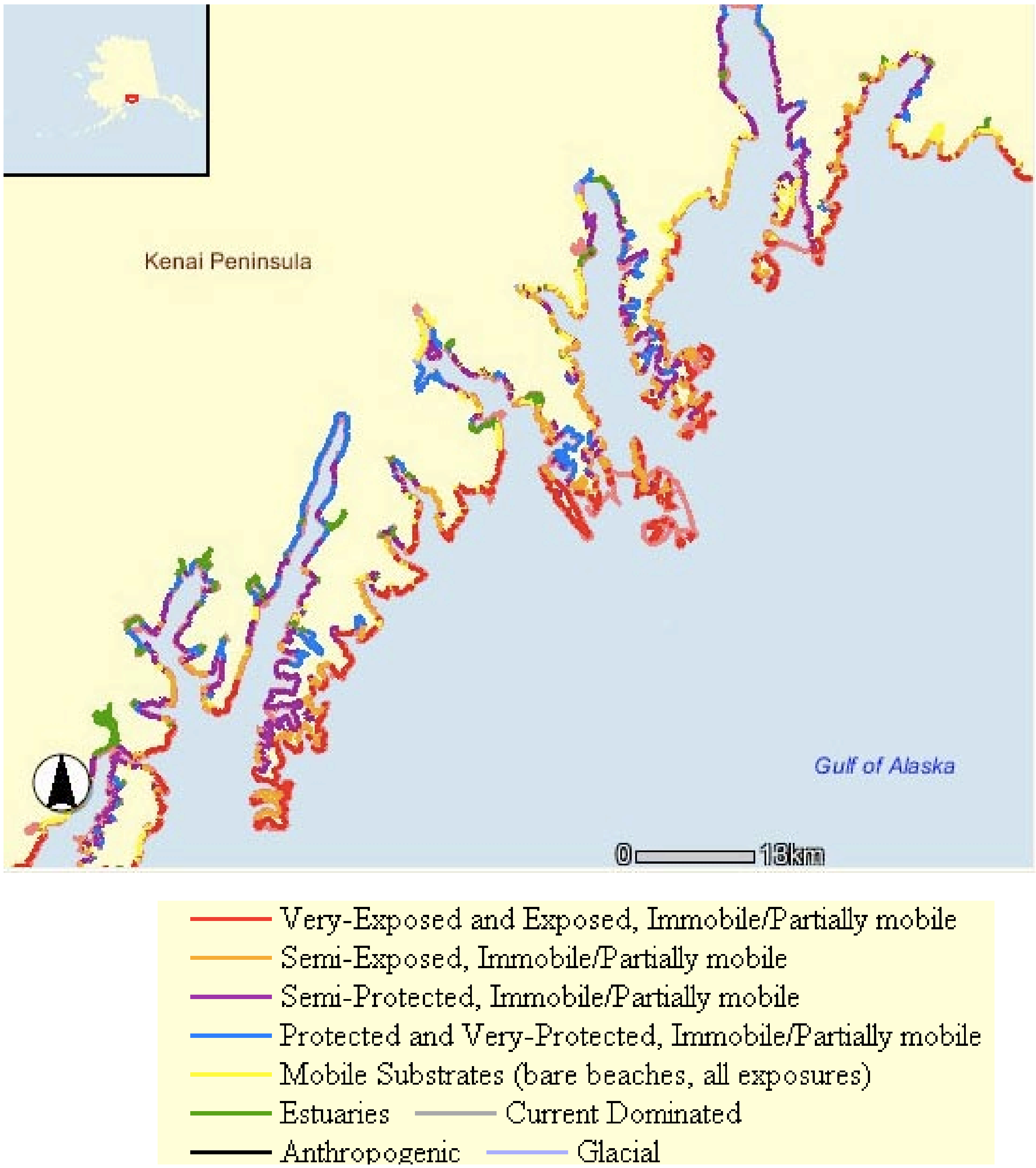


Figure 33. Habitat classes within KEFJ as classified by ShoreZone (http://mapping.fakr.noaa.gov/Website/ShoreZone/viewer.htm).

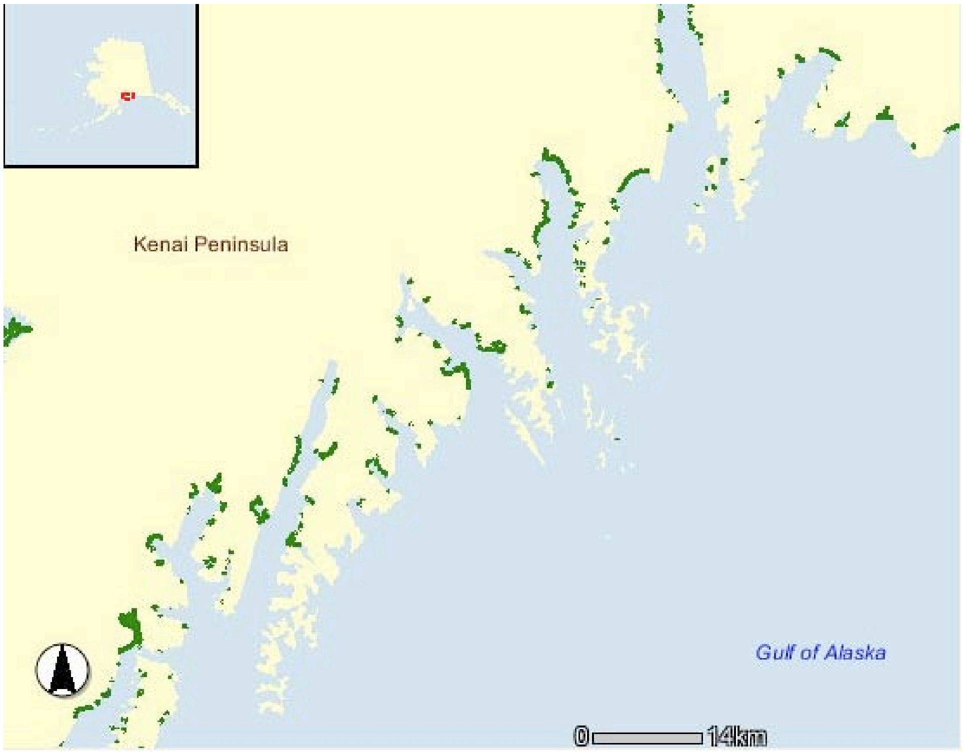


Figure 34. Salt marsh vegetation within KEFJ as classified by ShoreZone (http://mapping.fakr.noaa.gov/Website/ShoreZone/viewer.htm).

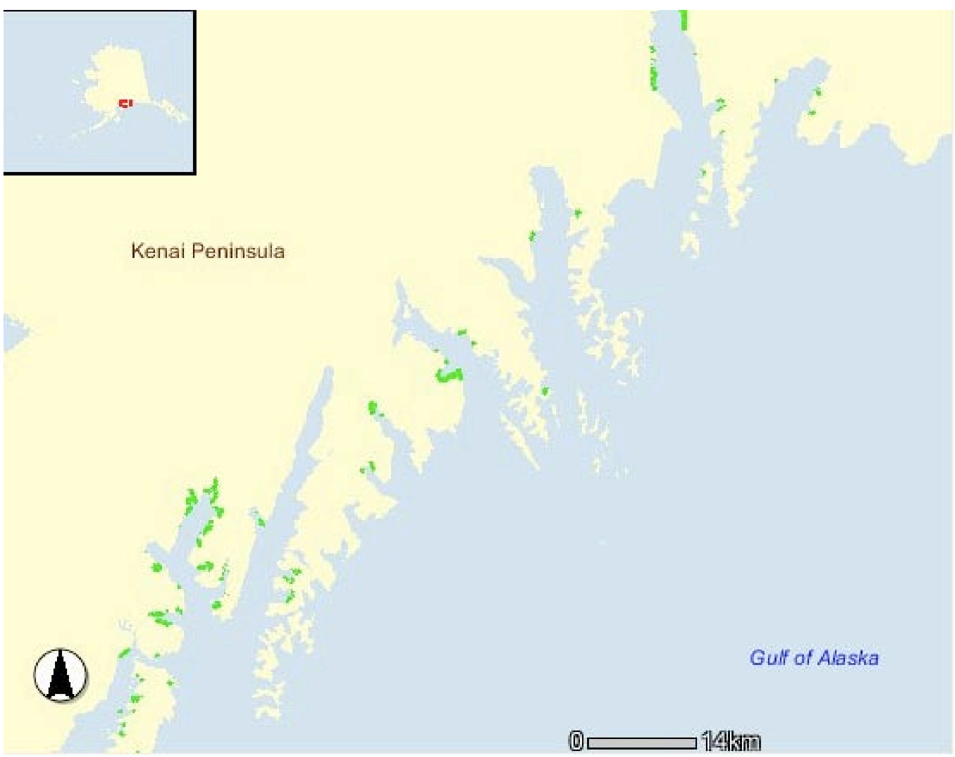


Figure 35. Sea grasses within KEFJ as classified by ShoreZone (http://mapping.fakr.noaa.gov/Website/ShoreZone/viewer.htm).

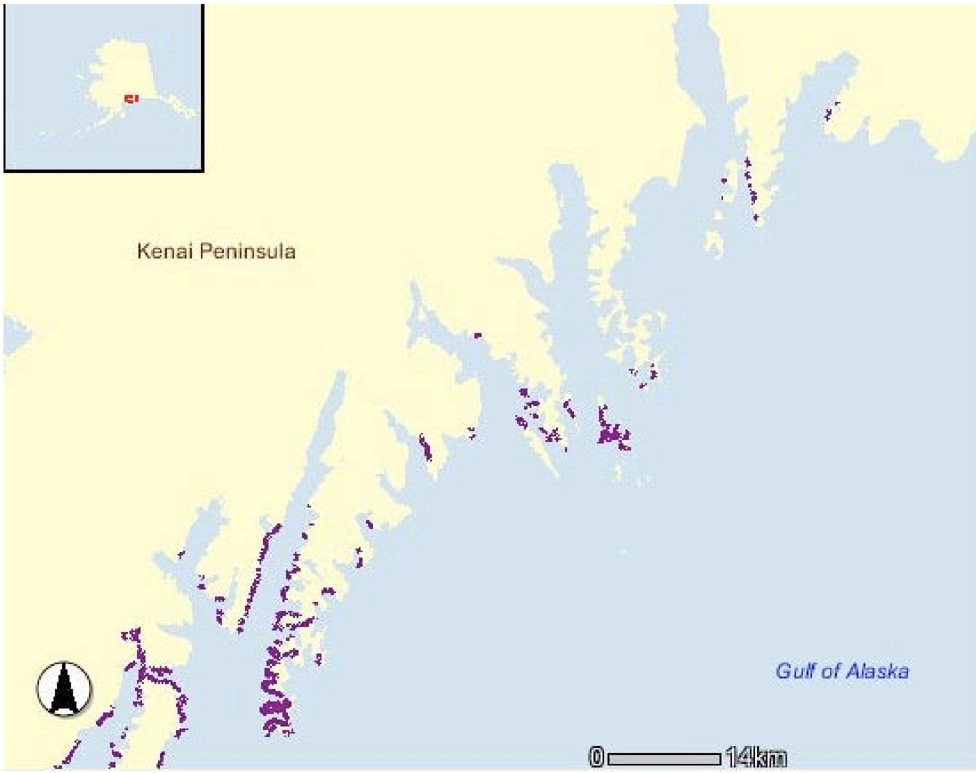


Figure 36. Canopy kelps in the nearshore of KEFJ as classified by ShoreZone (http://mapping.fakr.noaa.gov/Website/ShoreZone/viewer.htm).

Marine invertebrates: Intertidal marine invertebrates in KEFJ can serve as an indicator of disturbance, and are an important food source for migratory waterfowl and sea birds in the Gulf of Alaska, a conduit between terrestrial and marine environments, and an important resource for human harvest and recreation. The SWAN Vital Signs Monitoring program surveyed intertidal invertebrates and algae at KEFJ in 2007–2008 (Figure 37). In the soft sediment intertidal, the diversity, density, biomass and size class of clams were determined in 2007 (Bodkin et al. 2008). Clam diversity was dominated by *Macoma* sp. (Figure 38). Clam density was very variable within and between sites and ranged from 0 to 109 clams per 0.25 m^2, with a mean ± SD of 16.3 ± 6. Clam biomass varied within and between sites as well. Mean clam biomass ranged from 0 to 11.4 g ash-free dry weight (AFDW) (Figure 39). *Macoma* sp. generally dominates biomass, however not at all sites because of their small size. SWAN rocky intertidal sampling sites were established in 2007 and surveyed once in 2008. The specific objectives of this sampling on rocky shores are to assess changes in 1) the relative abundance of algae, sessile invertebrates, and motile invertebrates in the intertidal zone; 2) the diversity of algae and invertebrates; 3) the size distribution of limpets (*Lottia persona*) and mussels (*Mytilus trossulus*); and 4) the concentration of contaminants in mussel tissue, and temperature (either sea or air depending on tidal stage).

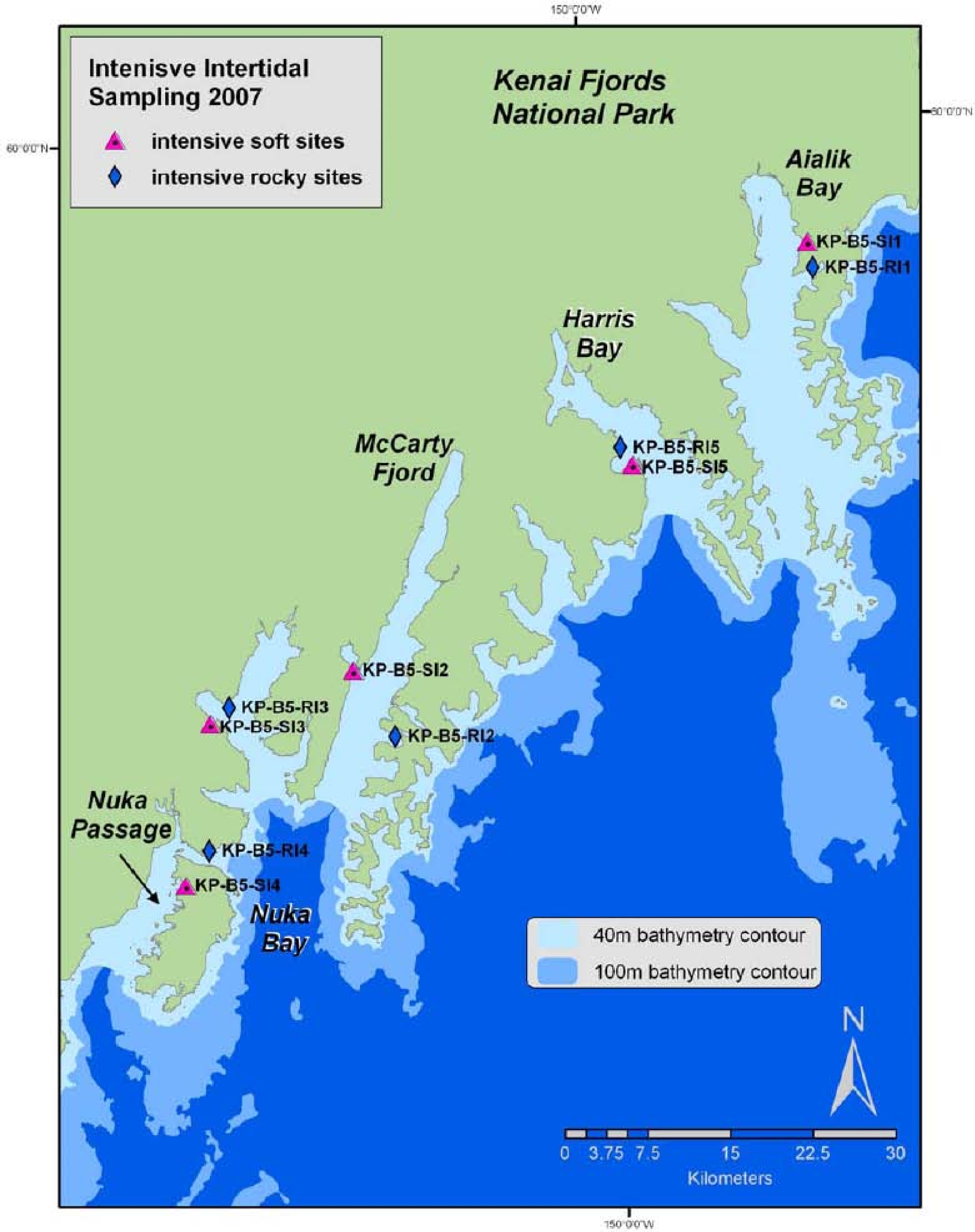


Figure 37. Locations of intensive soft substrate and rocky intertidal sites sampled by the SWAN I&M Program.

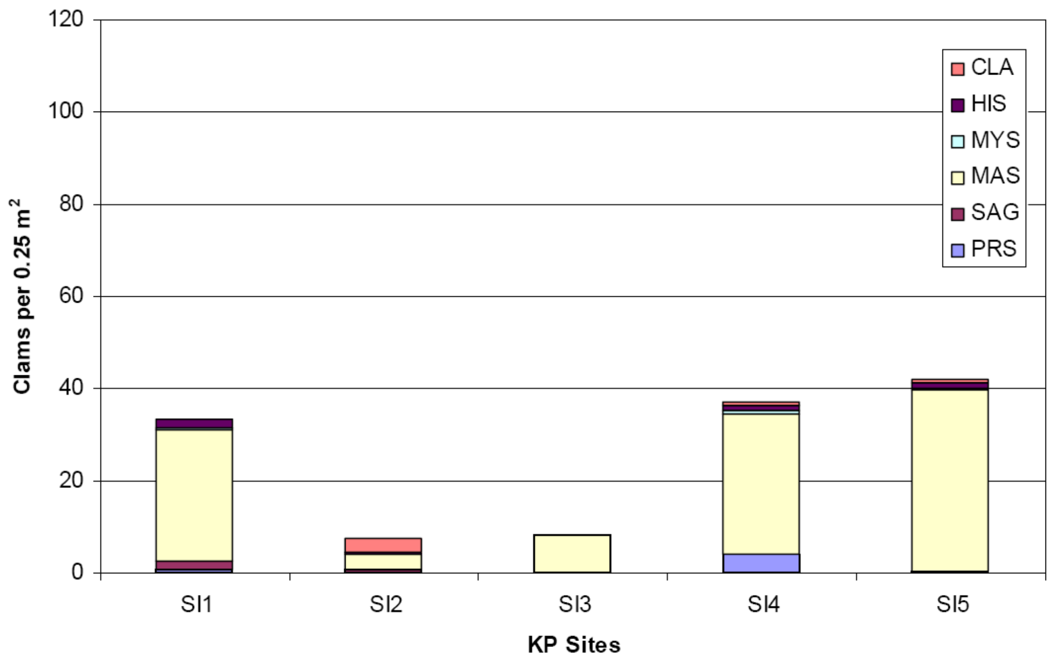


Figure 38. Density of clams at five sites in KEFJ. Clam species abbreviations are: Hiatella arcticus (HIS), Macoma spp. (MAS, pooled with M. nasuta (MAN), M. balthica (MAB)), Mya spp. (MYS, pooled M. truncata (MYT) and M. arenaria (MYA)), Protothaca staminea (PRS), Pseudopythina compressa (PSC), and Saxidomus gigantea (SAG), species occurring in low frequencies and pooled in the category other clam (CLA). Source: Bodkin et al. (2008).

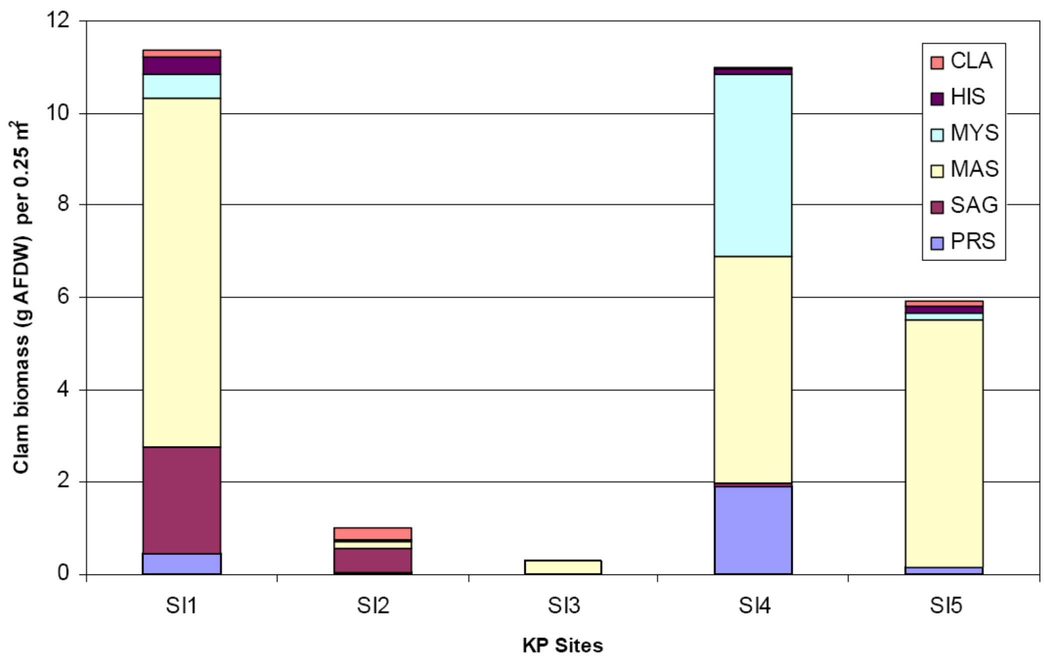


Figure 39. Biomass of clams at five sites in KEFJ. Clam species abbreviations as in **Figure 38**. Source: Bodkin et al. (2008).

Lees and Driskell (2006) conducted a reconnaissance survey of marine/estuarine bivalves in soft and gravel sediments in 2004 in KEFJ (Figure 40). Bivalves were surveyed using 0.25-m^2 (2.7 ft^2) and macrobivalve excavations and 0.0625-m^2 (0.67 ft^2) microinfaunal core samples. The soft sediment habitats in KEFJ were composed of sandy gravel (45%), gravelly sand (36%), sand (10%), and gravel, silty sand, sandy silt, and clayey silt (2% each) (Lees and Driskell 2006).

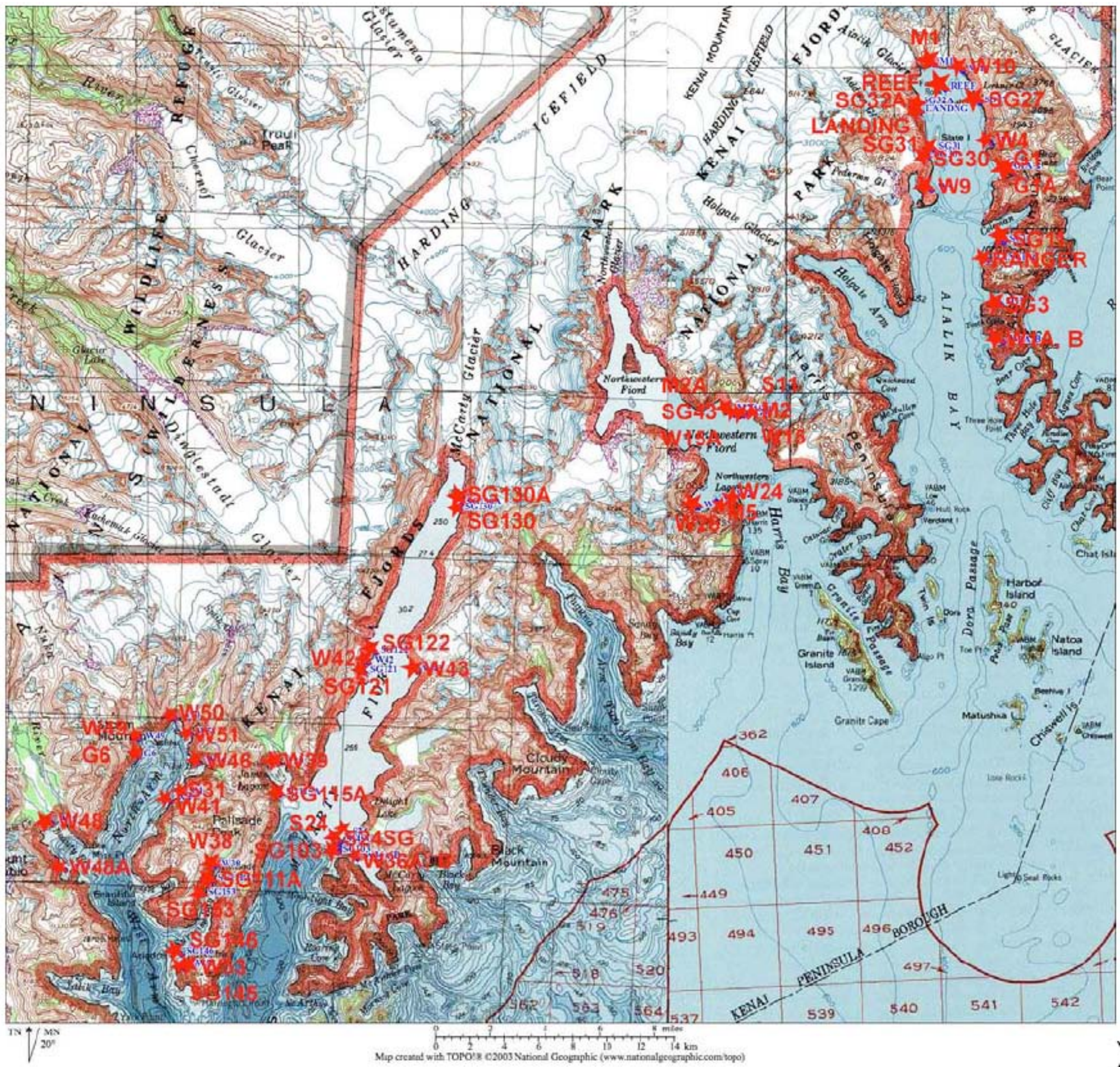


Figure 40. Sites visited by the soft-sediment intertidal reconnaissance survey in KEFJ in 2004 (Figure 3 in Lees and Driskell 2006).

A variety of bivalve species were observed (Table 7) and examined to determine which species might serve as sentinel species in a network-wide monitoring program. Bivalve diversity was substantially richer at KEFJ than at LACL or KATM, and 21 of the major bivalve species were observed (Table 7; Lees and Driskell 2006). Two species, the bay or foolish mussel (*Mytilus trossulus*) and Baltic macomas (*Macoma balthica*), dominated (85%). Mussel beds were well developed on gravel beaches in many areas in KEFJ. Several species were only observed in a single park. The species only found within KEFJ include northern horse mussels (*Modiolus*

modiolus) and Arctic hiatella (*Hiatella arctica*) (Table 8) (Lees and Driskell 2006), although *Hiatella arctica* was found in KATM in 2007 (Bodkin et al. 2008). The SWAN Vital Signs Monitoring program found 10 clam species/groups, compared to the 22 species found by Lees and Driskell (2006) (Table 9);(Bodkin et al. 2008).

Table 7. Common and scientific names of bivalves observed in soft-sediment intertidal reconnaissance surveys in KATM, KEFJ, and LACL (Table 1 in Lees and Driskell 2006).

Common Name	Scientific Name	Common Name	Scientific Name
Northern horsemussel	*Modiolus modiolus*	Foolish mussel	*Mytilus trossulus*
Silky axinopsid**	*Axinopsida serricata*	Rough diplodon	*Diplodonta impolita*
Suborbicular kellyclam*	*Kellia suborbicularis*	Compressed montacutid*	*Neaeromya ?compressa*
Robust mysella**	*Rochefortia tumida*	Basket cockle	*Clinocardium nuttallii*
Broad smoothcockle*	*Serripes ?laperousii*	Kennerley venus*	*Humilaria kennerleyi*
Butter clam	*Saxidomus giganteus*	Littleneck clam	*Protothaca staminea*
Lord dwarf-venus**	*Nutricola ?lordi*	Minute turton**	*Turtonia minuta*
Alaska great-tellin*	*Tellina lutea*	Salmon tellin	*Tellilna nuculoides*
Baltic macoma	*Macoma balthica*	Thick macoma*	*Macoma ?crassula*
Expanded macoma	*Macoma expansa*	Oval macoma	*Macoma golikovi*
?Pointed macoma	*Macoma ?inquinata*	Bent-nose macoma	*Macoma nasuta*
Alaska razor clam*	*Siliqua alta*	Pacific razor clam	*Siliqua patula*
Arctic surf clam	*Mactromeris polynyma*	Gaper clam*	*Tresus* sp.
Softshell clam	*Mya arenaria*	False softshell clam	*Mya pseudoarenaria*
Truncate softshell	*Mya truncata*	Arctic hiatella	*Hiatella arctica*

* Species observed only in excavation samples or extralimitally.
** Small species observed only in core samples.

Table 8. Major bivalve species, as a function of substrate, observed at soft-sediment intertidal sites in KATM, KEFJ and LACL (Table 11 in Lees and Driskell 2006).

Sediment Type	Grav-el	Mud			Sand			Mixed-soft		
Species / Park	Foolish Mussel	Baltic Macoma	Softshell Clam	False Softshell Clam	Arctic Surf Clam	Alaska Razor Clam	Pacific Razor Clam	Oval Macoma	Butter Clam	Littleneck Clam
KATM – No. of Sites	7	14	10	4	8	6	1	8	6	1
% of Sites	26	52	37	15	30	14	4	30	22	4
KEFJ– No. of Sites	24	21	2	4	0	0	0	11	10	13
% of Sites	71	62	6	12	0	0	0	32	30	38
LACL– No. of Sites	0	5	4	0	1	0	4	0	0	0
% of Sites	0	56	44	0	11	0	44	0	0	0
Feeding Mode	SF*	FSDF	SF	SF	SF	SF	SF	FSDF	SF	SF

* SF – Suspension feeder; FSDF – Facultative suspension/deposit feeder

Table 9. List of species found in the SWAN monitoring compared to Lees and Driskell (2006).

Species	This Study		Lees 2006		Notes
	KATM	KEFJ	KATM	KEFJ	
Axinopsida serricata				X	Too small for our SOP
Clinocardium blandum			X		Harbo says subtidal species
C. nuttallii	X	X	X	X	
Diplodonta impolita	X	X		X	
D. orbella	X				Foster & Harbo say this is a southern species. So either range expansion or actually *D. impolita*
Glycymeris septentrionalis				X	
Hiatella arctica	X	X		X	
Kellia suborbicularis				X	
Macoma balthica	X	X	X	X	
M. expansa			X	X	Our SOP doesn't distinguish most *Macomas* as it would be too time consuming and often requires destruction of the clam.
M. golikovi			X	X	
M. inquinata			X	X	
M. nasuta			X		
M. spp.	X	X			
Mactromeris polynyma			X		
Mya arenaria	X	X	X	X	
M. pseudoarenaria			X	X	
M. truncate	X	X	X	X	
Neaeromya compressa	X	X		X	AKA *Pseudopythina compressa*
Nutricola lordii			X		Too small for our SOP
Protothaca staminea	X	X	X	X	
Rochefortia tumida			X	X	Too small for our SOP
Saxidomas giganteus	X	X	X	X	
Serripes laperousii		X			
Siliqua alta			X		Habitat not part of our SOP
S. patula			X		Habitat not part of our SOP
Turtonia minata			X	X	Too small for our SOP
Tellina lutea			X		
T. nuculoides			X	X	
Tresus capax			X		

2.3.2. Freshwater Biological Resources

Freshwater and anadromous fishes: Information on presence and types of anadromous fishes in the coastal area is contained in the *Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes* (Johnson and Weiss 2006), which is regularly updated by the Alaska Department of Fish and Game and provides information on the presence and types of anadromous fishes in streams in the whole state. According to this catalog, fish species that occur in the main KEFJ streams are summarized in Table 10.

Information on species presence in numerous other streams in KEFJ is available through this catalog. Many other streams are unnamed but are identified by way of a cataloged numbering system and by geographic location (latitude and longitude, USGS quad map name).

Table 10. Anadromous fish species present in KEFJ streams according to Johnson and Weiss (2006). The Delusion Creek data are from Milner and York (2001).

Stream	Chinook salmon	Sockeye salmon	Coho salmon	Pink salmon	Chum Salmon	Dolly Varden
Moose Creek		X				
Placer Creek			X			
Resurrection River	X	X	X	X	X	
Tonsina Creek				X	X	
Bear Lake		X	X			
Babcock Creek				X		
Ferrum Creek				X		
Nuka River				X		
Delusion Creek		X	X	X		X

The SWAN I&M Program's freshwater fishes inventory process confirmed the presence of 13 freshwater fish species within KEFJ (Jones et al. 2005), although other studies identified an additional 11 species with ranges that included KEFJ (AKNHP 2000, Mecklenburg et al. 2002). The I&M Program predicted (but did not confirm) another 29 species considered tidepool or estuarine (Jones et al. 2005). The SWAN-wide inventory also stresses that the paucity of water quality and streamflow data make ecological assessments of fish habitats and distribution difficult or impossible (Jones et al. 2005).

Amphibians: Although no park-wide surveys of amphibians have been conducted in KEFJ and there are is no published record of amphibian occurrences within the park boundaries, the wood frog (*Rana sylvatica*) is a likely resident. This freeze-tolerant species, which is observed throughout the Alaska Peninsula and occurs as far as the north side of the Brooks Range, inhabits a wide variety of forest, muskeg, and tundra habitats, sometimes far from water (Hodge 1976). The closest verified record of wood frogs occurs approximately 15km northeast of the Resurrection River (Figure 41). There is also a very remote possibility that the boreal toad (*Bufo boreas*), which has probably declined throughout most of their historic range in Alaska (Pyare unpublished data), occurs in KEFJ. The northernmost observations of boreal toads occur approximately 200 km east of KEFJ in the Prince William Sound area; however, the extent of this species' range beyond these observations has not been established.

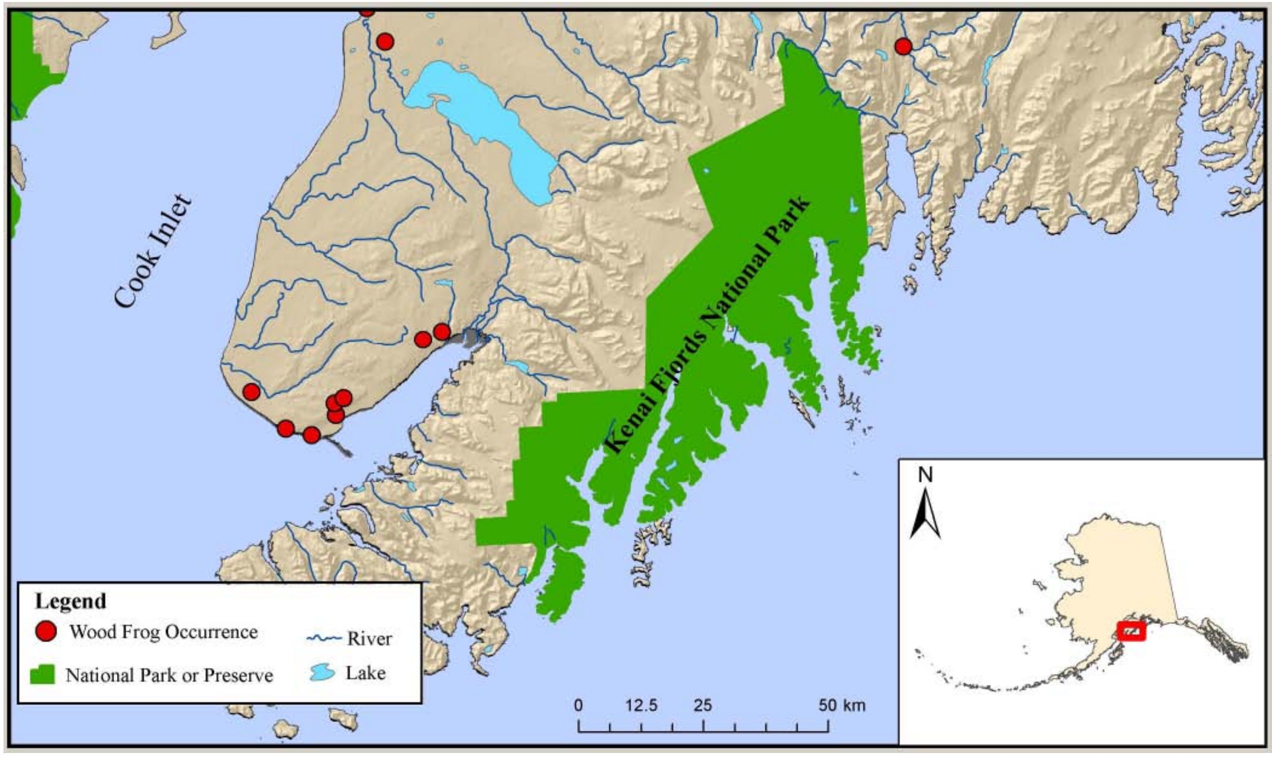


Figure 41. Amphibian occurrence on the Kenai Peninsula.

Aquatic invertebrates, chlorophyll, phytoplankton, zooplankton: A small number of studies have been conducted on aquatic invertebrates, chlorophyll, phytoplankton, and zooplankton in KEFJ. One evaluated the colonization of a young (40-year-old) stream (Delusion Creek in McCarty Fjord) formed since glacial recession and included evaluation of stream macroinvertebrates (Milner and York 2001, York and Milner 1999). The study found that the invertebrate community was mainly composed of chironomids, mayflies, and stoneflies, whereas other groups (e.g., caddisflies, other dipterans, and noninsect taxa) had not yet colonized the stream due to unsuitable conditions (e.g., unstable channels, high turbidity levels, and low primary productivity) and insufficient time to cross land barriers. There was negligible growth of epilithic algae and no filamentous algae in the stream except for during the late summer when there were large rainstorms and salmon spawning in the upper lake. Additionally, zooplankton densities were described as low in Upper and Lower Delusion lakes, and this in turn restricted sockeye salmon counts in the watershed. Chlorophyll-a concentrations did not exceed 0.23 μg/L, and most values at 1 m depth were <0.1 μg/L, which are exceedingly low concentrations. Mean values of <1.0 μg/L and peak values of <2.5 μg/L are indicative of ultraoligotrophic (very unproductive) waters (Mason 1996).

In a study of sockeye salmon productivity in 36 study lakes in southcentral Alaska, Edmundson and Mazumder (2001) included measurements of chlorophyll-a in Delight and Desire lakes as well as zooplankton biomass in Delight lake. Chlorophyll-a in Delight and Desire lakes was 0.7 and 0.5 μg/L, respectively, values which were on the low end of the range of values for the 18 clear-water lakes in the study (mean chlorophyll-a for clear lakes was 1.3 μg/L). Zooplankton samples, collected from the surface to a depth of 0.5 m above the lake bottom using a 153-μm mesh conical net and integrated over all sampling stations, indicated a zooplankton biomass in Delight Lake of 70 mg/m^2. This value was only 10% of the mean biomass (719 mg/m^2) measured in the 18 clear-water study lakes, but no specific discussion for the reason for these low values was provided (Edmundson and Mazumder 2001).

Finally, an unpublished study conducted in 2007 included a survey of aquatic macroinvertebrates and diatoms in the upper Nuka River, just below the Bradley Lake Hydroelectric Project's water withdrawal site, at N 59.67955°, W 150.69476° (Rinella and Bogan 2007). The study found that the number of invertebrate taxa found in the Nuka River was similar to those in regional reference streams, and the most dominant taxa were the mayflies *Cinygmula* sp. and *Baetis bicaudatus,* stonefly *Plumiperla diversa,* and several genera of chironomid midges. Eighteen taxa of diatoms were identified, and this fairly low diversity level was deemed representative of a glacier-fed subalpine stream.

Stream development following deglaciation: The biological development of a young stream (Delusion Creek in McCarty Fjord) in KEFJ formed in response to glacial retreat has been studied by Milner and York (2001). This ca. 40-year-old stream was found to have highly unstable stream channels, episodes of turbidity level spikes, and variable discharge during the summer months. The physical instability limited primary production and abundance and diversity of invertebrate communities in the stream channel. Nonetheless, dolly varden and three species of salmon (coho, pink, and sockeye) have successfully colonized the stream, the latter using kettle ponds as important rearing areas for juveniles. Nitrogen was identified as a limiting nutrient to primary production, and the researchers suggested that marine-derived nutrient contributions (through spawning anadromous salmon) likely provides a positive feedback system for stream productivity (Milner et al. 2008, Milner and York 2001).

Many other research investigations on the development of stream ecosystems following deglaciation have been conducted in Glacier Bay National Park and Preserve (GLBA), which is similar to KEFJ in that rapid glacial retreat is exposing and developing new watersheds. Research on Delusion Creek in KEFJ (Milner and York 2001) generally follows the same general patterns seen in evolving watersheds in GLBA (Milner et al. 2007). The literature on the topic of watershed development in GLBA, succinctly summarized in Milner et al. (2007) includes macroinvertebrate succession (Milner 1987, Milner 1988, Milner 1993, Milner 1994, Robertson and Milner 1999, Milner et al. 2000, Flory 2000, Robertson and Milner 2001, Milner et al., 2008); succession effects on streamwater chemistry (Stottlemyer 1988) and stream geomorphology (Sidle and Milner 1989); salmonid colonization (Milner and Bailey 1989); and soil, microbial, and vegetative succession patterns following deglaciation in watersheds (Cooper 1931, Crocker and Major 1955, Crocker and Dickson 1957, Lawrence et al. 1967, Hitchcock and Cronquist 1973, Binkley 1981, Stottlemyer and Rutkowski 1987, Chapin 1994, Fastie 1995, Hobbie 1998, Bardgett and Walker 2004). The youngest and most rapidly developing streams are those closest to glaciers. These stream systems are constantly changing and are characterized by high rates of sediment transport, variable flows, high turbidity, and poor-quality salmonid habitat (Milner et al. 2007). Milner et al. (2000) demonstrated that the successional development of plant and animal communities in streams is closely connected with the growth and maturation of adjacent terrestrial plant communities. Biological development in streams advances after stream sediment load is decreased, temperatures rise, and flow rates become less erratic—processes that accelerate where there are upstream lakes that can temper flow rates and sediment inputs (Milner

1997). Stream invertebrates colonize streams after dissolved organic carbon inputs by colonizing stream bank vegetation reach adequate levels. As plant succession continues, woody debris may accumulate in streams, providing shelter for fish and promoting the colonization by anadromous salmonids (Milner et al. 2000).

GLBA has also been the site of several investigations of lake evolution with specific focus on limno-terrestrial connections in the control of lake development (Engstrom and Fritz 1988, Fritz and Engstrom 1993); on chemical and biological trends during lake evolution (Engstrom et al. 2000, Fritz et al. 2004); and on aquatic community colonization (Olson 1993). Although lake development in KEFJ has not been studied directly, the work in GLBA is likely a valid analog to lake development in KEFJ.

2.3.3. Uplands

Plants and forest types: As part of the I&M Program, SWAN has conducted a vascular plant inventory of all units (Carlson et al. 2005). The inventory documented an estimated 77% of taxa in KEFJ and includes lists of rare species (of which there were seven) and range extensions (for which there were 11 species in KEFJ). A more recent study provides descriptions and detailed evaluation of ecological systems (Figure 42), landcover classes (Figure 43), and plant associations in KEFJ (Boggs et al. 2008). This report provides quantitative data on the numbers of hectares (and in terms of percent of the vegetated land) covered by each type of landscape; detailed descriptions of each landscape class and ecological system (including information on distribution, environment, succession dynamics, classification, and plant associations); photographs; and maps (Boggs et al. 2008). In the summer of 2008, the National Park Service and Alaska Natural Heritage Program documented short-term vegetation change in KEFJ by re-measuring inventory plots established in 1993 (Klasner 2009). Preliminary results of the survey showed an increase in shrub cover in both forested and non-forested areas over the 15-year period; a full report of the results is pending (Klasner 2009).

Briefly, forests in snow- and ice-free KEFJ upland areas are composed predominantly of Sitka spruce and mountain hemlock (Boggs et al. 2008). Shrubs include devil’s club, Sitka alder, rusty menziesia, Alaska spirea, trailing black current, northern red and black currents, high bush cranberry, Pacific red elder, Sitka mountain ash, Pacific serviceberry, blueberry, salmonberry, and rose (Bailey 1977, Boggs et al. 2008). Shoreline plants include cow parsnip, hemlock parsley, beach lovage, and beach rye, while sand beaches host beach pea oysterleaf, grounsel, and seabeach sandwort (Bailey 1977). Along the coast, mountains are composed of a mix of barren rocks along steep sections to bands of conifer forests and dense alder shrub thickets along avalanche paths (Tande and Michaelson 2001).

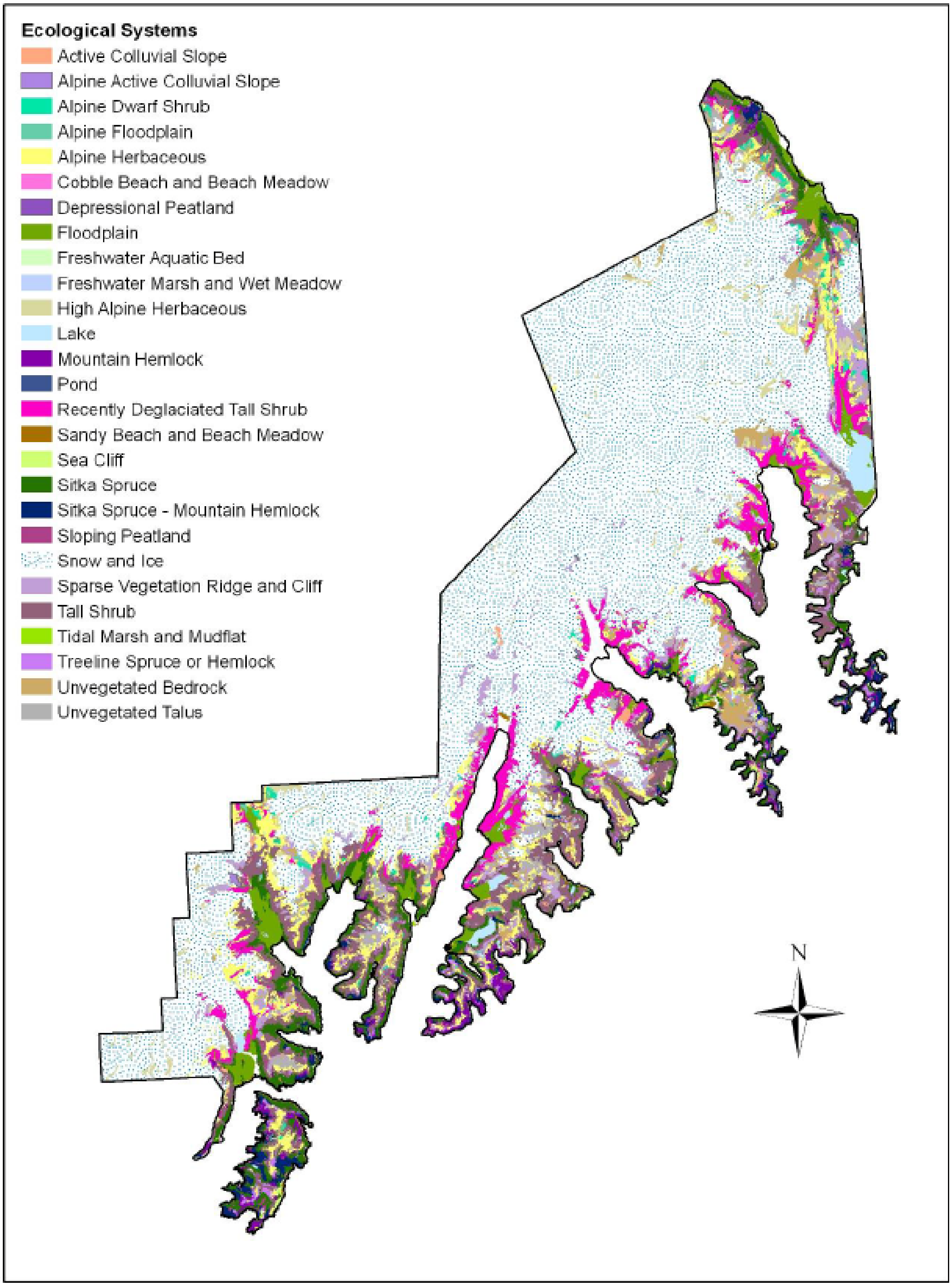


Figure 42. Map of ecological systems in KEFJ according to Boggs et al. (2008).

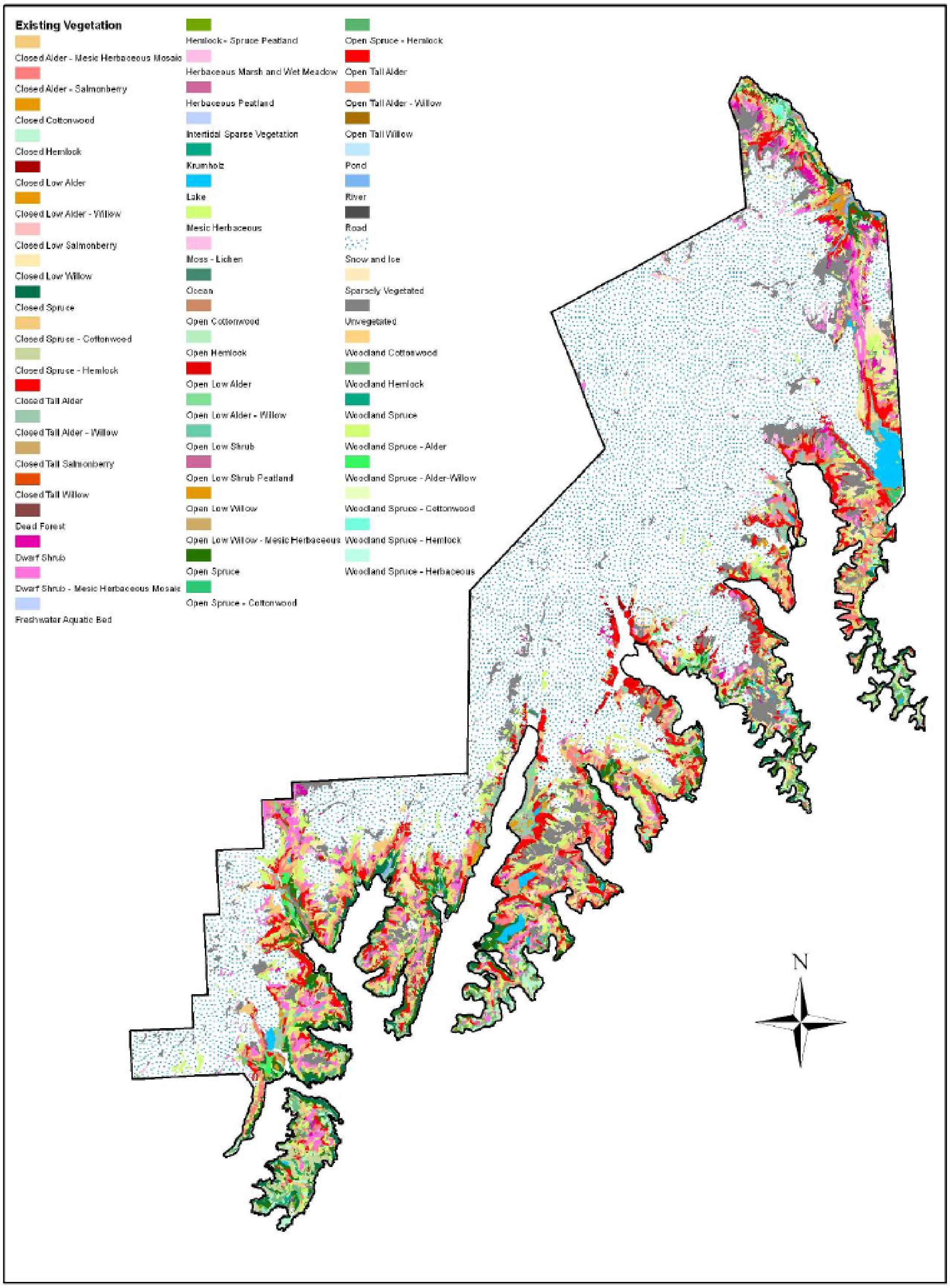


Figure 43. Map of landcover classes in KEFJ according to Boggs et al. (2008).

In recently deglaciated watersheds or those with actively retreating glaciers, a predictable sequence of vegetative succession occurs along age gradients of newly exposed soils (Boggs et al. 2008). Primary succession generally consists of lichens, mosses, grasses, and alder (progressing seaward), with many of the recently deglaciated watersheds being covered with nearly pure stands of nitrogen-fixing alder (Bailey 1977). Specifically, the vegetative chronosequence has been described for the outwash plain formed in front of the retreating Exit Glacier near Seward. Successional stages were identified as Barren, Isolated Plant, Patchy, Alder, Cottonwood, Spruce-Cottonwood, and Spruce-Hemlock (Helm and Allen 1995). Black cottonwood was the most abundant colonizer in the outwash plain, although the forested hillslopes above were dominated by the more typical Sitka spruce and mountain hemlock (Helm and Allen 1995).

As part of the SWAN Vital Signs program, vegetation composition and structure are beginning to be monitored using Landsat TM/ETM+ satellite images, orthorectified aerial photos and high-resolution IKONOS imagery, as well as ground-based monitoring (Miller et al. 2009b). As part of the program, 15-year-old inventory plots in KEFJ were revisited in 2008 as part of the ground-based monitoring, and measurable changes were found (Miller et al. 2009b). Ongoing work is quantifying the type and magnitude of landscape conversion (ice to barren, barren to shrum, shrub to tree) in upper and lower Aialik Bay, Northwest Arm, and East Arm (Boucher et al. 2009). Sensitive plant communities such as those found on nunataks are also targeted for long-term monitoring. Nunatak communities are particularly sensitive to climate because they are geographically isolated, include rare species that are sensitive to climatic shifts, and are potential seed sources for recently deglaciated areas (Miller et al. 2009a) (Figure 44). Baseline monitoring has begun on five nunatak sites in KEFJ as part of the Vital Signs program (Miller et al. 2006).

Figure 44. Nunataks on the northern Harding Icefield. Photo by Amy Miller, National Park Service.

Animal communities: A mammal inventory conducted throughout SWAN in 2003–2004 provided confirmation of many species in KEFJ as well as a recording of four new species (Cook and MacDonald 2005). The survey, which focused primarily on small mammals, found that cinereus shrews *(Sorex cinereus*), montane shrews *(Sorex monticolus)*, northern red-backed vole *(Clethrionomys rutilus)*, and tundra vole *(Microtus oeconomus)* were the most frequently captured species (comprising 92% of all specimens) at the ten KEFJ trapping sites. Also documented (either through specimens, sign, or reported sightings) were coyotes *(Canis latrans)*, wolves *(Canis lupus)*, Canada lynx *(Lynx canadensis)*, wolverine *(Gulo gulo)*, northern river otter (*Lontra canadensis)*, American marten *(Martes americana)*, ermine *(Mustela erminea)*, American mink *(Mustela vison)*, American black bear *(Ursus americanus)*, brown bear *(Ursus arctos)*, moose *(Alces alces)*, mountain goat *(Oreamnos americanus)*, hoary marmot *(Marmota caligata)*, red squirrel *(Tamiasciurus hudsonicus)*, American beaver *(Castor canadensis)*, porcupine *(Erethizon dorsatum)*, and snowshoe hare (*Lepus americanus*). Among the documented species, black bears and mountain goats are particularly common in KEFJ (Cook and MacDonald 2005). Coastal river otters have been the subject of detailed genetics-based studies on their abundance and distribution, especially in relation to habitat destruction caused by the *Exxon Valdez* oil spill (Ben-David et al. 2005, Ott and Ben-David 2004). Black bear activity, especially in terms of the bears' interaction with humans, is a management concern for KEFJ (Hahr 2008a, Hall et al. 2007). Although mammals have been reported to use the Harding Icefield and its emanating glaciers on occasion, the most apparent dwellers of these regions of the park are annelid ice worms *(Mesenchytraeus solifugus*: Enchytraeidae*)*, whose optimal elevational range is at about 1,100 m and actively forage on the glacier ice (Thomas 2006).

Landbirds: A summer inventory conducted in KEFJ as part of the SWAN I&M Program detected 101 species of birds, including 62 species of landbirds (Van Hemert et al. 2006). Commonly observed species included hermit thrush *(Catharus guttatus)*, orange-crowned warbler *(Vermivora celata)*, Wilson's warbler *(Wilsonia pusilla)*, fox sparrow *(Passerella iliaca)*, varied thrush *(Ixoreus naevius)*, ruby-crowned kinglet *(Regulus calendula)*, and yellow warbler *(Dendroica petechia)*. Species detected exclusively in near-coastal habitats included northwestern crow *(Corvus caurinus)*, winter wren *(Troglodytes troglodytes)*, rufous hummingbird *(Selasphorus rufus)*, and bald eagle *(Haliaeetus leucocephalus)*. The report highlighted the important habitats provided by the Nuka and Resurrection river corridors for regional landbirds.

3. Water Resources Assessment

3.1. Water Quality

3.1.1. Intertidal and Marine

SWAN I&M nearshore marine monitoring: At the core of the I&M Program is the selection of a suite of vital signs (Appendix A) that were chosen based on ecological significance and relevance to SWAN resource management issues (Bennett et al. 2006). Protocols for the monitoring of vital signs associated with the marine nearshore (including marine water chemistry, kelp and eelgrass, marine intertidal invertebrates, marine birds and mammals, black oystercatchers, and sea otters) have been or are in the process of being developed (Bennett et al. 2006). Most parameters are expected to be monitored annually based on a stratified systematic or stratified generalized random-tessellation (GRTS [Stevens and Olsen 2004]) design. The GRTS is a spatially balanced probability sampling method that allows units to be easily added to existing samples and that can incorporate stratification and units with unequal probabilities of selection (Bennett et al. 2006, Stevens and Olsen 2004). The nearshore monitoring protocol was field-tested at KATM in 2006 and 2007 and implemented in KEFJ in 2007.

In 2009 the SWAN nearshore monitoring program will complete installation of two salinity sensors, re-visit five different eelgrass beds initially surveyed in 2008 to look for changes in eelgrass distribution and density, and complete a third year of intertidal sampling in rocky substrate and second year of sampling in the soft substrate. Sampling includes invertebrate species composition and density; percent algae cover; limpet (*Lottia persona*) size distribution; clam and foolish mussel (*Mytilus trossulus*) distribution and density; sea otter foraging behavior (quantity, species composition, and size); black oystercatcher breeding pair density, nest productivity, and diet surveys; and marine bird and mammal surveys (Klasner 2009). As this program continues to collect data, it will provide valuable information on water quality and water resources. More information on the nearshore marine vital signs monitoring plan is provided in Bennett et al. (2006), in the 2007 (Bodkin et al. 2008) and 2008 (Coletti and Bodkin 2009) reports, and at the SWAN I&M website at http://science.nature.nps.gov/im/units/swan/index.cfm?theme=marine.

Long-term environmental monitoring program (LTEMP) in Prince William Sound and the Gulf of Alaska: Since 1993, the Prince William Sound Regional Citizens Advisory Council (PWSRCAC) has collected mussels and sediments at 10 sites in Prince William Sound and the Gulf of Alaska for monitoring petroleum hydrocarbons (http://www.pwsrcac.org) (Payne et al. 2008). One site is located at Aialik Bay within KEFJ (Figure 45). Mussel and sediment samples, collected in summer and late winter, provide a benchmark for assessing the ongoing impacts of routine tanker and terminal operations in Prince William Sound and the surrounding region. Mussels are used because they are an indicator species, an important prey of sea birds and sea otters, and commonly found throughout Prince William Sound and downstream habitats. The PWSRCAC LTEMP mussel sampling results demonstrate decreasing concentrations of total polycyclic aromatic hydrocarbons (TPAH) since 1999 to the stable, trace-level concentrations of biogenic and petroleum hydrocarbons from 2003 to 2006 (last available data), which currently represent excellent water quality and a near-pristine condition (Figure 46) (Payne et al. 2008). Any new inputs of hydrocarbons should be easily detected against this low background.

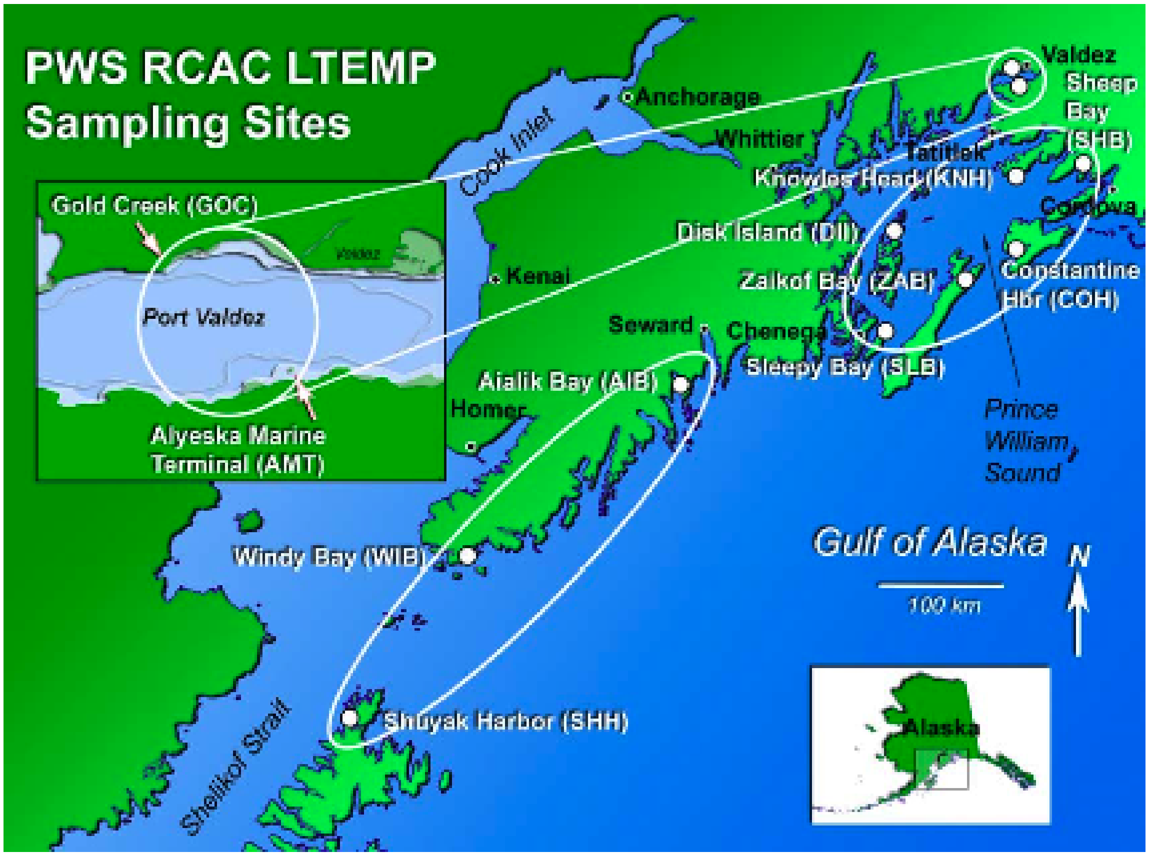


Figure 45. Locations of the 2005/2006 Long Term Environmental Monitoring Program (LTEMP) sites for monitoring petroleum in mussels (Payne et al. 2008).

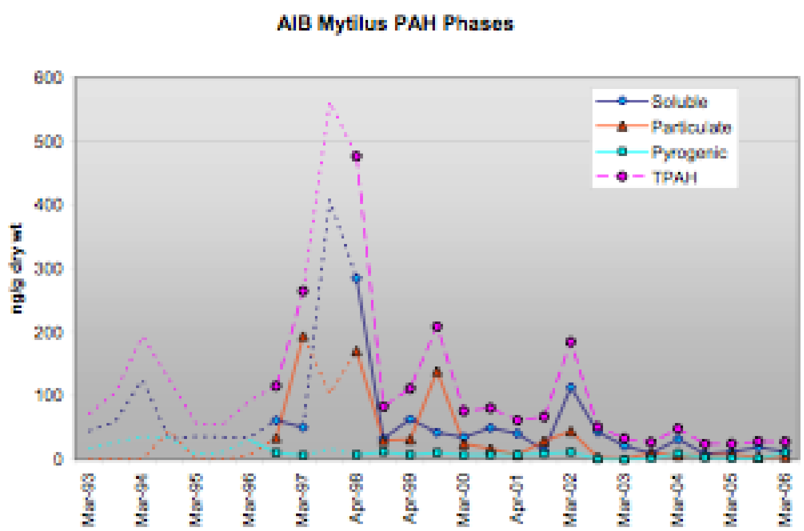


Figure 46. Polycyclic Aromatic Hydrocarbons (PAH) (TPAH = total PAH, soluble, particulate and pyrogenic fractions) measured in mussel tissue from 1996 to 2006. Dotted connecting lines without symbols indicate questionable data (Payne et al. 2008).

Environmental Monitoring and Assessment Program (EMAP) in southcentral Alaska: Under this program, administered by the Alaska Department of Environmental Conservation (ADEC), samples were collected at 55 sites (at 3–352 m [10–1,150 ft] depth) located throughout southcentral and southwest Alaska. Sites were located in Prince William Sound, Cook Inlet, and Shelikof Strait, and along the Alaska Peninsula (Figure 47). The program sampled dissolved oxygen concentration, salinity, water depth, pH, temperature, total suspended solids, fluorescence, chlorophyll-a concentration, transmittance, secchi depth, and nutrient concentrations (nitrates, nitrites, ammonia, and phosphate) in the water; organic and inorganic contaminants, total organic carbon, grain size, and toxicity in the sediment; and infaunal and fish species composition, infaunal and fish abundance, infaunal and fish species richness and diversity, fish tissue contaminants, histopathology specimens, and external pathological anomalies in fish on the benthos. EMAP information is available at http://www.dec.state.ak.us/water/wqamp/emap.htm).

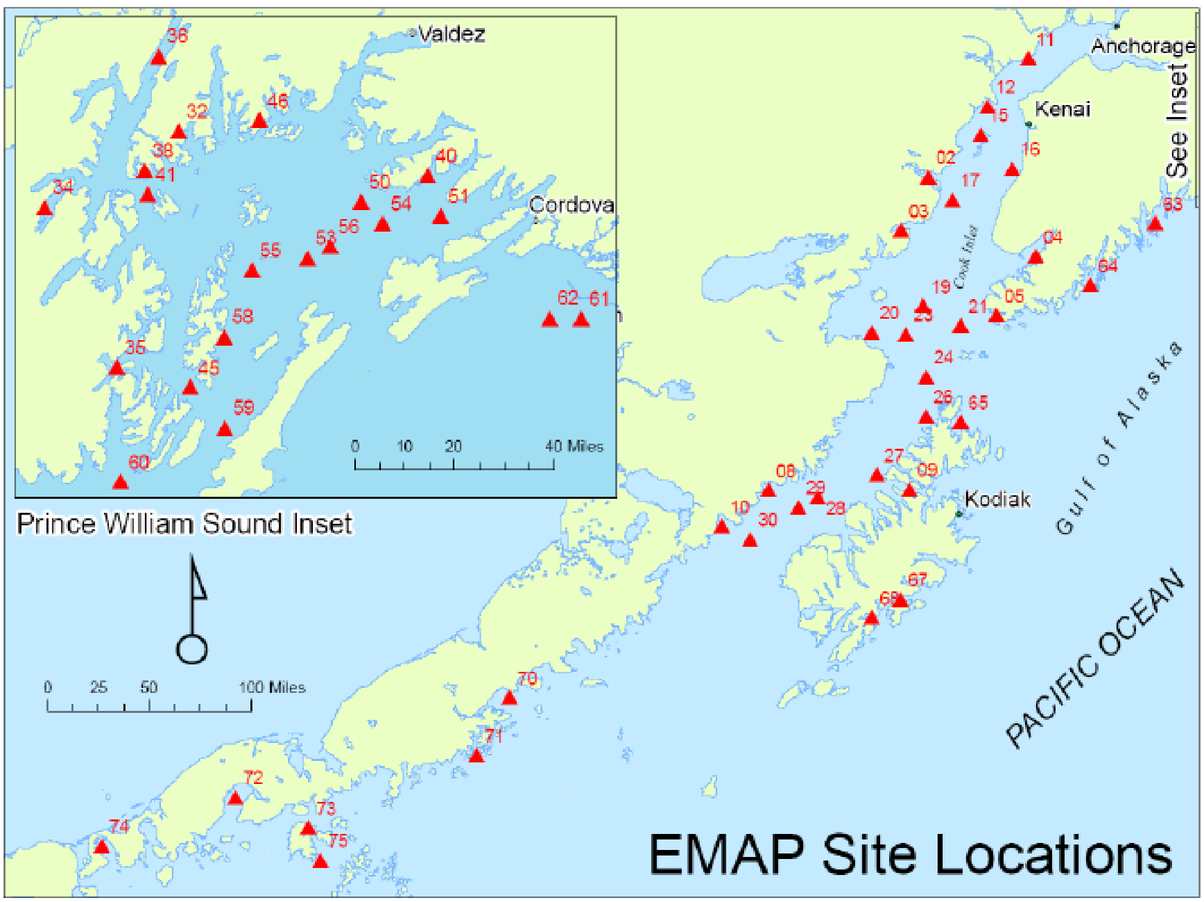


Figure 47. Sites sampled by EMAP in southcentral Alaska in the summer of 2002 (Saupe et al. 2005). The two-digit numbers reflect the last two numbers of each station. Prince William Sound is inset. Stations closest to KEFJ are #s 63 and 64.

Results from this sampling effort comprise the most comprehensive dataset available on the physical and biological conditions in the marine waters adjacent to KEFJ and are presented in Saupe et al. (2005). Overall, water quality conditions in the region were very good. For example, 100% of the study area met Alaska water quality standards for dissolved oxygen for all marine water uses. Water clarity (measured by Secchi depth and total suspended solids) indicated high light transmittance except for areas near inputs of glacial rivers, which contribute massive volumes of glacial flour. Surface and bottom chlorophyll-a concentrations indicated that waters in the study region were not eutrophic and were less than the NOAA value of 5 μg/L for low eutrophication (Bricker et al. 1999) at 100% of the sampled sites. Although measured only once at each station, dissolved nitrogen (nitrate-N, nitrite-N, and ammonium), which may vary significantly over short time scales, was below the NOAA threshold value (Bricker et al. 1999) of 1.0 mg/L for nitrate-N and nitrite-N (no State of Alaska or national EPA standards exist for coastal waters for nitrate-N and nitrite-N), and far below both the acute and chronic Alaska water quality standards for ammonium at all sample sites. Except for one outlier, identified as likely due to contamination, all phosphate-P concentrations fell below the NOAA threshold value of 0.1 mg/L (Bricker et al. 1999). Ninety-five percent of the study area had sediment total organic carbon concentrations that were between 0.5 and 3%; concentrations lower and higher than this range have been linked with adverse effects on benthic communities (Hyland et al. 2005).

In terms of contaminants, the EMAP project found few indications of levels of concern (Saupe et al. 2005). The project tested for 25 polycyclic aromatic hydrocarbons (PAHs), 21 polychlorinated biphenyls (PCBs), DDTs and 13 other chlorinated pesticides, and 15 metals in fish tissues and sediments. Sediment data were compared to sediment quality guidelines (SQGs) developed by NOAA's National Status and Trends (NS&T) Program (Long et al. 1995) and to Washington State Sediment Quality Standards (Washington State Legislature 1995). The concentrations of almost all metals (Ag, Al, Cd, Cr, Cu, Hg, Fe, Pb, Mn, Ni, Se, Sb, Sn, Zn) and arsenic in the sediments collected off the KEFJ coast were all below the Effecs Range Median (ERM) and Effects Range Low (ERL), as established by the Washington state guidelines, and almost all samples from the EMAP southcentral region were as well. Two metals—Cr and Ni—fell slightly above the ERL but not as high as the ERM. Saupe et al. (2005) provide detailed graphical and tabular presentations of the metal concentrations in the samples distributed across the sampling area.

Sediment hydrocarbon concentrations were generally low and within acceptable levels based on existing but limited standards (Figure 48) (Saupe et al. 2005). High concentrations may be indicative of natural sources (e.g., oil seeps, eroded source petroleum sedimentary rock, coal, terrestrial and marine plants and animals, peat, and forest fire deposits) and/or anthropogenic sources (e.g., petroleum industry discharges, municipal wastewater treatment discharges, non-point source runoff from urban zones, small spills from marine vessels, and large-scale spills such as the 1989 *Exxon Valdez* Oil Spill). Total polynuclear aromatic hydrocarbons (PAH) concentrations were below (and 90% were one order of magnitude below) the Effects Range Low (ERL) of 4,020 ng/g for 100% of samples in the study region (Long et al. 1995). Not all PAH analytes have associated ERL and Effects Range Median (ERM) values; however, for those with such standards, none exceeded the ERMs.

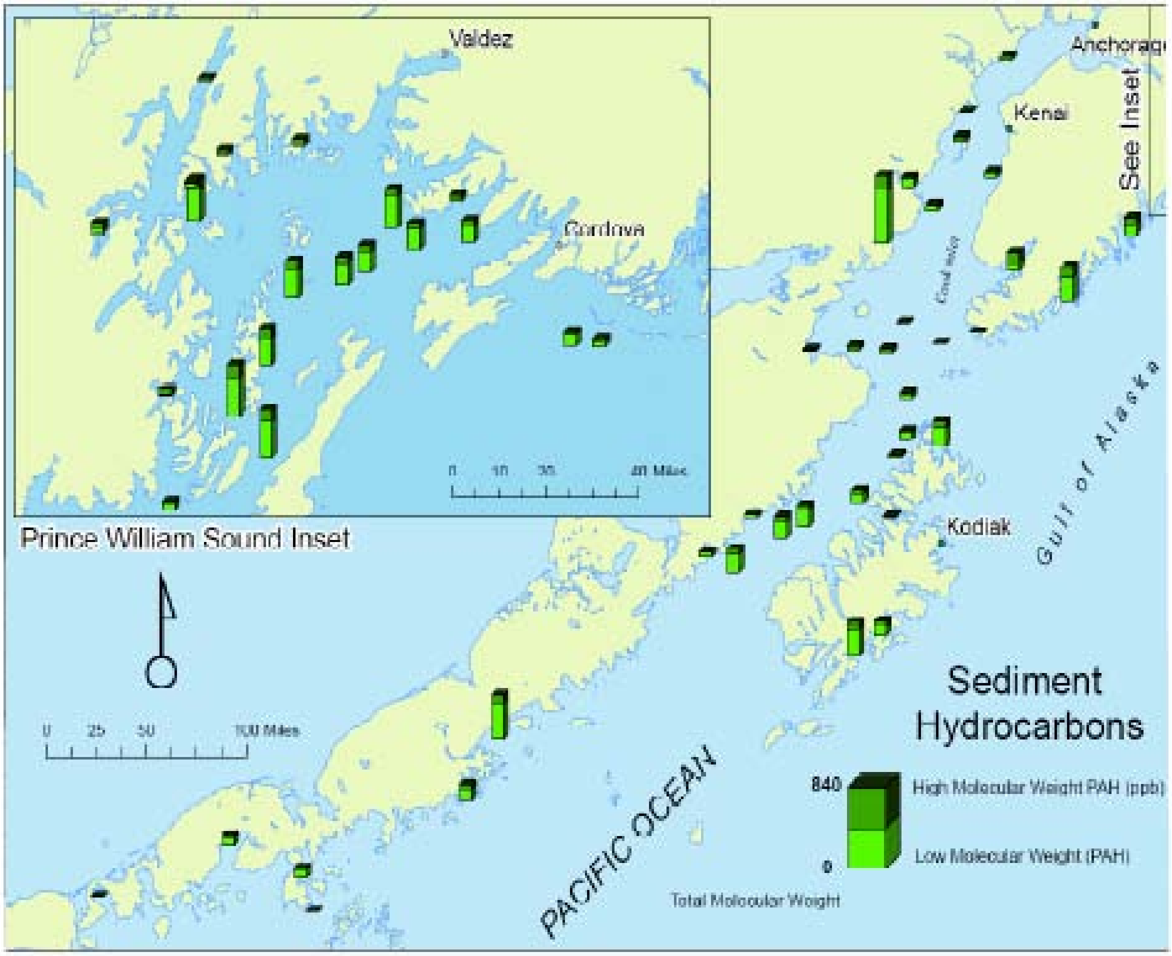


Figure 48. Sediment polynuclear aromatic hydrocarbon (PAH) concentrations (μg/g) at sampled stations across the EMAP study area, with low and high molecular weight PAHs shown as a fraction of total PAH. From Saupe et al. (2005).

No persistent organic pollutants were detected in sediments (Saupe et al. 2005). Sediment toxicity tests (bioassays based on a 10-day *Ampelisca abdita* amphipod survival test) showed only two stations (representing 1.1% of the study area) with amphipod survival rates of <80%, and these were not in the KEFJ coastal vicinity. Benthic infaunal communities near KEFJ were dominated by polychaetes and bivalves (Saupe et al. 2005). Fish tissue analyses (95 samples from the 55 stations) of metals and organic pollutants showed that 100% of samples fell below the EPA's Risk Guidelines for Recreational Fishers and also below the U.S. Food and Drug Administration's "Action Limits" for commercial fish.

The EMAP survey also included measurements of salinity and temperature, although the resolution was coarse along the southern Kenai coast. Surface temperature and salinity contours generated from the survey are shown in Figure 49 and Figure 50, where it is visible that the lowest salinities and temperatures occur closest to major inputs of principal rivers and glaciers.

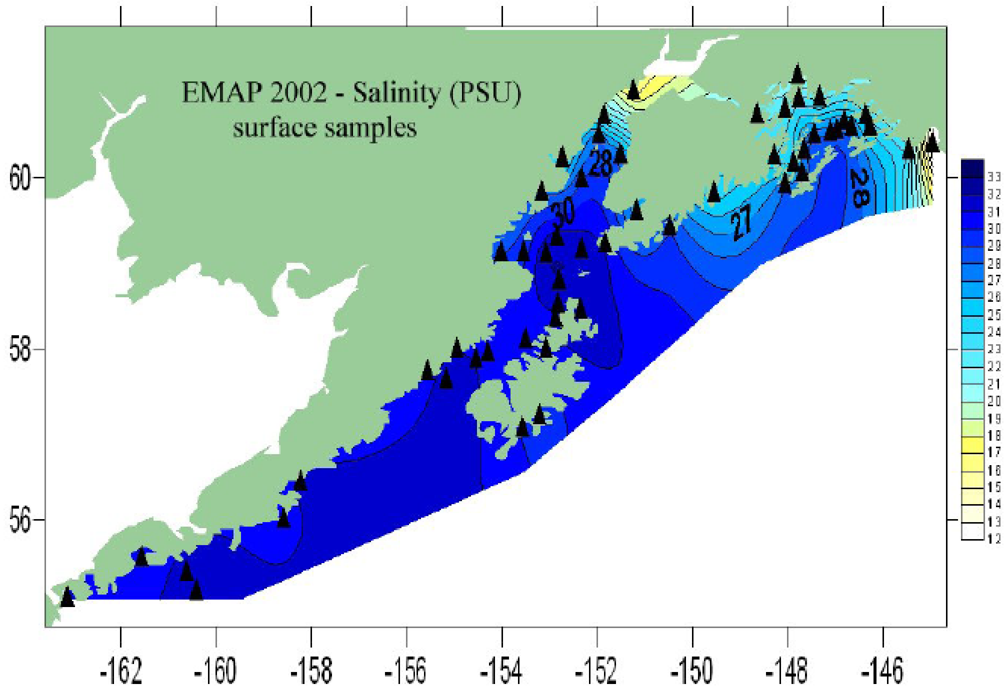


Figure 49. Surface salinity contours estimated from the 54 sampled stations (triangle) during the June–August 2002 sampling of the EMAP study. From Saupe et al. 2005.

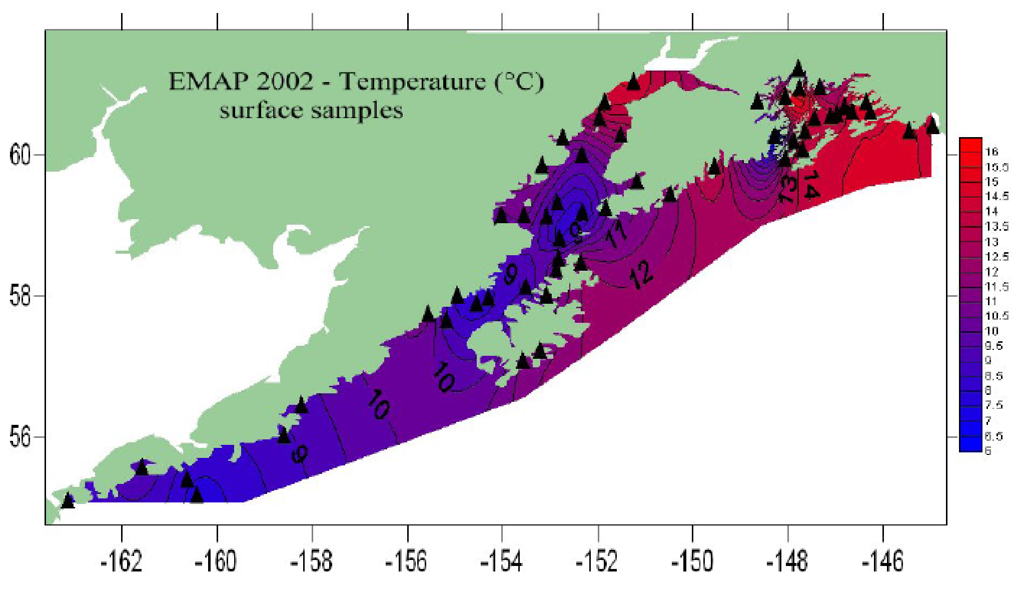


Figure 50. Surface temperature contours estimated from the 54 stations (triangles) sampled as part of the EMAP program. Sampling occurred between June and August 2002. From Saupe et al. 2005.

Water quality of estuaries, lagoons, and fjords: A study of seabirds along the KEFJ coast in 2007 (Arimitsu et al. 2008) included more detailed nearshore oceanographic measurements and water quality sampling (Figure 51) than provided by the EMAP study (Saupe et al. 2005). Water column profiles generally showed statistically significant colder temperatures and lower salinity in glacial stations (north of submerged moraines) compared with distal stations (south of submerged moraines) (Figure 52). However, nutrient analyses from samples at 10 m depth showed similar concentrations in glacial and distal stations, except for ammonium, which was higher in close proximity to tidewater glaciers (Table 11). Phosphate, nitrite, and dissolved inorganic nitrogen (DIN) were higher, and silicic acid was lower, at glacial stations in Aialik than in Northwestern Fjord. In Aialik Bay, primary productivity was higher in distal areas, and the authors credited this to relatively high suspended sediment loads inhibiting light penetration in glacial areas.

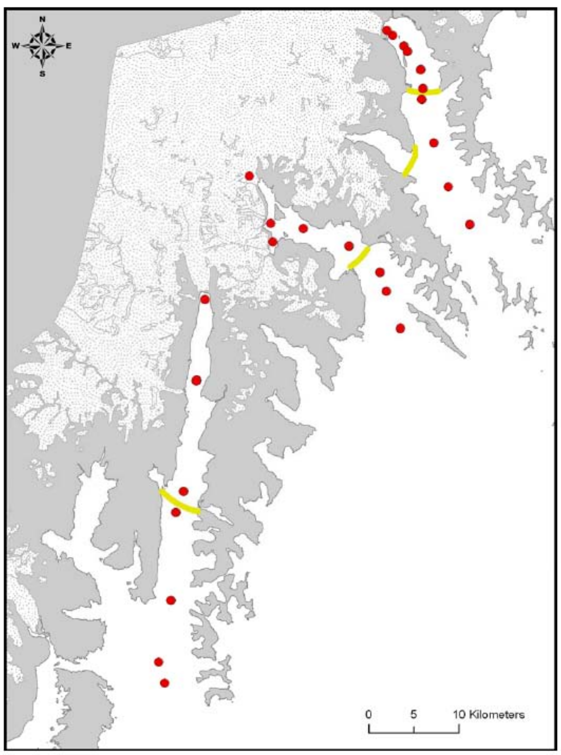


Figure 51. Oceanography stations (red circles) sampled with a conductivity-temperature-depth profiler in 2007. Yellow lines are boundaries of submerged glacial terminal moraines. From Arimitsu et al. (2008).

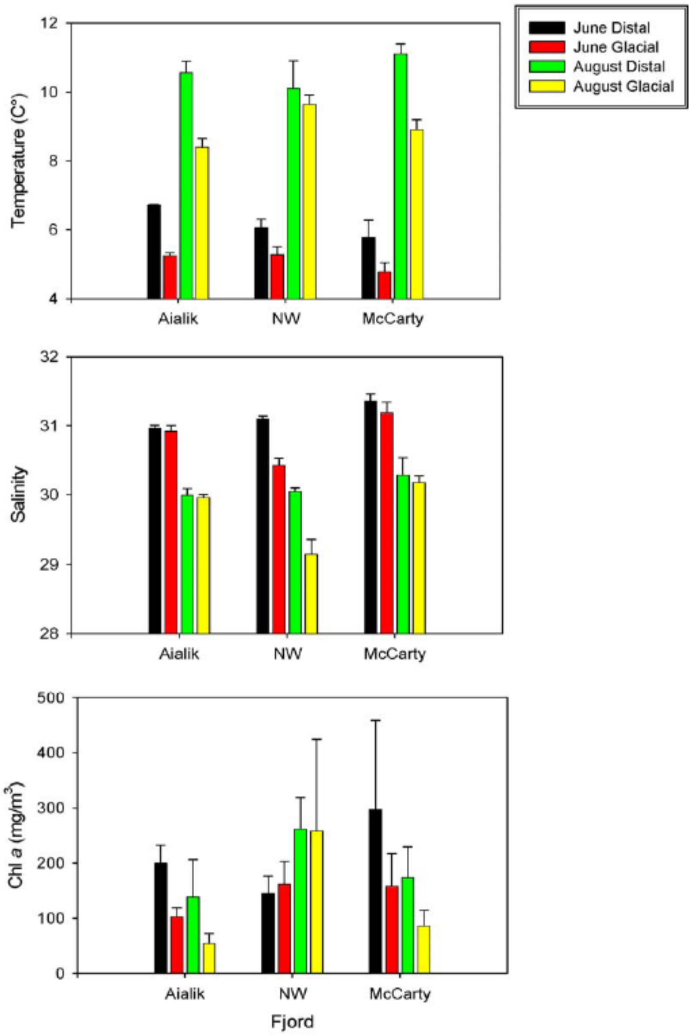


Figure 52. Early and late season temperature, salinity, and chlorophyll a within the upper 40 m of the water column at distal and glacial stations sampled in 2007. From Arimitsu et al. (2008).

Table 11. Mean (±SD) of nutrient levels at KEFJ stations sampled by Arimitsu et al. (2008).

	Glacial	Distal
Phosphate	0.82 ± 0.15	0.80 ± 0.18
Silicic Acid	14.58 ± 1.49	14.90 ± 2.92
Nitrate	4.17 ± 1.07	4.60 ± 2.91
Nitrite	0.20 ± 0.07	0.19 ± 0.08
Ammonium	1.83 ± 1.05	0.82 ± 0.74
DIN	6.20 ± 1.48	5.61 ± 3.60
DIN:P	7.49 ± 0.78	6.44 ± 3.75

As part of a water quality inventory conducted in 2003/2004, Bennett (2005) profiled Pedersen Lagoon with measurements of temperature, salinity, dissolved oxygen, and turbidity to a depth of 37 m (Figure 53). The profile showed a colder, more turbid, and better oxygenated layer at one meter compared with the surface. Temperature and dissolved oxygen declined steeply to 4.1°C and 7 mg/L between 10 and 20 m (Bennett 2005). All of these parameters met Alaska DEC water quality standards for estuarine waters (Alaska Department of Environmental Conservation 2008).

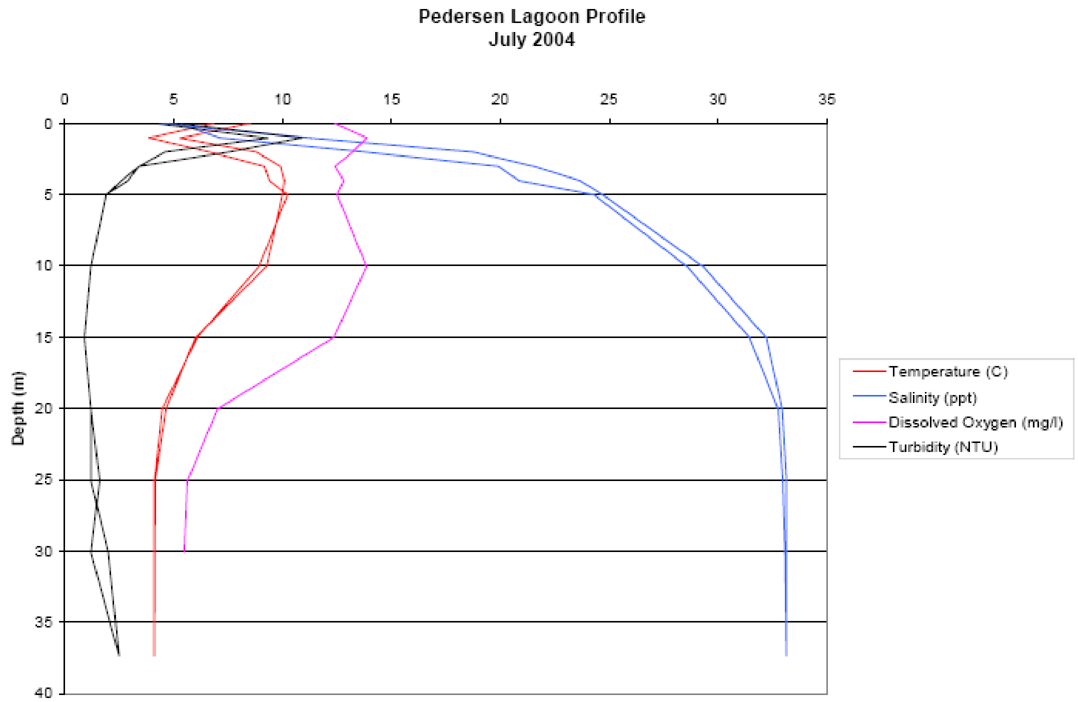


Figure 53. Depth profile of Pederson Lagoon, showing temperature, salinity, dissolved oxygen, and turbidity. From Bennett (2005).

Another Aialik Bay area lagoon sampled by Bennett (2005) was Quicksand Lagoon, which had a pH of 6.23, slightly below the regulatory limit of 6.5 (Alaska Department of Environmental Conservation 2008).

3.1.2. Freshwater

Overview of SWAN water quality component of I&M Program: Several vital signs were selected for the SWAN I&M Program that are directly related to freshwater resources, including surface water hydrology, freshwater chemistry, and landscape processes (including snow cover) (Bennett et al. 2006). The water quality monitoring design components are fully integrated into the SWAN vital signs monitoring program (Bennett et al. 2006). Results of water quality monitoring project review found no 303(d) waters present within KEFJ (or any other SWAN unit), and concluded that although water quality collection has been sporadic, conditions appear to be generally good with low nutrient levels and little evidence of anthropogenic impacts (Bennett et al. 2006).

The Network has developed a strategy for long-term monitoring of freshwater aquatic resources within the SWAN units. Streams and lakes were categorized into three tiers by a ranking procedure that considered access, level of use/management issues, and ecological and spatial cover (Bennett et al. 2006). Tier 1 lakes and streams are of the highest priority, have the easiest access, are heavily used by visitors, are of greatest management concern, and will be monitored annually. Tier 2 lakes are streams of medium priority, are less accessible, and will be randomly sampled for less frequent monitoring (every 2–5 years). Finally, Tier 3 lakes and streams (low priority) will be sampled every ~10 years, if at all (depending on funding constraints), for the purpose of expanding the scale of inference of Tier 1 and 2 water bodies. Vital sign metrics at Tiers 2 and 3 waterbodies may also be collected by seasonal park staff on an opportunistic basis. In KEFJ, the Exit Creek/Resurrection River was identified as Tier 1, and the Nuka River and Delusion Lake were designated as Tier 2 (Figure 54).

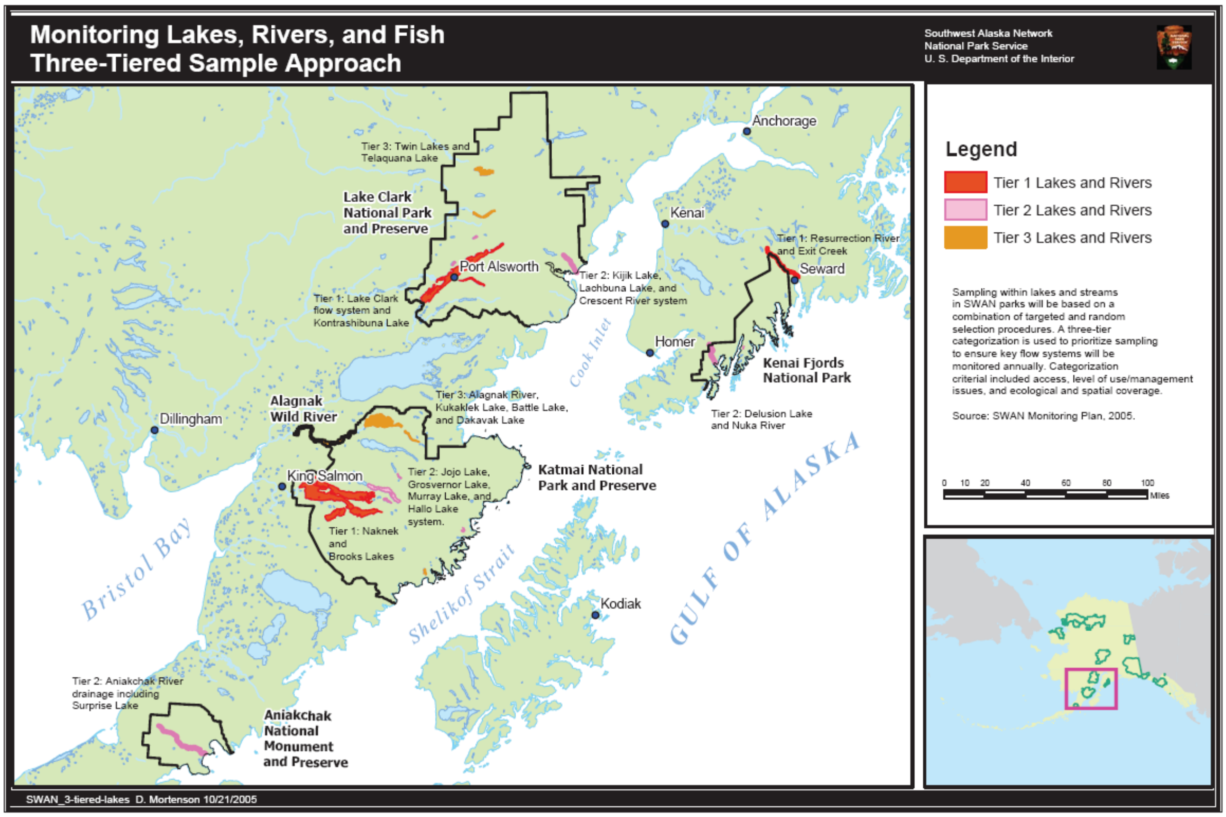


Figure 54. List and locations of proposed Tier 1, 2, and 3 lakes and rivers for monitoring aquatic resources in SWAN units. Within KEFJ, the Resurrection River was designated as Tier 1, and the Nuka River and Delusion Lake were selected as Tier 2 (Bennett et al. 2006).

Water quality of streams: Extremely little water quality data exist for streams within KEFJ. The largest source of information is an inventory of 62 sites in streams, lakes, and lagoons that was conducted in the summers of 2003 and 2004 by the SWAN I&M Program (Bennett 2005) (Figure 55). Bennett (2005) compared the measurement results with state water quality regulations, although we note that the State of Alaska recognizes that some conditions naturally exceed state water quality criteria and are not subject to the same regulations as criteria violations caused by human activity (Alaska Department of Environmental Conservation 2008).

Other sources of information include historical USGS sampling of the Nuka and Resurrection rivers and Exit Creek; a study on macroinvertebrates and salmonids by York and Milner (1999) in three lake systems on the McCarty Peninsula that also yielded some limnological and hydrochemical data; a study of the upper Nuka River diversion area; and lastly, some geochemical reconnaissance work in the Nuka River region in the early 1990s, for which there were no final or published reports.

Exit Creek: Exit Creek was sampled six times in the fall of 2001 at two locations (at 0.1 and 0.6 miles) by the USGS (Table 12). Samples from the creek turned up no detectable fecal coliform, *E. coli* or *Enterococci*.

From the inventory conducted by Bennett (2005), all three samples were collected in Exit Creek in 2004 met water quality criteria for parameters measured (temperature, dissolved oxygen, pH) (Alaska Department of Environmental Conservation 2008) (Table 13). High turbidity at two of three of the sites is typical of glacial-fed streams.

Because Exit Creek is a Tier 1 priority water body targeted by the SWAN I&M Program, long-term monitoring plans for the stream are currently being finalized (Jeff Shearer, NPS SWAN, written communication, 2009). At the same site where the NWS RFO and National Park Service are monitoring stage (and will be monitoring discharge), a continuous water quality meter that measures pH, temperature, specific conductance, dissolved oxygen, and turbidity is targeted for summertime deployment. This deployment was tested in the summer of 2008, and plans are currently being worked out to streamline instrument retrieval and sensor drift correction in order to continue and improve the monitoring (Jeff Shearer, 2009, NPS SWAN, written communication). Water quality monitoring on Exit Creek is expected to be fully operational by June 2010 (Jeff Shearer, NPS Anchorage, written communication, 2009). Results of the 2008 trial monitoring, which occurred between June and September 2008, indicated little temporal change in the values of the parameters measured, except for turbidity, and agreement with the findings reported in Bennett (2005) (Shearer and Moore 2009) (Table 14). Hourly sampling suggested minimal diel variation in the glacial stream, except again for turbidity, which varied by up to 709 NTU in one 24-hour period (Shearer and Moore 2009) (Table 14).

Resurrection River: USGS records show that the Resurrection River was sampled between 1–6 times/year for most years between 1952 and 1968 as well as once in 1995 (Table 12). These data indicate expected, normal values for glacial rivers: cold temperatures, low- to mid-range specific conductance, high dissolved oxygen, circumneutral pH, and occasionally high suspended sediment concentrations (Table 12).

The KEFJ water quality survey by Bennett (2005) showed that the Resurrection River met ADEC standards for temperature, dissolved oxygen, and pH (Alaska Department of Environmental Conservation 2008) (Table 13).

Nuka River and vicinity: Retrieval of USGS records indicates that the Nuka River was sampled once in 1960 and once in 1961 (Table 12). Results show similar water quality characteristics on both events, with slightly lower specific conductance, acid-neutralizing capacity, Na, and sulfate in January 1961 when discharge was higher than on the March 1960 sampling event (14 cfs vs. 5 cfs). Dissolved oxygen levels were not reported.

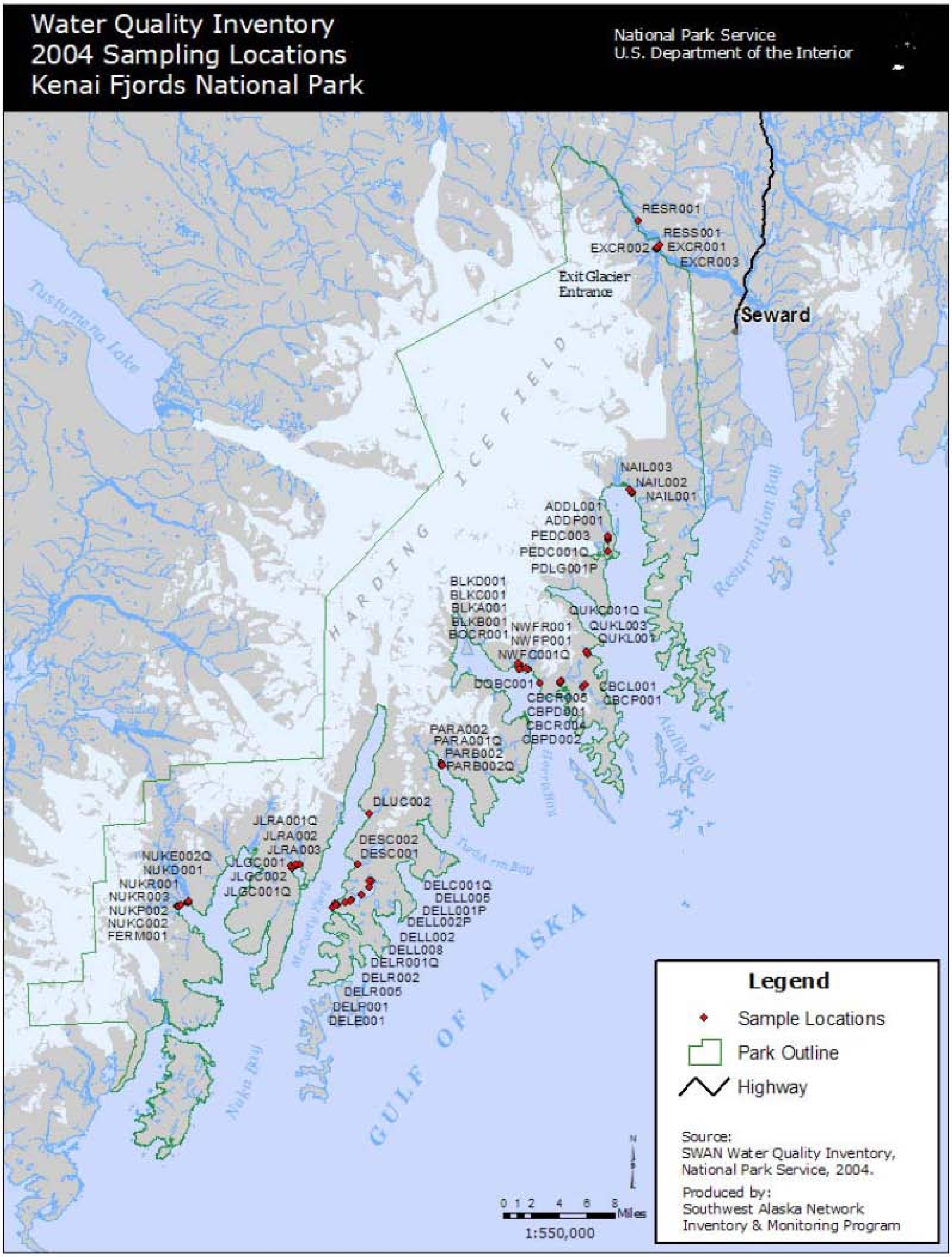


Figure 55. Locations of water quality samples taken by Bennett (2005) in May–July 2004 and August 2003. Figure from Bennett (2005).

Table 12. Water quality data retrieved from USGS records from Nuka River, Exit Creek, and Resurrection River, the only water bodies in KEFJ with available data. Data retrieved from http://water.usgs.gov/.

Site	USGS site ID	Sample Date	Water temp °C	Q cfs	Spec. Cond. µS/cm	DO mg/L	DO %sat	pH	ANC mg/L as $CaCO_3$	Hard.	N mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	Sulfate mg/L	Si mg/L	Susp. sed. mg/L
Nuka R. nr Homer	15238650	03/02/60		4.6	110			7.5	43	56	0	17	3.3	2.4	0.2	4	14		
		01/07/61		14	98			7.5	37	51	0.02	15	3.3	1.6	0.2	6	9		
Exit Gl C Tr at Mi 0.1 Harding Trail nr Seward	601105149382400	07/27/01	3.5	21	43	13.5		7.2											
		08/06/01	2	25	24	12.5	92	7.5											
		08/20/01	3	11	52	13.2	101	7.8											
		09/11/01	4	1.1	83	12.2	95	7.6											
		09/25/01	4	3.8	87			7.9											
		10/02/01	5	1.5	112	12.4	98	7.8											
	Also sampled but below detection: fecal coliform, E.Coli, Enterococci																		
Exit Gl C Tr at Mi 0.6 Harding Trail nr Seward	601105149385100	07/27/01	7.1	8.4	89	12.1	102	7.9	38	42	0.028	15.5	0.854	1.23	0.11	0.68	5.91	4.52	
		08/06/01	7.5	5.7	85	10.3	87	7.7											
		08/20/01	6.5	7	91	12.1		8.1											
		09/11/01	6	3	113	12.8		7.9											
		09/25/01	5.5	4.2	109	9.4	78	7.8											
		10/02/01	4.5	3	112	12.5	99			54	0.068	20	0.991	1.52	0.19	0.59	7.95	5.16	
	Also sampled but below detection: ammonia, nitrate, P, orthophosphate, F, Fe, Mn, fecal coliform, E.Coli, Enterococci																		
Resurrection R. at Seward	15237700	04/22/52	3.5		158			7.2	59	72	0.16	26	1.7			5	15	4.9	
		05/20/52	6		149			7.4	61	73	0.16	26	2			3.8	17	4.4	
		06/19/52	6		137			7.4	53	66	0.18	24	1.6			4.2	15	3.9	
		07/24/52			80			6.9	33	40	0.05	13	1.8	1.1	0.4	1	12	4.9	
		08/21/52	9		82				33	42	0.14	15	1.2	0.9	0.6	1	9.5	8	
		09/16/52	6.5		159			7.2	57	80	0.27	25	4.1	2.5	0.8	3.5	23	4.5	
		08/01/53	6.5		83			6.1	34	38	0.11	14	0.8	1.2	0.5	1.2	6.7	3.5	
		09/08/55			109			6.7	40	48	0.14	18	0.7	1.5	0.4	1.5	12	5	
		05/01/56			137			7.7	52	62	0.25	23	1.2	3	0.8	1.8	11	4.3	
		07/03/56			106			7.8	42	46	0.14	17	1	2.1	0.4	2.8	8.8	6.2	
		10/03/57	4.5		131			6.6	48	63	0.14	21	2.6	2	0.7	2.5	13	3.8	
		11/06/57	3.5		121			7.4	48	56	0.27	20	1.3	2	0.3	1.5	10	8.1	
		12/11/57	1		152			7.4	62	72	0.18	26	1.8	2.6	0.7	2.5	14	4.5	
		01/22/58	0		150			7.5	61	71	0.14	25	2.1	2.5	0.4	4	12	5.8	
		02/18/58			148			7	57	70	0.25	22	3.5	2.4	0.4	3.5	11	5.6	
		05/21/58	4.5		129			7.3	53	65	0.18	22	2.5	2.9	0.4	4	14	4.7	
		07/16/58	4.5		102			6.6	38	48	0.05	17	1.2	1.4	0.5	3	10	4	
		08/20/58	7		95			6.9	38	46	0.05	14	2.8	1.4	0.9	2.5	9	3.3	
		07/28/59	5.5	2070															300
		04/16/65	4	275															12
		06/20/65	6	1660															30
		07/20/65	5.5	2300															97
		08/29/65	9.5	1230															42
		09/28/65	5	2270															350
		09/28/65	5	2270	104			8	43	48	0.07	19	0.1	4.8	0.8	1.8	9.1	4.3	
		12/17/65	0	114															67
		04/05/66	3	107															14
		06/10/66	9	2310															237
		07/16/66		2890															322
		08/20/66	9	2250															157
		08/23/66	5	7790															1120
		11/11/66	1	395	150														10
		01/16/67	1	128	150														8
		04/06/67	5.5	99	153														8
		06/15/67	5.5	2180	100														172
		08/03/67	8	2660	83			7.2	31	38	0.32	14	1	1.5	0.3	0.4	8	2.2	
		08/03/67	8	2660	90														396
		09/09/67	5.5	2800	101														529
		09/09/67	5.5	2800	101			7.2	40	50		17	1.3	1.5	0.7	2.5	9	4	
		10/17/67	4	781	140			7.7	53	65	0.36	23	1.3	1.8	0.3	2.8	14	4.2	9
		11/16/67	4	522	145			7.6	56	69	0.29	25	1.5	1.9	0.5	2.5	15	3.8	6
		02/14/68	1.5	292	137			7.8	48	60	0.14	20	1.1	2.5	0.3	3.2	14	4.8	12
		04/17/68	1.5	169	155			7	59	68	0.16	25	1.4	1.8	0.6	2.8	11	3.8	5
		06/21/95	5	1990															107

Table 13. Water quality data collected for the Resurrection River watershed by Bennett (2005) as part of the KEFJ water quality inventory.

Site	Descrip.	Temp °C	Spec Cond uS/cm	DO %	DO mg/L	pH	Turbidity NTU
Exit Cr. 001	glacial	0.05	131	96.1	12.32	7.75	144
Exit Cr. 002	clear	4.5	158	86.7	11.21	7.53	5.1
Exit Cr. 003	glacial	4.82	126	95.7	12.28	7.69	107
Resurrection R.	clear	8.27	68	88.9	10.45	6.74	2.7
Resurrection R.	glacial	4.03	46		11.69	7.07	0.6
Resurrection R.	glacial	4.03	71		12.57	7.29	14

Table 14. Summary data for water temperature, pH, specific conductivity, dissolved oxygen, turbidity, and stage, measured in Exit Creek with the multi-parameter sonde. From Shearer and Moore (2009).

Parameter Statistic	June	July	August	September
Water Temperature (°C)				
Mean	1.74	1.20	1.25	1.00
Standard Deviation	0.96	0.39	0.37	0.27
Maximum	5.27	2.43	2.45	1.58
Minimum	0.61	0.54	0.61	0.09
pH (standard units)				
Mean	7.82	7.89	7.65	8.02
Standard Deviation	0.08	0.14	0.07	0.45
Maximum	8.31	8.33	7.98	9.24
Minimum	7.66	7.65	7.52	7.51
Specific Conductivity (µS/cm)				
Mean	30.0	39.3	38.7	41.2
Standard Deviation	4.3	3.4	2.3	8.8
Maximum	42.0	45.8	44.0	59.0
Minimum	23.3	33.6	34.4	29.0
Dissolved Oxygen (mg/L)				
Mean	14.58	14.83	14.76	14.30
Standard Deviation	0.29	0.12	0.14	0.51
Maximum	15.08	15.10	15.07	15.42
Minimum	13.56	14.52	14.40	13.49
Dissolved Oxygen (% Sat)				
Mean	105.3	107.0	105.9	100.6
Standard Deviation	1.5	1.0	2.1	3.9
Maximum	109.1	109.7	110.8	107.0
Minimum	101.2	104.8	102.1	94.3
Turbidity (NTU)				
Mean	122.3	179.7	87.6	200.9
Standard Deviation	87.2	58.9	40.4	159.3
Maximum	543.6	370.9	279.6	717.4
Minimum	18.9	1.2	0.2	0
Stage (ft)				
Mean	0.76	1.55	1.57	1.58
Standard Deviation	0.34	0.19	0.12	0.91
Maximum	1.24	1.92	1.88	3.13
Minimum	0.16	1.08	1.14	0.08

Parameter	Greatest Diel Fluctuation* Date	Range
Water Temperature (°C)	June 10	4.21
pH (standard units)	Sept 14	1.38
Specific Conductivity (µS/cm)	June 10 & 22, Sept 19	7.0
Dissolved Oxygen (mg/L)	June 10	0.90
Dissolved Oxygen (% Sat)	June 10 & 13	5.3
Turbidity (NTU)	Sept 4	709
Stage (ft)	Sept 7	0.70

* Based on hourly measurements over a 24-hour period.

An investigation into the possible effects of historic mines on water quality in the Nuka Bay region provided some information on base cations and heavy metals in several streams (Cieutat et al. 1994). Water was collected from a tributary to Ferrum Creek (in the vicinity of Little Creek Prospect, aka Beauty Bay mine); Ferrum Creek itself; a tributary to Babcock Creek (in the vicinity of the Sonny Fox mine); and a tributary from three small streams draining into Surprise Bay (by the Goyne prospect). The report found that during the summer high runoff season, no adverse impact was detected for heavy metals about 500 m from the mine workings (Cieutat et al. 1994). However, the report failed to define what was considered an adverse impact, and no comparisons with water quality standards were made. The report did point out that one sample (from immediately downstream of the main workings of the Little Creek Prospect) had anomalously high arsenic, at 130 ppb. In fact, this value is 13 times the EPA drinking water criterion of 10 ppb for the metalloid (EPA 2001). Indeed, this site was found to have excessive arsenic concentrations in mine tailings, and a clean-up of the tailings site occurred in 1998 (Shannon & Wilson Inc. 2006). Additionally, although many of the heavy metals measured by Cieutat et al. (1994) were below detection in most or all samples (e.g., Ag, Cd, Co, Cu, Mn, Pb, and Se), they were analyzed with fairly high detection limits (1–10 ppb, except for Ag, 50 ppt). The report's methods description does not indicate that special clean-techniques (Horowitz et al. 1994), which greatly minimize contamination of metals samples and is now standard in federal and state water quality surveys, were used and as a result the accuracy of the report's data is questionable.

The recent KEFJ water quality survey included five clearwater and two glacial streams (the Nuka River, its tributaries, and nearby Ferrum Creek) in Nuka Bay (Bennett 2005). Water quality standards set by the Alaska DEC for temperature, dissolved oxygen, and pH were met for all samples. However, some indications of lower-than-expected levels of dissolved oxygen were found at sites NUKD (9.09 mg/L or 75% saturation), NUKP (an estuarine pond with 6.64 mg/L), and in a portion of the glacial NUKR (6.32 mg/L or 51%) (full site names not provided in the report). Bennett (2005) suggested that these sites be revisited for future study.

Finally, a study on the Nuka River diversion area (see Section 4.7) included measurements of physico-chemical parameters, aquatic macroinvertebrates, diatoms, and stream discharge in the upper Nuka River on August 3, 2007 (Rinella and Bogan 2008). Samples were taken of glacier outflow and of a lower river section, and water samples indicated substantial groundwater input between the two, as indicated by higher flows, warmer temperatures, lower dissolved oxygen, and higher specific conductance (Table 15). Macroinvertebrate analyses showed that 15 taxa were present, all of which were expected and which were similar to those found in clearwater reference streams of the Cook Inlet basin (Rinella and Bogan 2007, 2008). Taxonomic diversity was expected to be relatively low in glacial streams, and Rinella and Bogan (2008) report that the taxonomic composition in the Nuka River was typical for a glacial stream and similar to that of Wolf Point Creek, a well-studied glacial stream in GLBA. The dominant taxa were the mayflies *Cinygmula* sp. (34% of total) and *Baetis bicaudatus* (15% of total); the stonefly *Plumiperla diversa* (11% of total); and several genera of chironomid midges (20% of total) (Rinella and Bogan 2008). The number of diatom taxa (18 in the 600-valve count and 12 in the rare taxa scan) found in the upper Nuka River was on the low end of the range of taxa counts in clearwater reference streams in the Cook Inlet basin but typical for glacial systems (Rinella and Bogan 2008). The dominant diatom encountered was the *Gomphonema pumilum*, which accounted for 79.3% of the sample and is common in streams with neutral pH and low nutrient levels. The Rinella and Bogan report (2008) also provides information on substrate embededness, canopy cover, channel slope, wetted width, bankfull width, depth, thalweg depth, filamentous algae, overhanging vegetation, and number of boulders.

Table 15. Stream discharge and physico-chemical measurements taken at two sites on the upper Nuka River. Coordinates for the sites are N 59.6859°, W 150.707° for the glacier outflow site, and N 59.67955°, W 150.69476° for the Sample Reach. From Rinella and Bogan (2008).

Location	Discharge (cfs)	Water temperature (°C)	pH	Specific conductance (µs/cm)	Dissolved oxygen (mg/L)	Dissolved oxygen (% saturation)
Glacier outflow	6.0	3.9	7.32	16.0	12.53	95.4
Sample reach	10.8	10.9	7.75	46.4	10.03	90.6

As a Tier 2 priority water body, the Nuka River is slated for occasional (every 2–5 years) sampling by the SWAN I&M Program (Jeff Shearer, NPS SWAN, written communication, 2009).

Aialik Bay streams: Streams sampled in the Aialik Bay area by Bennett (2005) met Alaska DEC water quality standards for temperature (range: 2.85–10.25°C), dissolved oxygen (range: 11.12–14.44 mg/L) and pH (6.6–8.5).

Harris Bay and Two Arm Bay streams: Five streams in Harris Bay/Northwest Fjord were sampled as part of the KEFJ water quality survey (Bennett 2005). Although sample locations are shown on a broad map (Figure 55), site names are not specifically described (using coordinates) and site names are given only in abbreviation for most streams, and so it is unclear which streams were included. Yet, all streams sampled met Alaska DEC standards for temperature and dissolved oxygen, although not all pH values did. The pH in BOCR (Boulder Creek, unofficially) was 6.23, or below the lower limit of 6.5. Also, the pH of DOBC (Dropoff Beach Creek, unofficially) was relatively high, at 9.26. Nonetheless, both streams supported salmonids (Bennett 2005).

McCarty Fjord: Four clear water and three glacial streams were sampled in the McCarty Fjord by Bennett (2005). Most sites met Alaska DEC standards for temperature, pH, and dissolved oxygen. Exceptions included James Lagoon Creek with low temperatures and site DELC (full name not provided but likely Delight Creek) with pH values lower than the 6.5 minimum standard (at 6.06–6.13).

A more detailed study of the Delusion Creek drainage was conducted during1992–1994, with a focus on salmonid and macroinvertebrate colonization in the stream formed approximately 40 years prior due to glacial retreat (York and Milner 1999). (Limnological results from the study are presented in the next section of this report, and aquatic invertebrate, chlorophyll, and zooplankton results are presented in Section 2.3.1). However, the study provided little specific data on water quality parameters in Delusion Creek itself. The available data show that Delusion Creek had variable temperatures and degrees of stability depending on its location. Leaf retention experiments indicated fast and efficient flushing of organic matter in the stream. Two stream sites were measured for water chemistry in August 1992. Results of this effort showed the following for the two sites: pH= 6.5 and 6.7; alkalinity=2.0 mg/L; turbidity=0.4 and 0.5 NTU, color=4 and 3 Pt units; Ca=1.0 mg/L; Mg=0.7 mg/L, Fe=388 and 606 μg/L; Total P=23.4 and 25.6 μg/L; Total N= 65.8 and 70.6 μg/L N (York and Milner 1999).

Water quality of lakes: A study on sockeye salmon growth in various southcentral Alaskan lakes included basic physical information on Delight and Desire Lakes (area, depth, volume); water temperature; chlorophyll-a concentration; and zooplankton biomass (Table 16) (Edmundson and Mazumder 2001). The study also noted that the length of growing season in these two lakes specifically was 175 and 215 days, respectively, and the summer heat budget was 12.6 and 7.2 kcal/cm^2, respectively.

Table 16. Physical and biological attributes of Delight and Desire Lakes, as reported by Edmundson and Mazumder (2001).

Lake	Area *km^2*	Mean depth *m*	Max depth *m*	Volume *10^6 m^3*	Mean water column temp *°C*	Mean surface water temp *°C*	Chloroph.-a *μg/L*	Zooplankton Biomass *mg/m^2*
Delight	2.8	22	40	60	7.8	14.2	0.7	70
Desire	1.8	14	27	25	7.4	16.0	0.5	*(no data)*

Bennett (2005) included several lakes in her inventory of water quality in KEFJ. Depth profiles (at 1 m intervals for the first 5 m, and every 5 m thereafter) were taken near the deepest areas of Delight Lake and Pederson Lagoon. Surface temperatures at Delight Lake were 15.3°C (59.5°F) and 15.6 C (60.1°F), which are above state limits for the growth and propagation of fish, shellfish, other aquatic life, and wildlife (Alaska Department of Environmental Conservation 2008) but consistent with the high measurements reported by Edmundson and Mazumder (2001). Temperature decreased and dissolved oxygen increased with depth in Delight Lake (Figure 56). For both profiles taken of Delight Lake, pH levels at depths of more than 20 m (66 ft) did not meet state standards (i.e., they were <6.5), although dissolved oxygen levels were passable. In Pederson Lagoon, temperature, turbidity, and dissolved oxygen were relatively high at 1 m (3 ft) depth, but together with dissolved oxygen, it declined sharply with depth (Bennett 2005)

In addition, eight lakes and ponds were sampled for temperature, dissolved oxygen, pH, and turbidity by Bennett (2005) in the Harris Bay and Two Arm Bay lakes area. Although several cases were found in which levels were outside of water quality standards for temperature and pH (Alaska Department of Environmental Conservation 2008), presence of fish indicated that this was a rare occurrence.

A more detailed limnological investigation was conducted in Upper and Lower Delusion lakes in the McCarty Fjord (Milner and York 2001, York and Milner 1999). They found that both lakes had low specific conductance (typically <20 μmhos/cm), sub-neutral pH (between 5.5 and 6.5), variable turbidity and light penetration, and no color staining (color <20 Pt units). Clarity decreased and turbidity increased during the summer months due to an increase in glacial runoff from the remnant ice sheet, and there was no indication of thermal stratification. Total N values were relatively high during large August rainstorms, and this was attributed to surface runoff contributing N and P from eroding shallow soils. Primary productivity in the lakes was likely light limited during such large rain events, consequently limiting zooplankton production as well.

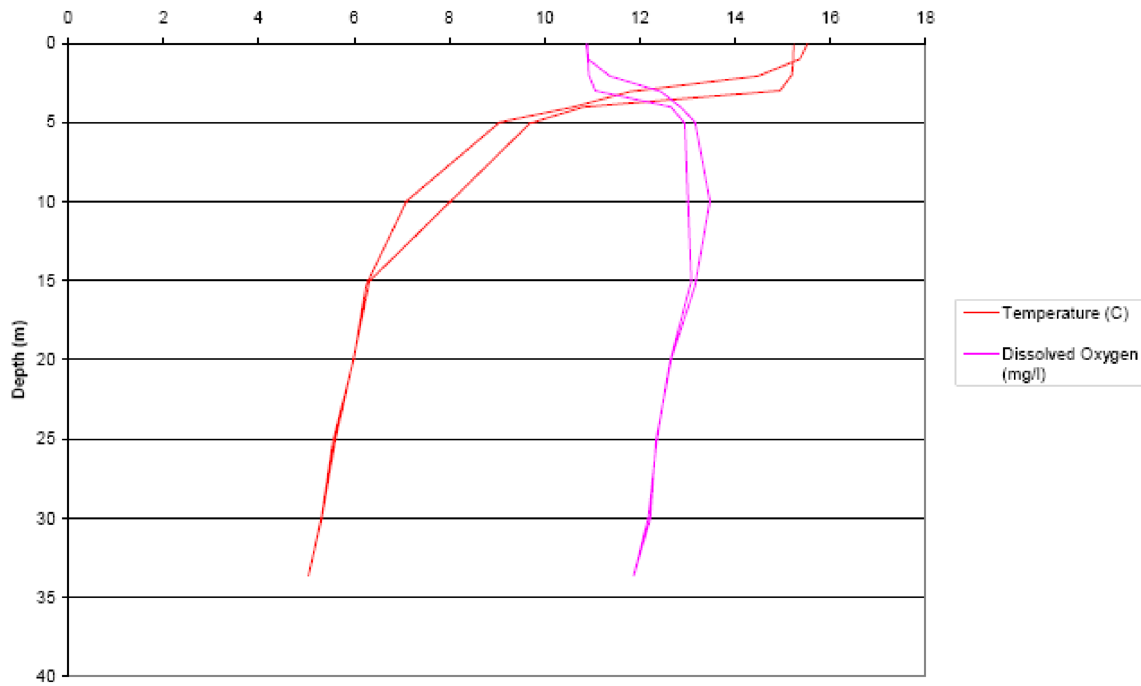


Figure 56. Temperature and dissolved oxygen (mg/L) profile (#2) of Delight Lake on June 27, 2004. From Bennett (2005).

Delusion Lake is ranked as a Tier 2 priority water body by the SWAN I&M Program, meaning it may be monitored once every 2–5 years (Jeff Shearer, NPS SWAN, written communication, 2009).

Groundwater: The lack of any information on groundwater resources in the KEFJ does not allow for an assessment of groundwater quality in the area. However, there is no reason to believe that groundwater quality is impaired by human factors due to the low level of use and disturbance in KEFJ. The nearest evaluations of regional groundwater resources include an evaluation of groundwater resources in the lower Kenai Peninsula (Nelson and Johnson 1981), a multi-agency collaborative study of groundwater contamination from oil drilling wastes in the Kenai Peninsula (Glass 1996, Kenai Peninsula Borough 1992), and more recently, from the USGS's NAWQA Program's focus on the Cook Inlet Basin (Glass et al. 2001, 2004). However, information from these studies is hardly applicable to KEFJ conditions due to the contrasting environmental settings and the urban and industrial influences in the neighboring regions that are not present in KEFJ.

Precipitation: At the current time, the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) provides continuous measurement and assessment of the chemical constituents in precipitation at more than 225 sites throughout the United States. This long-term, nationally consistent monitoring program provides critical information for evaluating the effectiveness of ongoing and future regulations aimed at reducing atmospheric emissions. There are five NADP sites in Alaska, three of which are administered by NPS (Denali, Gates of the Arctic, and SWAN [King Salmon-KATM]). The most representative NADP site for coastal KEFJ with data currently available through the NADP website (http://nadp.sws.uiuc.edu/sites/ntnmap.asp?) is the Juneau site located on the east coast of the Gulf of Alaska. However, the newly installed NADP site in King Salmon will provide better information about precipitation chemistry in KEFJ when data become available. Five years (2004–2008) of data from the Juneau site show a predominance of marine aerosols (chlorine, sulfate, and sodium) and very low levels of nitrogen (ammonium and nitrate) compared to sites in the contiguous United States.

3.1.3. Water Quality Impairments and Effects on Biological Resources

There are no water bodies in KEFJ that are listed as impaired under the 303d section of the Clean Water Act, although this is based on extremely little available data. There are no obvious sources of substantial pollutants to the park's streams, lakes, and groundwater. A survey of water quality conditions throughout the unit is required before making any definitive assessments of the effects of water quality on biological resources.

3.2. Availability of Geographic Datasets

The following represent geographic data sets that are most relevant to coastal watershed conditions and are currently archived at the NPS Alaska GIS clearinghouse (http://www.nps.gov/akso/gis/), unless otherwise noted.

Biological

Ecological Subsections
Exit Glacier Area Vegetation
Landcover (1999)
Statewide Archaeological Inventory Datasets (SAIP) pertaining to: Biological Resources, Ground Fish, Harbor Seals, Pacific Herring, and Shrimp
Shorebird Shoreline Segments

Cultural

Cabins
Coastal Camping Areas
Exit Glacier Infrastructure (Culverts, Waterbars)

Imagery

Topological-Map (DRG) Mosaics 1:250,000 and 1:63,360
Exit Glacier Aerial-Photo Sequence (1950 – 1998)
Landsat Satellite Imagery

Physical

Statewide 90m Digital Elevation Model
Shaded Relief Kenai
Geology
USGS / NHD Hydrological Data
Statewide Archaeological Inventory Datasets (SAIP) pertaining to: 19th Century Glacial Divide, Glacial Extent - mid 1980's, Glacial Features (Limiting Age), Stream Deltas, Water Level Changes, and Wave Energy
Exit Glacier features: Moraines, Subfossil Tree Sites
Shore-Zone Classification (http://mapping.fakr.noaa.gov/Website/ShoreZone/viewer.htm)

4. Threats to Water Resources

4.1. Sources of Past, Current, and Potential Future Pollutants

Pollutants to KEFJ can be categorized into oceanographic and atmospheric sources. Oceanographic sources include oil spill pollution, marine vessel pollution, gas and oil development in the Gulf of Alaska, and biological delivery of marine-derived toxic chemicals. Atmospheric sources include air masses that have the ability to deposit mercury (Hg) and persistent organic pollutants (POPs).

4.1.1. Oceanographic Sources

Oil spills: The release of petroleum poses a great environmental threat, whether as catastrophic spills or chronic discharges. In addition to physical impacts of large spills, the toxicity of many of the individual compounds contained in petroleum is significant, and even small releases can kill or damage organisms. The impact of a release of petroleum would depend on the size of the spill, the location of the spill, the type of petroleum product, and the effectiveness of the response to the spill.

Swift currents and large tidal ranges can quickly transport released petroleum great distances and over wide coastal zones, as evidenced by the *Exxon Valdez* Oil Spill (EVOS) in 1989. The grounding of the *Exxon Valdez* oil tanker on Bligh Reef in Prince William Sound in March 1989 released 10.8 million gal (35,500 metric tons) of crude oil, which was transported through Prince William Sound, along the northern Gulf of Alaska, and southwest into Shelikof Strait (Figure 57). KEFJ was not immediately affected. It was not until two weeks after the spill that a storm drove oil onto approximately 20 miles (32 km) of the KEFJ coastline, representing approximately 5% of the total coastline in the park (NPS 2009b). Pony Cove, Verdant Cove, Taroka Arm, Black Bay, Yalik Bay, and McArthur Pass were the most affected regions within KEFJ (NPS 1990). Booms were placed in three locations to protect salmon streams, and oil did not reach these streams (Figure 58). Patches of unweathered oil mousse have persisted and retained their toxicity along exposed, rocky shorelines with boulder-armored beaches in KEFJ (Irvine et al. 1999, Peterson et al. 2003). The nearshore I&M Program continues to monitor areas oiled by EVOS. One of the positive outcomes of EVOS was the purchase of 31,190 acres (12,622 ha) of private land within the boundaries of KEFJ that was paid by the *Exxon Valdez* Oil Spill Trust and the criminal restitution fund (NPS 2009b).

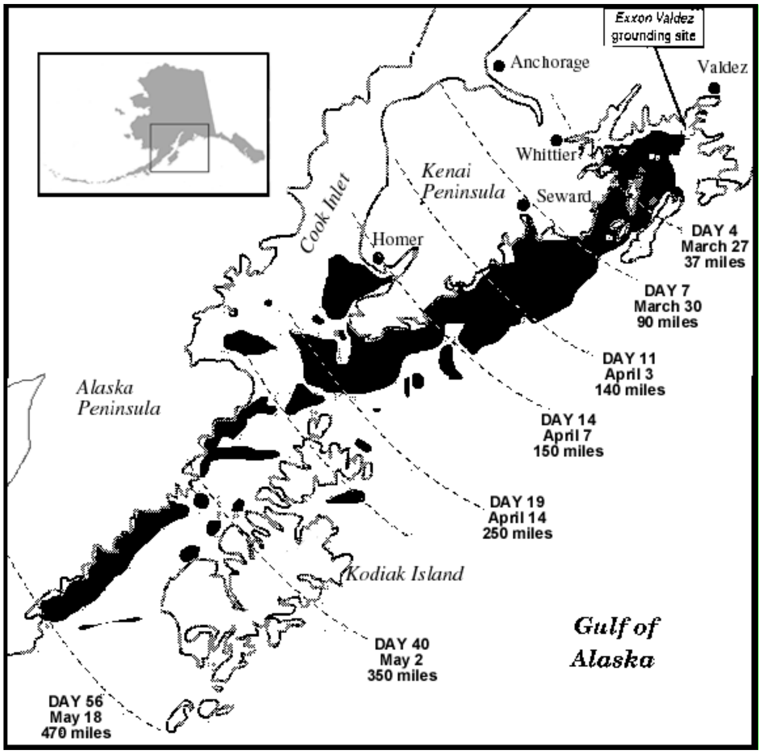


Figure 57. Geographical extent of the *Exxon Valdez* oil spill through time (24 March 1989 to 20 June 1989), from http://www.evostc.state.ak.us/

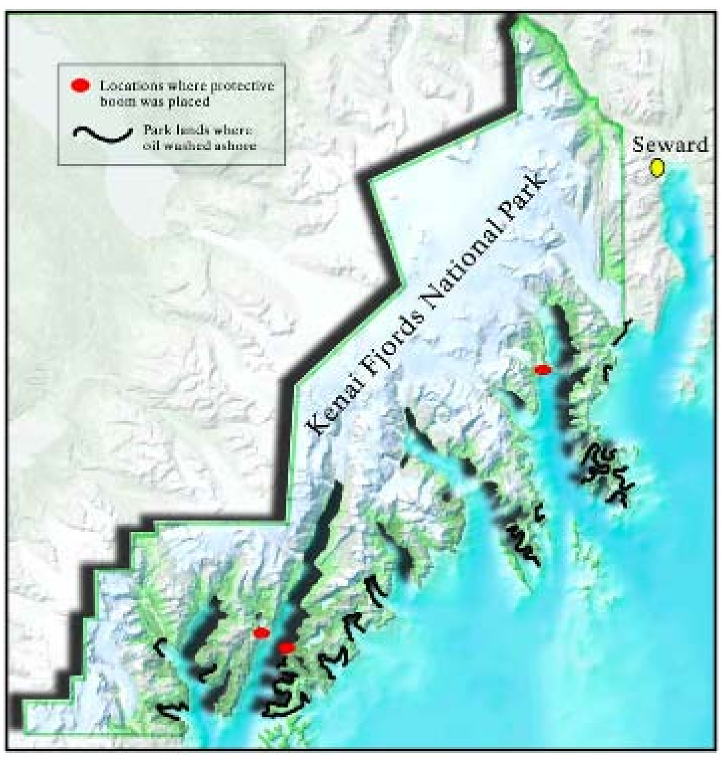


Figure 58. Booms were placed in three location (red dots) to protect salmon streams from the EVOS. Park lands where oil washed ashore are indicated in black. (NPS 2009)

Oil and gas development: Future oil spills similar in scale to that of EVOS continue to be possible in the region. Potential source areas include the Valdez Marine Terminal (Prince William Sound); Drift River Marine Terminal (Cook Inlet); Nikiski Oil Terminal and Refinery (Cook Inlet); Anchorage International airport jet fuel pipeline; and 17 gas and seven oil producing fields (Figure 59). Several more oil and gas sales are currently proposed for development over the next five years in the Cook Inlet region, and steady or rising demand for these fuels may prompt further long-term development (2006–2011; information at http://www.dog.dnr.state.ak.us/oil/index.htm). Many billions of barrels of oil and gas are potentially releasable into the environment from these petroindustrial areas, posing major pollution threats to the marine, estuarine, tidal, and intertidal environments in the region (Andres and Gill 2000). The Valdez terminal receives approximately 24 billion gallons (1.1x1011 L) annually via the TransAlaska Pipeline; the privately owned Drift River Marine Terminal (with an offshore oil loading platform and onshore storage facility) stores approximately 1 million barrels of crude oil received via the 68-km-long (42 mi) Cook Inlet Pipeline (which in turn has an annual capacity of 82 million barrels); the Nikiski station has an annual capacity of 260 million barrels (averages 183 million barrels); and the subsurface pipeline that runs beneath the intertidal zone between the Port of Anchorage and the Anchorage International Airport funnels 13 million barrels of jet fuel annually (Alaska Division of Oil and Gas 2003, Andres and Gill 2000, Chevron Corporation 2006, Kozlowski (in preparation), Weeks 1999). Not only are these activities subject to human error, but they are located along an extremely active volcanic and seismic area. Earthquakes, volcanoes, and tsunamis may destabilize any of these petroleum-related infrastructure and cause massive spills.

Currently, Geographic Response Strategies (GRS) are established within KEFJ (Figure 60 and Figure 61). These spill response plans are tailored by a workgroup made up of local, state, and federal agencies (including the National Park Service), spill response experts, oil spill contingency plan holders, and the Cook Inlet and Prince William Sound Citizens' advisory councils. The GRSs are map-based strategies that locate sensitive areas where oil spill responders should prioritize their efforts following a spill. GRS locations were selected based on their levels of environmental sensitivity, risk of being affected from a water-borne spill, and feasibility of successfully protecting the site with existing technology. Information is available at http://www.dec.state.ak.us/spar/perp/grs/ki/mainland.htm. At this website, more specific information on each GRS site is available, including site access, staging area, response resources, and special considerations.

In addition, the agencies (ADEC, Alaska Department of Natural Resources, Alaska Department of Fish and Game, EPA, NOAA, National Park Service, and others) in conjunction with private industry (Alyeska Pipeline Service Company) and local groups (City of Kodiak, Cook Inlet Regional Advisory Council, and others) have developed Potential Places of Refuge (PPORs) (Figure 62). The PPORs are designated as sheltered areas with adequate water depth where leaking or disabled vessels could dock, anchor, moor, and/or ground in order to minimize the amount of spilled product while undergoing repair or being unloaded (ADEC 2008). Information on the PPORs is available at http://www.dec.state.ak.us/spar/perp/ppor/home.htm. The identification of these PPORs should reduce the response time and regional environmental damage in the event of a spill from a distressed vessel, but it is also likely that the PPOR used in such an event will experience a disproportionately large amount of impact.

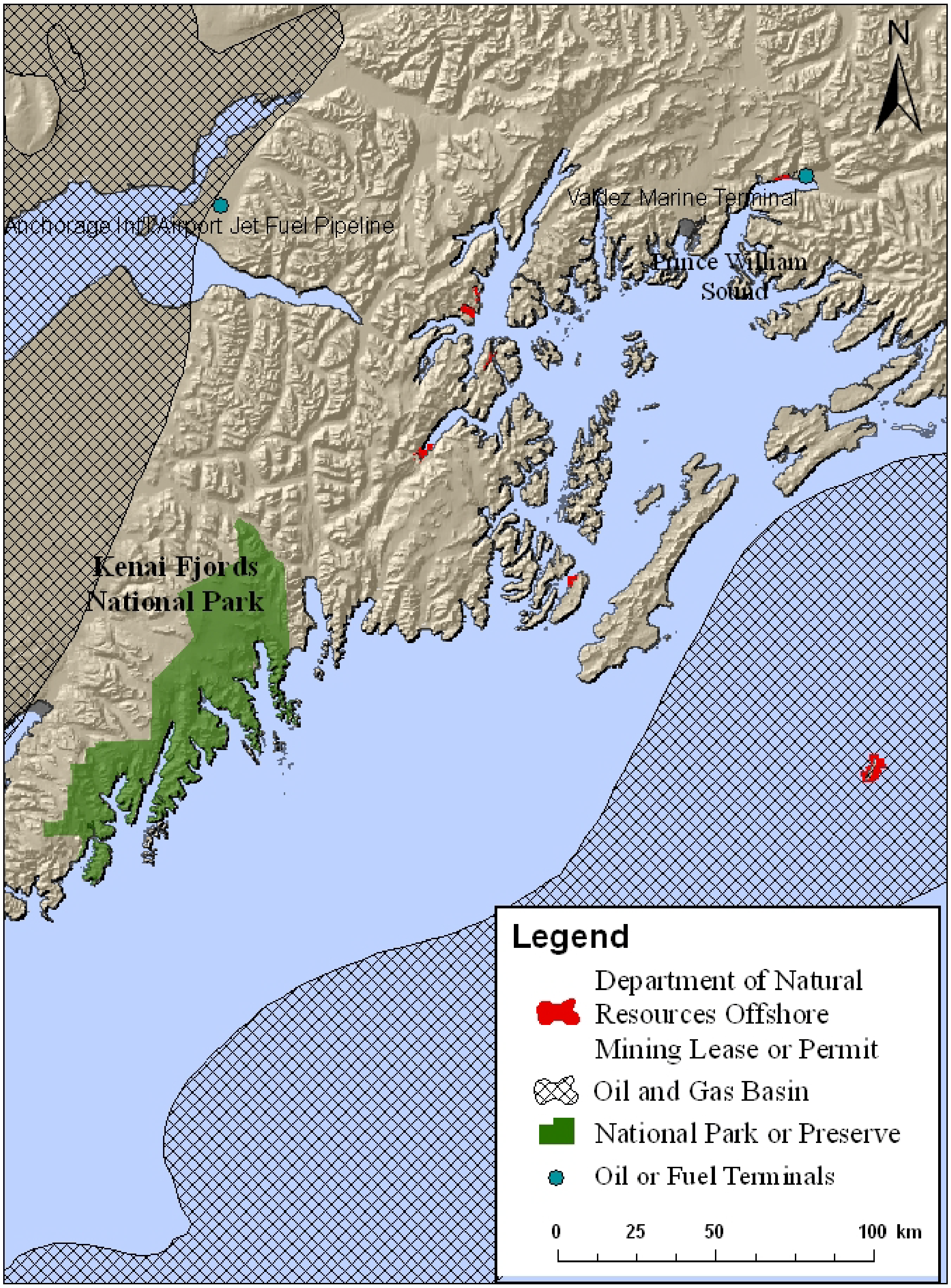


Figure 59. KEFJ is located adjacent to a large oil and gas basin.

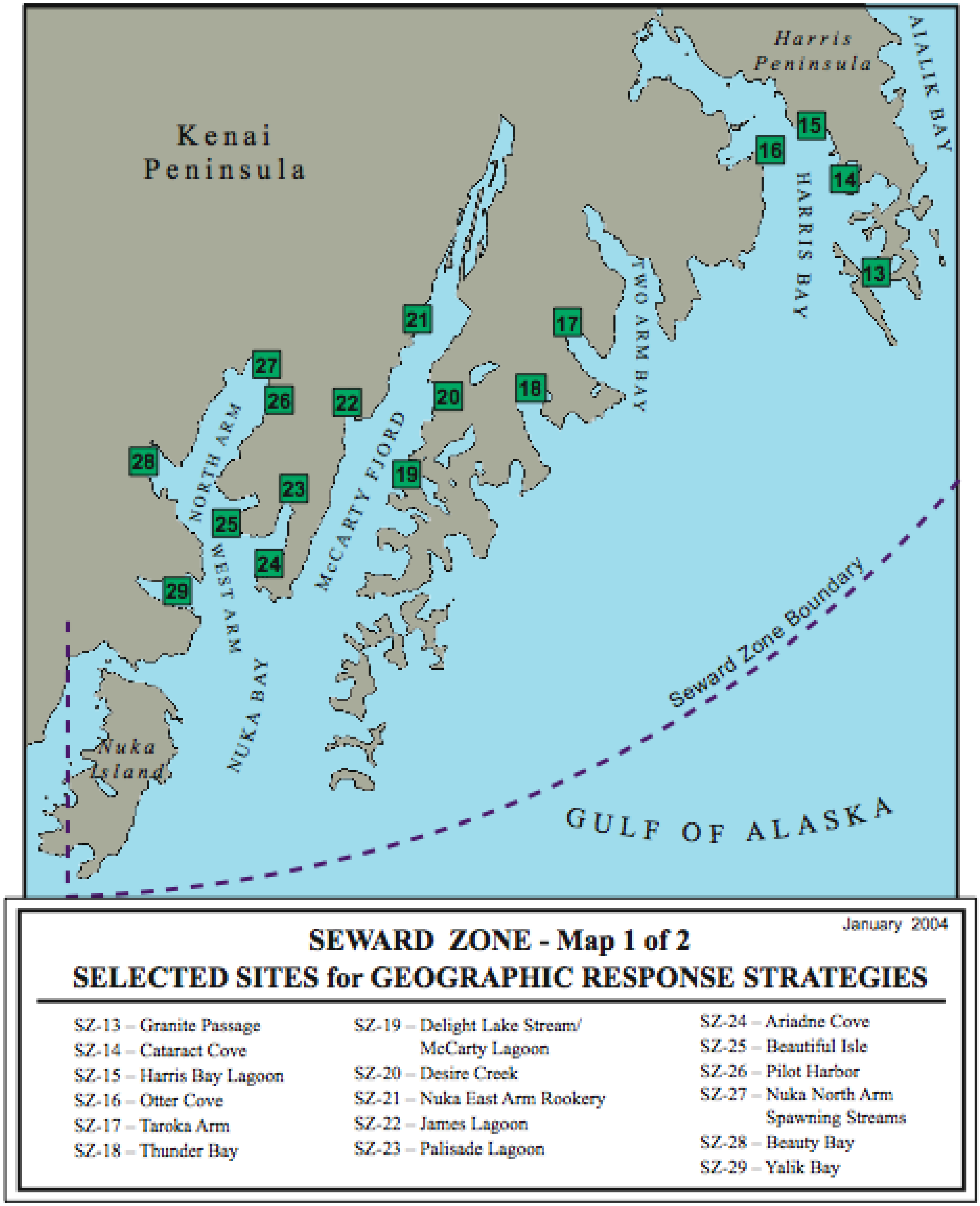


Figure 60. Geographic Response Strategies for the KEFJ coast (map 1 of 2). From http://www.dec.state.ak.us/spar/perp/grs/ci/cis/home.htm.

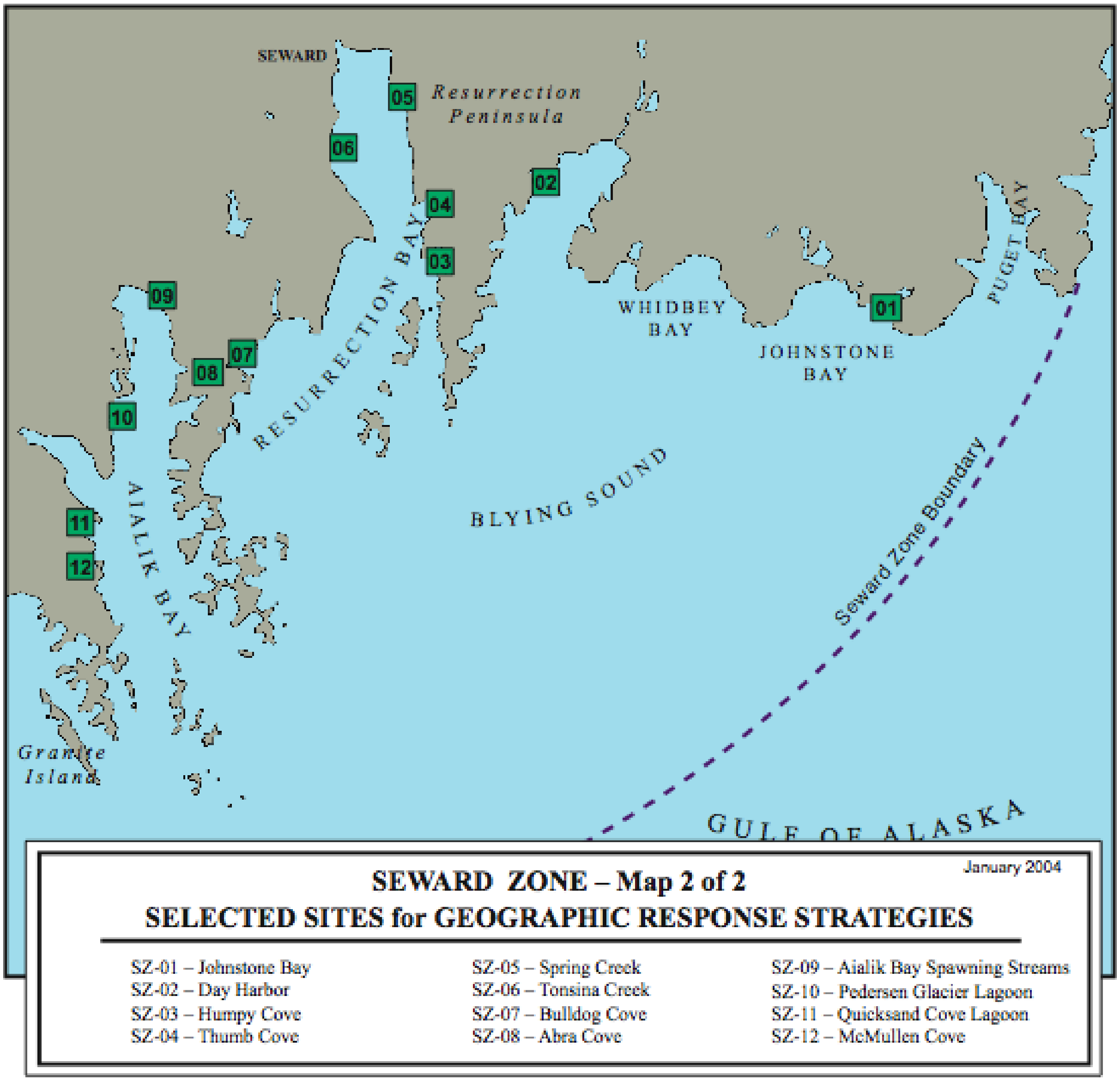
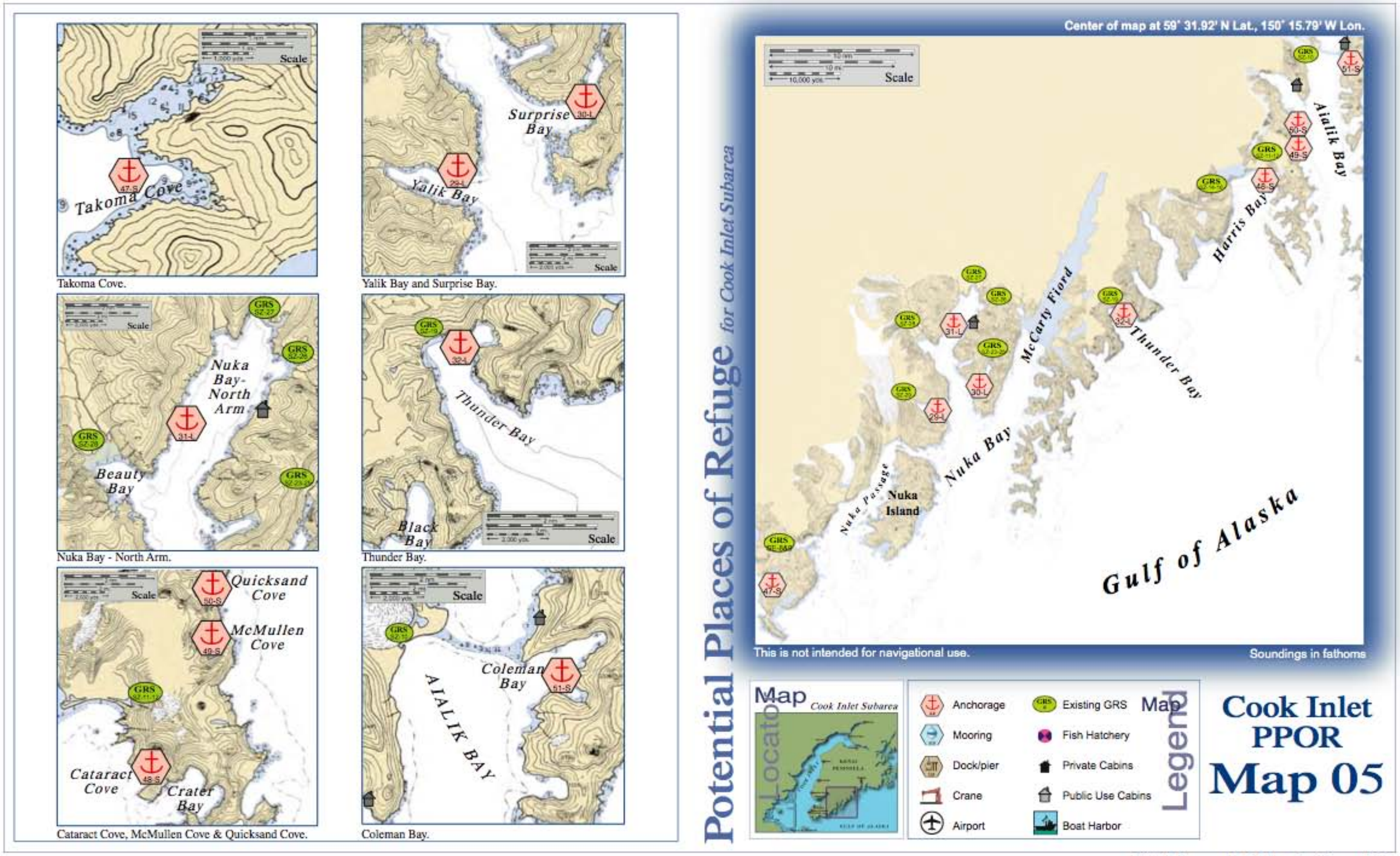


Figure 61. Geographic Response Strategies for the KEFJ coast (map 2 of 2). From http://www.dec.state.ak.us/spar/perp/grs/ci/cis/home.htm.



NUKA Research & Planning Group, LLC.

Cook Inlet SCP: PPOR, Part One

June 2008

Figure 62. Potential Places of Refuge along KEFJ, available at http://www.dec.state.ak.us/spar/perp/ppor/home.htm.

The ShoreZone mapping program computed an "Oil Residence Index" (ORI) along coastal KEFJ based on data on wave exposure levels and substrate types (Figure 63). Coarse sediments, unlike rock or sheet piling, are highly permeable and can trap and retain large volumes of oil. The level of wave exposure also regulates oil residence because wave action is the most effective process for removing stranded oil from shore (Harper 2004). Through imagery of physical attributes of the KEFJ coastline, ShoreZone identified areas particularly sensitive to oil spills, such as estuaries and wetlands, which have fine and organic sediment and have a low amount of wave exposure. ShoreZone also notes that cleanup in these areas is "difficult and can result in long-term damage if not conducted properly."

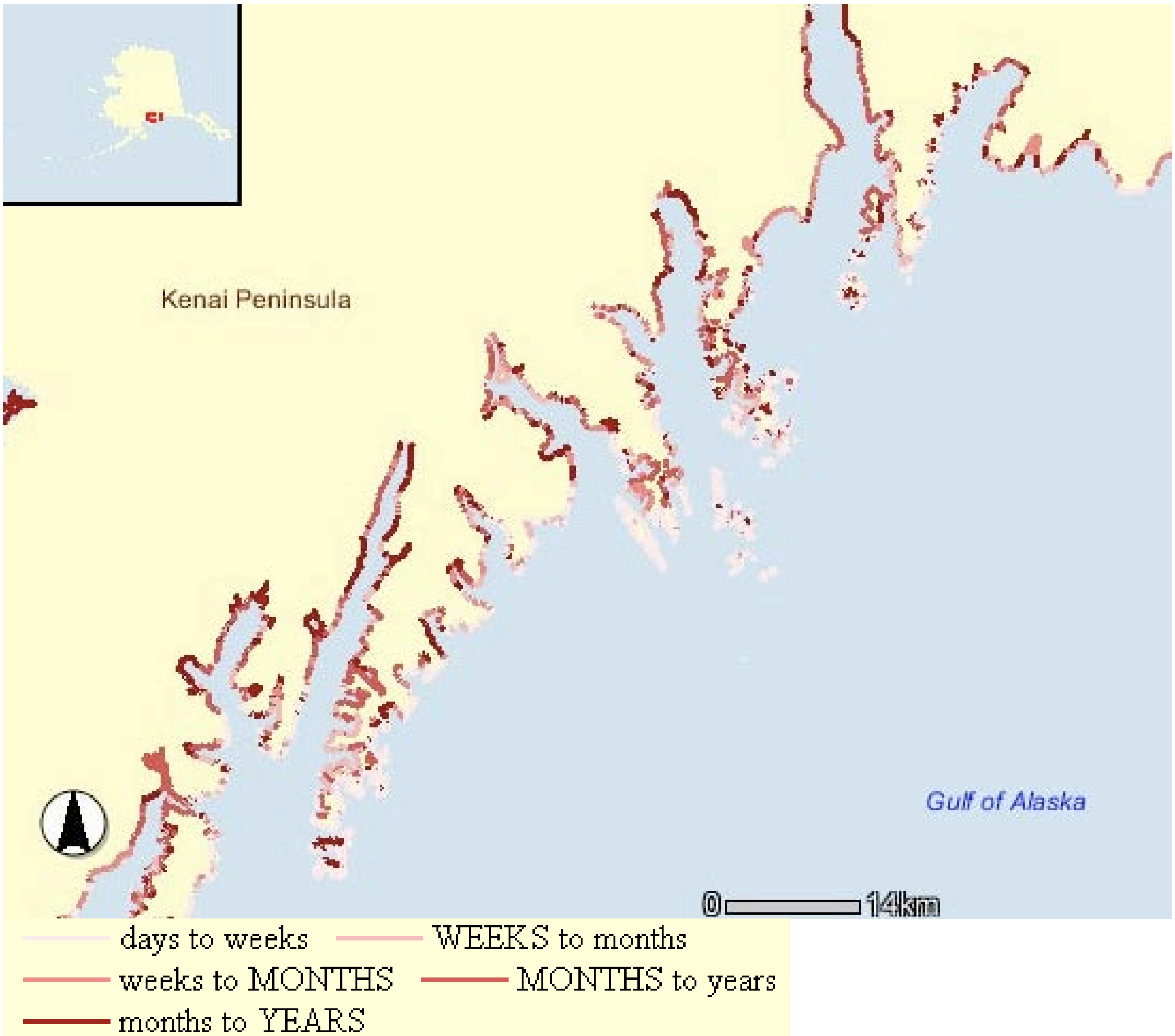


Figure 63. Oil residency index within KEFJ as classified by ShoreZone (http://mapping.fakr.noaa.gov/Website/ShoreZone/viewer.htm).

Marine vessel impacts: No analyses of marine vessel impacts have been conducted for the KEFJ coast, but based on an NPS study in GLBA in southeast Alaska, marine vessels have the potential to degrade water quality by the accidental release of petroleum products, the release of wastewater or other discharges, or the resuspension of sediments. Wastewater generated by marine vessels may serve as a source of marine pollution, including graywater (laundry, shower, and galley sink wastes); blackwater (treated sewage); hazardous waste; solid waste; and marine debris (NPS 2003). Private vessels may not be able to treat their wastewater before it is discharged; however the National Park Service (2003) reports that because of the small volumes and large dilution factor, the effects of this wastewater would not be significant. An Alaska Department of Environmental Conservation report on the impact of marine vessels on Alaska water quality reports that dilution levels for small marine vessels that treat and continuously discharge their wastewater are extremely high, and the only contaminant likely to be measured above ambient water levels would be fecal coliform bacteria (ADEC 2002). Another potential pollution source is solid waste, including food waste, plastic and glass containers, and paper products; however plastics and any garbage except dishwater, graywater, and fresh fish parts cannot be legally dumped within 5 km (3 mi) of the coast. Finally, the National Park Service (2003) suggests that vessels can affect water quality by resuspending sediments in marine waters through vessel movement, which can cause increased turbidity that can interfere with filter-feeding organisms and decreased water quality by reducing light penetration. The amount of sediment resuspension depends on the speed and size of the vessel, the sediment size, and the stability of the water column (NPS 2003). The effects to water quality along coastal KEFJ are unclear given the background wave action; effects are most likely temporary and limited to the immediate area of vessel traffic. The types and frequency of vessels found in KEFJ are discussed below in Section 4.4.1 Visitor Boat Traffic.

Marine-derived sources of pollutants: The benefits incurred by the contributions of salmon carcasses to the nutrient levels in aquatic systems may be partially offset by another contribution from the salmon: marine-derived contaminants such as mercury (Hg) and persistent organic pollutants (POPs). Mercury, a strongly toxic heavy metal, is emitted primarily by fossil fuel burning (Pacyna and Pacyna 2002). POPs comprise a long list of highly toxic and very stable organic compounds such as polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), dioxins, furans, and chlordane that are used as pesticides, industrial chemicals, and industrial waste products (EPA 2002). As salmon develop their biomass (95% in the pelagic environment), they incorporate marine contaminants such as Hg and POPs and transport them into watersheds where they spawn (Ewald et al. 1998, Krümmel et al. 2003, Senkowsky 2004, Zhang et al. 2001).

Krümmel et al. (2003) report strong correlations between the density of salmon runs with PCB concentrations in lake sediments in southwestern Alaska. Eight lakes in the Alaska Peninsula and on Kodiak Island, to the southwest of KEFJ, were studied (Figure 64). The researchers found that the input of PCBs by spawning salmon can result in a 6-fold increase above atmospheric loading in these remote areas with high-density salmon returns.

There is little published information on the direct contribution by spawning salmon to the Hg concentrations in streams, but a study of Bering Sea salmon returning to spawn in the Bristol Bay watersheds of southwestern Alaska (Kvichak, Naknek, Egegik, Ugashik, Wood, Igushik, Nushagak, and Togiak rivers) showed that salmon may be major transporters of marine-derived Hg into freshwater environments (Zhang et al. 2001). This research combined analyses of methylmercury concentrations in Bristol Bay salmon tissues with escapement data (ADF&G 1999) to conclude that biotransport of methylmercury by the salmon may have accounted for as much as 21 kg (46 lb) of methylmercury transported into eight Bristol Bay watersheds over the past 20 years. Another study more directly tested the effect of salmon carcasses on stream Hg concentrations in several tributary streams of Lake Ontario (Sarica et al. 2004). Comparing stream segments with variable salmon carcass densities, these researchers detected significantly higher concentrations of nutrients, total aqueous Hg and methylmercury, particulate Hg, and Hg in terrestrial invertebrates along stream segments with high salmon carcass densities compared to areas with low salmon carcass densities.

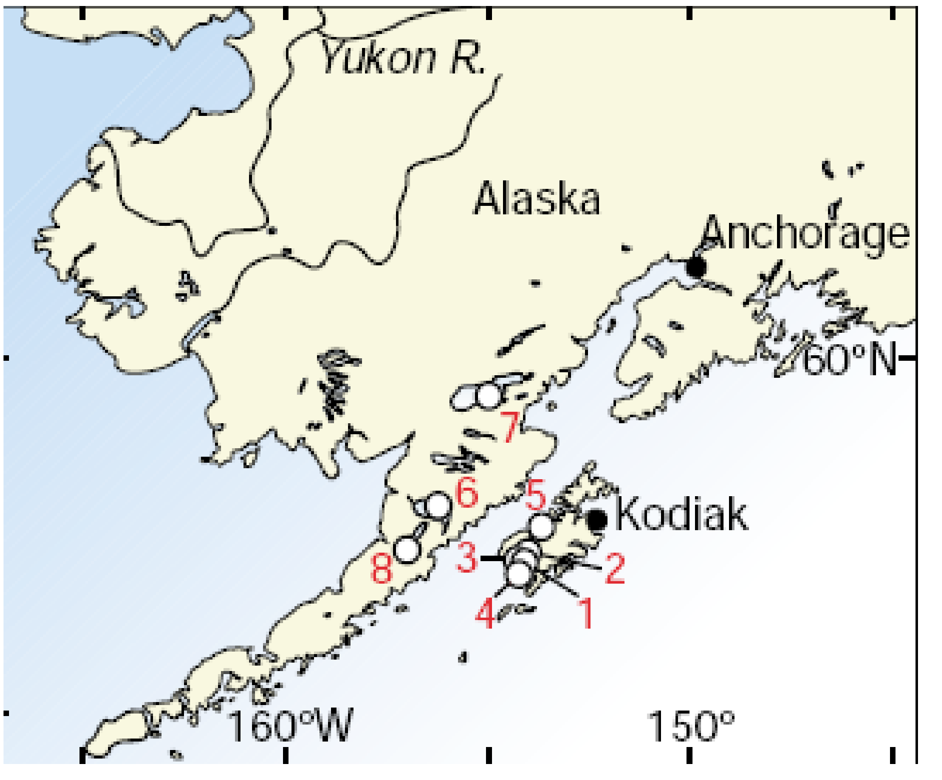


Figure 64. Sample locations of the eight lakes where surface sediments and sockeye salmon were collected for PCBs. Lake 1: Frazer; Lake 2: Karluk; Lake 3: Red; Lake 4: Olga; Lake 5: Spiridon; Lake 6: Becharof; Lake 7: Iliamna; Lake 8: Ugashik (Krümmel et al. 2003).

The available data indicate a strong likelihood that salmon are an important contributor to both the POPs and Hg budgets in streams where they spawn in areas such as KEFJ in southwest Alaska. These contaminants are not only released into the waters where they spawn, but also they can enter the food chain. For example, a study on grizzly bears in British Columbia, Canada, found that salmon delivered 70% of the organochlorine pesticides, up to 85% of the lower brominated PBDE congeners, and 90% of PCBs measured in salmon-eating grizzly bears. These pollutant levels in the salmon-eating bears were significantly higher than in their non-salmon eating counterparts in inland areas (Christensen et al. 2005).

4.1.2. Atmospheric Sources of Pollution

Mercury and POPs are the two major subjects of concern for much of Alaska in terms of atmospheric contaminants as well. They are global pollutants, crossing international borders and reaching remote areas that should otherwise be pristine (AMAP 2004, Fitzgerald et al. 1998, Nriagu and Pacyna 1988). Anthropogenic mercury deposition to Alaska appears to be similar in magnitude to that in temperate latitudes (Fitzgerald et al. 2005). Mercury and most POPs are carried to Alaska via long-range atmospheric pathways (Schroeder and Munthe 1998, Strand and Hov 1996, Wania and Mackay 1996), and upon deposition can biomagnify as they pass up trophic levels (EPA 2002).

Although there are no significant industrial sources of mercury (Hg) in southwest Alaska, Hg deposition to Alaska as well as to virtually all remote places on the planet has at least doubled since pre-industrial times (Engstrom and Swain 1997, Fitzgerald et al. 1998). Mercury deposition (through dry or wet processes) is particularly favored in high altitude and high latitude regions due to cold condensation mechanisms (Fitzgerald et al. 1998, Lindberg et al. 2002, Schindler 1999). Mercury and POPs have not been studied in KEFJ specifically, but several studies in southern coastal Alaska indicate the region is being affected by these contaminants.

One study examined contaminants in sea bird eggs and showed that concentrations of POPs in common murre eggs from two islands in the Gulf of Alaska (including East Amatuli Island, between the Kenai Peninsula and Kodiak Island and only 96 km [60 mi] from KEFJ) were significantly higher than in eggs from three colonies in the Bering Sea (Kucklick et al. 2002, Vander Pol et al. 2004). Mercury was also evaluated in the seabird egg studies (Day et al. 2006) that indicated mercury pollution may also be more of a concern in Gulf of Alaska compared to the Bering Sea region. The highest mean concentrations of mercury in murre eggs were from St. Lazaria Island (in southeast Alaska), and East Amatuli Island near KEFJ had the highest individual sample concentration (Day et al. 2006). The authors of these studies speculate that higher mercury concentrations in the Gulf of Alaska sites may be due to the relatively warm temperatures, abundance of organic matter in forested areas and wetlands in southern Alaska, and presence of estuaries—all factors that stimulate mercury methylation processes—as well as strong freshwater discharge and high erosion rates.

The NPS Air Resources Division, in cooperation with the EPA, USGS, U.S. Forest Service, and several universities, has recently begun to address the issue of global pollutants through a project called the Western Airborne Contaminants Assessment Project (WACAP) that aims to characterize the extent of airborne pollution to remote NPS units in the western United States and Alaska (NPS 2005). Snow, fish tissue, water, lake sediment, lichen, vegetation, and subsistence native foods were collected by WACAP at eight NPS units, including three in Alaska: Denali National Park and Preserve, Gates of the Arctic National Park and Preserve, and Noatak National Preserve. Samples were analyzed for a group of semi-volatile organic compounds, which include a variety of POPs, and mercury and other trace metals (but not all sample media received full analyses). Information from the three NPS units elsewhere in the state provide important indications of the extent and magnitude of the contaminants' threats to park ecosystems. Results of the WACAP study showed that contaminants were found in all park units studied (Landers et al. 2008). In the Alaska park units, very low concentrations of most current-use chemicals were found; however, the occurrence of historic-use compounds in Alaska matching levels found in the lower 48 states further suggests that Alaska is being affected by atmospheric transport from global sources (Landers et al. 2008).

In DENA, the park closest to KEFJ in the WACAP study, notable findings (Landers et al. 2008) include:

- Median mercury concentrations in both lakes sampled (Wonder and McLeod lakes) exceeded contaminant health thresholds for piscivorous birds (kingfishers), and one lake (Wonder Lake) also exceeded the thresholds for mammals (otter and mink).
- For current-use SOCs, median dieldrin concentrations in Wonder Lake fish and in some individual fish in McLeod Lake exceeded contaminant health thresholds for subsistence fishers.
- Primary contaminants detected in air were historic-use pesticides (HCB and a-HCH).
- In snow, contaminant deposition was among the lowest in all the parks.
- In vegetation, DENA had the lowest concentrations of SOCs, nutrients, metals, and mercury among the parks, after NOAT and GAAR.
- In sediments, most SOCs were below detection in DENA lakes. PCBs were present but at low concentrations. Wonder Lake showed enrichment of mercury and lead since the 1920s, probably due to rising global emissions.

The full report of the WACAP study is available online at http://www.nature.nps.gov/air/Studies/air_toxics/wacap.cfm.

Contaminant monitoring has begun in SWAN parks as part of the SWAN I&M Program. Fish were collected for analyses of heavy metals and organics in the drainage of Lake Clark (in LACL) in 2005 (Dan Young, NPS Port Alsworth, personal communication, 2007). In addition, the network has initiated a small pilot project to collect stair-step moss (*Hylocomium splendens)* in LACL, KEFJ, and ANIA, with the goals of designing a larger project and getting a better baseline of airborne contaminants across SWAN (Michael Shephard, NPS SWAN, personal communication, 2008). Further, occasional sampling of intertidal mussels for mercury and other heavy metal sampling has begun in KEFJ and KATM as part of the nearshore monitoring component of the Vital Signs Program.

The SWAN I&M Program is also currently conducting analyses of total Hg in sediment samples from the following SWAN lakes (none of which is in KEFJ): Lake Clark, Naknek, Brooks, Kontrashibuna, and Idavain (Munk et al. 2008). The age-dated cores are expected to produce multi-decadal profiles tracking Hg accumulation over time in the lakes. Results will be comparable to two published studies of dated sediment cores collected in southeast Alaska—from lakes in Glacier Bay National Park (GLBA) and in neighboring Chichagof Island—which show that Hg accumulation rates through the 1980s in sediments are two to three times pre-industrial accumulation rates (Engstrom and Swain 1997, Fitzgerald et al. 2006). Additionally, Hg deposition in GLBA did not show the recent declines (since the1960s) observed at sites in the continental United States where regional mercury emissions have been reduced. An updated study of mercury accumulation in sediment cores through the 1990s and into the 2000s, which shows that mercury deposition continues to be on the rise in Alaska, is expected to be published in 2009 (Dan Engstrom, St. Croix Watershed Research Station, Minnesota, personal communication, 2008). These results suggest that southern Alaska is being affected by mercury emissions from remote sources (e.g., in Asia), which are steadily increasing their output (Streets et al. 2009).

Finally, the Alaska Department of Environmental Conservation (DEC) has recently established a Mercury Deposition Network (MDN) stations in Kodiak (Heidi Strader, Alaska DEC-Anchorage, personal communication, 2008). The Kodiak site has been running since mid-September 2007 and data from the site ("AK98") are available through the MDN website (http://nadp.sws.uiuc.edu/mdn/). There is also a possibility of a second site going up in Dutch Harbor, although specific plans and timing for that site are currently unresolved (Cynthia Dettmer-Shea, Alaska DEC-Anchorage, personal communication, 2009). Additionally, the Southeast Alaska Network of the National Park Service is planning to establish an MDN site in Bartlett Cove in GLBA in mid-2009 (Brendan Moynahan, NPS, written communication, 2009.) The data generated by these future studies will be instrumental in tracking Hg levels in southern Alaska.

4.2. Climate Change

Climate change is increasingly being recognized as an important natural resource issue for national parks in Alaska. Recent scientific research suggests that changes in climate may dramatically impact water resources in Alaskan parks (Kyle and Brabets 2001). On a global scale, mean surface air temperature has risen by about 0.6 ºC (1.1 ºF) in the last century. Recent climate change is dominated by human influences, and there is now a relatively broad scientific consensus that the primary cause of climate change is human-induced changes in atmospheric composition (Karl and Trenberth 2003). In particular, there have been rapid increases in the concentration of greenhouse gases such as carbon dioxide and methane, which absorb and counter-radiate outgoing terrestrial longwave radiation. Over the last fifty years, there is evidence of anthropogenic warming on every continent (Figure 65) (IPCC 2007). This warming trend is projected to continue throughout the coming century. The best estimates of the International Panel on Climate Change is that temperatures will rise by another 1.8–4.0 ºC (3.2–7.2 ºF) by 2100, depending on trends in emissions of greenhouse gases (IPCC 2007).

Models and recent observations both suggest that climate warming is amplified at higher latitudes (Hall 1988, Serreze et al. 2000), and future changes in temperature are projected to be proportionally higher in high-latitude ecosystems (Chapin et al. 2002, Douglas et al. 1994, Overpeck 1997). Over the past 50 years, Siberia, Alaska, and northern Canada, and the Antarctic Peninsula have warmed more than any other regions on earth, and the 20^{th}-century arctic is the warmest of the past 400 years (Overpeck 1997, Serreze et al. 2000). Alaska's climate has warmed by approximately 2.2 ºC (4º F) since the 1950s and is projected to rise an additional 2.8–10 ºC (5–18 ºF) by 2100 (Parson et al. 2000). Moreover, stations north of 60º N indicate that the average surface temperature have increased by approximately 0.09 ºC/decade (0.15 ºF/decade) during the past century, which is 50% greater than the 0.06 ºC/decade (0.11 ºF/decade) increase averaged over the entire Northern Hemisphere (Figure 66) (ACIA 2006). This analysis by the Arctic Climate Impact Assessment team further suggested that climate models project greater temperature increases at high northern latitudes than anywhere else in the world in the coming century (Table 17) (ACIA 2006). Within Alaska, a compilation of mean annual and seasonal air temperatures for19 first-order observing stations from across the state that have more than 50 years of climate records indicates that during the period 1949–2004, average air temperature increased by 1.9 ºC with most of the warming occurring in winter and spring (Molnia 2007). The reasons for the larger temperature increases at high latitudes are not fully understood but are thought to involve cryospheric effects such as the snow/ice albedo feedback effect (Sturm et al. 2005), coupled with changes in the atmospheric circulation and possibly ocean currents. In addition, some analyses suggest that much of the recent warming occurred coincident with the most recent of the large-scale Arctic atmosphere and ocean regime shifts in the mid-1970s (Weller and Anderson 1997).

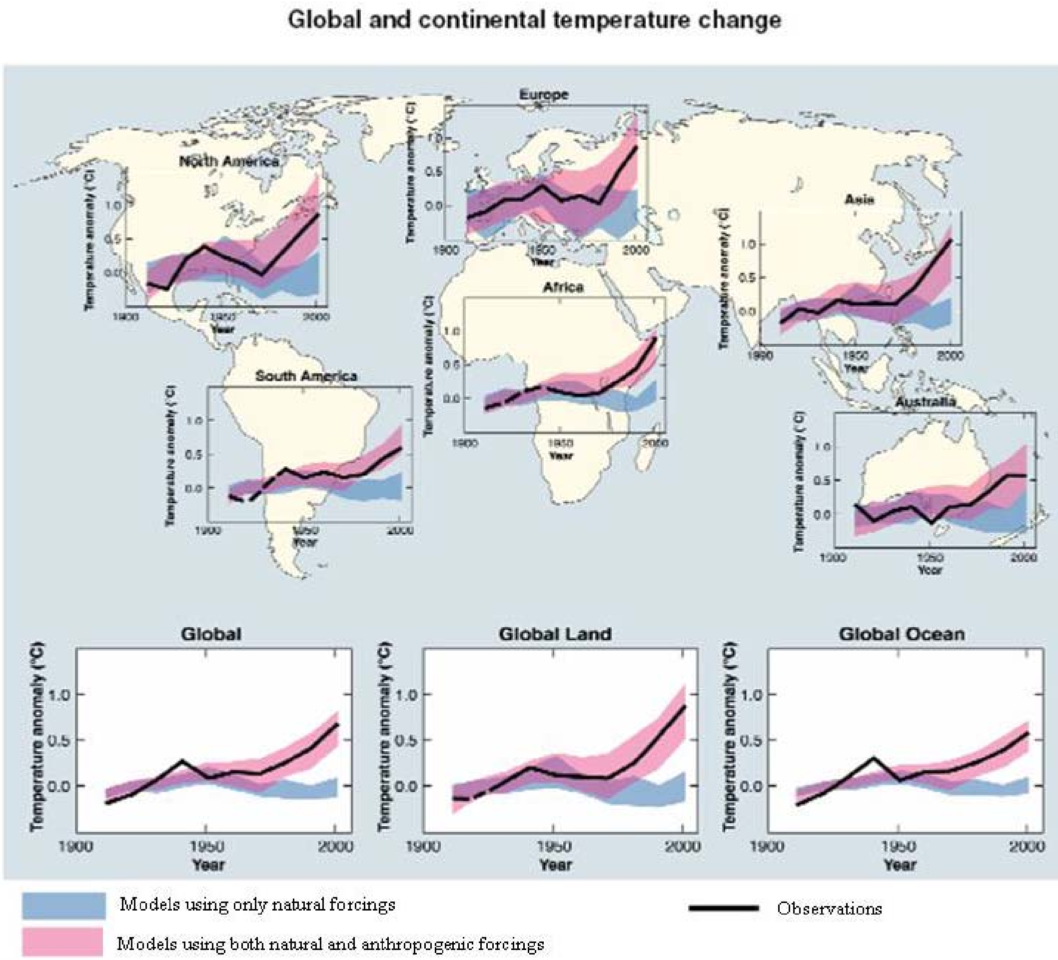


Figure 65. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906–2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the period 1901–1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5–95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5–95% range for 58 simulations from 14 climate models using natural and anthropogenic forcings (IPCC 2007).

Climate warming is already affecting the physical landscape in Alaska. The most obvious effects of climate change on hydrologic resources in Alaska are changes in the extent of permafrost, snow cover, glaciers, and sea and lake ice cover (Oswood et al. 1992). The environment and water resources of KEFJ are highly susceptible to climate change in large part because more than half of KEFJ is covered by glacial ice and permanent snowfields. These glaciers and snowfields are an important source of summer time streamflow in park watersheds, and the balance of accumulation and ablation in these hydrologic reservoirs is being altered by climate change. Data from the past half century suggest that the most dramatic climate warming in Alaska has occurred during winter months (Weller et al. 1997). In coastal KEFJ, mean winter (November–March) temperatures are typically between -4–0 ºC (25–32 ºF), which is close to the freezing point of water (Section 2.2.6). As a result, climate warming has the potential to alter patterns of snow accumulation within the park. For example, as winter temperatures increase, the incidence of rain events during winter increases, and the hydrologic storage of water in seasonal snowpacks decreases. The result of this trend is a shift toward higher winter streamflows and lower streamflows during snowmelt runoff in the spring and summer.

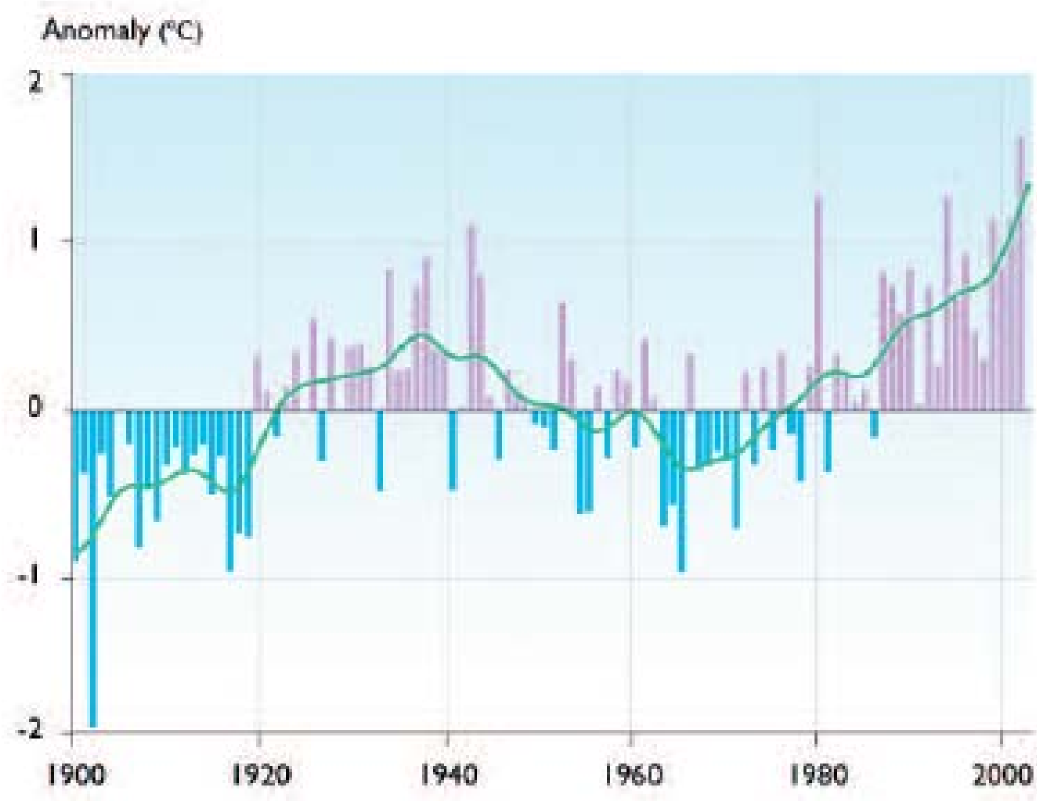


Figure 66. Annual anomalies of land-surface air temperature in the Arctic (60˚ to 90˚ N) for the period 1900 to 2003. From the Arctic Climate Impact Assessment (ACIA 2006).

Table 17. Increases in mean annual surface air temperature in the Arctic (60˚ to 90˚ N) for the period 2011-2090 as projected by five models used by the Arctic Climate Impact Assessment (ACIA 2006).

	Temperature change (°C)					
	CGCM2	CSM_1.4	ECHAM4/OPYC3	GFDL-R30_c	HadCM3	Five-model mean
2011–2030	1.2	1.5	1.3	1.0	1.1	1.2
2041–2060	2.5	2.2	3.2	2.5	2.2	2.5
2071–2090	3.7	2.8	4.6	3.8	4.0	3.7

A shift in the timing of springtime snowmelt towards earlier in the year has already been observed in lower latitude western rivers in the Cascades and Sierra Nevada, and models suggest that temporal centroid of streamflow (mid-point of runoff volume) will occur 30–40 days earlier in these rivers by the end of the current century (Stewart et al. 2004). There are no long-term hydrologic data available for KEFJ to evaluate climate-driven shifts in streamflow. Streamflow in many KEFJ streams is driven by glacial runoff, thus changes in glacial extent within the park will have a pronounced influence on the physical properties of park streams. For example, research on glacial streams located at a similar latitude in southeastern Alaska has shown that streamwater temperature and turbidity are strongly correlated with the percentage of glacial coverage within coastal watersheds (Figure 67; Hood and Berner 2009). Overall, climate-driven decreases in the volume (depth and extent) and duration of seasonal snowcovers and the areal extent of glaciers within KEFJ will likely be associated with lower summer streamflows and may also lead to increased streamwater temperatures in the late summer and fall.

Recent research on the Lower Kenai Peninsula has shown that water temperatures in salmon streams in this area regularly exceed 13 ºC, which is the State of Alaska standard for egg and fry incubation (Mauger 2005). Additionally, a USGS study (Kyle and Brabets 2001) analyzed water temperature data from 32 sites in the Cook Inlet Basin west of KEFJ and showed that streams draining low land areas are the most at risk to be affected by climate warming. They also modeled future climate scenarios based on a doubling of atmospheric carbon dioxide levels and found that 15 of the 32 streams had a predicted water temperature increase of 3ºC or more, an increase that is considered significant for the incidence of disease in fish populations. Taken together, these studies suggest that climate warming and attendant shifts in the timing and quality of streamflow within KEFJ have the potential to influence patterns and success of salmon spawning within the park.

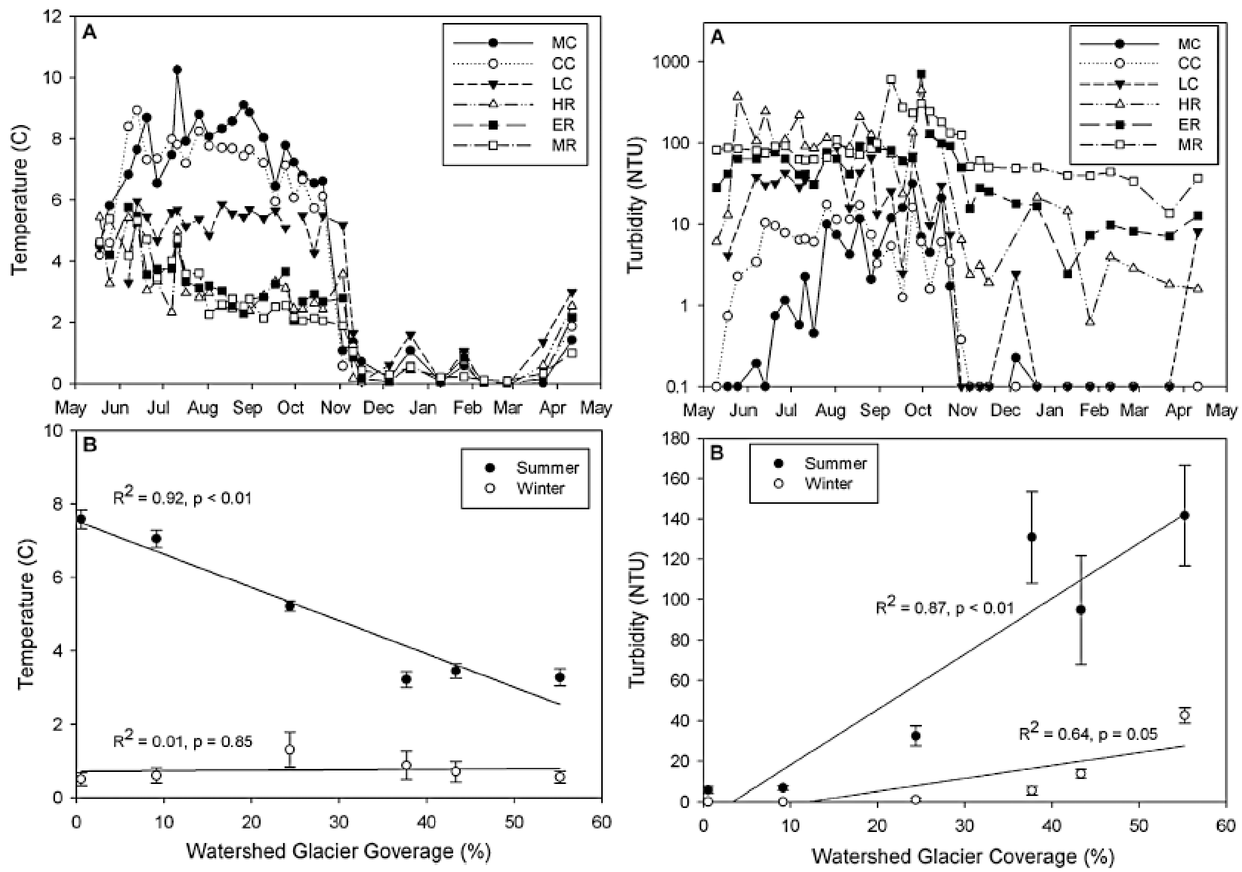


Figure 67. (A) Seasonal trends in streamwater temperature (left) and turbidity (right) for six watersheds in southeastern Alaska that vary in glacial coverage from 0% (MC) to 55% (MR). (B) Relationship between the percentage of the watershed covered by glacier and streamwater temperature (left) and turbidity (right) for the summer and winter seasons (Hood and Berner 2009). Winter was defined as the six months where the average air temperature in the study watersheds was <0°C (Nov–Apr).

In addition to altering snowcover patterns, climate warming is having pronounced effects on glaciers in Alaska. By the early 21st century, nearly all of the glaciers in Alaska extending below 1,500 m were retreating, and every mountain group in the state, including both maritime and continental climates, was characterized by significant glacial retreat (Molnia 2007). Within KEFJ, the Harding Icefield has been thinning and shrinking since the 1950s (Adalgeirsdottir et al. 1998, VanLooy et al. 2006). Giffen et al. (2009) have also demonstrated substantial decreases in glacier extent in KEFJ (Section 2.2.6). Arendt et al. (2002) compared recent laser altimetry surveys with digital elevation models (DMEs) from historic USGS maps from the 1950s to determine changes in glacier thickness for glaciers throughout Alaska and the Yukon. Results from thirteen glaciers in and around KEFJ suggest that glacier thinning rates within KEFJ over the second half of the 20th century were on the order of 0.1 to 1.0 m/yr (0.4 to 3.3 ft/yr) (Arendt et al. 2002). More recently, comparisons of original USGS DEMs with DEMs produced from 1) LiDAR profiles of glacier center-lines indicate thinning rates from the mid-1990s to 1999 and 2) the 2000 Shuttle Radar Topographic Mission (SRTM) indicate that thinning rates from the mid-1990s to 1999 (0.72 ± 0.13 m/yr or 2.36 ± 0.43 ft/yr) accelerated by a factor of 1.5 as compared with 1950 to the mid-1990s (0.47 ± 0.01 m/yr or 1.54 ± 0.03 ft/yr) for glaciers on the Harding

Icefield (VanLooy et al. 2006). Moreover, VanLooy et al (2006) estimated that overall thinning of the Harding Icefield and Grewingk-Yalik Glacier Complex was 0.61 ± 0.12 m/yr (2.00 ± 0.39 ft/yr) between 1950 and 1999. The loss of ice volume from Alaska glaciers has global consequences because of the contribution of glacial meltwater to sea level rise. Arendt et al. (2002) estimated that in the last decade of the 20th century, Alaskan glaciers contributed at least 0.24 mm/yr to sea level rise, which is 8% of the total sea level rise during this period (and nearly double the contribution from melting of the Greenland Ice Sheet).

The recent increase in the wastage rate of Alaska glaciers is consistent with other glaciated regions of the world. For example, the satellite-derived Swiss glacier inventory revealed that mean glacier area loss per decade from 1985 to 1998/99 has accelerated by a factor of seven compared to the period 1850–1973 (Paul et al. 2007). Further, Paul et al. (2007) note that for Swiss glaciers "many of the observed changes (growing rock outcrops, tongue separation, formation of pro-glacial lakes, albedo lowering, collapse structures) are related to positive feedbacks which accelerate further glacier disintegration once they are initiated. As such, it is unlikely that the recent trend of glacier wastage will stop (or reverse) in the near future." Glacial runoff strongly influences the physical and biological characteristics of aquatic ecosystems (both freshwater and marine) within and around KEFJ. For example, recent research has shown that changing glacial coverage within coastal watersheds will alter the fluxes of important macronutrients (C, N, and P) to downstream freshwater and marine ecosystems (Hood and Scott 2008). This finding highlights the importance of monitoring and predicting future changes in the extent and volume of glaciers within KEFJ.

A Swiss research team has recently developed a simple method for calculating and visualizing future glacier extent for a large number of individual glaciers (>100) according to different climate change scenarios (Paul et al. 2007). This method is automated and requires only digital glacier outlines (available from satellite images) and a digital elevation model (DEM) and calculates new glacier geometries from a given shift of the steady-state equilibrium line altitude (ELA_0) by means of hypsographic modeling. The resulting visualizations of glacier change (Figure 68) are useful for resource managers and also represent an excellent tool for communicating research results related to glacier changes to the general public (Paul et al. 2007). A modeling effort of this type could be undertaken with currently existing topographic data for glaciers in KEFJ; however, the final products would be enhanced by the availability of a relatively high-quality DEM (<30 m spatial resolution) for the park.

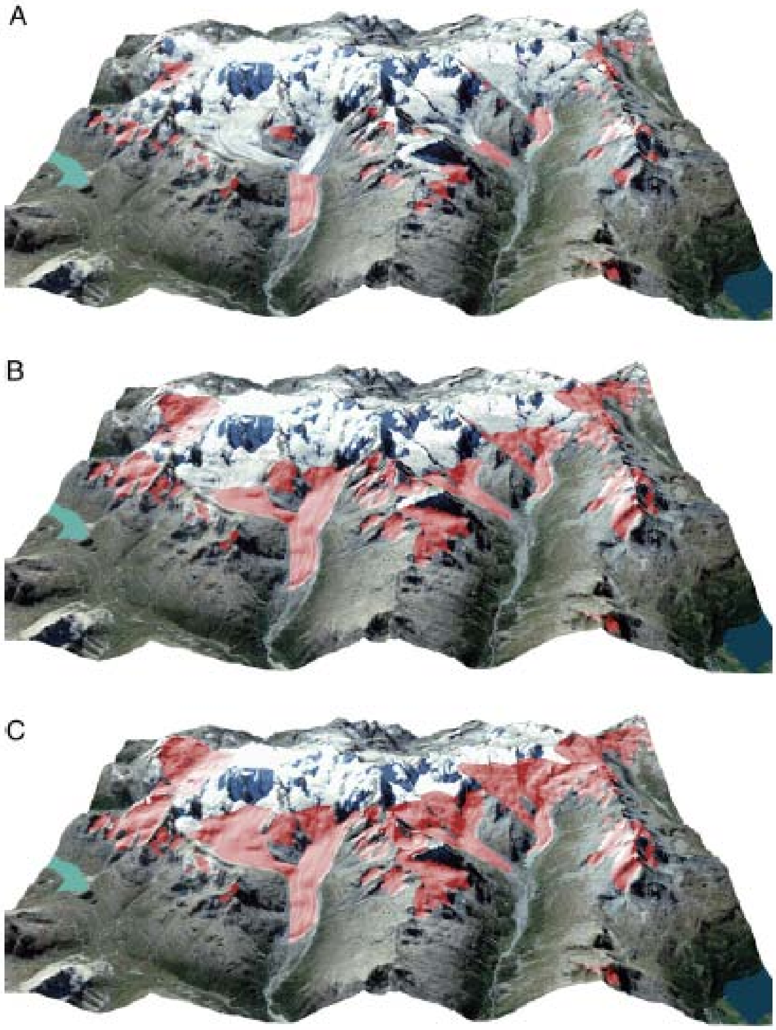


Figure 68. Visualization of new modeled glacier size in the Swiss Alps for Equilibrium Line Altitude upward shifts of 100m (A), 300 m (B), and 500 m (C). Areas of ice lost are shown in the red shaded color.

An important hydrologic effect of increased glacier melt is an increase in the volume of runoff from glaciers and a concomitant increase in the discharge of glacial streams. Such a trend is already apparent in coastal glacial watersheds such as the Mendenhall Glacier in southeastern Alaska that have multi-decade discharge records (Neal et al. 2002). Increased runoff can lead to the creation of new streams and can alter the sediment, streamflow, and temperature regimes in surrounding streams (Oswood et al. 1992). Changes in runoff and sediment loads can change stream channel morphology and stability, as well as the composition of stream substrates and habitat complexity (Williams 1989). Non-glacial streams may experience increased stream temperatures as a result of reduced streamflows and climate warming; however, glacial streams are likely to have lower stream temperatures as a result of increased glacial runoff. Decreases in stream temperature can depress primary production, impact or eliminate certain invertebrates, and lower salmonid rates of production (Lloyd 1987, Lloyd et al. 1987). Over longer time scales, water yields from glacial watersheds in KEFJ may decrease as glaciers continue to thin and recede.

Climate warming within KEFJ also has the potential to affect the occurrence of lakes and ponds within the park. Recent research from the Seward Peninsula and Kenai Peninsula has demonstrated a substantial landscape-level trend toward reduced surface water area as well as fewer closed-basin ponds (Riordan et al. 2006). Since the 1950s the surface water area of closed-basin ponds in eight boreal regions in Alaska has decreased by 4–31%, and the total number of closed-basin ponds has decreased by 5–54%. This loss and shrinkage of ponds is hypothesized to be due to increased drainage from warming permafrost and increased evapotranspiration during a warmer and extended growing season (Riordan et al. 2006). Because of the large number of glaciers within KEFJ, it is alternatively possible that new lakes may be formed within the park as glaciers continue to thin and recede. Wetlands in KEFJ are also at risk from climate warming. Increased evapotranspiration and lower water levels have the potential to decrease the area of shallow wetlands within the park. The loss of surface water bodies and wetlands within KEFJ has the potential to affect park fauna such as migratory waterfowl that depend on these resources.

The effects of climate change on the chemistry of lakes and streams are unknown. Research on linkages between terrestrial and aquatic systems suggests that elevated temperatures and carbon dioxide levels will affect the distribution and productivity of plants, which will in turn affect the amount and quality of leaf litter entering streams and rivers (Meyer and Pulliam 1992). Increases in woody debris entering streams are also predicted (Sweeney et al. 1992). Because soil microbial activity is linked to soil temperature, moisture, and soil organic matter, climate shifts will affect microbial processing of organic material in terrestrial systems, which will in turn affect the flow of nutrients from terrestrial to aquatic ecosystems. In addition, surface water quality could also be altered by predicted changes in the frequency of disturbances such as forest fires, wind storms, and coastal floods (Meyer and Pulliam 1992; Parson et al. 2000). Ultimately, changes to the quality and quantity of runoff from terrestrial ecosystems will affect nearshore marine systems in KEFJ because the productivity of these nearshore ecosystems is influenced by the input of nutrients from coastal terrestrial watersheds.

4.3. Physical Hazards: Volcanoes, Earthquakes, Tsunamis

4.3.1.Volcanic Activity

Unlike the other SWAN units, KEFJ does not contain any active volcanoes. However, the unit is located near the eastern edge of the 2,500 km (1,560 mi) Aleutian volcanic arc, which is one of the world's most active volcanic areas (Miller and Smith 1987; Neal 2005) (Figure 69). Subduction of the Pacific plate under the Alaska section of the North American plate generates frequent earthquakes and volcanic activity throughout the Aleutian chain. In the past century, one to two volcanoes in Alaska have erupted each year, most notably Novarupta (1912)—the largest 20th-century eruption in the world and the largest rhyolite eruption in recorded history, Redoubt (1989), Mount Spurr (1992), Pavlof (1996), Okmok (1997), and, more recently, Augustine and Fourpeaked (both in 2006), Pavlof (2007), and Redoubt again (eruption in March 2009 and ongoing as of this writing in April 2009) (Alaska Volcano Observatory 1998, 2009).

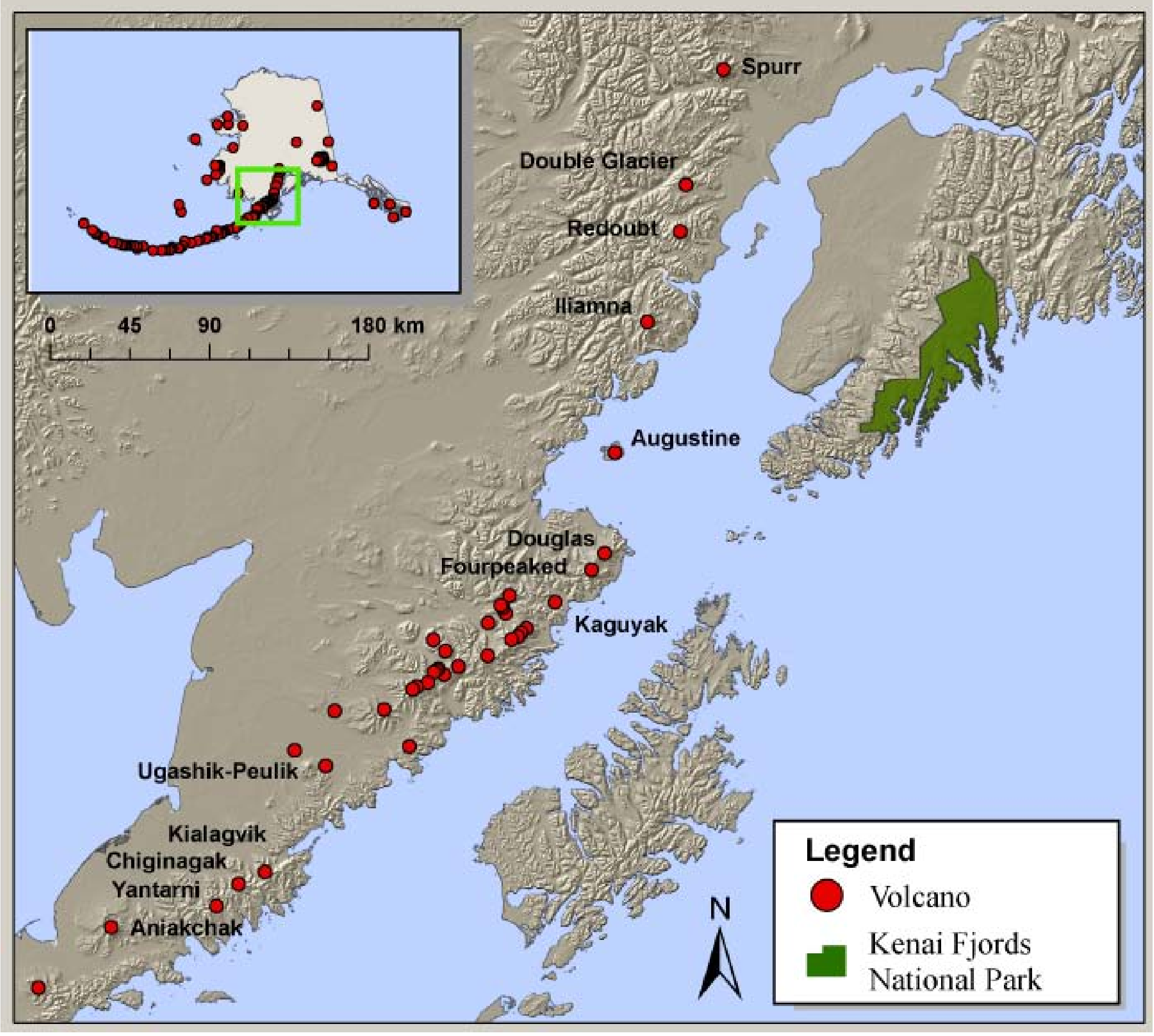


Figure 69. Volcanoes in the vicinity of KEFJ.

Volcanic eruptions outside KEFJ can impact park resources. Most Aleutian arc volcano-related hazards are identified as ash clouds, ash fall, pyroclastic flows and surges, mudflows (lahars), lava flows, and volcanic gases (Neal 2005). Specifically, volcanic ash clouds can create hazardous conditions for regional aircraft traffic, potentially endangering areas on the ground that could be affected by an airliner crash (Waythomas et al. 1997, Waythomas and Miller 1999b). Directed blasts, volcanic gases, and lava flows are listed as the less likely but possible consequences of the eruption (Waythomas and Miller 1999a). Hazards posed to watersheds are primarily from the deposition of ashfall, which can accumulate in streams and impede the movement of fish and can create conditions of lethally high suspended sediment concentrations in streamwaters (Brabets et al. 1999). Additionally, debris moving in the stream can be deposited over spawning areas, suffocating incubating eggs (Brabets et al. 1999). An additional risk to KEFJ resources may be an albedo affect change on the icefield as a result of a thick ash cover resulting from an eruption.

The impacts of volcanic eruptions on water quality may also be more subtle, providing longer term influences on biological productivity within lakes and streams due to ashfall contributions. For example, a study of sediment cores from two lakes on Afognak Island (120 km [75 mi] from KEFJ) showed that volcanic ashfalls, such as those derived from the 1912 Novarupta eruption, stimulated diatom growth in the lakes due to the increase in silica supply (Barsdate and Dungdale 1972). An earlier study (Eicher and Rounsefell 1957) argued that despite immediate destructive effects of volcanic eruptions on plant, fish, and wildlife populations in lakes and streams, there appears to be a long-term net benefit to the watersheds from volcanic eruptions. Eicher and Rounsefell (1957) report that volcanic ashfall is relatively rich in key nutrients such as phosphorus, which can be utilized by algae at the base of the food chain in aquatic systems and which can enrich soils, and they show that several years following the Novarupta eruption in 1912 there was accelerated plant growth and a fast rebound in salmon abundance in lakes and streams in the region. It is notable that some of the world's richest salmon runs are in the nearby Bristol Bay region, and this region is regularly affected by ashfall from volcanic events along the Aleutian chain.

Due to risks posed by volcanic eruptions to natural resources and to air safety traffic, and to enhance scientific understanding of volcanic processes, the Alaska Volcano Observatory (AVO) in Anchorage continues to monitor and research volcanic activity throughout the region (Murray 2005). Volcanoes along the Aleutian chain are actively monitored by the AVO at 19 stations (visit http://www.avo.alaska.edu/ for more information). Monitoring is conducted using "webicorders" (computerized seismographs) at all stations, webcams at some stations, and Real-time Seismic Amplitude Measurement (at Pavlof Volcano only). The AVO is also conducting detailed volcanic hazard assessments for many of Alaska's other potentially active volcanoes. Volcanic and earthquake activity is also one of the vital signs for which monitoring protocols are currently being developed and implemented by the SWAN I&M Program (see http://science.nature.nps.gov/im/units/swan/index.cfm?theme=volcano_eq for more information).

4.3.2. Coastal Change: Earthquakes, Tsunamis, Subsidence, and Uplift

Earthquakes have been a powerful force of geomorphologic and ecologic change along the Kenai coast (Mann 1998). They have triggered both subaerial and submarine landslides, resultant tsunamis, seiches caused by the rocking of water masses in enclosed basins, ice avalanches, and relative sea level alteration (Mann 1998, Mann and Crowell 1996, Plafker 1969). Sea level differences between sites only 50–100 km apart has varied markedly due to the combination of tectonic activity and isostatic rebound effects from glacier recession (Mann 1998). The Aleutian seismic zone, which follows the southern border of the Alaska Peninsula and the Aleutian Islands, is one of the most active seismic zones in the world (Stevens and Craw 2004) (see information and map at http://quake.usgs.gov/prepare/alaska/index.html).

In 1964, the largest earthquake in North America—and the second largest earthquake ever recorded, at a magnitude of 9.2—occurred in the northern Prince William Sound (Sokolowski 2006). The earthquake raised some southcentral Alaskan areas up to 8 m (30 ft) and triggered landslides and avalanches, which in turn set off tsunamis that killed 115 people and caused extensive structural damage in Anchorage and other Alaskan communities (Sokolowski 2006). As a result of the earthquake, land around the Kenai Mountains dropped more than 2 m (6.6 ft) (Mann 1998). This subsidence left a ubiquitous swath of dead conifer forests along the coast, as they were killed by saltwater inundation of their root systems (Mann 1998). Geomorphological changes resultant from the earthquake included steepening and inland-migration of barrier beaches (e.g., at Verdant Cove Spit and Bulldog, Quicksand, Bear, and McMullen coves) and the building of new barrier beaches at sites in upper Aialik Bay and Holgate Arm where glacier-fed streams develop alluvial fans at sea level (Mann 1998).

In the three decades following the 1964 earthquake, the KEFJ coastline has been uplifted up to 40 cm, as determined from GPS measurements and water level recorders (Cohen and Freymueller 1997, 2001) (Figure 70). Current uplift rates currently outpace the rise of global sea-level, which is approximately 1.8 mm/yr.

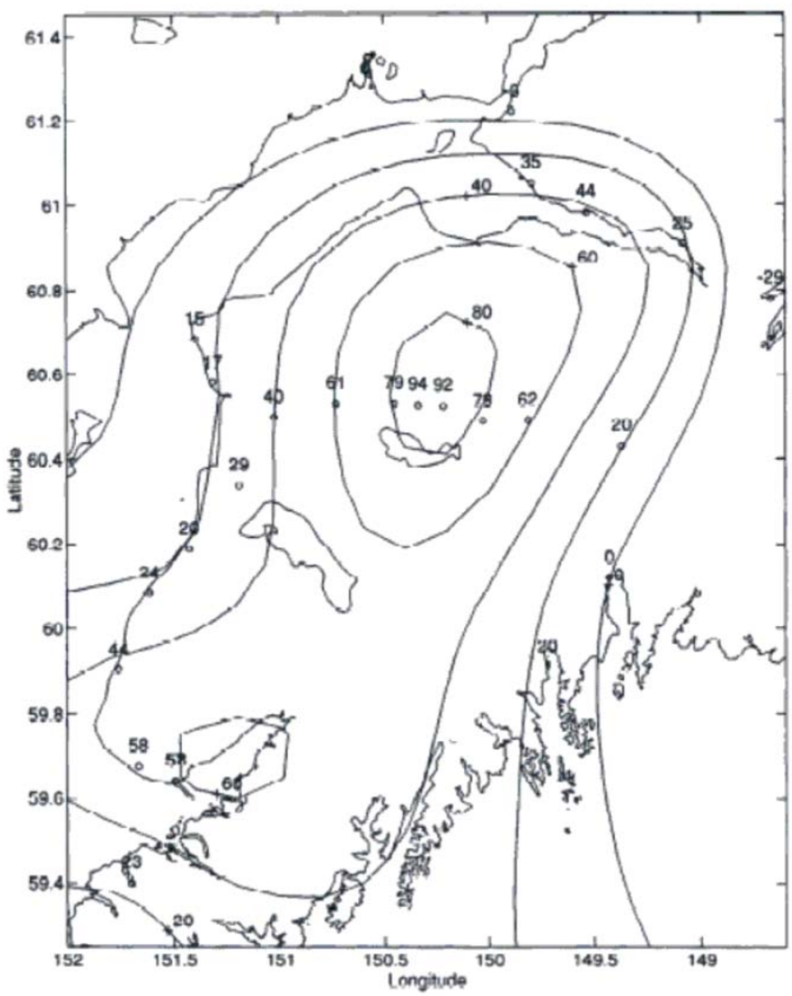


Figure 70. Regional cumulative post-seismic uplift from GPS measurements and tide gauges, as determined by Cohen and Freymueller: 1964–1995. Contour and point values are in cm. From Cohen and Freymueller (1997).

Archeological evidence of pre-historic earthquakes point to even more powerful events than the one that occurred in 1964. An earthquake that occurred about 780 years ago caused sudden subsidence of about 2 m at Verdant Cove in Aialik Bay, almost double the coseismic subsidence occurring there in the 1964 great earthquake (Mann 1998). Although large-scale earthquakes along the Aleutian chain are often remotely triggered by regional tectonic processes (Power et al. 2005), earthquakes of smaller magnitudes are common, particularly during a build-up to a volcanic eruption (Fierstein and Hildreth 2000, Moran 2003, Ward et al. 1991).

Tsunamis striking coastal KEFJ may originate from tectonic movement almost anywhere along the convergent Pacific plate boundary off Alaska's southern coast, from along the strike-slip boundary along southeast Alaska, or from far more distant sources along the massive Pacific plate. Submarine landslides and/or volcanic eruptions that release pyroclastic flows or other materials from a volcanic collapse into the ocean may also initiate a tsunami in the Gulf of Alaska (Beget and Kowalik 2006, Kowalik and Murty 1989, Waythomas and Watts 2003). For example, the volcanic eruption ~3,500 years ago that formed the Aniakchak Caldera resulted in the release of large-scale (>50 km^3) pyroclastic flows that set off major tsunamis (up to 7.8 m [26 ft] high) in Bristol Bay (Waythomas and Neal 1998, Waythomas and Watts 2003).

Pacific tsunami warning systems are in place and are currently being enhanced due to efforts motivated by the Indian Ocean tsunami that killed more than 200,000 people in Asia in December 2004. Relevant tsunami warning centers are the West Coast and Alaska Tsunami Warning Center based in Palmer, Alaska (http://wcatwc.arh.noaa.gov/), and the Pacific Tsunami Warning Center in Ewa Beach, Hawaii (http://www.prh.noaa.gov/ptwc/). The AVO also operates seismic networks throughout the Aleutian chain and has recorded and located approximately 5,600 earthquakes at Redoubt Volcano and 2,300 at Iliamna Volcano since 1989 (Moran et al. 2005).

In 2004, the USGS created a map of the coastal change potential of the KEFJ shoreline to future sea-level changes (Pendleton et al. 2004). These rankings, calculated at a resolution of 1-minute grid cells in the park, were performed using a change potential index (CPI), which ranks the following parameters in terms of their physical contribution to coastal change: geomorphology, regional coastal slope, rate of relative sea-level change, historical shoreline change rates, mean tidal range, and mean significant wave height. All of KEFJ was ranked as having a moderate change potential with respect to tidal range, and a very low change potential with respect to relative sea-level change. The other parameters show a varied change-potential ranking (from very low to very high), depending on factors such as wave-energy regimes, geographic variations in areas of elevation change, and geomorphic characteristics. The six parameters taken together indicate that overall areas in KEFJ most susceptible to sea-level changes are tidewater glaciers and outer coast shorelines of unconsolidated sediment (Figure 71).

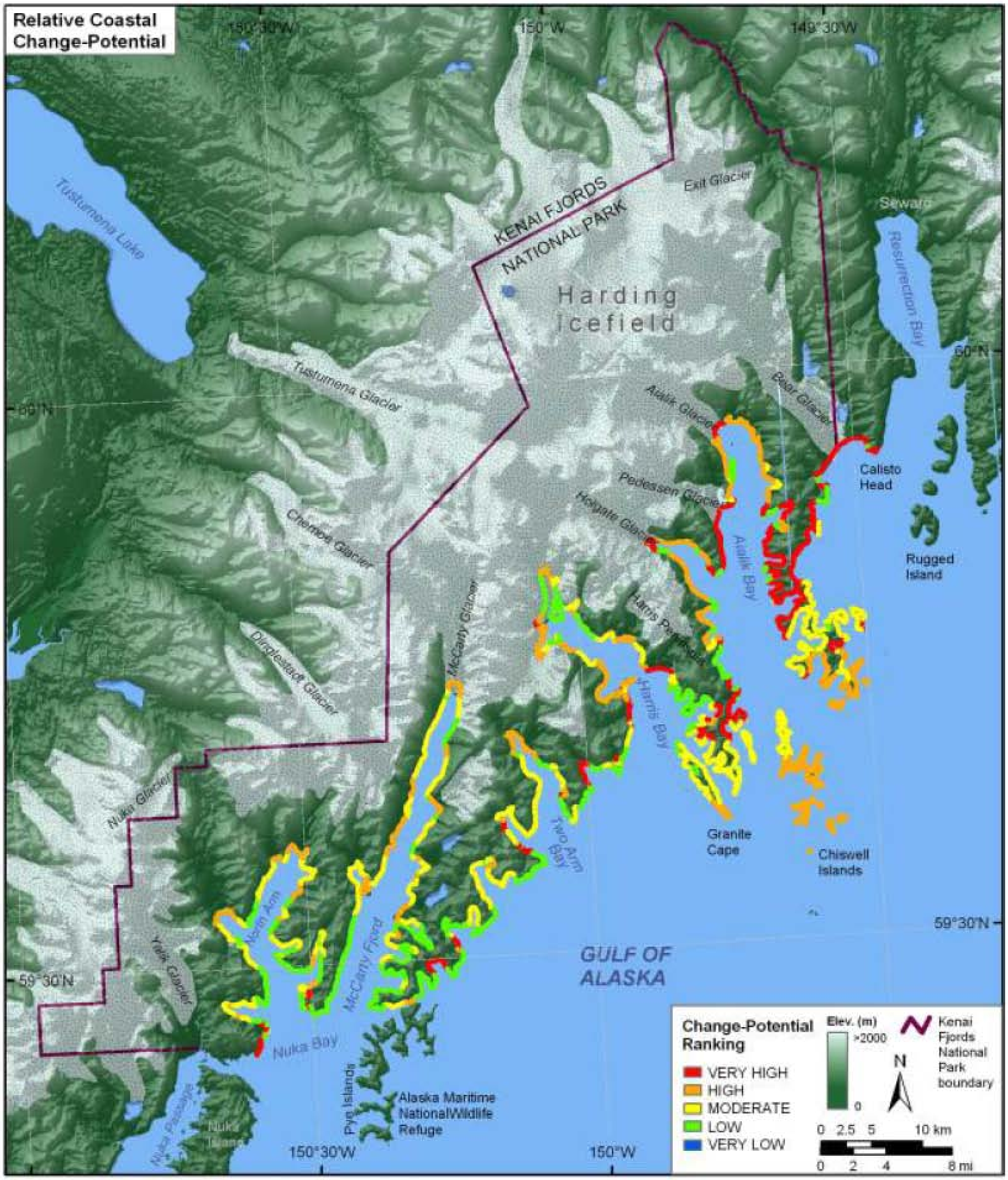


Figure 71. Relative coastal change-potential for KEFJ, as determined by the USGS (Pendleton et al. 2004).

4.4. Visitor Impacts

Visitor use of KEFJ has increased nearly twenty-fold since 1982, rising particularly sharply in the past 15 years (Table 18). It is largely concentrated in the Exit Glacier area, where there is a nature center and ranger station, well-maintained trails, flush toilets (summer only), a 12-site campground, and parking. All other areas in the park lack road access and are reached only by boat or air. Glacier and wildlife cruises are becoming an increasingly popular way of exploring the coastline, with numerous tour boats departing from Seward daily during the summer. The vast majority of visitors to the park do not overnight, although the campground and public use cabins are in high demand (Table 19). Snowmobiling at the Exit Glacier area is growing in popularity as well (Tetreau 2000).

Table 18. Visitor use statistics for KEFJ. Data table retrieved from http://www.nature.nps.gov/stats/park.cfm?parkid=499.

Year	Recreational Visitors
2008	272,190
2007	284,604
2006	251,630
2005	258,297
2004	244,232
2003	243,719
2002	251,799
2001	262,353
2000	254,790
1999	290,673
1998	263,948
1997	306,164
1996	274,034
1995	230,657
1994	209,516
1993	189,712
1992	108,130
1991	107,041
1990	66,115
1989	75,557
1988	59,017
1987	60,428
1986	54,296
1985	35,758
1984	30,703
1983	24,048
1982	16,118
Total	4,725,529

Table 19. Most recent (2008) visitor statistics for KEFJ. Data table retrieved from http://www.nature.nps.gov/stats/park.cfm?parkid=499.

2008	Rec Visits	Tent Campers	Back Country Campers	Total Overnight Stays
January	223	0	5	5
February	173	0	8	8
March	224	0	17	17
April	0	0	0	0
May	14,286	0	19	19
June	68,501	246	50	296
July	83,794	542	68	610
August	80,307	580	21	601
September	23,288	110	5	115
October	1,373	0	0	0
November	21	0	1	1
December	0	0	0	0
2008 Total	**272,190**	**1,478**	**194**	**1,672**
Report Total	**272,190**	**1,478**	**194**	**1,672**

Number of Non-Rec visits, concession lodging, RV campers, concession campground, and misc campers: 0

Three public-use cabins are available to the public during the summer season: in upper Aialik Bay, Holgate Arm, and the North Arm of Nuka Bay. At Exit Glacier, there is a public-use cabin available in the winter. One new cabin resort development is located within the park (Kenai Fjords Glacier Lodge) and one outside but adjacent to the park (Kenai Fjords Wilderness Lodge on Fox Island) that attract visitors who typically combine boat tours of the KEFJ coastline with their lodge visits. Visitor centers include the information center in the town of Seward and the Exit Glacier Nature Center. Finally, there is also a ranger station in Aialik Bay that is staffed for most of the summer season. KEFJ suggests but does not require backcountry permits, although reservations for the backcountry cabins are required.

Potential impacts from visitor use include wildlife disturbance and displacement; damage to soil and vegetation; spreading of exotic/invasive species; fuel spills from motorized vehicle/airplane use; noise pollution from visitors and motorized vehicles; air pollution from watercraft and snowmobiles; stress imposed on marine mammals targeted for close viewing by tour boats and kayakers; damage of nesting sites along beaches; and human-bear interactions.

4.4.1. Visitor Boat Traffic

The majority of the tourists visit the KEFJ coast on small tour boats, and only 1% of park visitors stay overnight in the backcountry (Colt et al. 2002). Small tour boats, including Kenai Fjords Tours, Renown, and Major Marine, offer day tours from Seward. A large cruise ship stops in Seward every two to five days during the May–September season and transits near (but does not enter) KEFJ on its way to or from the town. NPS staff suggests that boat traffic is problematic and causes noise and disturbs wildlife (Shelley Hall, NPS Seward, personal communication, 2005); however, the limited studies on this topic have not detected an influence on wildlife.

Morse et al. (2006) found that human (recreational) disturbance was not an important factor affecting black oystercatcher nest productivity. Rather, nest failure was strongly affected by extreme high tides because of the tendency of the birds to nest in the nearshore, sometimes below the high tide line.

4.4.2. Backcountry Camping

Only a small portion of the tremendous length (ca. 800 km [500 mi]) of the KEFJ coastline provides sheltered sand/gravel beaches that are suitable for camping (Klasner 2009). The vast majority of all backcountry camping occurs at about 30 sites in Aialik Bay and Northwestern Lagoon. Monitoring of the impacts of camping on cultural and natural resources in the park is currently being developed (Monz 2005). Surveys to date have identified fire rings, charred wood, cut stumps, root exposure, vegetation trampling, trash, human waste, soil erosion, campsite proliferation, increased human-wildlife interactions, and social trails as some of the impacts by camping activity in these heavily used sites (Klasner 2009).

4.4.3. Hiking

The Harding Icefield Trail (HIT) at Exit Glacier has been receiving increasingly heavy use during the summer months; for example, 10,029 people signed in at the trail register between May and October 2007 (Wetherbee 2007a), which was nearly twice as many as those who registered during the same period in 2006 (Wetherbee 2006a). NPS staff have been monitoring the impact of hikers on the HIT (Kriedeman 2007) and have conducted a hiker encounter survey (Kriedeman 2008).

The top of the cliffs at the Glacier Overlook area are particularly heavily affected and are therefore a focus of monitoring and restoration efforts (Wetherbee 2006a). New vegetation was transplanted into two particularly heavily affected areas, at 2.0 km (1.25 mi) and 2.7 km (1.7 mi) up the HIT in 2007 (Wetherbee 2007a). For the past several summers, KEFJ staff have been regularly flagging the trail during the early spring when it is snow-covered to help prevent visitors from hiking off the trail, which can cause vegetation trampling, erosion, trail widening, and the creation of new side trails (Wetherbee 2006a, 2007a). The use of jute mesh has also aided in the recovery of vegetation by holding down soils and seeds and providing a physical deterrent to hikers trying to step off the trail (Figure 72).

Figure 72. Social trails leaving from the Glacier Overlook along the Harding Icefield Trail. These trails were blanketed with jute mesh to aid in soil and vegetation recovery. From Wetherbee (2007a).

4.4.4. Public Use Cabins

Three cabins are available for public use along the KEFJ coast during the summer months: in Aialik, Holgate, and North Arm (http://www.nps.gov/kefj/planyourvisit/publicusecabins_summer.htm). Due to the lack of roads and trails, the cabins must be accessed by float plane, water taxi, private vessels, or charter boat. Another cabin, called Willow Cabin, is available in the winter months to snowmobilers, cross-country skiers, snowshoers, and dogsledders, and is located 7 miles from where Exit Glacier Road closes in the winter. The public-use cabins themselves may not produce much of an impact outside of potential local trampling of soil and vegetation and contamination from pit toilets and propane fuel containers. However, visitor travel to and from the cabins via motorized vessels, planes, or snowmobiles present larger risks in terms of fuel spills, wildlife disturbance, noise disturbance, and exotic species introduction. The Aialik Bay cabin is leased from the Port Graham Corporation.

4.4.5. Development on Native-Owned Lands

In 2008, the only lodge within KEFJ was constructed on 10 acres of Native-owned (Port Graham Corporation [PGC]) land along the eastern shore of Pedersen Lagoon. The Kenai Fjords Glacier Lodge, operated by Alaska Wildland Adventures (AWA), consists of a main lodge, 16 private cabins, and staff support facilities, and it is slated to open for business in the summer of 2009. The company advertises that from the lodge visitors can sea kayak, hike, or travel by motorized skiff in an area rich with harbor seals, sea and river otters, mountain goats, black bears, and birds (http://www.alaskawildland.com/kenai-fjords-glacier-lodge.htm). According to a fact sheet from AWA and PGC, approximately 800 ha (2000 acres) of PGC land surrounding the development will be known as the Pedersen Lagoon Wildlife Sanctuary, and no other development will occur in the Sanctuary (Hoessle 2008). Furthermore, the lodge strives to be an "ecolodge" by keeping the project small scale, conserving energy, providing guided trips to small groups, and offering educational opportunities for the guests (Hoessle 2008). Nonetheless, the development, maintenance, and operation of this lodge (including boat traffic to and from the lodge and visitors hiking and kayaking in the area) will provide some level of disturbance to birds and marine and terrestrial wildlife in this biologically rich area that contains the highest species diversity along the KEFJ coast. Examples of this possible disturbance include wildlife harassment, motorized vessel leaks, and exotic/invasive species introduction.

4.5. Historic Mine Sites

Several mining sites are located in the Historic Mining District of Nuka Bay. Gold mining activity in the area commenced after discovery in the 1900s, with production peaking in the 1930s. One mining claim at the Goyne prospect remains administratively active, as it existed prior to the establishment of the park and has been continuously re-filed since then (M. Tetreau, NPS, pers. comm., 2005). A rudimentary survey of water quality conditions at mining sites in the Ferrum Creek (Beauty Bay site) and Babcock Creek areas (Cieutat et al. 1994) indicated detectable and in some cases high concentration signatures of the orebody mineralization in some water samples but also rapid downstream dilution from the mine workings (see Section 3.1.2 Water Quality – Nuka River and vicinity). The report concluded that "mining of mesothermal gold veins on lands along the northern Gulf of Alaska is unlikely to have significant effects on surface-water quality" (Cieutat et al. 1994). However, a follow-up study prompted by the discovery of a dead moose calf in the area found that arsenic levels in mine tailings exceeded regulatory cleanup levels, and this led to a several-year process in which the tailings were treated at the site by installation of a cement cap in 1998 (Shannon & Wilson Inc. 2006). As for the Sonny Fox Mine site, a later NPS survey of the mine sites recommended that Babcock Creek be either diverted or rip-rapped in order to prevent erosion of the road, mill tailings, and structures of the mine (Griffiths et al. 1999); however, later work deemed that such mitigation was not necessary (Meg Hahr, NPS, pers. comm., 2008).

A 2007 mine site condition assessment report, which assessed the sites as cultural resources, categorized two of six surveyed sites to be in good condition (Alaska Hills Cabin and Alaska Hills Mill &Mine); three to be in fair condition (Glass & Heifner Mine, Rosness Larson Mine Site, and Sonny Fox Mine); and one site (Nuka Bay Mine) to be of unknown condition due to snow cover at the time of the assessment (Kovak 2008). In the 2007 survey, remains of the Glass & Heifner Mine (also known as the Beauty Bay site) included an open trench, a collapsed adit, more than 50 deteriorating 55-gallon fuel-storage barrels, and gelatin dynamite (disposed of by NPS staff upon discovery in 2007). Removal of hazardous waste from the site was recommended by the assessment (Kovak 2008) as well as an earlier KEFJ Resource Management Plan (NPS 1999). The Rosness Larson Mine site remains included surface trenching, three adits, a mill with scattered mining equipment debris, and a cabin. The Sonny Fox Mine had a mill, aerial tram, six adits, open cuts and camp buildings, and five pounds of gelatin dynamite, which was also destroyed in 2007. In 2008 the barrels at the Glass & Heifner Mine were removed, an open adit in the Nuka Bay Mine was closed off with a steel grate, and a shaft was closed with a foam plug (Russ Kucinski, NPS Seward, written communication, 2009). Six mine openings in the district are scheduled for closure in 2010 (Russ Kucinski, NPS Seward, written communication, 2009). The Surprise Bay No.1 is the only remaining active federal mining claim in the district (Russ Kucinski, NPS Seward, written communication, 2009).

4.6. Exit Glacier Area Flooding

The hydrologic setting of the Exit Glacier area (including the KEFJ nature center and trails) and the road leading to it has proved to be complex in terms of flood prevention and abatement. Prior to development of the area, a hydrologic investigation identified avalanches, floods, and bank erosion as potential hazards in the area (Sloan 1985). The report found no evidence of flooding in the development area since at least 1950 and stated that there is a low risk to roads and structures from large, infrequent flood events, and that the risk could be minimized with careful location of the facilities (Sloan 1985). Since construction of the nature center and trails, it quickly became apparent that flooding risk in the area was much greater than earlier thought. The Exit Glacier area is a young, recently deglaciated area still in the process of formation, with frequently and sometimes drastic shifts in physical flow conditions over the hummocky topography of morainal deposits (Martin 2005) (Figure 73). Although the flooding potential in the area is not considered to be life-threatening, a major flood could pose a “substantial hazard” to trapped individuals (Martin 2005).

The primary source of flooding to the Exit Glacier area is a tributary stream to Exit Creek called the “unnamed drainage” in Figure 73 (Martin 2005). (The following discussion is summarized from Martin [2005]). This stream drains a 2.8 km^2 (1.1 mi^2) watershed and joins Exit Creek as a series of intermorainal channels flowing from the northwest. The shallow and poorly formed stream channels crossing through the Exit Glacier development area are easily flooded by water contributed by the unnamed channel, especially during the fall months when rainstorms are large and frequent. The foundation of the nature center rests on about 46 cm (18 in) of compacted fill, which could be compromised following prolonged exposure to flow. The six channel crossings (culverts, bridge spans, and, in one case, blockage of the channel by fill to support the trail) present between the nature center and the end of the nature trail were identified as being undersized for even small (two-year) flood events. Flooding through the area has been recurring since construction of the nature center in 2002, when floods resulted in the placement of a diversion upstream and culverts under the development and paved nature trail. Another unintended consequence to these diversions is deprivation of flow to an adjacent wetland area, potentially producing deleterious effects on the wetland floral community.

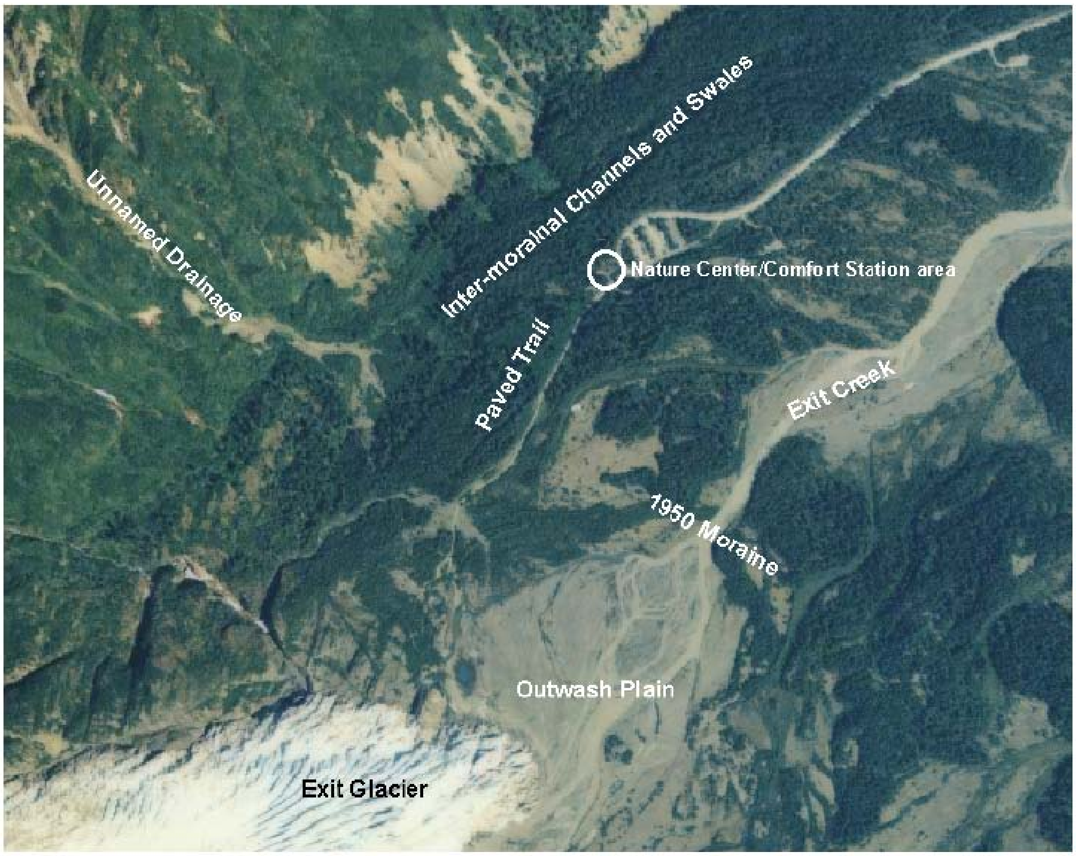


Figure 73. Air photo of the Exit Glacier area taken in 1993. Note the unnamed drainage feeding into the inter-morainal area. From Martin (2006).

The Martin report (2005) suggests that from a flood abatement standpoint, it would be best if all unnatural flow constrictions should be removed. Although this would not save the infrastructure from a large-magnitude (100-year) flood event, it would decrease the number of smaller floods, and it would allow natural processes to keep re-working the glacial deposits. At a minimum, Martin (2005) recommends that the channel blocked by trail fill should be opened, as this would spread out the flow between two channels and reinstate seasonal flow into the small wetland area from which flow is currently diverted. Another recommendation, specifically for the nature center, is to construct a small levee on its upslope side.

In addition to the flooding in the nature center area, flooding also occurs along the portion of the Exit Glacier access road that crosses floodplain and wetland environments supported by both the

Resurrection River and Exit Creek as well as at the maintenance facility on Old Exit Road. In the former case, the original road grade was composed entirely of fill, with no passage for flood flows, leading to the washing out of a section of road. As a result, several culverts were put in, although these are considered too few to adequately convey floodwaters, leaving the road to flood during periods of overbank flow (Martin 2005). In the case of the maintenance facility (part of a low-density residential subdivision outside KEFJ borders, constructed in 1990), flooding occurs due to the location of the facility on a broad and gently sloping alluvial fan formed by Box Canyon Creek (Martin 2005). The creek was isolated to the western portion of its alluvial fan with an earthen levee maintained by Kenai Peninsula Borough. Nonetheless, major flooding occurred in October 2006, when torrential rains flooded Box Canyon Creek (a tributary to Exit Creek), which broke through its levees and sent water, ice, and debris through the area and flooded the road half a foot (Jeff Mow, NPS, written communication, 2006).

4.7. Nuka River Diversion

The terminus of the Nuka Glacier, located just outside of KEFJ, has two main outflow streams: one flowing into Bradley Lake Hydroelectric Project (BLHP) (and ultimately to Kachemak Bay), and the second that forms the headwaters of the Nuka River, which flows 19 km (12 mi) before emptying into Beauty Bay and the Gulf of Alaska (Figure 74). This headwater stream of the Nuka River flows for approximately 3 km (2 mi) from the glacier before crossing into KEFJ. Concern for NPS resources stems from the partial diversion of flow from this upper reach of the Nuka River toward the BLHP (NPS 1986). When the BLHP was constructed in 1986, an agreement was reached to allow the diversion of all but 5 cfs (142 l/s) to the BLHP.

Figure 74. View of the terminus of the Nuka Glacier, showing the east side stream that drains to the Nuka River and the west side stream that drains to Bradley Lake. From Rinella and Bogan (2008).

However, in 2003, the National Park Service noticed that as the Nuka Glacier has retreated, its outflow was greatly shifted toward Bradley Lake, leaving the upper ~1 km of the Nuka River without much of its surface flow during portions of the year. It was not clear if this change was entirely natural, as shifting of the channels has been known to occur in the past (NPS 1986), or if it was intensified by the diversion structures (Shelley Hall, NPS Seward, personal communication, 2005). The National Park Service directed a habitat assessment and biological inventory of the area (Rinella and Bogan 2008). This report provides information on habitat physico-chemical conditions, diatom taxa, and macroinvertebrate taxa in the uppermost reach of the Nuka River within KEFJ. Although the National Park Service plans to continue to stay involved in the management of the Nuka River water resources, dewatering of the short, uppermost section appears to be largely a natural process and likely does not present a threat to the biological integrity of the Nuka River (S. Hall and M. Tetreau, NPS Seward, personal communication, 2005).

4.8. Exotic Species

Exotic plants are a management concern to National Park Service because they can hybridize with native flora, can outcompete resident species for limited resources, and can change the structure and function of ecosystems through alterations of biogeochemical and geophysical processes (Rapp 2008). KEFJ has been following the NPS Alaska Region's Exotic Plant Management Team protocol to try to treat exotic plant populations, which typically are concentrated along roads and trails and at campsites and other places used by visitors (Wetherbee 2006b, 2007d). The most common exotic plants in KEFJ are the common dandelion (*Taraxacum officinale)*, common plantain *(Plantago major)*, and white clover (*Trifolium repens)* (Rapp 2008, Wetherbee 2007d). There are an additional 15 non-native species documented in the park and an additional 16 species in the surrounding area (Rapp 2008). The main area of infestation by exotic plants in KEFJ is along the Exit Glacier Road. Exotic plants are also found on the HIT, where the common dandelion and common plantain are the main exotics (Wetherbee 2007a, b, c). The farthest distance up the trail where an exotic plant (dandelion, in this case) has been found was at Marmot Meadow, which is 2.0 km (1.25 mi) up the HIT (Wetherbee 2007a), but the plant was eradicated in 2008 (D. Kurtz, NPS, written communication, 2009). Between 2005 and 2007, the common timothy *(Phleum pretense)* and oxeye daisy were found and treated at the Beauty Bay airstrip but were not observed in a 2008 survey (Kurtz 2008). Small common dandelion infestations at the Dinglestadt glacier in McCarty Fjord and at Pedersen Lagoon were also treated (Wetherbee 2006b, 2007c) and resurveyed and further treated (by pulling) in 2009 (D. Kurtz, NPS, written communication, 2009). In a KEFJ plant inventory survey, two invasive plant species—annual bluegrass (*Poa annua)* and mouse-ear chickweed (*Cerastium fontanum)*—were collected near remote coastal cabins in Aialik Bay and at James Lagoon in McCarty Fjord, respectively (Carlson et al. 2005, Rapp 2008). The Exotic Plants Management Team is planning to remove the bluegrass from the Aialik Bay cabin in 2009 (D. Kurtz, NPS, written communication, 2009).

Exotic plant treatment efforts have concentrated on the Exit Glacier area and Harding Icefield Trail. Manual pulling of plants is the only removal method used by KEFJ staff, and this has proven to be highly successful with several species (Wetherbee 2007a). In 2008 alone, 360 kg (793 lbs) of weeds (primarily common plantain, common dandelion, and pineapple weed) were pulled in the Exit Glacier area, and similar efforts are planned for 2009 (Klasner 2009). Some species cannot be controlled with manual pulling, however, and therefore an NPS Regional Invasive Plant Management Plan has been developed, and decisions regarding other control strategies are pending (Klasner 2009). Also in 2009, KEFJ plans to manually remove yellow sweetclover along the Resurrection River, inventory and map exotic plants in the vicinity of the newly built Kenai Fjords Glacier Lodge in Pedersen Lagoon, and conduct surveys in Aialik Bay (Klasner 2009). Furthermore, KEFJ is collaborating with local agencies and non-profit organizations in Seward to organize weed pulls to removed invasives growing outside the park along Exit Glacier Road (D. Kurtz, NPS, written communication, 2009).

Exotic aquatic invasive species are also a serious management concern, and those that have been introduced or are moving into Alaskan waters include multiple species of fish, plants, and invertebrates (Appendix B). Water bodies of Alaska are more likely than terrestrial habitats to be invaded by exotic species because the temperature ranges of oceans, rivers, and lakes vary much less than terrestrial temperature ranges (ADFG 2002a). The introduction of invasive species into Alaskan waters may be either accidental, purposeful, or due to negligence. Pathways of introduction include fish farms, aquaculture, transport on or in ballast water from ships or fishing vessels, live seafood trade, or sport fishing gear (ADFG 2002a). In order to minimize the impact of invasive species in Alaska, the Alaska Department of Fish and Game (ADFG) developed an Aquatic Nuisance Species Management Plan (ADFG 2002a) with the purpose of focusing on preventing the invasion of those invasive species that are considered the highest threat (see the ADFG Invasive Species Website at http://www.adfg.state.ak.us/special/invasive/invasive.php.) Additionally, the Alaska SeaLife Center in Seward received a grant in 2009 to launch a non-indigenous marine species monitoring program in Resurrection Bay.

The presence and scale of exotic species in the coastal waters of KEFJ is not known or documented (A. Bennett, NPS SWAN, personal communication, 2005). The potential for the spread of invasive species is substantial, with sources that include marine vessels, float planes, and aquaculture in Cook Inlet. Bennett et al. (2006) highlight the particular concern surrounding the continued northward migration of escaped farmed Atlantic salmon *(Salmo salar),* expansion of the northern pike *(Esox lucius)* from the Susitna River drainage basin, and the introduction of other non-native migrating species. Farmed Atlantic salmon in Washington State and British Columbia are accidentally released into the North Pacific Ocean each year and may affect native populations through disease, colonization, interbreeding, predation, habitat destruction, and competition (ADFG, 2002b). These farmed fish are thriving in the wild with captures in both British Columbia and Alaska, with the first catches of Atlantic salmon in Southeast Alaska in 1991 (ADFG, 2002b). Although ADFG has documented more than 700 catches of Atlantic salmon in Alaskan waters, representing an estimated 3,000 immigrants per year, no Atlantic salmon have been documented in southcentral/southwestern Alaska (T. Hamon, NPS King Salmon, personal communication, 2005). The risk posed by northern pike to coastal watersheds in the Gulf of Alaska (they are native to Bristol Bay drainages) stems from their propensity to prey on small salmon and trout, thereby potentially restructuring fish communities (Bennett et al. 2006, Mann et al. 1998). If northern pike colonized coastal lakes and watersheds, they could impact the natural pattern of colonization, succession, and niche specialization that would occur as fish species successfully gain access to coastal lakes following glacial recession (T. Hamon, NPS King Salmon, personal communication, 2005). Their ability to migrate to coastal drainages is restricted due to their intolerance for changes in salinity. New Zealand mudsnails represent a threat to freshwater systems, as they may impact the food chain for native trout and the physical characteristics of streams themselves (ADFG 2002b).

Little is known about the potential threat of invasive species in the marine environment, but the best-known invasive marine invertebrate species of concern is the green crab (*Carcinus maenas*) which is originally from northern Europe, became established in California in the 1990s, and has since become established in estuaries as far north as British Columbia (Vancouver Island and possibly Queen Charlotte Island). Harbors near KEFJ are currently being monitored for the species (Fritz Klasner, NPS Seward, written communication, 2009). Bacteria, viruses, and parasites are also a threat to Alaskan waters because these can be easily introduced through exotic species.

4.9. Insect Outbreaks and Disease Concerns

Unchecked spruce bark beetle (*Dendroctonus rufipennis*) outbreaks are a growing concern throughout much of the southern Alaskan coastal region, particularly on the Kenai Peninsula. Spruce bark beetles are native and play important roles in ecosystem processes; however, a build-up of weakened trees may be conducive to spruce beetle population outbreaks which may become destructive on a large scale (Manski 1986). Warming of the regional climate will likely exacerbate the problem by speeding up reproductive cycles and reducing cold-induced mortality (Bentz 2008, Berg et al. 2006). As part of the SWAN I&M Program, a tree-ring study is being conducted in KATM and LACL to determine the extent of historic and modern bark beetle outbreaks (see http://science.nature.nps.gov/im/units/swan/index.cfm?theme=insect_outbreak). Spruce beetle-caused tree mortality is exceptionally high on the Kenai Peninsula but only slight in KEFJ, mainly confined to the Resurrection River corridor (Snyder et al. 2008). Resultant large-scale tree mortality affects water resources through changes in vegetative cover to streams, rates of soil adsorption of precipitation, extent of large woody debris contributions to streams, and nutrient cycling in watersheds.

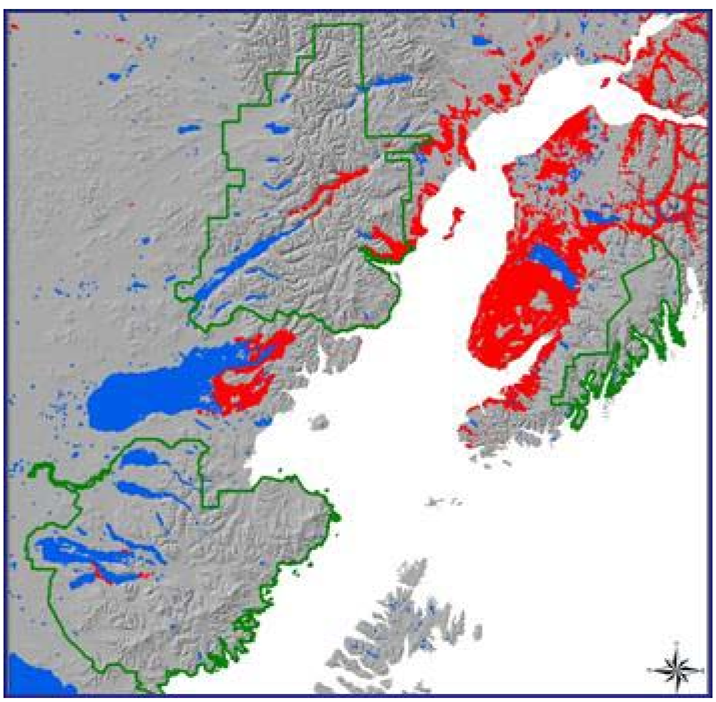


Figure 75. Map of spruce bark beetle mortality extent (1989–2004). From U.S. Forest Service & State of Alaska Department of Natural Resources, 2004.

A disease of concern, the Highly Pathogenic Avian Influenza virus (H5N1 virus) has not been detected in North America; however, the potential exists for it to enter Alaska via migratory birds, particularly those coming from Asia. The Alaska Departments of Fish and Game, Health and Social Services, and Environmental Conservation are currently collaborating with the U.S. Fish and Wildlife Service and USGS Alaska Science Center to closely monitor wild birds, primarily in western Alaska, for the presence of the virus (State of Alaska 2006) (see http://alaska.usgs.gov/science/biology/avian_influenza/index.html). An outbreak of the virus has the potential to decimate bird populations in the KEFJ region and elsewhere and have cascading effects on the food web; however, it is difficult to foresee significant impacts on the quality and quantity of water resources if the virus remains limited to birds and does not spread to other species. Conversely, water bodies may support the spread of the virus because it can be transmitted through water contact. In response to the threat of the avian flu, KEFJ initiated an avian flu surveillance program in 2006, and no cases have been found to date (Wright 2007). In 2009, KEFJ Resource Management staff and coastal law enforcement rangers will be conducing monthly surveys of coastal beaches (Bulldog Cove, North Verdant, Pederson, Northwestern Spit, James Lagoon, and Aialik) for dead and injured birds as part of the Coast Observation and Seabird Survey Team (COASST) (Klasner 2009). Additionally, KEFJ staff will be on the lookout for potentially infected birds during all routine visit to the coast and during marine mammal and bird surveys planned this summer as part of the SWAN I&M Program (Klasner 2009).

Finally, chytridiomycosis is an emerging infectious disease caused by a waterborne fungus that, alone or in consort with other environmental stressors, has caused severe declines in amphibians. Although wood frogs and chytrid fungus are not known to occupy the park currently, the fungus could have impacted populations that historically may have occupied the park. Both have been detected on the adjacent Kenai National Wildlife Refuge (S. Pyare, personal observation).

4.10. Harmful Algal Blooms

Harmful algal blooms (HABs) are caused by a few dozen marine phytoplankton that produce toxins. Although commonly called red tides, this term is misleading as with many HABs, there is no discoloration to the water, and many seaweeds produce colored blooms. HABs cause significant ecosystem, human health, and economic impacts (Anderson et al. 2000). HABs have become a national and international research focus in the past decade. Most areas of the world have some form(s) of harmful algal bloom, although the frequency, severity, and diversity vary greatly. What is certain is that although HABs have been documented for centuries, they have been occurring more frequently and in more areas during the past few decades (Anderson 1995, Burke et al. 2000). HABs have caused mass mortalities of marine bird, mammal, and fish populations, and have caused a variety of human illnesses that vary by type of toxic phytoplankton or diatom. HABs are known to cause a variety of shellfish poisoning.

The largest problem caused by HABs in Alaska is paralytic shellfish poisoning (PSP) from shellfish that have bioaccumulated the dinoflagellate *Alexandrium* sp. Alaska has one of the highest incidences of reported PSP in the world (Gessner and Schloss 1996). Paralytic shellfish poisoning can cause paralysis, gastrointestinal problems, and respiratory arrest and can be fatal if prompt medical care and respiratory support are not available. There is no antidote. People have died in Alaska from PSP as recently as a decade ago, and there is at least one human health incident per year. Since 1973, there have been 176 incidences of PSP in Alaska from 66 outbreaks, with the majority in Southeast Alaska (Gessner 1996) (Figure 76).

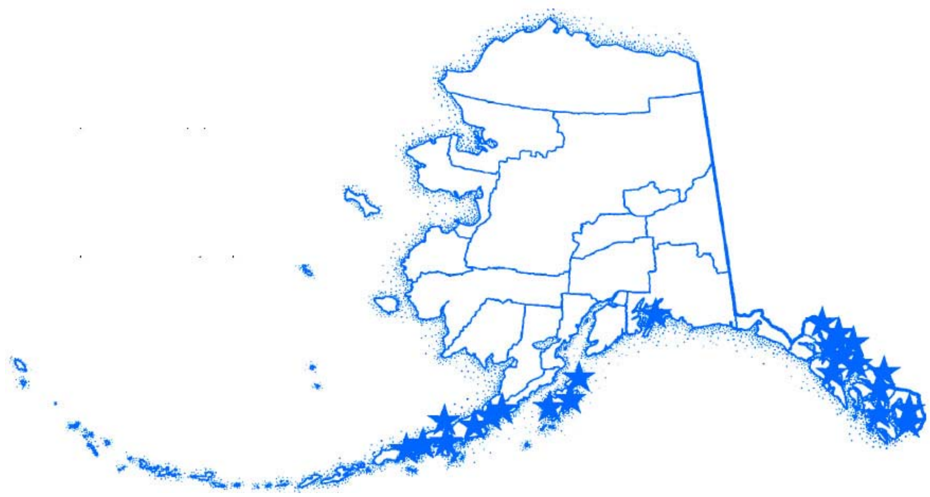


Figure 76. Location of PSP outbreaks in Alaska Each star represents one or more outbreaks. Source: Gessner (1996).

Little is known about the distribution or abundance of PSPs in KEFJ. The Alaska Department of Environmental Conservation is responsible for testing shellfish for PSP. Due to the geographic extent of Alaska (more than 81,000 km [50,000 mi] of coastline) and the remote nature of many regions of the state, shellfish are only tested for PSP in association with a commercial harvest or mariculture facility. Non-commercial harvests are not tested, and people are advised not to eat shellfish that they collect. More information is needed in order to evaluate if HABs are an issue of concern in KEFJ. Any unusual incidences of mass mortalities of marine bird, mammal, and fish populations should be suspected as possible HAB-related events. The National Park Service should advise against non-commercial harvests of shellfish because of the risks associated with PSP.

5. Condition overview and recommendations

5.1 Condition Overview

Based on our research of available data and our best professional judgment, we summarize the potential, existing, and probably future stressors of aquatic resources in KEFJ in the following table (**Table 20**).

Table 20. Water resources-related indicators and current/potential stressors of aquatic resources in Kenai Fjords National Park.

Indicator	Freshwater	Intertidal, Bays, Estuaries & Salt Marshes	Coastal waters
Water Quality			
Nutrients/ Eutrophication	OK	OK	OK
Contaminants	OK	OK	OK
Hypoxia	OK	OK	OK
Temperature	OK	OK	OK
Turbidity (non-glacial)	OK	OK	OK
Pathogens	OK	OK	OK
Habitat Disruption			
Climate change	EP	EP	EP
Oil spills	NA	EP	EP
Aquatic/marine invasive species	PP	PP	PP
Exotic plant species	EP	PP	NA
Insect outbreaks and disease	EP	PP	NA
Coastal development	PP	PP	NA
Water quantity/ withdrawals	OK	NA	NA
Natural geologic hazards	IP	IP	IP

Indicator	Freshwater	Intertidal, Bays, Estuaries & Salt Marshes	Coastal waters
Natural coastal uplift and erosion	OK	IP	OK
Historic mine sites	EP	PP	OK
Logging in private inholdings	OK	OK	OK
Flooding	EP	NA	NA
Recreational usage			
Coastal tour boats and kayaks	PP	PP	PP
Backcountry camping, hiking	PP	PP	NA
Other Indicators			
Harmful algal blooms	NA	OK	OK

Definitions: EP= existing problem, IP= Intermittent Problem, PP = potential problem, OK= no detectable problem, shaded =limited data, NA= not applicable.

The three main stressors to KEFJ coastal water resources are oil spills, climate change, and coastal visitor use. Less-pressing threats include exotic plant introductions, abandoned mine sites, snowmachine use, and backcountry hiking, camping, and cabin use. Several natural geologic issues are major drivers of change in KEFJ as well, including earthquakes, subsidence, uplift, and regional volcanic activity, which threaten coastal resources especially when considering the cumulative impacts of natural and anthropogenic stressors.

5.2 Recommendations

The SWAN is currently implementing their Vital Signs Monitoring Plan, which is based on a tremendous research and planning effort that is certain to greatly expand the current level of understanding of water and other resources in the network. Most of the main issues and data gaps that we initially identified throughout our research for this project are being addressed, or are planning to be addressed, according to the Vital Signs Monitoring Plan (Bennett et al. 2006). During the course of writing this report, we identified data gaps and areas in which further investigation or monitoring is warranted, or at least recommended if resources become available beyond the I&M Program. These recommendations are listed in Table 21 and described in the following sections.

Table 21. List of recommendations.

A. Inter-agency coordination

B. Data and mapping availability, access, and management

1. Online archives of NPS publications and reports, publicly accessible
2. Integration and development of information into centralized and web-accessible GIS
3. Derivation of a GIS-based biophysical classification system for coastal watershed conditions
4. Derivation of a higher-resolution Digital Elevation Model (DEM)

C. Water quality

1. Oil spill response planning
2. Assessment of threat from atmospheric and marine-derived contaminants
3. Expansion on efforts to establish baseline freshwater water quality and watershed condition

D. Biological resources and habitats

1. Vessel impacts
2. Invasive species survey
3. Planning for natural hazards
4. Wetlands inventory

E. Hydrology and Oceanography

1. Glacier monitoring
2. Water management
3. Streamflow gaging

5.2.1. Interagency Management

Possibly the largest impediment to effective coastal management issues is an apparent lack of connectivity and coordination among agencies and Native corporations whose jurisdictions over places and biota practically overlap. For example, NMFS is empowered to oversee issues concerning marine mammals; the U.S. Fish and Wildlife Service manages seabird populations; the State of Alaska has jurisdiction of coastal waters below the mean high tide line, including commercial fisheries; the National Park Service and Native corporations manage lands above mean high tide; and all the while private tourboat operators (with no business permits within the park) navigate coastal waters and impact many of these marine, intertidal, and terrestrial resources. There is little effort to coordinate management of the coastal areas of KEFJ that include extraordinary (and in some cases threatened/endangered) biological resources and are undergoing major surges in visitor use while feeling the impacts of climate warming, oil spill recovery, exotic species introductions, and natural geologic forces. Our overarching recommendation is therefore to greatly increase the amount of planning, monitoring, and remedial actions the National Park Service conducts with other agencies and to seriously explore the possibility of establishing a Marine Protected Area along the KEFJ coast.

5.2.2. Data and Mapping Availability, Access, and Management

Online archives of NPS publications and reports, publicly accessible: A large number of NPS-related documents are available in electronic format online through NatureBib. However, several important documents, (e.g., the Bennett (2005) water quality survey of KEFJ) were not obtainable through this searchable database, and although many citations are listed for KEFJ, only a fraction (typically the most recent ones) have downloadable files attached to the citation information. We recommend continuing the effort of adding old and new report files to the NatureBib database.

Integration and development of information into centralized and web-accessible GIS: Data from surveys, monitoring activities, impairments, and inventories should be integrated into a centralized and publicly accessible web format, with study locations geographically referenced and integrated with the current web-accessible NPS GIS clearinghouse (http://www.nps.gov/akso/gis/).

Derivation of a GIS-based biophysical classification system for coastal watershed conditions: GIS and remote sensing data for KEFJ could be improved, in particular through development of an ecologically based classification system of coastal watershed conditions. This and other useful classified products for water resource monitoring could be developed through a stepwise remote-sensing procedure that first involves development of a training dataset derived from a combination of existing ecological/physiographic data sources and ShoreZone data, which has been reasonably ground-truthed and mapped at a reasonable spatial resolution. Multispectral IKONOS imagery that was recently acquired for KEFJ could be used in consort with training data to adequately classify the entire coastal study area, as well as derive other hydrological parameters within the park, such as the extent of permanent snowfields and the number and aerial coverage of lakes and ponds.

Derivation of a higher-quality Digital Elevation Model (DEM): We recommend acquisition of a complete, consistent, and accurate digital elevation model at a higher resolution (e.g., 10 m) than what is currently available for the KEFJ. Topographic data are currently provided by either a statewide 60-m USGS DEM of moderate accuracy and/or a 90-m DEM from the Space Shuttle Radar Topography Mission (SRTM). Although these may be sufficient for basic terrain visualization and orthorectification of imagery, a high-quality DEM would be more valuable for analytical purposes relating to the monitoring of coastal watershed conditions. In particular, a high quality DEM would be beneficial for more accurately delineating coastal watersheds and drainages and monitoring glacial recession, as well as supporting a fine-scale ecological classification for terrestrial portions of coastal watersheds, as described above. A sub-meter scale, LiDAR-based DEM has been created in coastal areas of Resurrection Bay outside of KEFJ boundaries, and this type of resource could be extended to coastal areas of KEFJ.

5.2.3. Water Quality

Oil spill response planning: The National Park Service should continue its partnership with other responsible agencies (Coast Guard, ADEC, etc.) to further develop and maintain GRS and oil spill response plans for the KEFJ coast. The National Park Service and its partners may want to collaborate with organizations developing circulation models for Prince William Sound and the Gulf of Alaska to predict potential oil spill trajectories. The National Park Service may want to monitor future expansion of oil and gas facilities in the region.

Assessment of threat from atmospheric and marine-derived contaminants: SWAN should continue its recently initiated efforts to assess the threat from global-scale pollutants such as mercury and POPs. Because these pollutants are not derived from localized sources, monitoring these pollutants in one park within the network would provide information that would be useful for assessing general impacts in the other NPS units. However, data specifically from KEFJ would be best, as distances and landscape differences among park units are large, and to our knowledge there are currently no contaminants studies conducted in the freshwater/terrestrial areas of KEFJ. Recently initiated studies of contaminants in mussel tissues along coastal KEFJ will provide important information on marine contaminants and should be continued for long-term trend detection. Recently published results of the WACAP project also provide important information on contaminants in Alaska, as well as protocols for sampling of parameters such as snow, lake water, sediment, lichens, and fish and other subsistence foods that may be of use for future contaminant monitoring plans. SWAN should also monitor results coming from the Mercury Deposition Network (MDN) sites recently launched by the State of Alaska in nearby Kodiak and by the National Park Service in GLBA in southeastern Alaska.

Expansion on efforts to establish baseline freshwater water quality and watershed condition: Very little information is available on water quality in the KEFJ. Although the implementation of the Vital Signs Monitoring Plan for the SWAN will greatly enhance the understanding of baseline freshwater water quality in Exit Creek, no other water bodies in KEFJ will be subject to annual monitoring. Although the remote and challenging access and terrain in KEFJ create difficult and expensive logistical constraints, it would be relatively simple and cost effective to set out low-maintenance temperature loggers in a variety of coastal streams. These could provide long-term, reliable data on temperature variations in the streams and may provide the most achievable way of monitoring the impacts of climate change on streamwaters. In addition, it would be valuable to build on the baseline water quality survey of a subset of coastal streams conducted by Bennett (2005). That study measured only core water quality parameters (pH, temperature, dissolved oxygen [DO], specific conductance, and turbidity), but in the terms of establishing baseline information on stream water conditions, it would be beneficial to revisit the streams and to add parameters such as total dissolved solids (TDS), organic and inorganic nitrogen and phosphorus, sulfate, dissolved organic carbon (DOC), DOC quality, trace elements, organic pollutants, and inventories of macroinvertebrate communities.

5.2.4. Biological Resources and Habitats

Vessel impacts: Very limited information on vessel impacts on biological resources and habitats are available. Additional studies, including estimates on the number of visitors, are needed. Potential impacts of vessels include marine mammal and bird disturbance/harassment, noise pollution, and impacts of boat wakes. The National Park Service currently has no control over the actions of private operators that use motorized tour boats to closely approach marine mammals. However, KEFJ has an agreement with three of the tour boat operators to staff NPS rangers on the tourboats. This should be encouraged for all tour boat operators in the area, and rangers are encouraged to report any potentially threatening activity by boat captains to the appropriate agencies.

Invasive species survey: Invasive species work in KEFJ has focused on vegetation, but aquatic and marine environments should be surveyed as well. Additionally, freshwater streams should be checked for the presence of potential invasive species such as northern pike or Atlantic salmon. We recommend that vegetative and animal invasive/exotic species surveys not be limited to areas of dense human use but that they extend into more remote areas of the park, especially in light of growing visitor use of distant coastal areas. Areas that should be surveyed for invasive/exotic species introduction include the area around the new lodge in Pedersen Lagoon, backcountry cabins and camping areas, and the upper Nuka River where heavy equipment and operators visit for maintenance of the Bradley Lake Hydroelectric Project.

Planning for natural hazards: Future tectonic activity is inevitable in and near KEFJ, and the likely impacts of an earthquake, tsunami, volcanic eruption, and/or catastrophic flood may have devastating short-term consequences to park resources despite some long-term benefits. Although the timing and magnitude of such natural events cannot be manipulated by resource managers, certain measures can be taken to minimize secondary damage incurred by the destruction of human-related infrastructure. For example, the National Park Service should be actively involved in oil spill prevention and response planning and in the rerouting of marine and air traffic away from the area so that these vessels and any hazardous materials they may contain will not injure KEFJ resources in the event of their destruction.

Wetlands inventory: The extent of wetlands resources in the park is not well documented. KEFJ staff should work with the U.S. Fish and Wildlife Service to develop National Wetlands Inventory (NWI) maps for KEFJ.

5.2.5. Hydrology and Oceanography

Glacier monitoring: SWAN is currently monitoring glacial extent (a two-dimensional measurement), but it would be more informative to monitor glacier mass balance. Obtaining LIDAR imagery of all the glaciers would allow for far more accurate measurements of glacial change. These data would also aid in estimating the amount of freshwater flux coming off the glaciers (including tidewater glaciers that lack streams) and flowing into the Gulf of Alaska. Additionally, as many glaciers retreat and go from being tidewater to land-based, tremendous changes are expected, including formation of new streams; changes in sediment supply, salinity, and temperature; circulation in receiving fjords; and the many cascading effects on biota, such as Kittlitz's murrelets, that are closely tied to glacial landform features.

Water management: The problem of frequent and sometimes destructive flooding in the Exit Creek visitor center area is one that is unlikely to be fully resolved due to the nature of the ever-changing geologic environment: the retreating glacier with productive summertime flows, steep tributary streams that are prone to massive flooding during fall rainstorms, and the shifting, soft alluvium that underlies the developments, trails, and roads. Certain measures can be taken to help minimize the damage, as pointed out by Martin (2005). We recommend that KEFJ heed his recommendation to remove trail fill that blocks one of the channels in order to provide flow passage and to reinstate flow into an adjacent wetland area. Further development in the area is not recommended.

No further action is recommended regarding water management of the Nuka River diversion area along the KEFJ boundary.

Streamflow gaging: Logistical and cost constraints understandably limit streamgaging by the SWAN I&M Program to just one site (Exit Creek), but we recommend that more streams be gaged in KEFJ, perhaps in partnership with other federal and state agencies. The Nuka River is an obvious choice site, because it has historic gages operated by the USGS. With its numerous glaciers and inclusion of one of the largest icefield in the USA, KEFJ is particularly sensitive to a warming climate, and measuring streamflow on KEFJ glacial streams would provide highly valuable information on the timing and magnitude of meltwater fluxes into the Gulf of Alaska.

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Appendix A. Core Vital Signs

The 21 core vital signs that are currently being monitored or undergoing development by SWAN staff, park staff, and/or cooperators. Seven additional vital signs are primarily data harvest alone, and one (wolves) is still being tested by LACL for feasibility (M. Shepherd, NPS Anchorage, written communication, 2009).

SWAN Project	Vital Sign and Protocol
Weather and Climate	Visibility & Particulate Matter
	Weather and Climate
Landscape Dynamics and Terrestrial Vegetation	Glacier Extent
	Sensitive vegetation Communities Salt Marshes, Nunataks, Mt. Hemlock
	Vegetation Composition and Structure (ground based)
	Vegetation Composition and Structure+ Land Cover/Land Use (remote sensing)
	Landscape Processes
Marine Nearshore	Geomorphic Coastal Change
	Marine Water Chemistry
	Kelp and Eelgrass
	Marine Intertidal Invertebrates
	Black Oystercatcher
	Seabirds
	Sea Otter
Lakes, Rivers, and Fish	Surface Hydrology
	Freshwater Chemistry
	Resident Lake Fish (contaminants only)
	Salmon (data harvest in part)
Terrestrial Animals	Bald Eagle
	Brown Bear
	Moose

Appendix B. Non-Indigenous Species

Non-indigenous invasive species that have invaded or could soon invade Alaska. The species listed are all highly invasive, have caused severe impact in areas they have spread to, and are capable of living in Alaska's climate. Many of these species have already spread to the Pacific Northwest and are a risk to Alaska. From Alaska Department of Fish and Game (2002a) and with updates from Amy Miller (NPS Anchorage, written communication, 2008).

Species	Originally from…	Now located in…	Why it is a concern
Fish:			
Northern Pike	Alaska	Spreading to other areas of Alaska; found in lakes on Kenai Peninsula and Susitna River drainage	Highest priority threat to southcentral Alaska. They eliminate or greatly reduce the native species. Cause damage to resident species (rainbow trout and grayling). Potential impact to coho salmon stocks.
Atlantic Salmon	Escape from fish farms in BC and Washington	Cordova Ketchikan Yakutat Bering Sea	Serious threat to native species due to competition in stream habitat. Displace native fish by out-competing for food and spawning habitat.
Yellow perch		Kenai Peninsula	Compete with all resident fish species and salmon fry. This population has been eradicated.
Ornamental aquarium fish			Compete with and may feed on native species.
Invertebrates:			
Green crab	N. Europe	California to Vancouver Island	Out-competes resident species for shoreline habitat. Very aggressive.
New Zealand mud snail	New Zealand	Europe Asia Idaho Montana Wyoming California Arizona	May impact the food chain for native trout and the physical characteristics of streams themselves. A serious threat to Alaska's sport fisheries.
Chinese mitten crab	China	San Francisco Bay/delta Possible it is in Oregon's Columbia River	Similar life history to American eel and can move upriver hundreds of miles displacing native species. Feeds on salmonid eggs.
Zebra mussel	Europe	Great Lakes	Out-compete resident mussels, clog water intake lines, sequester nutrients for primary production.
Signal crayfish	W. Canada	Kodiak Island	Out-compete stream fauna, eat everything, can survive extended periods of drought and famine.
Spiny water flea	Europe	Great Lakes California	Displaces existing zooplankton communities, but is unpalatable to fish resulting in lower fish numbers.

Species	Originally from…	Now located in…	Why it is a concern
Parasites:			
Whirling disease	Eurasian continent	Present in 22 states. Found in all western states except Arizona and Alaska.	Parasitic infection that attacks juvenile trout and salmon. Causes fish to swim erratically and in severe cases, to die.
Plants:			
Hydrilla or water thyme	Originally from S. India and Korea.	Present in 15 states including California and Washington	Hydrilla is a noxious water weed that can quickly spread to become an impenetrable mat. Fills lakes and rivers completely until it "tops out" at the surface. Native plants are out-competed. Greatly slows water flow and clogs the area. Can alter water chemistry and oxygen levels. Hinders fish development.
Dotted duckweed	Australia and Southeast Asia	Present in 22 states including Oregon	This small floating plant grows rapidly into dense masses in still water covering the entire surface in a green "bloom".
Purple loosestrife	Eurasia	Present in all states except Hawaii. Also found in Canada. Found in Anchorage in 2005	Loosestrife is able to rapidly establish and replace native vegetation with a dense, homogeneous stand that reduces local biodiversity, endangers rare species and provides little value to wildlife.
Eurasian water-milfoil	Europe and North Africa	Present in 46 states including Alaska	Found in a variety of habits, becoming established in both impoundments and natural waters, sometimes brackish water or in clear, cool, spring-fed rivers. Problems include displacement of native vegetation, disruption of navigation and recreation by the formation of impenetrable mats, and decreased water flow.
Reed Canary grass	Eurasia	All but the southeastern portion of the United States including Alaska. Also found in Canada. Widespread in the lower Kenai Peninsula	Is invading freshwater wetlands and in some places choking channels of small streams. Its creeping rhizomes out-compete native grasses leading to less biodiversity.
Japanese knotweed	Great Britain	Sitka Juneau Other Southeast Alaska areas	Spreads rapidly, choking out native plants. Can spread along streambanks, shorelines, and estuaries. Loss of springtime cover and woody streamside vegetation causes destabilized stream banks and less woody debris in streams.
Foxtail barley	Western North America	Juneau Interior Alaska	Invades salt marsh habitats

Species	Originally from…	Now located in…	Why it is a concern
Salt marsh cordgrass	Eastern seaboard of the United States from Maine to Texas	Has spread to Canada and western United States including Washington, Oregon, and California.	Able to trap sediment leading to higher deposition rates. Changes water circulation patterns. Competitive replacement of native plants and impacts native flora and fauna in intertidal zone. Also, decreases production of bottom-dwelling algae, changes bottom-dwelling invertebrate populations, and loss of shorebird foraging areas.
Dense-flowered cordgrass	Chile South America	California	Outcompetes native flora and impacts native fauna. Eliminates foraging habitat for shorebirds and waterfowl. Dense clusters slow the flow of water and increase sedimentation (raising the wetland).
Swollen bladderwort	Southeastern United States	Western Washington	Grows in still or slow-moving water and forms dense beds of floating plants. Impacts native plants and animals and water quality.

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