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Assessment of Coastal Water Resources and Watershed Conditions at Katmai National Park and Preserve (Alaska)

Natural Resource Technical Report NPS/NRWRD/NRTR—2007/372

Cover photo:

Glacier emerging from the slopes of Mt Douglas toward the Katmai coastline. August 2005. Photo: S.Nagorski

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Commonly used abbreviations

AC- Alaska Current
ACC- Alaska Coastal Current
ADEC – Alaska Department of Environmental Conservation
ADF&G – Alaska Department of Fish and Game
ADNR – Alaska Department of Natural Resources
ALAG- Alagnak Wild River
ANIA – Aniakchak National Monument and Preserve (National Park Service Designation)
ANILCA – Alaska National Interest Land Conservation Act
AVO- Alaska Volcano Observatory
BNWF- Becharof National Wildlife Refuge
CWA- Clean Water Act
EMAP – Environmental Monitoring and Assessment Program (of the US Environmental Protection Agency)
ENSO - El Niño Southern Oscillation
EPA – US Environmental Protection Agency
EVOS – Exxon Valdez Oil Spill
GEM – Gulf Ecosystem Monitoring (Exxon Valdez Oil Spill Trustee Council)
GLBA- Glacier Bay National Park and Preserve
GOA – Gulf of Alaska
GRS- Geographic Response Strategies
HAB – Harmful Algal Bloom
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
NADP – National Atmospheric Deposition Program
NOAA – National Oceanic and Atmospheric Administration (US Department of Commerce)
NMFS- National Marine Fisheries Service
NPS – National Park Service (US Department of Interior)
NS&T – National Status and Trends (NOAA)

NWI – National Wetlands Inventory (of the US Fish and Wildlife Service)
ORI- Oil Residence Index
PAHs – Polycyclic aromatic hydrocarbons
PCBs – Polychlorinated biphenyls
PDO – Pacific Decadal Oscillation
POPs – Persistent Organic Pollutants
PPOR- Potential Places of Refuge
PSP – Paralytic Shellfish Poisoning
SQG- Sediment Quality Guidelines
SWAN – Southwest Alaska Network
UAS – University of Alaska Southeast
USDA – US Department of Agriculture
USFWS - US Fish and Wildlife Service (US Department of Interior)
USGS – US Geological Survey (US Department of Interior)
WACAP- Western Airborne Contaminants Assessment Project

I. Executive Summary

This assessment of coastal water resources and watershed conditions in Katmai National Monument and Preserve (KATM) is provided in response to a U.S. Congressional authorization to assess the environmental conditions in coastal watersheds inside National Park units. KATM 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 Kenai Fjords National Park (KEFJ). While very little work has been collected on the coastal water resources of KATM, 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. Another major source of recent information on KATM (including coastal KATM) is the Water Resources Management Report for KATM and ALAG, currently in preparation by the NPS.

Physical, Oceanographic, and Climatic Setting

The 1.6 million hectare (4 million acre) KATM is located in southwestern Alaska between Shelikof Strait in the Gulf of Alaska and Bristol Bay. The eastern, coastal portion of KATM that drains into Shelikof Strait is the subject of this report. The KATM coastline is 795 km (497 mi) long and coastal watersheds occupy approximately 400,000 hectares (1 million acres). The KATM coastline is broad, dominated by natural influences, and encompasses rich intertidal resources. The shoreline is composed of bedrock (9%), mixtures of bedrock and sediment (36%), sediment (35%), and wetland (20%). Of this shoreline, 2% is categorized as wave exposed, 37% is semi-exposed, 31% is semi-protected, 29% is protected, and 1% very protected.

Coastal KATM has a maritime climate with abundant precipitation and relatively moderate winter and summer air temperatures. There is no long term climate monitoring station within the park, although anecdotal evidence suggests that precipitation levels and winds along the coast are consistently higher compared to interior areas of KATM. Kodiak, which has long term climate records, is representative of coastal climate conditions along the Shelikof Strait east of KATM Mean monthly temperature in Kodiak ranges from -1-13º C (30-55˚F) and annual precipitation averages 190 cm (75 in). Climate in inland KATM is more continental in nature and King Salmon at the western boundary of KATM averages only 48.5 cm (19.1 in) of precipitation and has a large range in monthly mean air temperature.

Hydrologic information

The hydrologic regime of watersheds in coastal KATM is dominated by runoff from seasonal snow cover and glaciers. Streams are generally short (<33 km, 21 mi long) and steep, many drain glaciers, and several are choked with ash and are heavily braided due to volcanic input. Streamflow data from the USGS is not available for any of the streams or rivers within KATM, although the Terror River gage in Kodiak may be representative of non-glacial streams in coastal KATM, and the Johnson River gage in LACL may be representative of KATM glacial streams. In addition, there is some historic streamflow information available from three USGS gages 55-100 km from KATM. The absence of current and historic streamflow gauging stations within coastal KATM prohibits any direct interpretation of temporal and spatial hydrological dynamics of streams within coastal KATM.

Lakes in coastal KATM include Kaguyak Crater Lake, the Crater Lake of Mount Katmai (Katmai Lake), and Dakavak Lake, as well as more numerous smaller and generally clear lakes. Small hanging lakes with high waterfalls are present at the heads of Amalik and Kinak Bays. Low-lying areas near the coast are pockmarked with ponds, many of which appear to be interconnected by extensive wetland systems. Virtually nothing is known about these waterbodies. Some information is available regarding the post-eruption formation of Katmai Lake as well the chemistry and physical characteristics of it and other KATM crater lakes, none of which has an outlet stream.

There are no known data available concerning groundwater resources in coastal KATM except for minimal information on geothermal springs in some areas.

KATM contains a diversity of wetland types including marine, estuarine, riverine, paulstrine, and lacustrine. These wetland areas are important because they serve as an interface between terrestrial habitats and aquatic environments such as streams, lakes and nearshore marine zones. Wetlands also have a variety of important hydrological and ecological functions. For the entire park, estimates of wetland coverage exceed 4000 km^2 (1500 mi^2), and it is estimated that wetlands make up 20% of coastal KATM. KATM wetlands have not been comprehensively mapped.

Within the coastal region of KATM, glaciers cover approximately 71,000 ha (175,000 acres) or 12% of the land area and have been retreating since the end of the Little Ice Age ~250 years ago. There are currently no glaciers in KATM that have ongoing programs to measure mass balance, however changes in glacial extent are being monitored by the SWAN I&M program using satellite imagery. Initial results from this effort suggest that glacial area in the park decreased by approximately 9% during the period 1986-2000. Historically, the glacier within the Katmai Caldera is one of the more studied glaciers within the park. On Mount Mageik, the ice volume of glaciers has decreased substantially and the termini of all glaciers receded during the period 1951-1984. In contrast, glaciers on Mount Snowy have demonstrated an inconsistent pattern of glacier behavior during the same time period, with most glaciers retreating but some examples of stationary or advancing glaciers. The non-retreating glaciers are likely influenced by insulating ash deposits from the 1912 eruption of Novarupta. KATM glaciers have profound effects on the landscape, including erosion and deposition that produce moraines, pro-glacial lakes, and eskers.

Biological Resources

The NPS I&M program conducts the most extensive effort to describe, catalog, and assess the condition of biological resources in KATM. As part of the NPS I&M Program, species lists have been compiled and there are 868 vascular plant species, 41 fish species, 254 bird species, and 69 mammal species reported to inhabit KATM (not exclusive to coastal zone). 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. Key ecological features of coastal KATM have been identified as: 1) sheltered salt marshes and tidal flats; 2) cliffs, headlands, and islands; 3) eelgrass and kelp beds; and 4) tidally influenced coastal freshwater streams.

Several threatened or endangered species occur in KATM, including Steller sea lions, northern sea otters, and Steller's eider. The U.S. western stock of Steller sea lions, including the KATM region, is federally-listed as endangered due to declining populations throughout the western Gulf of Alaska and Bering Sea regions. Harbor seals have suffered a similar decline to that of Steller sea lions and this decline has occurred in roughly the same time period. The Southwest Alaska stock of sea otters was federally listed as threatened in 2005. Several whale species have been sighted along the KATM coast, including humpback whales, fin whales, beluga whales, minke whales and orca whales. Harbor and Dall's porpoises have also been documented. Many marine birds reside in or spend some time along the KATM coast. During a 2006 survey, the most abundant marine birds were the glaucous-winged gull, the black-legged kittiwake, the black oystercatcher, and the harlequin duck. Marine fishery resources in waters off the KATM coast are very rich and include or have historically included herring, pollock, halibut, cod, scallops, Dungeness crab, king crab, tanner crab, shrimp, razor clam, and hardshell clam.

Intertidal algae are diverse, with over 110 species documented in 2003. Important species include seagrasses and kelp beds, and supratidal vegetation common along the shoreline are composed largely of marsh grasses, herbs and sedges (23%) and dune grasses (46%). Coastal wetlands are spatially complex and stratified elevationally according to salt tolerance among wetland plant species. The dominant vegetation types in the coastal region of KATM are tall alder and tall willow shrubs. Numerous species of mammals have been documented in the area, specifically in a NPS survey in Amalik Bay. Brown bear density in coastal KATM, specifically between Hallo Bay and Amalik Bay, is possibly the highest in the world.

Freshwater and anadromous fisheries surveys in the region indicate that 5 species of salmon, Dolly Varden, Arctic char, sticklebacks, and sculpins are present in coastal KATM streams. The most significant factor affecting salmon populations in KATM is the commercial fishing industry. The maintenance of healthy salmon stocks and appropriate fish passage in coastal streams and rivers is important not only for fisheries resources but also because spawning salmonids have significant impacts on biological resources in both terrestrial and freshwater aquatic ecosystems due to their carcasses' contributions of marine-derived nutrients.

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 (EMAP), which showed that water and sediment quality conditions in the region were very high. Earlier sediment sampling (between 1989 and 1994, in response to the Exxon Valdez Oil Spill (EVOS)) at 40 offshore stations outside but immediately adjacent to the coastal boundary of KATM provides a baseline dataset to which future changes in hydrocarbon contamination levels can be compared.

Vital signs monitoring by the SWAN I & M program is a significant part of Katmai's natural resource management. Resources to be monitored are chosen based on ecological significance and relevance to SWAN resource management issues. Vital signs selected for the SWAN I&M program that are directly related to the marine nearshore include marine water chemistry; kelp and eelgrass; marine intertidal invertebrates; seabirds; and sea otters. Vital signs related to freshwater resources include: surface water hydrology, freshwater chemistry, and landscape processes. Results of an I&M water quality review found no 303(d) waters present within KATM, 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 3 tiers by using a ranking procedure that considered access, level of use/management issues, and ecological and spatial cover. In the coastal KATM area, no waterbodies were identified as Tier 1, the Hallo Lake system was designated as Tier 2 (targeted for sampling every 2-5 years); and Dakavak Lake was categorized as Tier 3 (sampling every ~10 years, if at all).

For most water bodies in coastal KATM, water quality conditions are unknown. While scattered data exist on a few targeted streams and lakes, no studies have been designed and conducted specifically to survey water quality in the coastal watersheds of KATM. Without documented baseline information, it is not possible to make an assessment of their condition. Yet due to their remoteness, lack of trails and human infrastructure, and near inaccessibility to humans it is fair to assume that their water quality conditions are almost entirely naturally influenced. In contrast, beaches along the Shelikof Strait and adjacent marine waters are listed under Tier III of Alaska's 303(d) list; that is, although they do not meet Clear Water Act Section 303(d) criteria, they are of concern (due to EVOS) and have a recovery plan.

A baseline water quality inventory study of KATM and ALAG conducted by the NPS presents results of extensive data retrievals using six of the EPA's national databases and concluded that the KATM surface water bodies are generally of good quality, with some impacts from natural and human activities. In particular, the KATM coastal shores showed effects of the EVOS in 1989, based on offshore sediment quality. Some water quality standard criteria were exceeded at Kaguyak Lake, at thermal springs near Mageik Creek, and in the Crater Lake of Mount Katmai, although they were all of natural (volcanic) origin. The rare visitor to this part of KATM should be cautioned against drinking water from these areas.

Several important GIS data sources important for water resource monitoring are currently lacking in KATM. Classified GIS products, such as wetlands, could be derived through a combination of existing data sources and relatively inexpensive remote sensing imagery that encompasses all of KATM. This imagery could also be useful for monitoring key hydrologic parameters within the park.

Past and potential future threats to water quality: oil spills, atmospheric and biologically-transported pollutants, and climate change

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. Swift currents and large tidal ranges can quickly transport released petroleum great distances and over wide coastal zones, as evidenced by EVOS in 1989. As a result of EVOS, two to four percent of the released oil came ashore on Shelikof Strait within KATM, resulting in the most extensive single human-caused disaster to strike a National Park. Ecological communities in Prince William Sound (and likely Shelikof Strait) have been slow to recover from this catastrophic disturbance. The lingering effects of EVOS in KATM are now considered part of the baseline. 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 7 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 KATM based on data on wave exposure levels and substrate types. According to their analyses, only 38% of the coastline had an ORI on the scale of days to months, and 62% had an ORI on the scale of months to years—indicating the strong potential for long term damage to the coast in the event of another oil spill. Currently, Geographic Response Strategies (GRS) and Potential Places of Refuge (PPORs) are in development for certain areas of KATM. 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.

Few large commercial vessels and cruise ships travel in the immediate vicinity of KATM, but tour boats are becoming increasingly common along KATM's coast, 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 KATM 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 KATM 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 KATM via transport and deposition by spawning salmon that accumulate these toxins in the marine environment and by atmospheric deposition. Studies in nearby Bristol Bay watersheds showed that salmon may be major transporters of marine-derived Hg into freshwater environments, and that strong correlations exist between the densities of salmon runs with PCB concentrations in lake sediments. Hg and most POPs are carried to Alaska via long-range atmospheric pathways and upon deposition (wet or dry) can biomagnify as they pass up trophic levels. Mercury and POPs in northern latitudes show significant concentration increases over the last few decades, and although Hg and POPs have not been studied in KATM specifically, several studies in southern coastal Alaska (focusing on sea bird eggs, lake sediments, and streambed sediment) indicate the region is being impacted by these contaminants and deserve further evaluation and monitoring.

Climate change is an important natural resource issue for national parks in Alaska, and recent research suggests that changes in climate may dramatically impact water resources in Alaskan parks. Alaska's climate has warmed by approximately 2ºC (4ºF) since the 1950s and is projected to rise an additional 3-10ºC (5-18ºF) by 2100. 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. In coastal KATM, winter temperatures are typically close to the freezing point of water. As a result, climate warming has the potential to alter patterns of snow accumulation within the park and cause a shift toward higher winter streamflows and lower summer streamflows. Glaciers in coastal KATM have been retreating since the end of the Little Ice Age in the late 1700s and climate warming is continuing to affect the dynamics of glaciers within KATM. An important hydrologic effect of increased glacier melt is an increase in the volume of runoff from glaciers. Unlike glacial rivers, the amount of water in lakes, ponds, and wetlands within KATM will likely decrease as climate warms because of increased evapotranspiration and lower water table levels.

Visitor impacts

Visitor use along coastal KATM is driven by bear-watching tours and fishing trips, and main destinations are Geographic Harbor, Hallo Bay, Big River, Kamishak Bay, Swishak Lagoon, and Kaflia Bay. Charter hunting and fishing trips—both fly-in and boat-accessed-- have been growing rapidly in the last two decades, and even the occasional cruise ship has been known to launch a series of zodiacs in search of bear viewing along the coast. Visitor use to coastal KATM is not monitored and permits are not required, and as a result, there are no accurate data on the number of visitors to the area or of their environmental impacts. Impacts of coastal tourism to water and biologic resources include wildlife disturbance, harassment, and displacement; human waste and garbage; vegetation trampling and loss; stream bank erosion; fire rings; and tree damage. An increase in marine vessel traffic will raise the risk of fuel spills and potentially harmful wastewater discharge and increase disturbance to marine and coastal biological communities.

Natural geologic hazards

Natural geologic hazards such as volcanic eruptions, earthquakes, and tsunamis are common in KATM, and present persistent threats to hydrologic and biological resources. The string of Aleutian Mountain volcanoes running parallel to the Shelikof Strait in KATM form one of the world's most active volcanic areas and is the site of the highest density of young volcanic centers in Alaska. At least 10 major eruptions have occurred in the KATM area in the last 7000 years, including the 1912 eruption of Novarupta, which was the largest 20th century eruption in the world. Future eruptive hazards are identified as ash clouds, ash fall, pyroclastic flows and surges, mudflows (lahars), lava flows, and volcanic gases. The Aleutian seismic zone is one of the most active seismic zones in the world and is predicted to trigger a major earthquake (and hence, resulting tsunamis) in the next few decades. Uplift or subsidence of the land due to tectonic activity may be extremely sudden and is superimposed upon the relatively slow process of ongoing isostatic rebound from deglaciation. While natural geologic events may be destructive in their own right, they may also trigger secondary hazardous conditions by damaging human infrastructure (such as petrochemical industrial infrastructure) that could lead to pollution of park resources.

Other threats

The presence and scale of exotic species in KATM's coastal watersheds is not known or documented, as no studies have been directed at this issue. However, the continued northward migration of escaped farmed Atlantic salmon and other non-native migrating species pose large 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. An NPS survey of cabins along the KATM coast found insignificant evidence of environmental risk associated with abandoned structures and their waste, although this risk level was qualitative and not quantitative. Disease concerns include high intensity spruce beetle infestations and potential arrival of the avian influenza (H5N1) virus in Alaska. More information is needed in order to evaluate if harmful algal blooms (HABs) are an issue of concern in KATM. Chytridiomycosis, a waterborne infectious disease contributing to amphibian declines globally, has been detected in southcentral and southeast Alaska and is likely an emerging threat to KATM wood frog populations, although chytrid prevalence in KATM is currently unknown. Coastal debris and garbage is also thought to be a serious issue in the SWAN, however there is almost no information regarding the scale of this issue along the coast.

Specific recommendations for management and monitoring of both freshwater and marine water resources in KATM are provided in **Table 1** below and detailed in *VI. Condition Overview and Recommendations*.

Table 1. Water resources-related indicators and current/potential stressors of aquatic resources in Katmai National Park and Preserve.

Indicator	Freshwater	Intertidal, Bays & Estuaries	Coastal waters
Water Quality			
Nutrients/ Eutrophication	OK	OK	OK
Contaminants	PP	PP	PP
Hypoxia	OK	OK	OK
Turbidity	OK	OK	OK
Pathogens	PP	OK	OK
Habitat Disruption			
Coastal development	OK	OK	OK
Water quantity/ withdrawals	OK	OK	OK
Coastal erosion/shoreline modification by humans	OK	OK	OK
Natural geologic hazards	IP	IP	IP
Recreational usage			
Tourism	PP	PP	OK
Other Indicators			
Oil spills	NA	EP	PP
Harmful algal blooms	NA	PP	PP
Aquatic invasive species	PP	PP	PP
Climate change	PP	PP	PP

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

II. Purpose and Scope

This assessment of coastal water resources and watershed conditions in Katmai National Park and Preserve (KATM; Figure 1) is provided in response to the NPS Natural Resource Challenge in 2003 to assess the environmental conditions in watersheds inside National Park units. Of particular interest are the threats posed by point source and non-point source pollutants, nutrient enrichment, coastal development and tourism, and resource extractive uses, and the spread of exotic species. The Watershed Assessment Program has been tasked with synthesizing existing data and formulating recommendations that may guide management actions to reduce factors which currently stress, or threaten to stress, the health of NPS watershed resources. This report is the Phase I assessment of coastal and watershed resources in KATM and provides a synopsis of existing knowledge about KATM coastal watersheds. This report specifically focuses on watersheds emptying into the Gulf of Alaska (**Figure 2**). Watersheds including the Naknek River and Lake system, American Creek, and Nonvianuk River and Lake system, all of which lie partially within KATM boundaries but drain north toward the Kvichak Bay, are not within the scope of this report

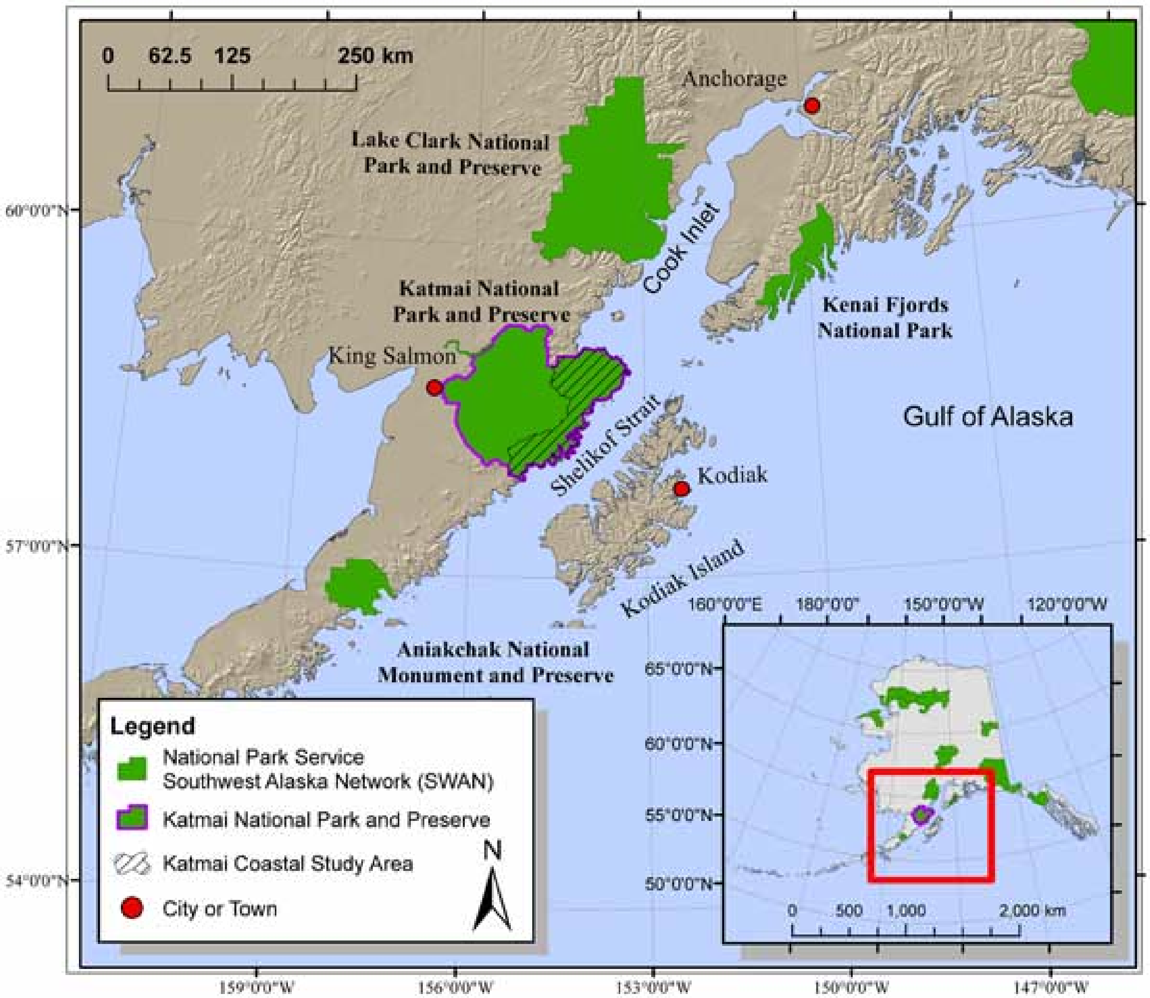

Figure 1: Location of Katmai National Park and Preserve and other SWAN NPS units in Alaska

KATM is part of the Southwest Alaska Inventory & Monitoring Network (SWAN I&M), which also includes the Alagnak Wild River (ALAG), Aniakchak National Monument and Preserve (ANIA), Lake Clark National Park and Preserve (LACL), and Kenai Fjords National Park (KEFJ) (**Figure 1**). These parks are currently part of the Inventory and Monitoring Program, for which baseline inventories and long-term monitoring have recently been designed for biological and geophysical parameters identified as "vital signs", or key indicators of ecological and physical conditions. 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 SWAM I&M Program are found at http://www1.nature.nps.gov/im/units/swan/.

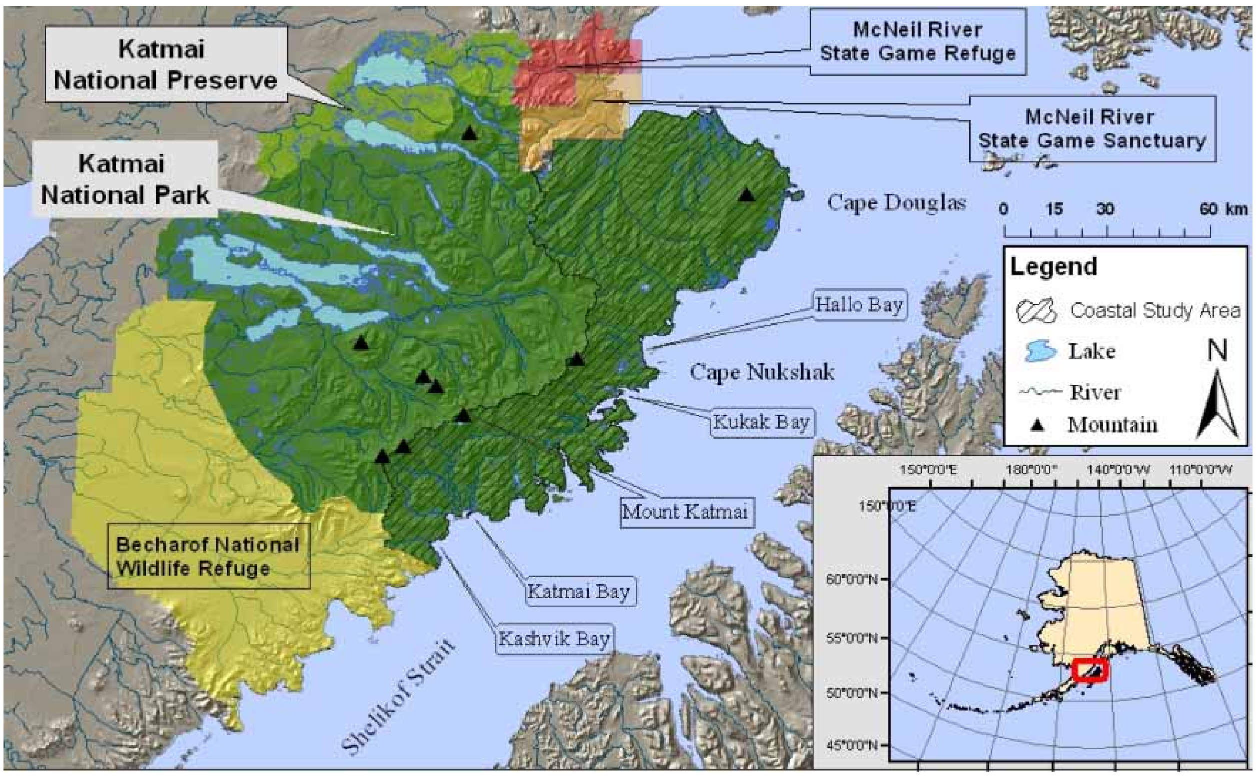

Figure 2. Location of Katmai National Park, Preserve, coastal study area, and neighboring areas.

An additional and major source of recent information on KATM is currently in preparation by the NPS and is expected to be published in the near future (Kozlowski, in preparation). This Water Resource Management Report provides an extensive summary of past research and the current state of knowledge in both KATM and ALAG, and includes a framework for monitoring, management, and research of aquatic resources in these NPS units for the next 10 to 20 years. This report is a comprehensive and detailed evaluation of the water resources in KATM and ALAG, and the reader is referred to this report for additional information

III. Park Description and History

A. Setting

A1. Geographic setting

Katmai National Park and Preserve (KATM) (58.57º N, 155.26º W) is located in southwestern Alaska between Shelikof Strait in the Gulf of Alaska and Bristol Bay, an arm of the Bering Sea. This 1.7 million ha (4.1 million acre) protected area consists of the 1.5 million ha (3.67 million-acre) Katmai National Park and the 0.17 million ha (0.42 million-acre) Katmai National Preserve (Figure 2). Although KATM's areal dimensions make it only the 5th largest NPS unit in Alaska, it is nearly twice as large as the largest national park in the lower 48. KATM is located on the northeastern base of the Alaska Peninsula, which is an approximately 800 km (500 mi) long landmass that extends to the southwest toward the Aleutian Islands and is lined with a string of highly active volcanoes that are fueled by the subduction of the Pacific lithospheric plate under the North American plate just offshore. The western portion of KATM is marked by rolling hills, low mountains covered by tundra vegetation, abundant palustrine waterbodies, several northwest-trending, long, narrow lakes (including Naknek Lake, the largest freshwater lake in the NPS system), wetlands, and numerous salmon-rich streams. The eastern, coastal portion of KATM that drains into Shelikof Strait is the subject of this report. This area is defined by jagged, glaciated peaks of the Aleutian Mountains and steep, relatively short drainages leading toward the ocean along a rugged topographic zone of cliffs, waterfalls, canyons, bays and beaches. The Aleutian Mountain range is 16-64 km (10-40 mi) wide within KATM, with peaks ranging from 1000 m (3300 ft) to 2318 m (7600 ft) (Mt. Denison).

The KATM coastline is 795 km (497 mi) long and includes ca. 20 offshore islands within 8 km (5 mi) of the coast. The KATM coastal zone encompasses the approximately 400,000 hectares (1 million acres) of coastal watersheds, all of which are contained entirely within KATM except for Little Kamishak River and Strike Creek, which pass through part of the McNeil River State Game Sanctuary before discharging into Kamishak Bay. NPS jurisdiction along the coast extends to the mean high tide line, except that marine waters within Geographic Harbor are considered to be within KATM borders. However, no boundary maps have been released since the passage of Alaska National Interest Lands Conservation Act (ANILCA) in 1980, and questions remain regarding the extent of NPS jurisdiction in harbors and submerged lands (T. Hamon, NPS-King Salmon, personal communication, 2005). The tidelands along KATM's coastline are managed by the State of Alaska Department of Natural Resources (DNR). Most of KATM (1.4 million ha, 3.5 million acre) is designated wilderness for management under the Wilderness Act of 1964 and in accordance to ANILCA where applicable (NPS, 2005b). Several rivers, including 3 on the coast (Big River, Hallo Creek, and the Katmai River) have been designated as potential Wild and Scenic Rivers and must be treated as such until the U.S. Congress decides on their status (NPS, 2006c). North of KATM's coastal area lies the McNeil River State Game Sanctuary, and south of the unit is the Becharof National Wildlife Refuge.

KATM became an NPS unit after it was thrust into global recognition due to the immense eruption of Novarupta, near Mount Katmai, on June 6, 1912. This eruption was the largest volcanic explosion of the 20th century and one of the largest in recorded history. The original designation of Katmai National Monument in 1918 by former President Wilson was motivated by efforts by the National Geographic Society to protect the rich geological features shaped by the cataclysmic 1912 eruption. The boundaries were extended four times in subsequent years, primarily via ANILCA in 1980, but these future expansions were driven largely by efforts to protect the area for its rich biodiversity. Specifically, the protection of its brown bears was a primary justification for the area's designation in 1980 as a National Park and Preserve. The coastal segment of KATM was brought under NPS jurisdiction in 1931, when the Monument expansion also extended into the interior lake system to project "features of historical and scientific interest, and for the protection of the brown bear, moose and other wildlife."

King Salmon is the nearest town to KATM, situated 8 km (5 mi) from the unit. Both King Salmon and Kodiak are approximately 100 km (60 mi) from the coastal study area. Most visitor use is in interior Katmai, where Brooks Camp offers exceptional bear viewing, and in the Valley of Ten Thousand Smokes emanating from the Novarupta site for tours of the massive volcanic landscape. The jagged, glaciated, and roadless Aleutian Mountain peaks shield off interior Katmai from coastal Katmai, forcing coastal visitors to access the area by float or wheeled plane or by boat, often negotiating logistical difficulties associated with adverse weather conditions. Coastal Katmai tourism is growing rapidly; the NPS estimates a 100% increase in use and visitation in the last 12 years (NPS, 2006a). Tourism is centered around bear-viewing expeditions, fishing trips, and sightseeing tours that typically originate from Kodiak Island or Homer. The areas that receive heaviest visitor use (up to ~30 people/day) include Hallo Bay, Geographic Harbor, Big River, and Kamishak Bay (T. Hamon, NPS-King Salmon, personal communication, 2005).

A2. Human utilization

Historical and archeological evidence indicates that native peoples of the Alutiiq culture inhabited or used the Alaska Peninsula as early as 10,000 years ago, at the end of the last (Pleistocene) ice age when the area became habitable (Crowell et al., 2001). Along the KATM coast specifically, archeological finds have been made along Swikshak Bay, Cape Chiniak, Kukak Bay, Kaflia Bay, Missak Bay, on Takli Island in Amalik Bay, near the old village of Katmai, and in Dakavak Bay (Clark, 1974; Saleeby, 2002). Evidence indicates that the difficult coastal conditions of these areas did not support large and consistent human populations in the area, although those who did use it took advantage of the abundant fishing and hunting opportunities (Norris, 1996). Paleo-environmental records indicate that a series of catastrophic eruptions between 4000 and 3500 years ago may have reduced populations in coastal KATM, and another large-scale eruption about 2800 years ago may have further reduced the number of inhabitants of the area (Hilton, 2000). Dumond (1979) provides an overview of the historical and archeological record linking human utilization of the area with major volcanic events. The Alutiiq peoples were more highly concentrated on nearby Kodiak Island, and archeological evidence indicates frequent culture exchanges across the Shelikof Strait (Clark, 1974).

Russian fur traders arrived on the Shelikof Strait in the late eighteenth century, heralding an era of political subjugation, disease, hunger, forced labor, and drastic population declines for the Alutiiq peoples (Crowell et al., 2001). The Russians and their native workers had their main outpost in Kodiak, but they used the KATM coast extensively to harvest sea otters. Up to 3000 sea otter pelts passed through a newly-established trading post for the Russian American Company (from 1799-1867) at Katmai village, near the southern tip of KATM's current coastal boundaries (Norris, 1996). After Alaska was purchased by the United States in October 1867, several trading companies brought in novel, more intensive hunting methods that nearly decimated the sea otter populations by the turn of the century. Trading posts in Katmai and Douglas were valueless and abandoned, but the local economy was saved by the concurrent establishment of the commercial salmon fishing industry (Norris, 1996). A seasonal fishing station was established at Kaflia Bay, but no canneries were opened along the KATM coast and were instead operated on Kodiak Island.

At the turn of the century, KATM country was used by gold prospectors using the Katmai pass to access the gold rush in Nome, and it was also by oil and coal seekers who announced discoveries near Cape Douglas that eventually proved to be too minor to exploit (Norris, 1996). The 1912 eruption of Novarupta added to the economic and culture demise of the local area and caused the permanent abandonment of at least four separate settlements of three distinct native communities (Crowell et al., 2001; Dumond, 1979). The eruption also heralded an era of scientific exploration and research in the area by the National Geographic Society, which was instrumental in obtaining Monument status for the Novarupta area in 1918 (Norris, 1996).

Boundary extensions of the NPS unit were complicated by the establishment of clam and salmon canneries and supporting infrastructure in Swikshak, Kukak, and Kamishak Bays after World War I. These clamming operations functioned intermittently up until the 1960's (mainly in Swikshak Bay) and their activities were permitted to continue following the expansion of Katmai Monument's boundaries (Norris, 1996). Concerns about poisonous shellfish closed all beaches in Alaska to commercial clam, mussel, and similar shellfish harvest in the mid-1960s. Following a several-year hiatus, clamming restarted in Swikshak Bay but at a smaller scale than historically (Clemens and Norris, 1999). KATM beaches became a dumping ground for discarded car bodies, old shacks, wood stoves, and debris, and as a result, the number of special use permits issued for commercial harvest by the NPS declined to only one by 1977. Harvesters were ordered to remove their structures after their harvest seasons, and NPS staff destroyed remaining infrastructure from the clamming canneries at Kukak and Swikshak Bays in the 1970s and 1980s (Norris, 1996). One illegal clam operation briefly took place at Hallo Bay in 1985 (Norris, 1996).

B. Hydrologic information

B1. Oceanographic setting

KATM is located in the northern Gulf of Alaska (GOA). The GOA is bordered by the Alaska Peninsula to the northwest and the Canadian mainland at Queen Charlotte Sound to the southeast (**Figure 3**). Dominant habitats include continental shelf, slope and abyssal plain. Within the GOA, the continental shelf area represents more then 12% of the continental shelf holdings of the U.S. (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 et al., 2005). Abyssal depths (>7000 m, 23,000 ft) occur in the northwest portion of the GOA within the Aleutian Trench.

Slope and plain environments are dotted with subsurface banks, ridges, and seamounts which rise from over a kilometer depth to within a few hundred meters of the surface. Fjords, convoluted shorelines, underwater canyons and ridges, and multiple islands create a mosaic of geological features that contribute to a complex oceanographic domain. The oceanography of the GOA is composed of gyres, surface currents, predominant downwellings, and punctuated localized upwellings. 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 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, 5-52 in/s) current driven by winds and density gradients established through freshwater input (Hood and Zimmerman, 1986).

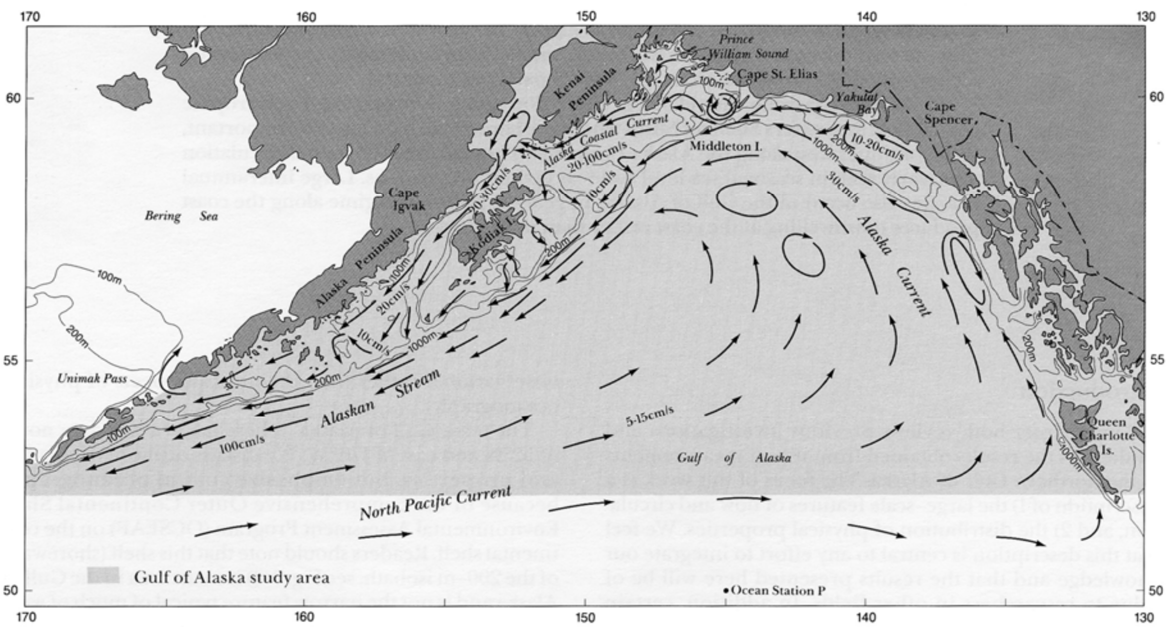

Figure 3. Predominant currents in the GOA (Reed & Schumacher 1986).

Precipitation within the GOA ranges from 2 – 6 m (7-20 ft) 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 promote downwelling favorable conditions for much of the GOA; 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 GOA along the ACC, but eddies have also been generated west of Shelikof Strait (Crawford et al., 2000). Eddies in the GOA range from 10-50 km (6-30 mi) and normally persist for 1 to 4 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).

The GOA 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 (49 ft) waves and gale strength winds (Wilson and Overland, 1986). The Low oscillates in strength and location throughout the year but maintains its influence on the regional climate (Mundy and Olsson, 2005; Wilson and Overland, 1986). 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 GOA. 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). Wintertime location of the Aleutian Low creates a proxy which characterizes the regime of the PDO. A negative PDO occurs when the Aleutian Low is centered in the southwestern GOA, over the Aleutians and southern Bering Sea. A positive PDO occurs when the Aleutian Low has a northeastern GOA locus, and the climate of the GOA is characterized by warmer sea surface temperatures, higher precipitation, and windier conditions (Hare et al., 1999). Opposite patterns for the Gulf are observed during negative phases of the PDO. Winters with strong Aleutian Lows tend to be associated with ENSO warming events (Niebauer, 1988). During a warming event (El Niño), sea levels rise, upwelling shuts off, and water temperatures in equatorial Pacific near Peru may rise as much as 5.4°C (9.7°F). During a cool phase (La Niña), cooler surface waters (< 20°C, 68°F) extend offshore of Peru and intensify upwelling currents in that region. Warming in the equatorial Pacific is not always associated with intensification of the Aleutian Low and vice-versa.

Storms, wind mixing, and terrestrial inputs result in high productivity and a dramatic marine environment along the KATM coast. Storms are more common and wave heights are larger in winter (Figure 7) when average wave heights in the Barren Islands, located 60 km (37 mi) offshore of Cape Douglas in KATM, are over 2.5 m (8.2 ft) and maximum storm wave heights can reach 6.5 m (21 ft) (**Figure 4**). Within Shelikof Strait, the ACC travels southwestward at the surface at speeds ranging from 20 cm/s (8 in/s) in early summer to 100 cm/s (40 in/s) in the fall (**Figure 5**) (Reed and Schumacher, 1986). This high-speed current transports freshwater, nutrients, contaminants and sediments from the eastern GOA and Prince William Sound to the Lower Cook Inlet and Shelikof Strait region. About half of the bottom sediments in Shelikof Strait are from the Copper River in the eastern GOA (Prentki, 1997). The high amount of freshwater input in the region results in estuarine flow in Shelikof Strait, with a northward inflow of deep water (Reed et al., 1987).

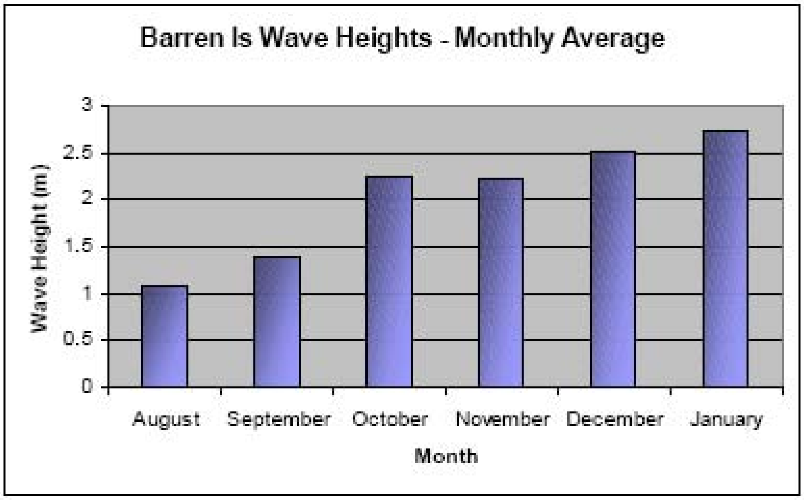

Figure 4. Average monthly wave heights from NOAA Buoy 46079 from August 2001 to January 2002 (Figure 7 in Harper and Morris 2005).

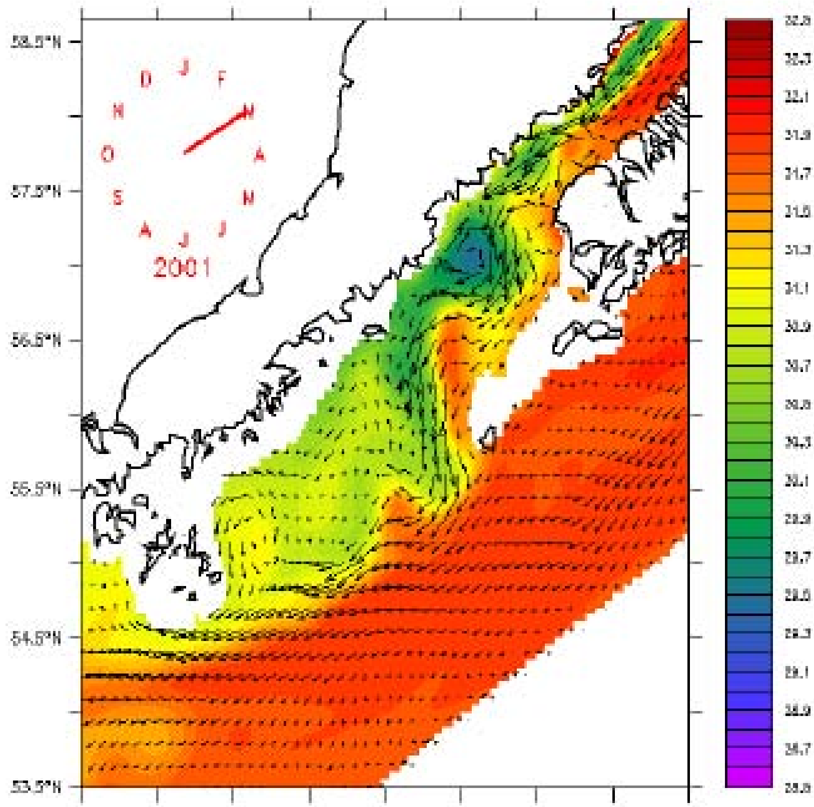

Figure 5. Results from a NOAA circulation model of Shelikof Strait for March 2001. Water salinity is indicated by the colors and arrows indicate water movement (NOAA model http://www.pmel.noaa.gov/sciapp/spem/shelikof.html).

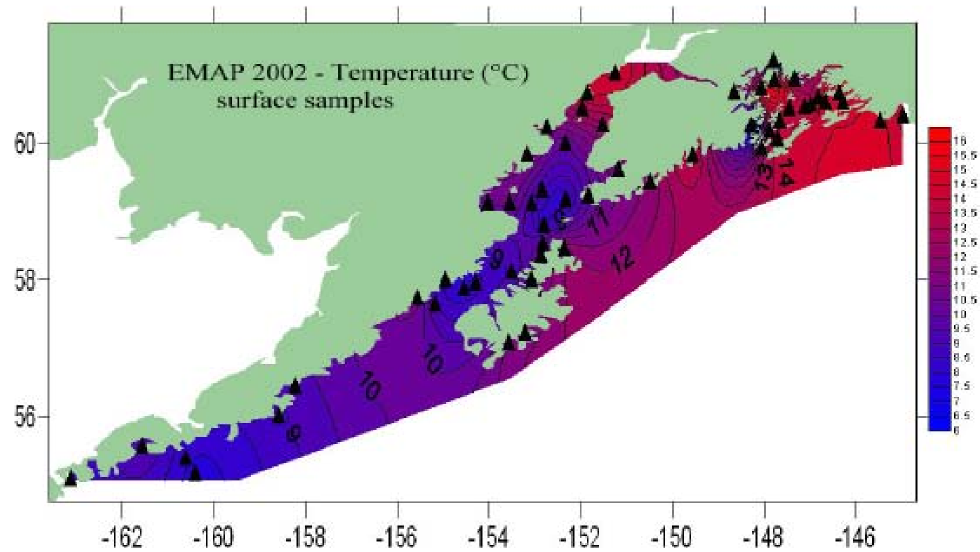

Figure 6. Surface temperature contours estimated from the 54 stations (triangles) sampled as part of the EMAP program (see section IV.A.1.a). Sampling occurred between June-August 2002 (Saupe et al., 2005).

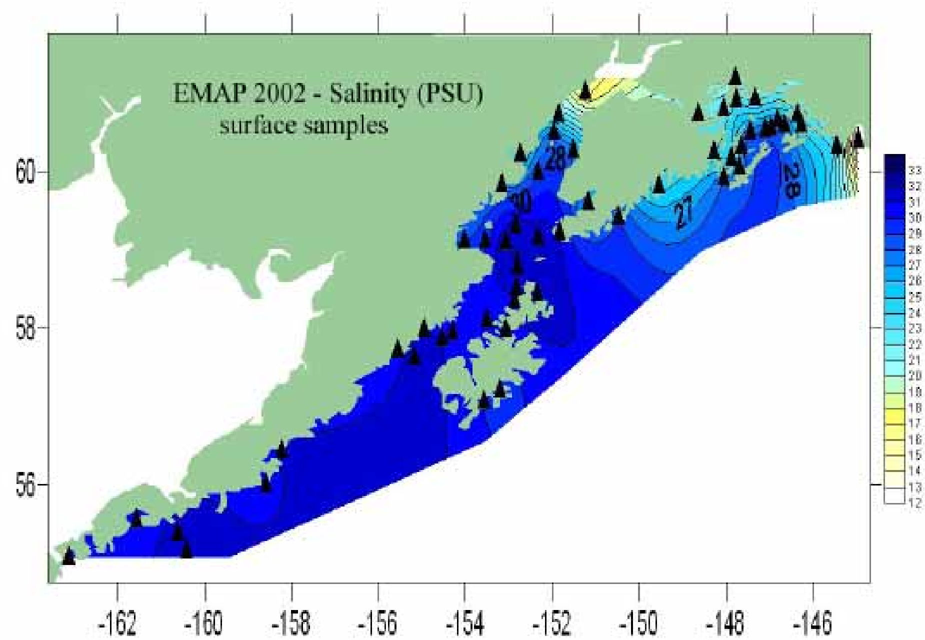

Figure 7. Surface salinity contours estimated from the 54 sampled stations (triangles), showing the lowest salinities occur relative to the major inputs of the principal rivers (Saupe et al., 2005).

Temperature and salinity in Shelikof Strait and Lower Cook Inlet were surveyed in the summer of 2002 by the EMAP program (Saupe et al., 2005). In this survey of southcentral and southwest Alaska, surface seawater temperature ranged from 5.1 to 16.5 ºC (41-61.2°F), averaging 11.1 ± 2.6 ºC (52.0 ± 4.7ºF), and bottom temperatures ranged from 4.3 ºC (40.ºF) to 14.6 ºC (58.3ºF), averaging 7.0 ºC ± 2.7 ºC (45 ± 4.9º F) (**Figure 6**). Surface salinity ranged from 13 to 32 and bottom salinity ranged from 17.6 to 32.2 in this same region, and salinities in Shelikof Strait were in the high end of this range (**Figure 7**).

B2. Climatic setting

B2a. Precipitation, temperature data

Climatic conditions in KATM are highly variable between the coastal region along the Shelikof Strait and the interior region on the lee side of the Aleutian Range. In particular, there are higher levels of cloud cover and precipitation and windier conditions along the coast as compared to areas like Brooks Camp in the interior (Norris, 1996). Coastal KATM has a maritime climate with abundant precipitation and relatively moderate winter and summer air temperatures. Williwaws (violent downdrafts associated with open water and mountains) are regular occurrences in coastal KATM. These wind storms can produce highly localized winds of greater than 80 km/hr (50 mi/hr) (Litch and Blackie, 1988). There are no long term climate monitoring stations within the park. Kodiak, which has long term climate records, represents coastal climate conditions along the Shelikof Strait east of KATM (Weeks, 1999). Mean monthly temperature in Kodiak ranges from -1-13º C (30-55˚F) and annual precipitation averages 190 cm (75 in) with peaks in the fall and winter (Figure 8). Climate in the inland and western portions of KATM is more continental in nature. King Salmon at the western boundary of KATM averages only 48.5 cm (19.1 in) of precipitation, and has a large range in monthly mean air temperature compared to Kodiak (Figure 9).

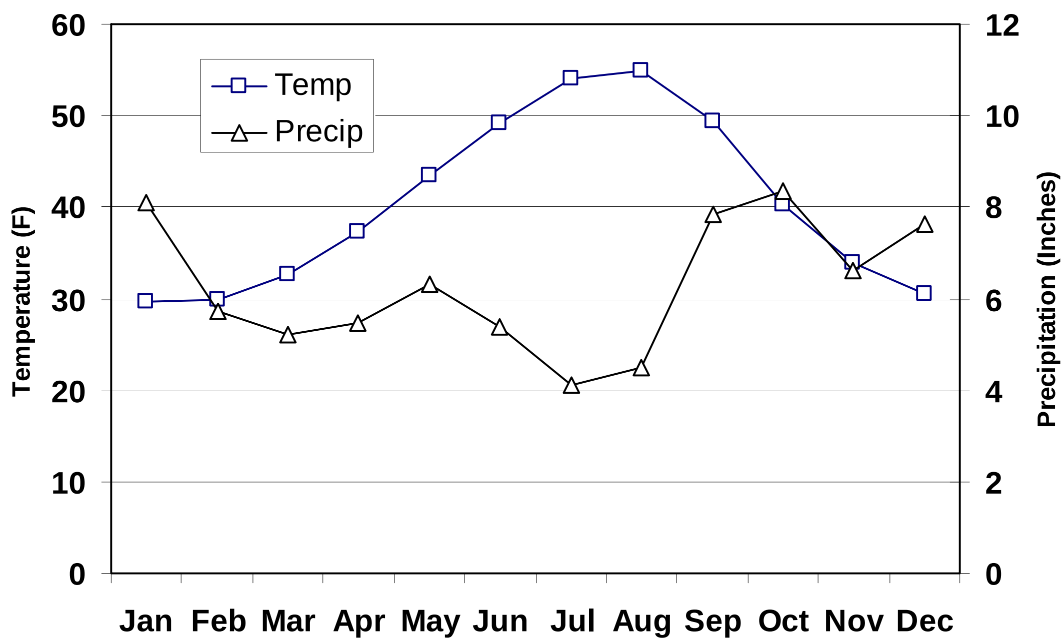

Figure 8. Mean monthly temperature and precipitation in Kodiak, Alaska for the period 1971-2000. Data from NOAA National Climatic Data Center (http://cdo.ncdc.noaa.gov/cgi-bin/climatenormals/climatenormals.pl)

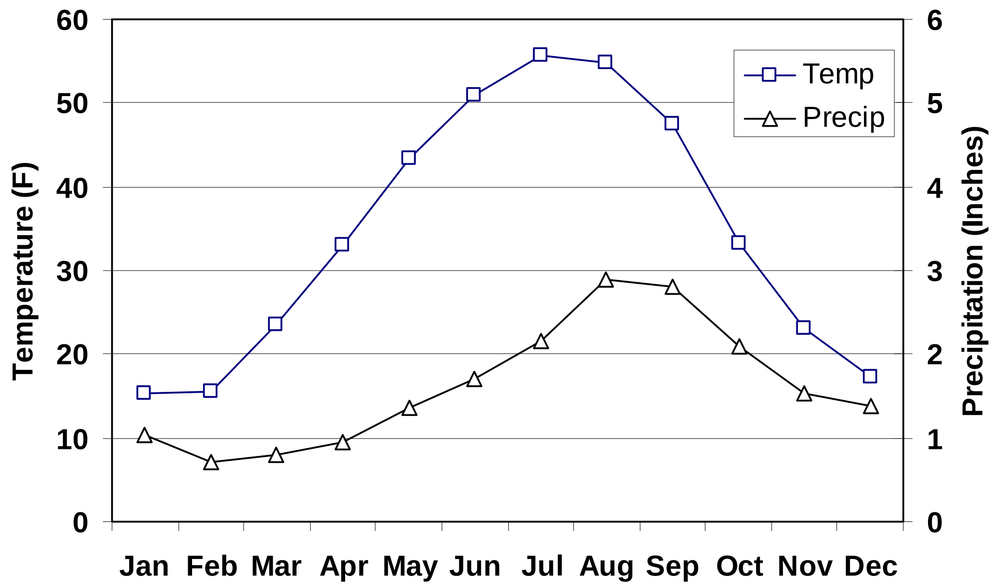

Figure 9. Mean monthly temperature and precipitation in King Salmon, Alaska at the western edge of KATM for the period 1971-2000. Data from NOAA National Climatic Data Center (http://cdo.ncdc.noaa.gov/cgi-bin/climatenormals/climatenormals.pl)

B3. Streams and Streamflow

B3a. Descriptions and lists of streams and stream habitat

Major drainages and bays in coastal KATM include (from north to south): Kamishak River, Douglas River, Cape Douglas, Big River, Swikshak, Hallo, Kukak, Kaflia, Kuliak, Missak, and Kinak Bays, Amalik Bay, Dakavak Bay, Katmai River and Bay, and at the southern boundary, Kashvik Bay (**Figure 10**). Most streams in the study area are unnamed and few are connected to lakes. They are generally short (<33 km, 21 mi long), steep, and many drain glaciers.

Because much of the southern end of the coast is blanketed by several meters of volcanic ash from the Novarupta eruption, streams in the area such as the Katmai River, Soluka Creek and unnamed streams that flow into Kukak Bay are heavily braided (Katmai River is 5 km wide) and choked with volcanic ash (Heard et al., 1969). Further north up the coast, the Swikshak River and two streams that empty into Hallo Bay are also extensively braided, although in their case this is largely due to high loads of glacial silt. Glacially-influenced streams draining into Hallo Bay, Kukak Bay, and near Cape Douglas produce extensive alluvial fans, wide beaches, and dune fields (Harper and Morris, 2005) (**Figure 11**, **Figure 12**). In contrast, the streambeds of the Big River, Alagogoshak Creek, the outflow streams from Dakavak Lake and Kuliak Bay Lakes, and the inflow and outflow streams from Devils Cove Lake are fairly stable with moderate gradients (Heard et al., 1969). The lateral streams draining the steep mountain slopes along the fjords as short and precipitous with irregular flows and unstable streambeds (Brabets et al., 1999; NPS, 1983). However, Big River, which drains a lower elevation and non-glaciated area is described as having alternate stretches of pools and riffles, numerous small oxbows and cutoff meanders, and a low-gradient, slow-flowing section above its mouth (Heard et al., 1969).

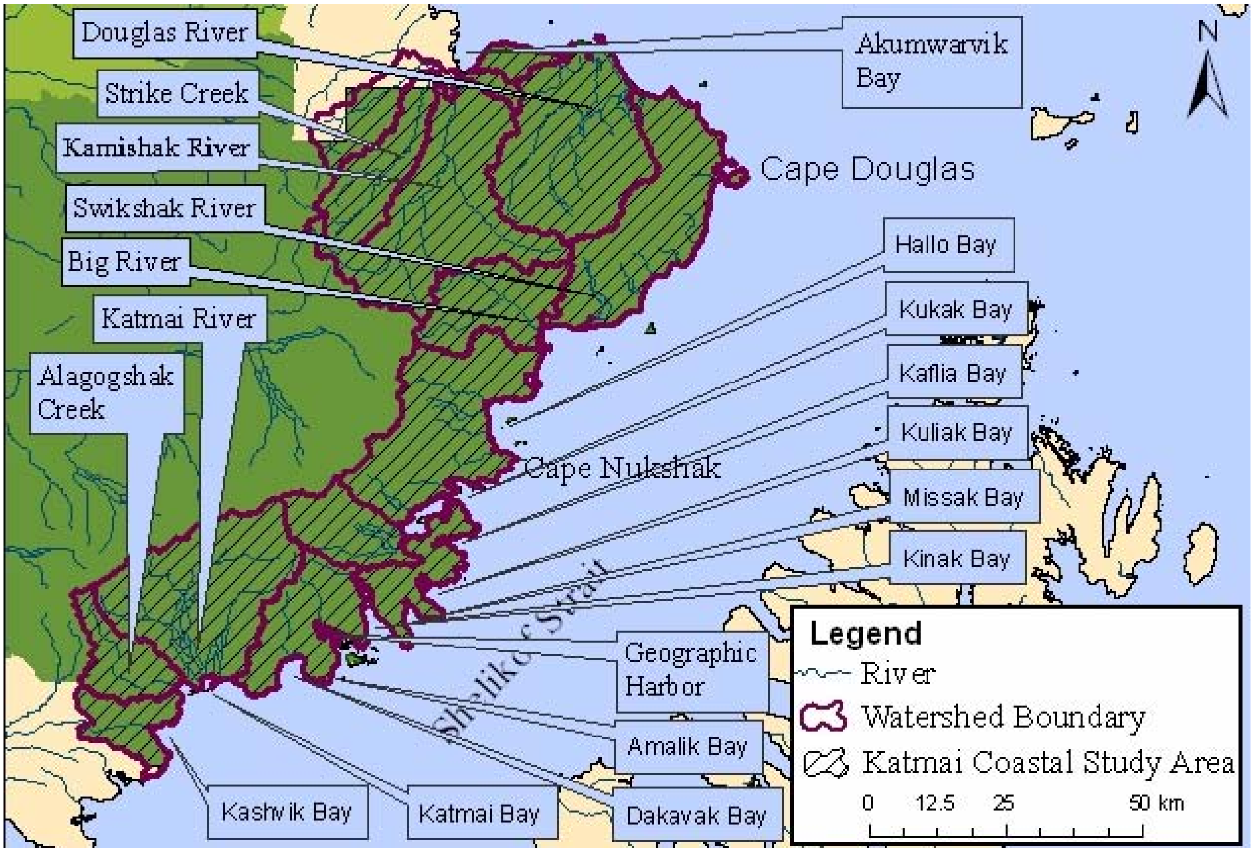

Figure 10: KATM coastal watersheds and bays.


Figure 11. The highly braided Douglas River near its mouth. August 2005. Photo: S. Nagorski


Figure 12. Mouth of the Douglas River. August 2005. Photo: S.Nagorski

B3b. Streamflow

The hydrologic regime of these watersheds in coastal KATM is dominated by runoff from seasonal snow cover and glaciers. Streamflow data from the USGS is not available for any of the streams or rivers within KATM. There are six operational USGS streamflow gages located within approximately 100 km (60 mi) of KATM (**Figure 13**, **Table 2**). With the exception of the Terror River on Kodiak Island, all of these gages are located at interior locations and thus are probably not representative of the hydrologic regime of streams in coastal KATM. The hydrograph of the Terror River may be representative of streamflow in non-glacial streams within coastal KATM. The hydrograph shows a streamflow peak in June associated with snowmelt runoff and a secondary peak in September associated with the fall precipitation maximum (**Figure 14**a). The Johnson River in Lake Clark NP has similar watershed characteristics to glacial coastal watersheds in KATM (Harper and Morris, 2005), and thus provides a representative glacial hydrograph for KATM. The Johnson River hydrograph is less influenced by precipitation and shows a broad peak in the period June-September when glacial melt is at a maximum (**Figure 14**b).

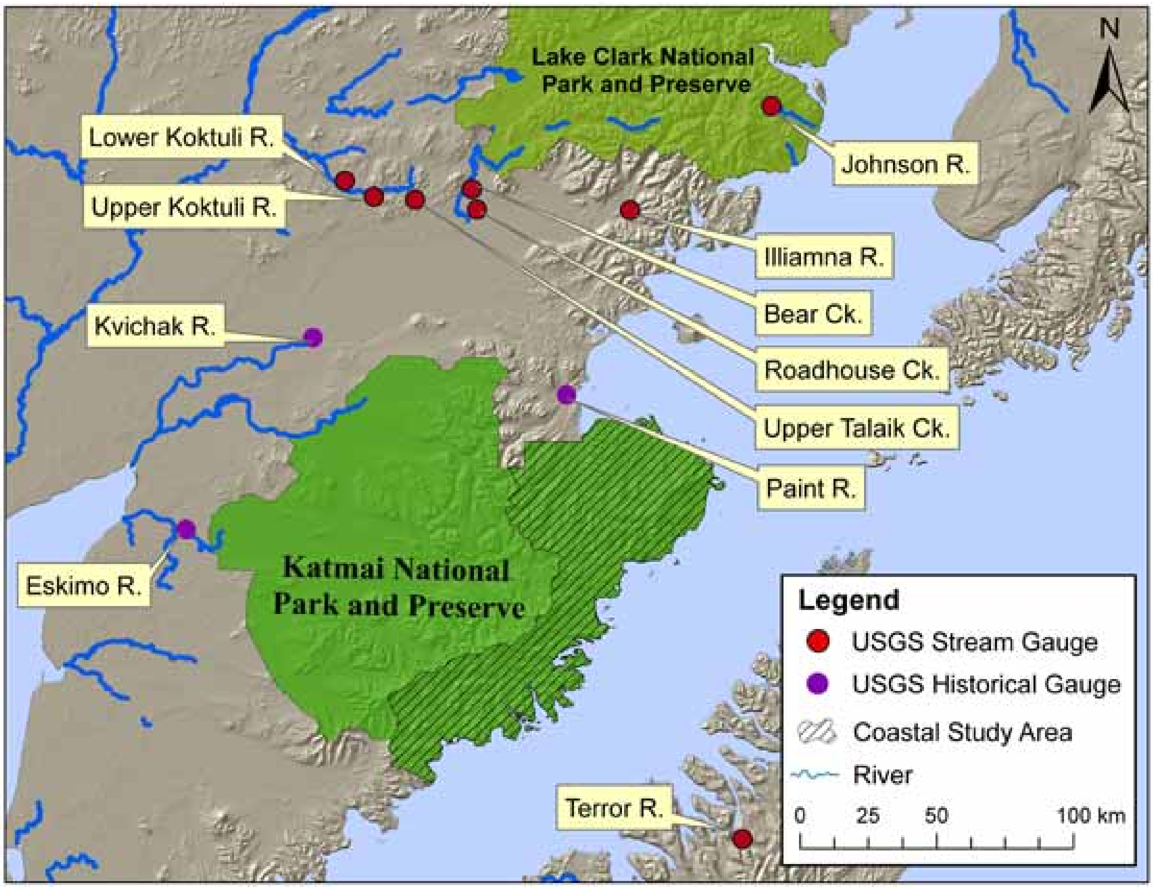

Figure 13. USGS streamflow gages in the vicinity of KATM.

Table 2. USGS streamflow gages near KATM. Coordinates are in NAD83. Data from USGS streamflow database for Alaska (http://waterdata.usgs.gov/ak/nwis/sw).

Station Name	Gauge #	Lat.	Long.	Dist. From KATM (km)	Period of Record
Terror R	15295700	57.694	-153.164	100	1964-present
Iliamna R	15300300	59.758	-153.847	77	1996-present
Koktuli Upper R	15302200	59.793	-155.525	60	2004-present
Koktuli Lower R	15302250	59.843	-155.719	68	2004-present
Roadhouse Ck	15300200	59.757	-154.849	55	2005-present
Upper Talarik Ck	15300250	59.786	-155.255	58	2004-present
Johnson R	19020602	60.095	-152.911	137	1995-2004
Eskimo Ck	15297900	58.696	-156.669	9	1973-1984
Kvichak R	15300500	59.329	-155.899	25	1967-1987
Paint R	15294900	59.155	-154.259	14	1983-1995

In addition to the six operational stream gages, there is historic streamflow information available from three USGS gages near coastal KATM. To the west of the park, Eskimo Creek was gaged from 1973-1984 and the Kvichak River was gaged from 1967-1987. North of KATM, the Paint River draining into McNeil Cove was gaged from 1983-1995. However, these are all between 55 km (34 mi) and 100 km (62 mi) away from the KATM coastal watersheds. The absence of current and historic streamflow gauging stations in or near KATM prohibits any direct interpretation of temporal and spatial hydrological dynamics of streams within coastal KATM. However, the dominant influence on the hydrologic regime in coastal KATM streams is clearly the presence or absence of glaciers. Glacial streams have higher water and sediment yields, and a lower water temperature and ionic strength compared to non-glacial streams (Brabets et al., 1999).

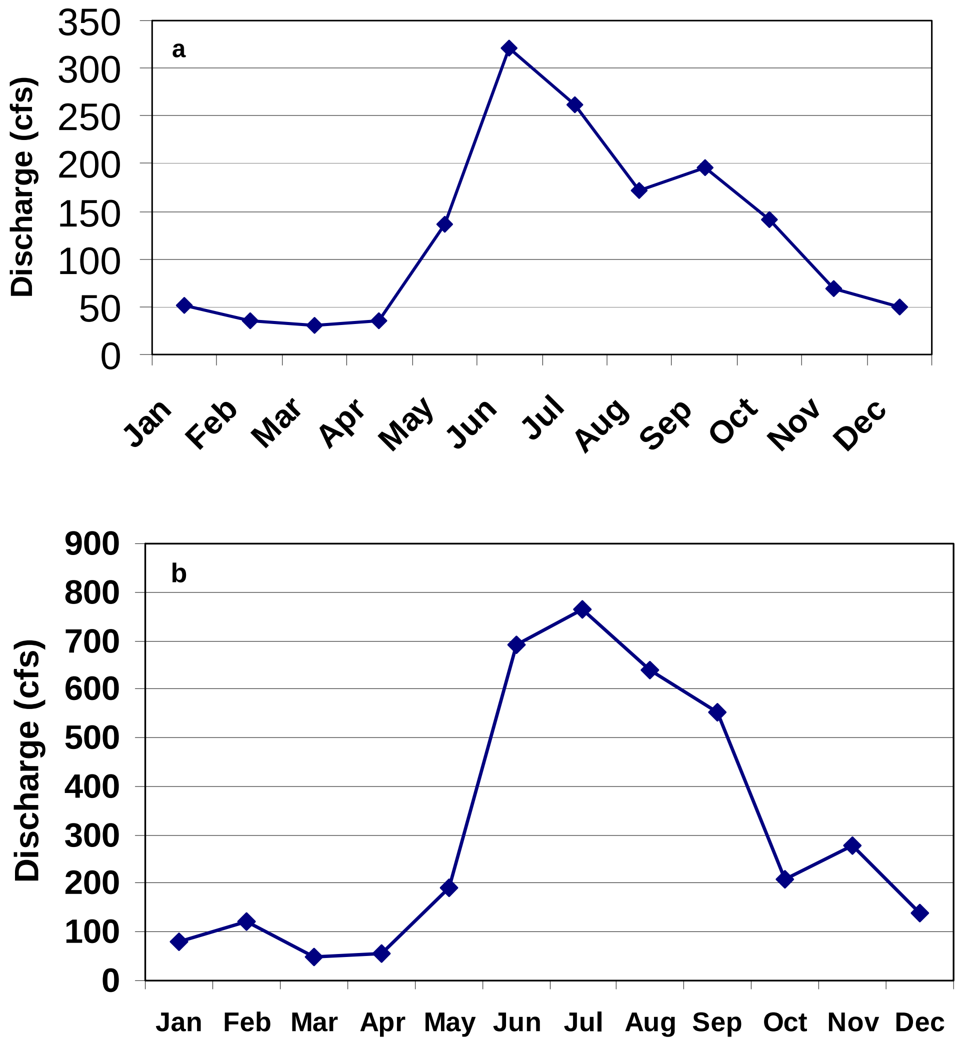

Figure 14. Monthly mean streamflow for the Terror River (a) and Johnson River (b) near coastal KATM. Data for the Terror River cover the period 1964-2006, while data for the Johnson River cover the period for the period 1995-2004. Data from USGS streamflow database for Alaska (http://waterdata.usgs.gov/ak/nwis/sw).

B4. Lakes and Ponds

While interior KATM has an extensive lake system, including the largest freshwater lake in the National Park system, coastal KATM hosts relatively few lakes. The major lakes in coastal KATM are Kaguyak (sometimes spelled "Kuguyak") Crater Lake near Big River, the Crater Lake of Mount Katmai, and Dakavak Lake, southeast of Katmai's Crater Lake (**Figure 15**). Although small compared to lakes in interior KATM, these lakes are relatively deep for their size (Heard et al., 1969). The largest lake on the coast is Dakavak Lake, which is approximately 4.5

km (2.8 mi) long and 1.0 (0.6 mi) wide and at least 21 m (69 ft) deep (Weeks, 1999). Dakavak Lake has a chalky, blue-gray color due to the influence of pumice and ash in this area close to Novarupta. Smaller and generally clear lakes include: Hallo Glacier Lake, Devils Cove Lake, Kaflia Bay Lakes, and Kuliak Bay Lake (Heard et al., 1969) Heard et al. (1969) also reports small hanging lakes with high waterfalls at the heads of Amalik and Kinak Bays. Low-lying areas near the coast are pockmarked with ponds, many of which appear to be interconnected by extensive wetland systems (**Figure 16**). Virtually nothing is known about these waterbodies.

Katmai Lake (1242 m (4074 ft) elevation; 4.1 km^2 (1.6 mi^2)surface area) is a very recently formed waterbody (Motyka, 1978). It formed as a result of the collapse of several peaks on Mount Katmai due to the withdrawal of interior magma during the 1912 eruption of Novarupta (Hildreth and Fierstein, 2000). The caldera formed a closed basin and the small lake, which was present in 1916-1919 (Griggs, 1922). However, in 1923 a vigorous mud geyser was present in place of the lake (Fenner, 1920). Sometime later, meltwater contributions to the crater drowned out the geyser and a lake again began to form (Keith et al., 1992). Between 1953 and 1974 it rose approximately 2 m/year (7 ft/yr) and grew to a depth of 230 m by 1975 (Motyka, 1978). Drowned fumaroles(s) on the caldera floor continued to emit magmatic gases into the lake at least as of 1990 (Keith et al., 1992).

Four other caldera lakes are present in coastal KATM, and like Katmai's crater lake, none has an outlet stream (Kozlowski, 2006, in preparation). Motyka et al. (1993) describes Martin, Mageik, and Douglas crater lakes in the same category as Katmai's crater lake-- as having acidic waters that absorb the high temperatures and sulfur- and chlorite-rich volcanic gases emanating from the geothermally-active subsurface. Mt. Magiek's lake is a bluish yellow lake approximately 300 m (1000 ft) in diameter and 100 m (300 ft) deep, and with a pH of ~1 (Motyka et al., 1993). Mt. Douglas's crater lake is larger: 160x200 m, and while blue-green is covered in a black scum of sulfide minerals fed by subaqueous fumaroles, and also has a pH of ~1 (Motyka et al., 1993). Kaguyak Lake, near Big River, lies at an elevation of 366 m (1200 ft), has a surface area of 3.5 km^2 (1.4 mi^2), and has an unknown depth (Cameron and Larson, 1993).

Figure 15. Major lakes in coastal KATM.

Figure 16. Nearshore landscape along Cape Douglas showing the dominance of ponds and wetlands along the lower elevations. August 2005. Photo: S. Nagorski.

B5. Groundwater and springs

There are no known data available concerning groundwater resources in coastal KATM. The water resources scoping report for KATM makes the general observations that coastal aquifers in KATM are likely influenced by salt water and that groundwater flow, depth, quantity, and quality likely vary strongly over short distances (Weeks, 1999). The only exceptions to this lack of any specific data in the region are some estimated calculations of groundwater temperatures (~70ºC, 160ºF) in the Mageik Creek thermal springs region near Mt. Katmai (Keith et al., 1992). Keith et al. (1992) describe the thermal springs as part of a deeply circulating, long-lived system heated by the geologically active Katmai-Novarupta volcanic system, which also fuels the hydrothermal systems in the Valley of Ten Thousand Smokes to the northwest of Mt. Katmai. Information on groundwater resources in areas in the Cook Inlet region, near coastal KATM, is available from the USGS's National Water Quality Assessment Program (NAWQA) (Glass et al., 2001).

B6. Wetlands

KATM contains a diversity of wetland types including marine, estuarine, riverine, paulstrine, and lacustrine. These wetland areas are important because they serve as an interface between terrestrial habitats and aquatic environments such as streams, lakes and nearshore marine zones. Wetlands provide a number of important hydrological and ecological functions including: controlling floods and regulating streamflow, providing organic nutrients to aquatic ecosystems, controlling erosion, and filtering impurities from water that passes through them. For the entire park, estimates of wetland coverage exceed 4000 km^2 (>1 million acres; Weeks, 1999). It is not possible to estimate the wetland area in coastal KATM because the wetlands in the park have not been comprehensively mapped. KATM is one of several national parks in Alaska that have not been mapped through the US Fish and Wildlife Service National Wetlands Inventory mapping program (http://wetlandsfws.er.usgs.gov/). However, Harper and Morris (2005) estimate that wetlands make up 20% of the coastal area of KATM. The majority of wetlands in coastal KATM are estuarine wetlands as well as palustrine and riverine wetlands located along valley bottoms. Harper and Morris (2005) describe a variety of wetland/estuary shores in KATM including: embayment estuaries, alluvial fan estuaries, lagoon estuaries, and pocket beach estuaries. These coastal wetlands provide valuable habitat for fish, waterfowl and bears. Flora within these wetlands typically exhibit a high degree of spatial variability based on changes in topography and salt water exposure (Figure 17).

It is important to note that the estuarine and marine wetlands in KATM are primarily under the jurisdiction of the state of Alaska. The Alaska Department of Environmental Conservation recently developed a guidebook and methodology for functional assessment of streamside wetlands in southern Alaska (Powell et al., 2003). The Hydrogeomorphic Approach Methodology (HGM) provides a basis for assessing the hydrologic, biogeochemical, plant community and faunal support/habitat functions of wetlands.

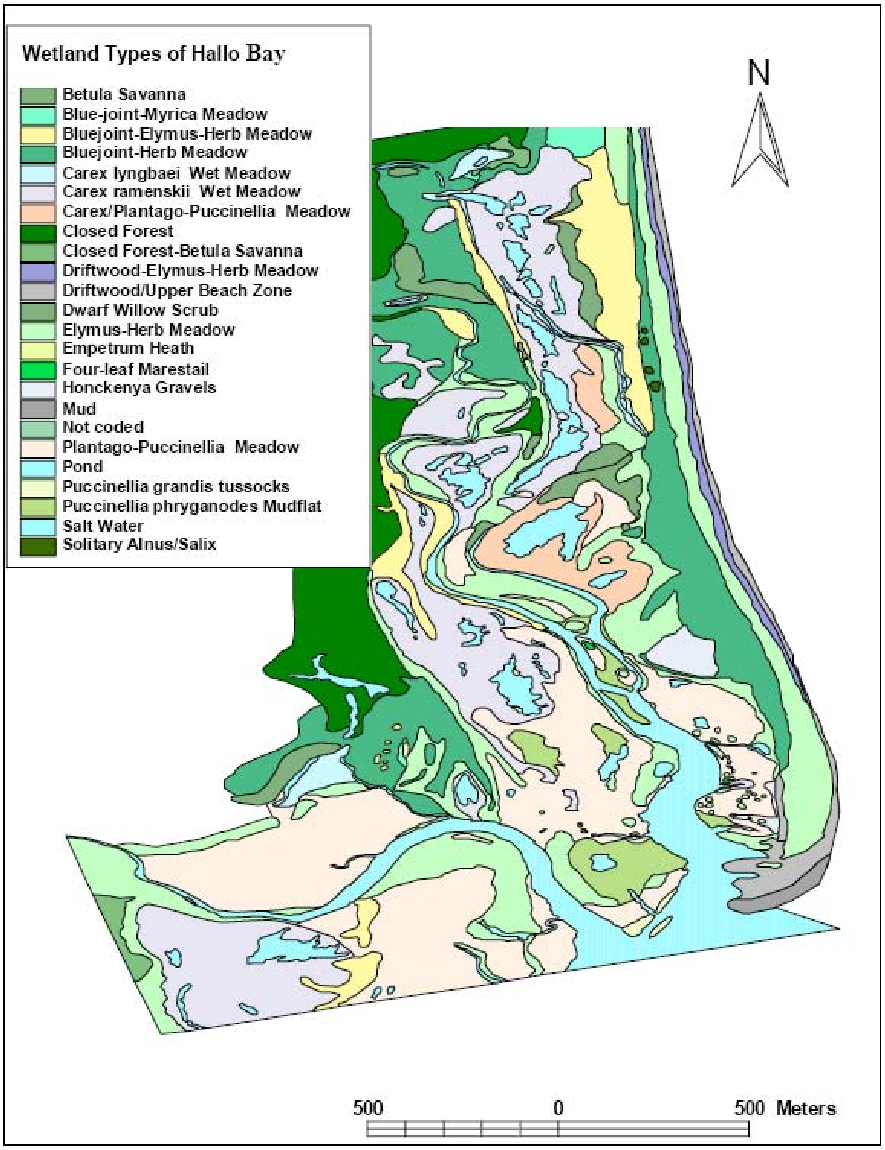

Figure 17. Map of wetland types in northeastern Hallo Bay, coastal KATM. From Harper and Morris (2005).

B7. Snow, Ice, and Glaciers

There are numerous permanent snowfields within KATM , however there are no known studies on the aerial dimensions and/or chemical attributes of these water resources. Glaciers are also abundant within KATM. Glacial ice is formed when snowfall in the accumulation zone of a glacier is progressively compressed by weight of successive annual snowfalls. Glacial ice is lighter than liquid water, has a density of 0.9 kg/m^3 (0.07 lb/ft^3), and is characterized by air bubbles isolated from gas exchange with the overlying atmosphere. The mass of water contained within an individual glacier changes yearly depending on the glacier mass balance, which is the difference between the amount of water the glacier gains annually through snowfall and refreezing rainwater and the amount of water lost through ice melt, iceberg calving, evaporation and sublimation. As a result, glacial mass balance is affected by shifts in local and regional temperature and precipitation regimes as well as by calving dynamics in the case of tidewater glaciers. Recent studies have shown that the majority of mountain glaciers in the world have been retreating and thinning for the last several decades (Dyurgerov and Meier, 2000). There are currently no glaciers in KATM that have ongoing programs to measure mass balance. The closest glaciers to KATM that have long-term records of mass balance are the Wolverine Glacier on the Kenai Peninsula and the Gulkana Glacier in the Alaska Range, both of which are USGS Benchmark Glaciers (http://ak.water.usgs.gov/glaciology/). Repeat photography has also been used to document glacial retreat for Alaskan glaciers (Molnia and Sfraga, 1999).

Glacial ice has been a dominant landform in the Katmai region and its glacial history contains multiple piedmont glaciations (Harper and Morris, 2005). Currently, about 6 percent of KATM, 87,400 ha (216,000 acres), is covered by glacial ice (Weeks, 1999). Within the coastal region of KATM which is the subject of this report, glaciers cover approximately 71,000 ha (180,000 acre) or 12% of the land area (Figure 18). Most of the glaciers in KATM have been retreating since the end of the Little Ice Age ~250 years ago and continue to retreat today. For a discussion of the impacts of climate change on KATM glaciers, see section V.B. *Climate Change*. Coastal KATM contains dozens of glaciers along the peaks of the Aleutian Range. The majority of the glaciers within KATM have grounded termini; there are no tidewater glaciers of the type found in Glacier Bay and Kenai Fjords National Parks. However, there are a number of lacustrine glaciers with termini in pro-glacial lakes (Figures 20-21). The largest glaciers in KATM are located in the Mt Douglas and Mt Steller areas and include the Fourpeaked, Spotted, Serpent Tongue, and Hallo Glaciers (Figure 18-21). The longest of these glaciers exceed 15 km (9.3 mi) in length. Despite the widespread occurrence of glacial ice, the coastal region is relatively free of permafrost because of the mild, maritime climate (Brabets et al., 1999).

Historically, there has been relatively little glacial research in KATM compared to other SWAN parks containing glaciers. Cahalane (1959) provides a brief description of some of the glacial resources in KATM in the mid 20th century. The glacier within the Katmai Caldera is one of the more studied glaciers within the park (Motyka, 1977; Muller and Coulter, 1957). In addition, the geomorphic role of snow and ice during the 1912 Katmai eruption has been studied and it appears that remnant glacier ice buried by the eruption may have persisted in the upper Lethe Valley until at least the 1970s (Hamilton, 1973). In the 1990s, glaciers on Mount Mageik and Snowy Mountain were studied by Hildreth et al. (2000, 2001). On Mount Mageik, the ice volume of glaciers has decreased substantially and the termini of all glaciers receded during the period 1951-1984. In contrast, glaciers on Mount Snowy have demonstrated an inconsistent pattern of glacier behavior during the same time period, with most glaciers retreating but some examples of stationary or advancing glaciers. The non-retreating glaciers are likely influenced by insulating ash deposits from the 1912 eruption. Currently, the SWAN I&M program is implementing a plan for long term monitoring of glacier extent in KATM using satellite imagery and repeat photography. Initial results from this effort, which is headed by Dr. Dorothy Hall from the NASA-Goddard Space Flight Center, indicate that glacier extent in KATM has decreased by approximately 9% between 1986 and 2000 (NPS, 2007).

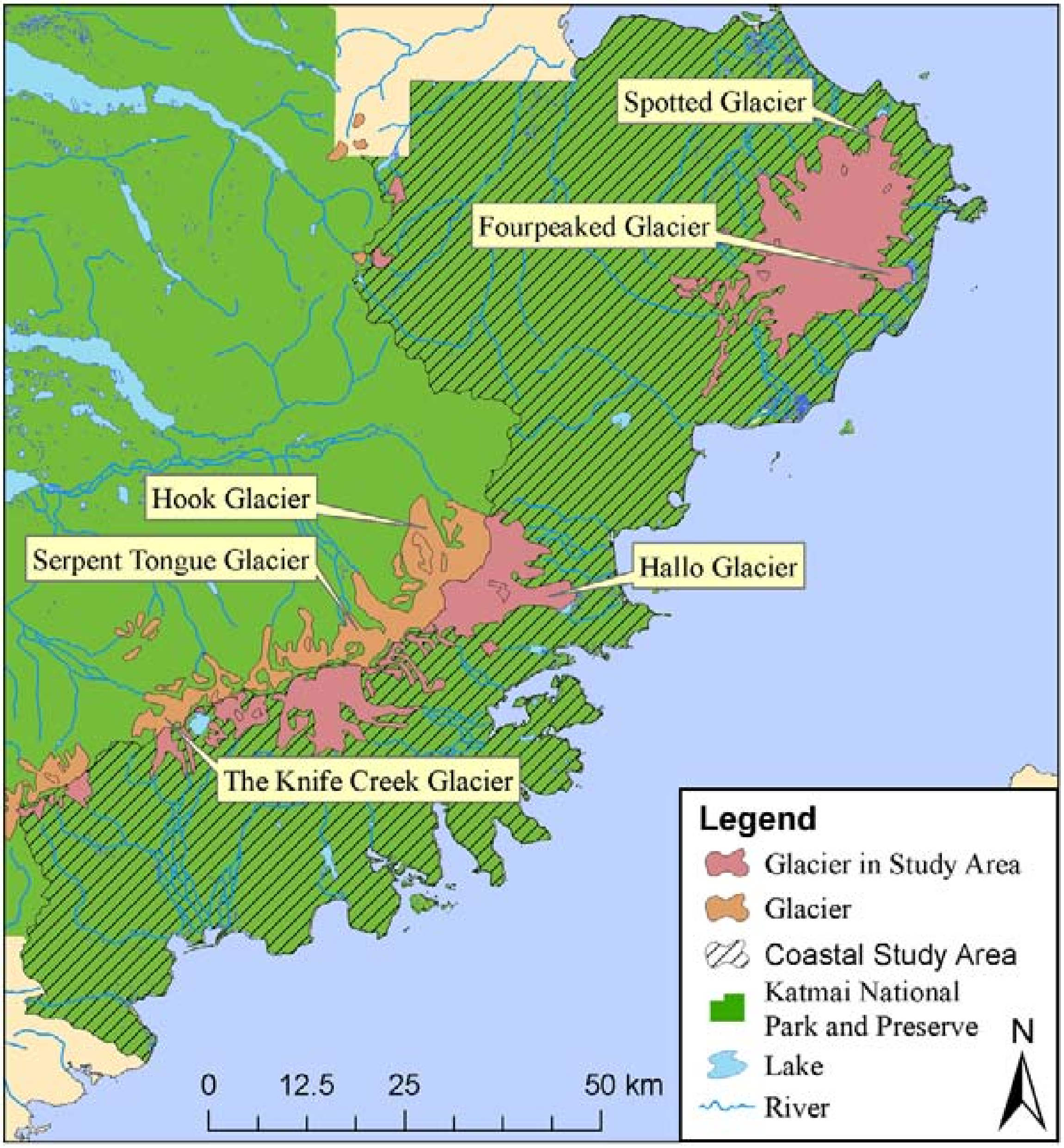

Figure 18. Glacier coverage and major glaciers within coastal KATM.

KATM glaciers have profound effects on the landscape, including erosion and deposition that produce moraines, pro-glacial lakes, and eskers. Additionally, meltwater flowing from glaciers creates broad outwash zones and braided stream channels (Figure 22) and has a dramatic influence on the annual sediment yield and hydrograph of 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), 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 KATM 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.

Figure 19. Glacier and glacial lake, with ponds and wetlands in foreground, along the slopes of Mt Douglas. August 2005. Photo: S.Nagorski

Figure 20. Glacier terminating in a glacial lake on the eastern side of Mt. Douglas. August 2005. Photo: S.Nagorski.

Figure 21. Spotted Glacier terminating at glacial lake. August 2005. Photo: S. Nagorski.

Figure 22. Stream draining Spotted Glacier. Notice stream braiding, moraines/unconsolidated deposits, and high suspended silt load. August 2005. Photo: S. Nagorski.

C. Biological Resources

Coastal KATM is rich in biological resources. The NPS I&M program in KATM is the most extensive effort to describe, catalog, and assess the condition of biological resources in KATM. Information on the SWAN I&M program can be found at http://www.nature.nps.gov/im/units/swan/ 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). As of 9/30/2001, there were 868 vascular plant species, 41 fish species, 254 bird species, and 69 mammal species reported to inhabit KATM (entire), although not all species were confirmed as present (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 NPS (NPS, 2004a, b, c). A 2003 survey of non-NPS research projects taking place within the SWAN region revealed no individual projects taking place exclusively within KATM (Thompson, 2004).

Bennett et al. (2004) identify key ecological features of coastal KATM as: 1) sheltered salt marshes and tidal flats that support lush, brackish vegetation and large populations of benthic organisms and serve as important feeding and resting areas for brown bears (*Ursus arctos*), shorebirds, and fish; 2) cliffs, headlands, and islands that support seabird rookeries and marine mammal haulouts; 3) eelgrass and kelp beds that provide herring spawning areas and a nursery substrate that supports the base of the nearshore food chain; and 4) tidally influenced coastal freshwater streams that support wild stocks of anadromous salmon.

C1. Marine Resources

SWAN monitoring of marine resources, including a description of vital signs and site maps, is described in section *A1c. SWAN I&M nearshore marine monitoring*.

C1a. Marine mammals

Steller Sea Lions

The U.S. western stock of Steller sea lions (*Eumetopias jubatus*), located westward of Cape Suckling, 144º W, and including the KATM region, is federally-listed as endangered due to declining populations throughout the western Gulf of Alaska and Bering Sea regions (Figure 24; (Sease and Loughlin, 1997). The NOAA National Marine Mammal Laboratory (NMML) conducts aerial surveys of the western stock of Steller sea lions (**Figure 23**); however, their data are not broken down to resolve abundances within KATM. The eastern stock of Stellar sea lions (east of Cape Suckling, 144º W) in Southeast Alaska is currently stable (Calkins, 1999) but listed as threatened (Gelatt et al., 2004).

The designation of the western stock as endangered provides protection for Steller sea lion populations as well as "critical" habitats that support reproduction, foraging, rest, and refuge. The Shelikof Strait region (including KATM) is designated critical habitat for Steller sea lions and is defined as "the area between the Alaska Peninsula and Tugidak, Sitkinak, Aiaktilik, Kodiak, Raspberry, Afognak and Shuyak Islands (connected by the shortest lines); bounded on the west by a line connecting Cape Kumlik (56 deg.38"/157 deg.27'W) and the southwestern tip of Tugidak Island (56 deg.24'N/154 deg.41'W) and bounded in the east by a line connecting Cape Douglas (58 deg.51'N/153 deg.15'W) and the northernmost tip of Shuyak Island (58 deg.37'N/152 deg.22'W)" (50 CFR 226.202 available at http://www.fakr.noaa.gov/protectedresources/stellers/habitat.htm). Along the Katmai coast, major haulouts are included in the established "critical habitat" areas, including Shakun Rock (58º 33.0' N, 153 º 41.5' W) and Cape Kuliak or Kuliak Rocks (58º 08.0' N, 154º 12.5' W) (T. Smith, personal communication, 2001; cited in Koslowski, in preparation). Within this area a complex suite of fishery management measures are in place to reduce competition between commercial fishing and Steller sea lions.

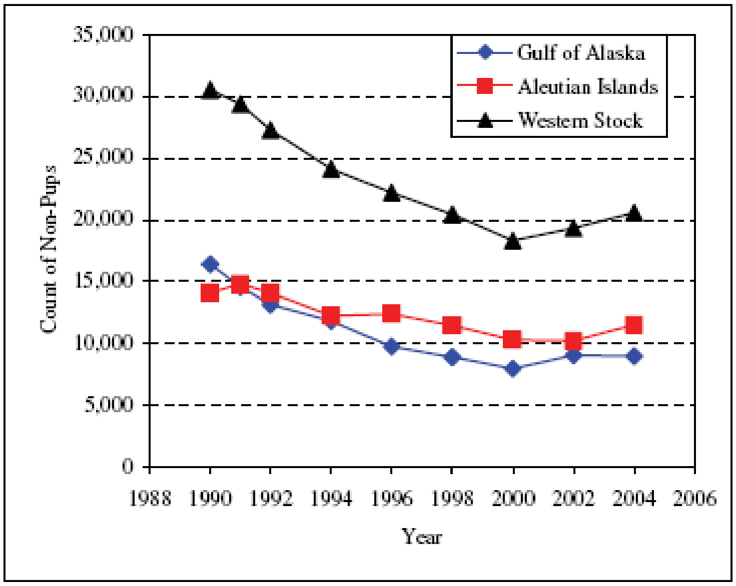

Figure 23. Counts of juvenile and adult Steller sea lions at rookery and trend sites throughout the range of the western U.S. stock (Fritz and Stinchcomb, 2005).

Early surveys of Steller sea lions along the KATM coast were conducted by park biologists (Prasil, 1971; Prasil and Blaisdell, 1968), who observed 201 sea lions on March 19, 1965, 185 sea lions on June 8, 1968, and 2310 in April, 1971, but these surveys were not conducted in a consistent manner, which makes comparisons across surveys difficult. No observations of pupping were made along the KATM coast (Prasil, 1971). Sea lions were concentrated at two haulout areas at Kuliak rocks and at the islets off Cape Ilktugitak. Peak counts at these two sites in the summer of 1991 totaled less than 40 sea lions (Starr and Starr, 1991). Bodkin et al. (2007) conducted bird and mammal surveys within a 200m strip contiguous with the shoreline and recorded 103 Steller sea lions at a density of 6.2 $\pm$ 6.2 per km^2 (16.3 $\pm$ 16.3 per mi^2; **Figure 24**), but they note that their surveys likely undersampled marine mammals that occur greater than 200 m (656 ft) from shore are not be comparable to surveys that include offshore habitats.

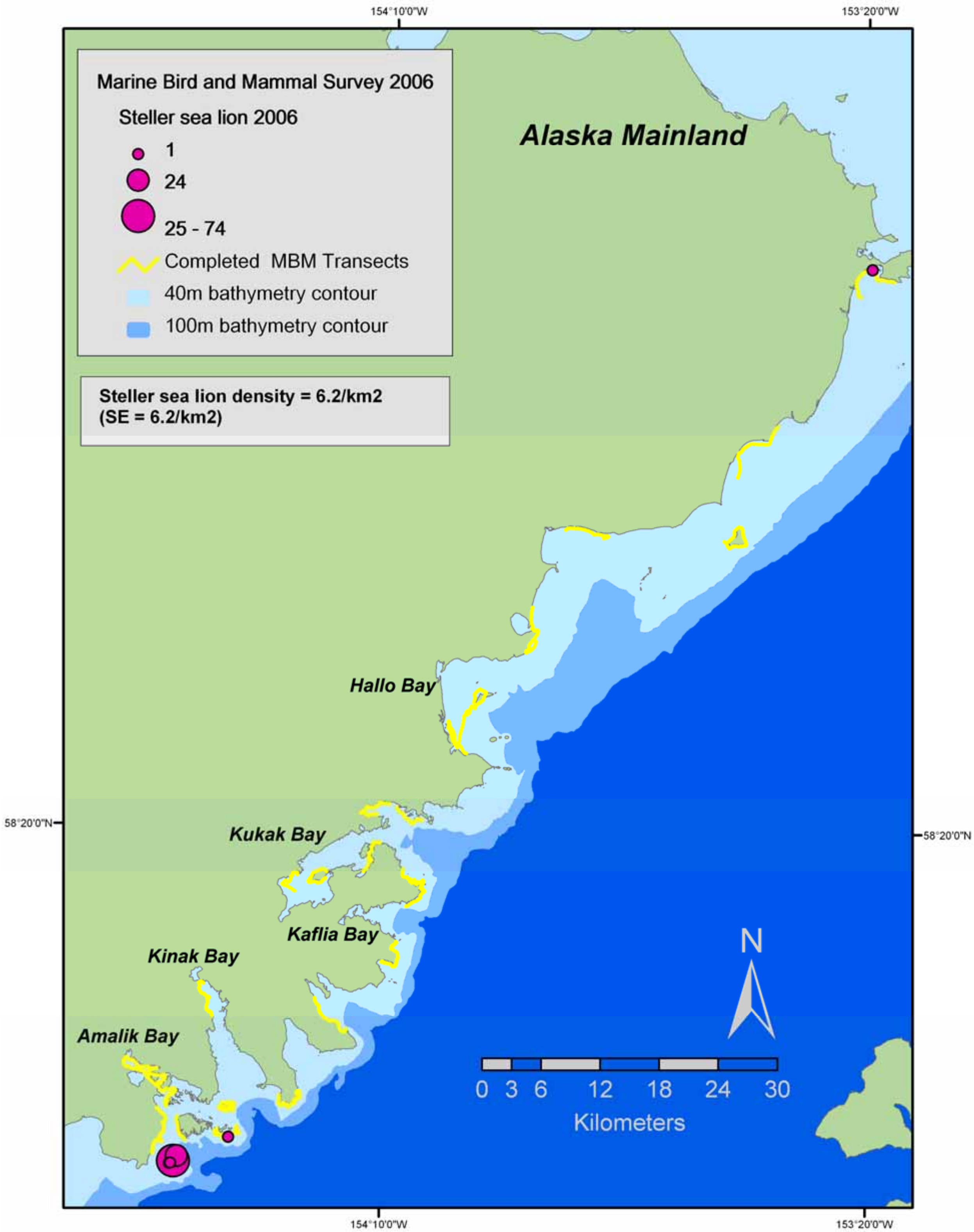

Figure 24. Distribution, abundance, and density of Steller sea lions in KATM, June 2006 (Figure 3.13 from Bodkin et al., 2007).

Harbor Seals

Harbor seals (*Phoca vitulina*) have suffered a similar decline to that of Steller sea lions and this decline has occurred in roughly the same time period. The National Marine Fisheries Service (NMFS) has joined efforts with ADFG, the Alaska Sealife Center and the Alaska Native Harbor Seal Commission to produce a joint research plan (NMFS et al. 2003) in which harbor seals in different regions of Alaska are surveyed every 5 years. Harbor seals in the Gulf of Alaska were most recently surveyed by NMFS in 2006. However, stock status reports by NMFS have not been updated since December, 1998, because the geographic boundaries of Alaskan stocks are under consideration (Angliss and Outlaw, 2005).

Specifically along the KATM coast, early aerial surveys by park biologists recorded 328 harbor seals in March, 1965, 329 harbor seals in June 1968, and 238 harbor seals in June 1993 (Goatcher, 1993; Prasil and Blaisdell, 1968), but these surveys were not conducted in a consistent manner, which makes comparisons across surveys difficult. A recent study of terrestrial mammals observed harbor seals in Amalik Bay while conducting a survey in the area (Cook and MacDonald, 2004). Bodkin et al. (2007) conducted bird and mammal surveys within a 200m strip contiguous with the shoreline and recorded 100 harbor seals at a density of 2.8 $\pm$ 1.2 per km^2 (7.4 $\pm$ 3.2 per mi^2; **Figure 25**), but they note that their surveys likely undersampled marne mammals that occur greater than 200 m (656 ft) from shore are not be comparable to surveys that include offshore habitats.

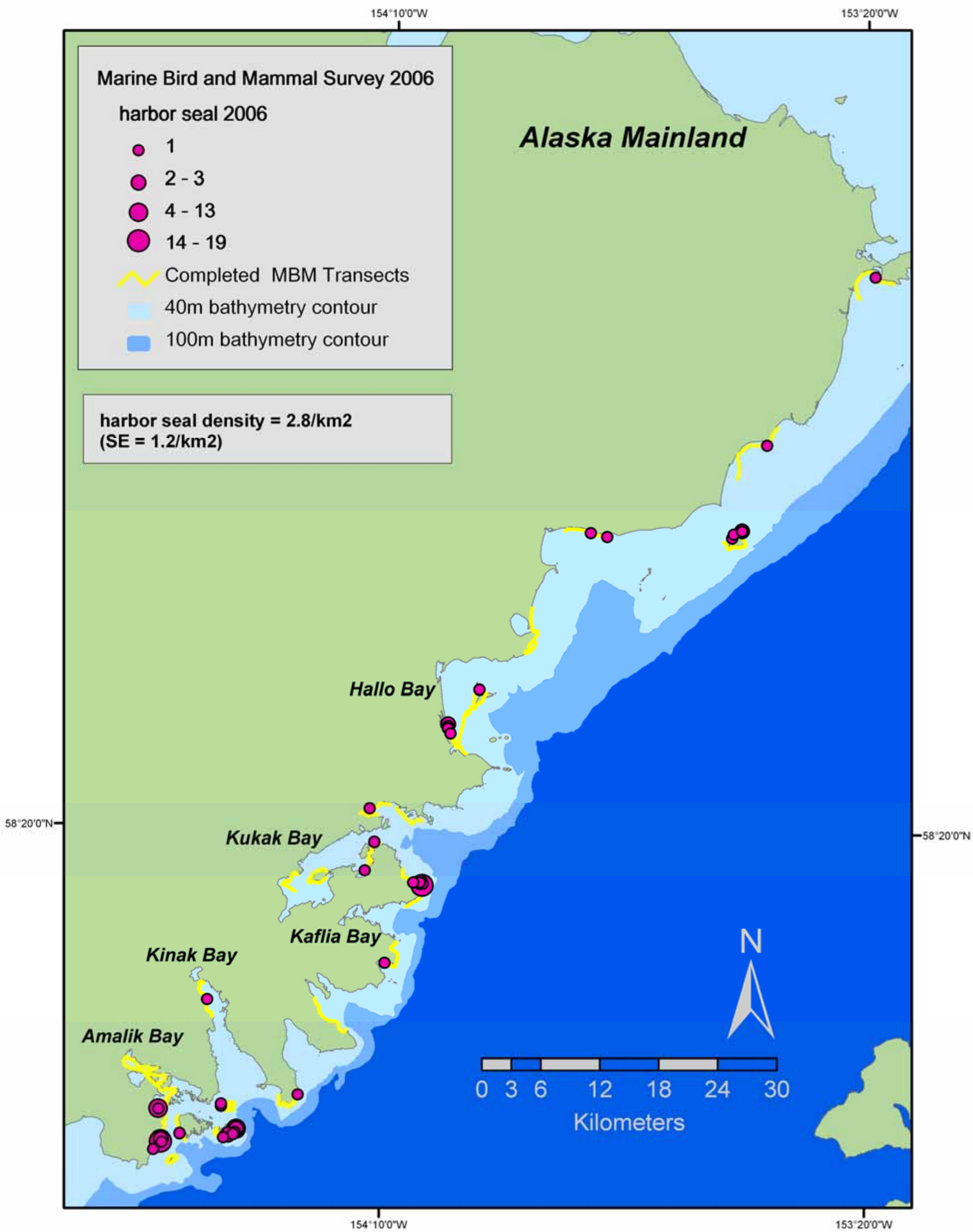

Figure 25. Distribution, abundance, and density of harbor seals in KATM, June 2006 (Figure 3.14 in Bodkin et al., 2007).

Sea Otters

Northern sea otters (*Enhydris lutris kenyoni*) in Southwest Alaska, including the Aleutian Islands, Alaska Peninsula coast, and Kodiak Archipelago, were federally-listed as threatened in 2005 (NMFS, 2007). Otters were killed by the *Exxon Valdez* oil spill (Garshelis, 1997), however the impacts on otter populations in the region (Garshelis and Johnson, 2001), especially in the KATM region, are difficult to assess. The population status of sea otters is declining through much of Southwest Alaska, although populations in the eastern region of the Peninsula may be stable or increasing (Burn and Doroff, 2005). Burn and Doroff (2005) repeated a sea otter survey along the Alaska Peninsula to evaluate changes in the population from 1989 to 2001 (**Figure 26**). From 1989 to 2001, population estimates changed from 1.75 to 1.33 otters per km^2 (4.53 to 3.44 otters per mi^2)(-24.2%) from Cape Douglas to Cape Aklek (region encompassing KATM); 0.89 to 1.55 otters per km^2 (2.3 to 4.01 otters per mi^2) (+72.9%) from Cape Kuyuyukak to Cape Aklek; and 3.94 to 4.06 otters per km^2 (10.2 to 10.5 otters per mi^2) (+3.0%) from Castle Cape to Cape Kuyuyukak (Burn and Doroff, 2005).

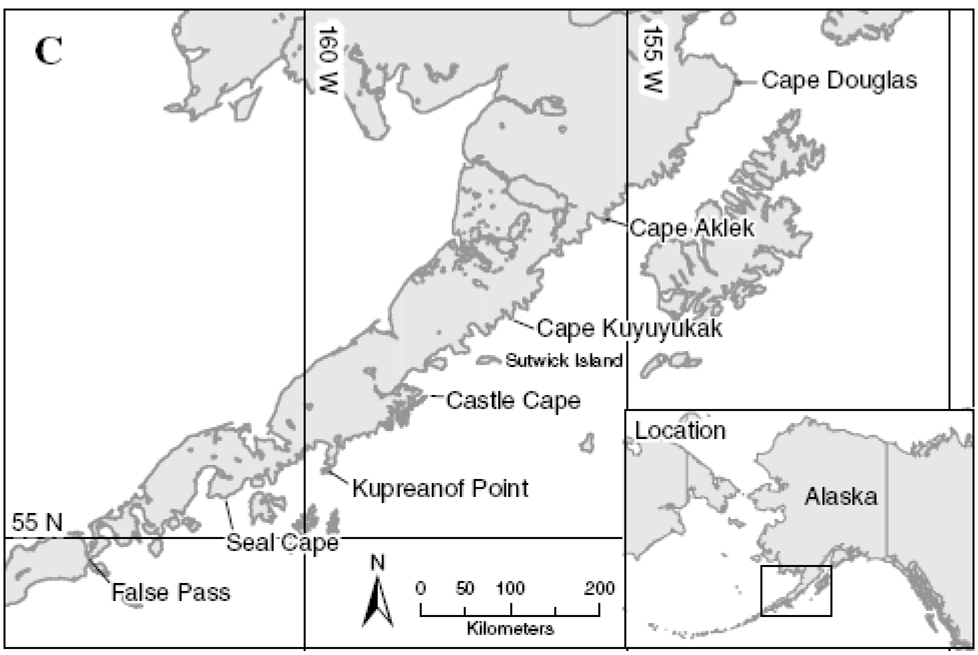

Figure 26. Sea otter survey areas along the Alaska Peninsula coastline (from Burn and Doroff, 2005).

Sea otters (*Enhydris lutris*) are common along the KATM coast. Aerial surveys of the KATM coast by park biologists recorded 101 individuals in March 1965, 3 individuals in June 1968, and 129 in 1993 (Goatcher, 1994; Prasil and Blaisdell, 1968), but these surveys were not conducted in a consistent manner across sampling periods. Aggregations of otters occur on Douglas Reef, Kiukpalik Island, Nukshak Island, and Shakun Reef (Goatcher, 1994). Shoreline surveys conducted by the SWAN I & M program in June, 2006 of 25 shoreline transects totaling 159 km (98.8 mi) or 24.5% of the KATM shoreline observed 130 adult otters, at a density of $4.9 \pm 0.5/km^2$ (12.9 ± 1.31 per mi^2) and 24 pups, at a density of 0.8 ± 0.4 per km^2 (2.1 ± 1.1 per km^2;

Bodkin et al., 2007). These sea otters were patchily distributed in KATM and were relatively more abundant on the outer coast than in bays (**Figure 27**). The density recorded by Bodkin et al. (2007) was higher than that recorded in 2001 by Burn and Doroff (2005) for the region from Cape Douglas to Cape Aklek. An aerial sea otter survey is planned for 2007 by the SWAN I&M program (Bodkin et al., 2007).

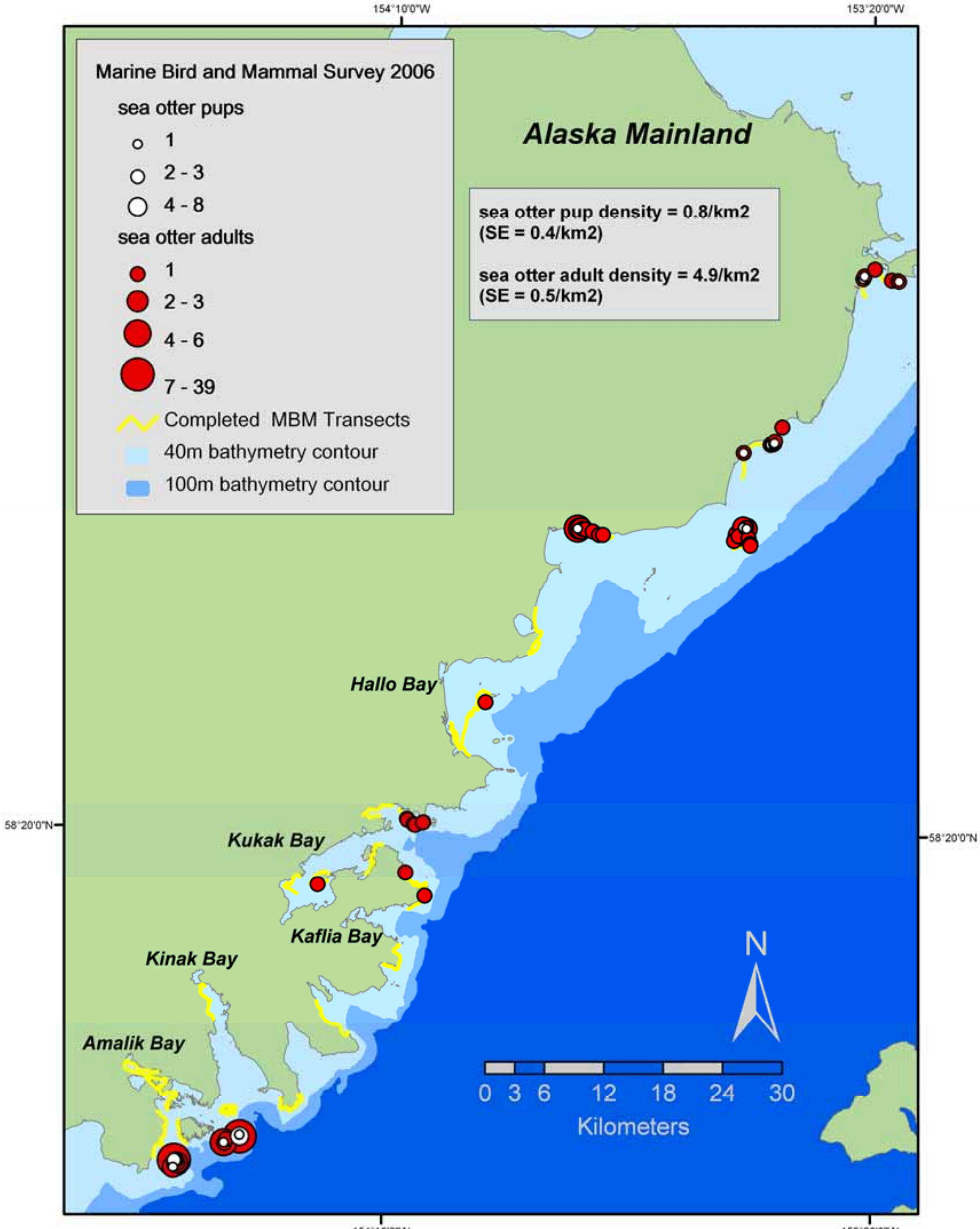

Figure 27. Distribution, abundance, and density of sea otters in KATM, June 2006 (Figure 3.12 in Bodkin et al., 2007).

Whales

Several whale species inhabit Alaskan waters and have been sighted along the KATM coast, including the fin whale (*Balaenoptera physalus*), beluga whale (*Balaena mysticetus*) and humpback whale (*Megaptera novaeangliae*) (Kavanagh, personal communication, 1999, cited in Weeks 1999). Species occurrence and concentration areas of whale species were mapped by the Kodiak Borough and species that occur or concentrate in waters off KATM include humpback and fin whales (**Figure 28**), Dall's porpoise (*Phocoenoides dalli*), minke whales (*Balaenoptera acutorostrata*) and orca whales (*Orcinus orca*) (**Figure 29**).

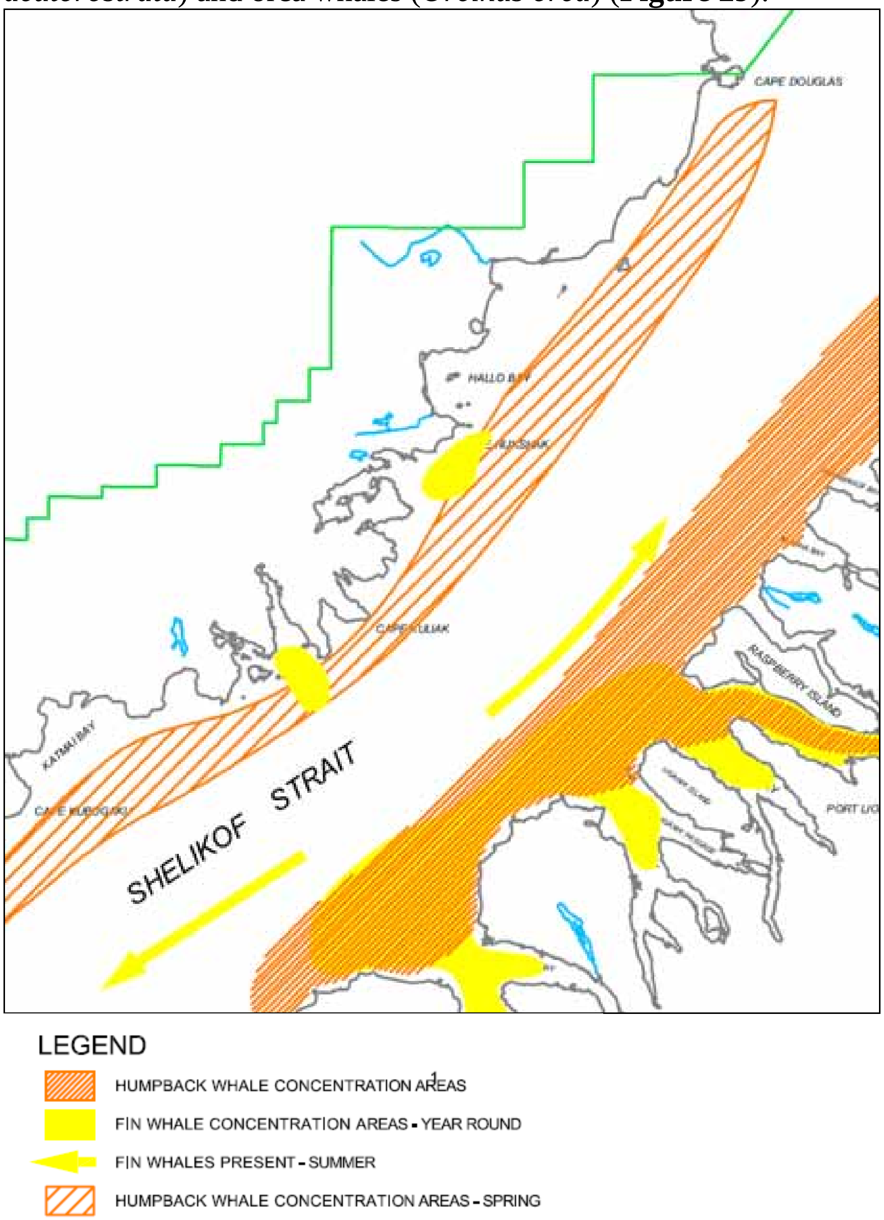

Figure 28. Excerpt of map of humpback and fin whale concentration areas near KATM. Map available from the Alaska State Geospatial Clearinghouse website for the Kodiak region (at http://www.asgdc.state.ak.us/maps/cplans/subareas.html#kodiak). Map data are based on NMFS resources, with additional information by local communities, resource agencies, and resource focus groups.

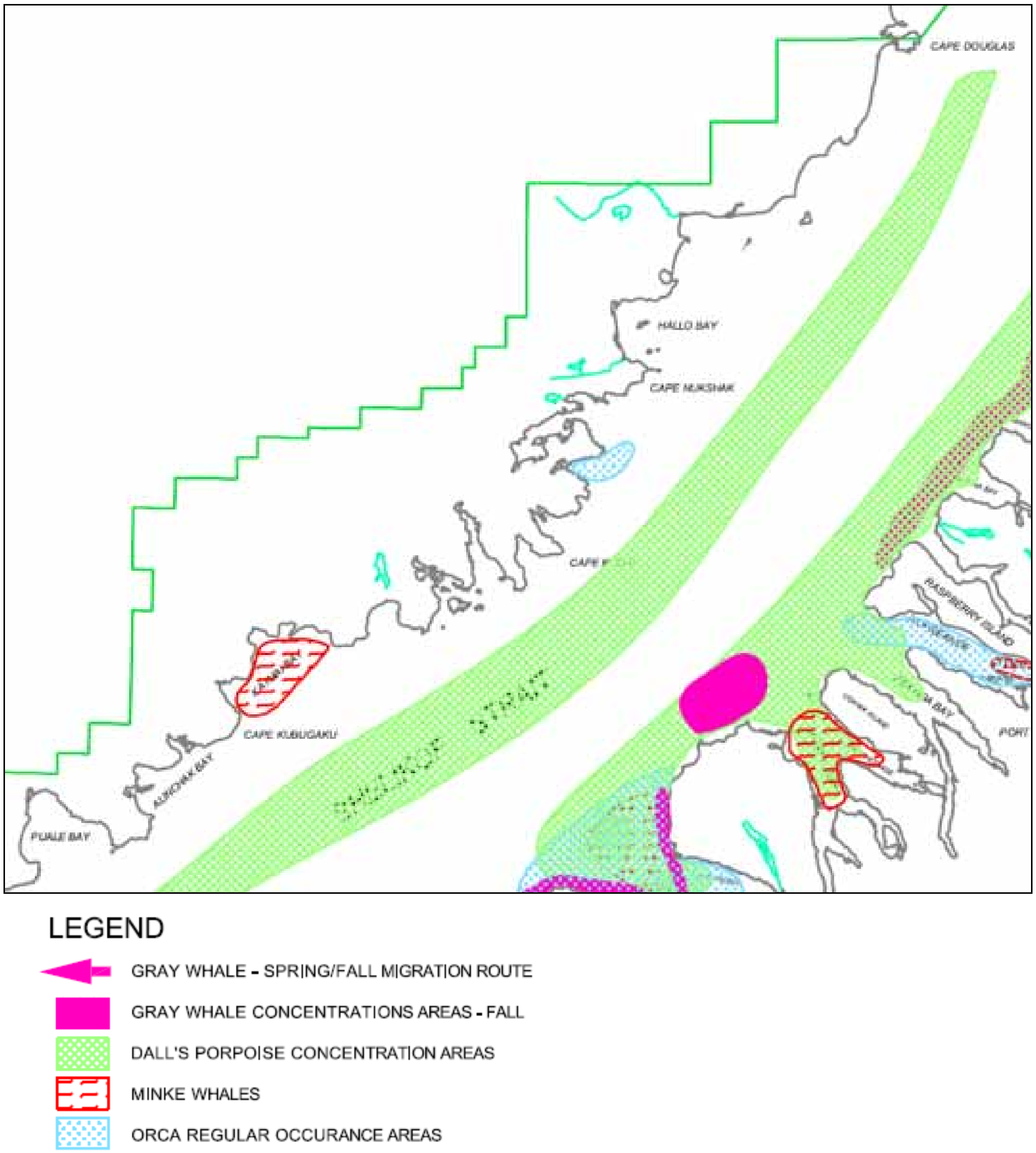

Figure 29. Excerpt of map of Gray whale, Dall's porpoise, minke whale, and orca whale occurrence and concentration areas near KATM Map available from the Alaska State Geospatial Clearinghouse website for the Kodiak region (at http://www.asgdc.state.ak.us/maps/cplans/subareas.html#kodiak). Map data are based on NMFS resources, with additional information by local communities, resource agencies, and resource focus groups.

Other Marine Mammals

Harbor porpoise (*Phocoena phocoena*) were documented to occur in Amalik Bay by Cook and MacDonald (2004), who were conducting an inventory of terrestrial mammals in the area.

C1b. Marine fishes

Anadromous and freshwater fish species are addressed in section III.C.6 a. *Freshwater Fishes*. Many species of marine fish likely occur in marine waters off the KATM coast, although a complete survey has not been conducted. Several species of marine fishes have been found in shallow waters on the KATM coast during beach seining in Kukak, Hallo and Swikshak Bays, including Pacific herring (*Clupea pallasii pallasii*), a type of sole, tubenose poacher (*Pallasina barbata*) and Pacific sandfish (*Trichodon trichodon*) (Fechhelm et al., 1999). The NPSpecies list includes 10 species of marine fishes (**Table 3**).

Table 3. Marine fishes on the NPSpecies list for KATM (NPS 2004b).

Family	Species Name	Common Name
Agonidae	*Asterotheca alascana*	Gray starsnout
Agonidae	*Pallasina barbata*	Tubenose poacher
Clupeidae	*Clupea pallasii pallasii*	Pacific herring
Cottidae	*Cottus aleuticus*	Coastrange sculpin
Cottidae	*Icelinus borealis*	Northern sculpin
Cottidae	*Leptocottus armatus*	Pacific staghorn sculpin
Cyclopteridae	*Liparis gibbus*	Variegated snailfish
Gadidae	*Gadus macrocephalus*	Pacific cod
Pleuronectidae	*Platichthys stellatus*	Starry flounder
Trichodontidae	*Trichodon trichodon*	Pacific sandfish

C1b1. Marine fisheries

The Shelikof Strait region is a very rich area for commercial fishing. Fishing of anadromous species is discussed in section *C3a. Freshwater resources – Fishes*. Documenting the marine commercial fisheries that occur within the vicinity of KATM is a large task that is well beyond the scope of this report (and the boundaries of KATM). The Kodiak Borough mapped the distribution of important areas for commercial fisheries and critical nursery areas, including pollock and herring spawning areas and pollock juvenile rearing area (Figure 30); herring, pollock, halibut, cod, scallops fishing areas (**Figure 31**); king and tanner crab resource areas (**Figure 32**); and Dungeness crab, shrimp, razor clam, and hardshell clam resource areas (**Figure 33**).

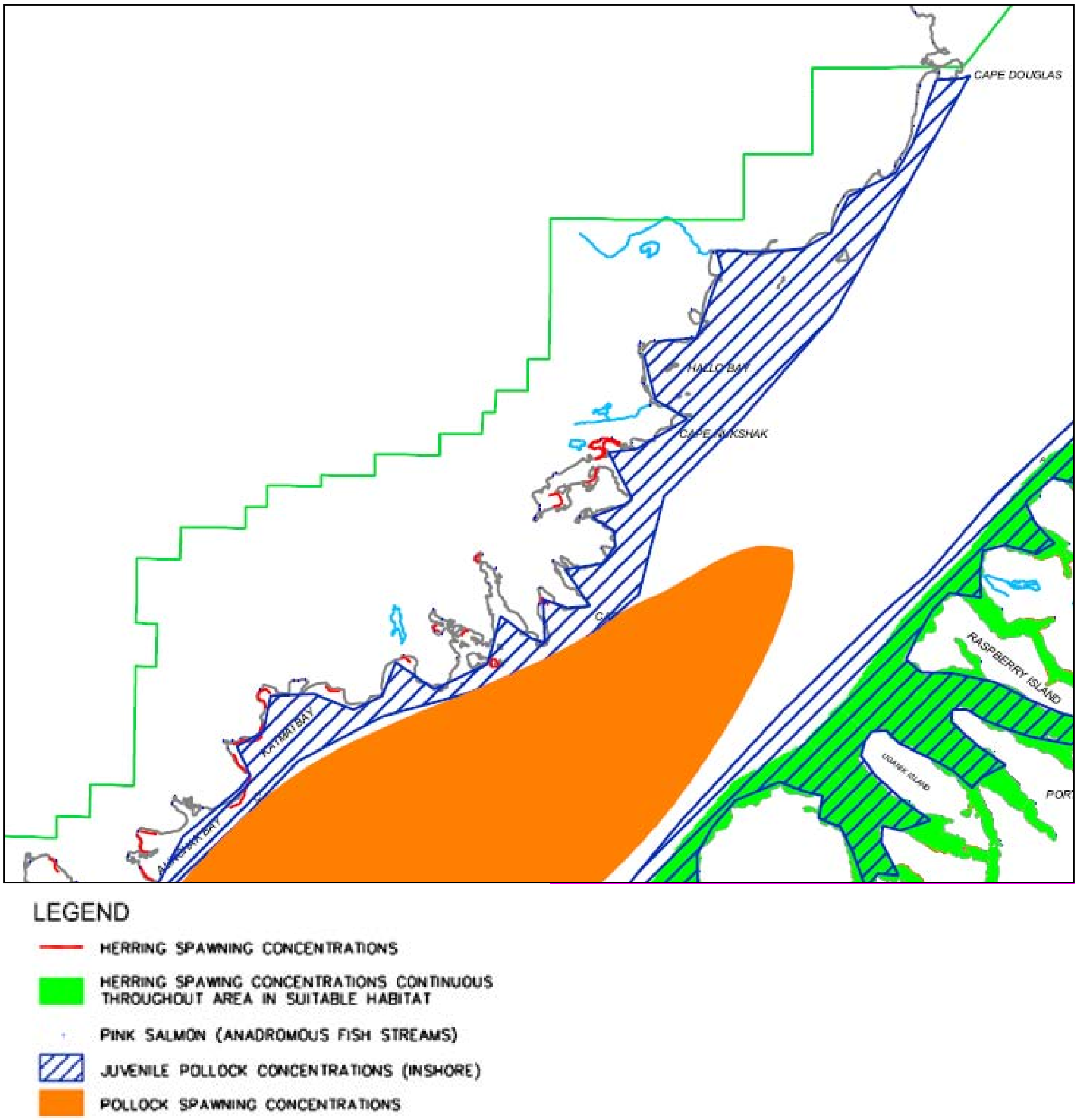

Figure 30. Excerpt of herring spawning, pollock spawning, pollock juvenile rearing, anadromous fish streams in the Shelikof Strait area. Map available from the Alaska State Geospatial Clearinghouse website for the Kodiak region (at http://www.asgdc.state.ak.us/maps/cplans/subareas.html#kodiak). Map data are based on Alaska Department of Fish and Game and NOAA resources, with additional information by local communities, resource agencies, and resource focus groups.

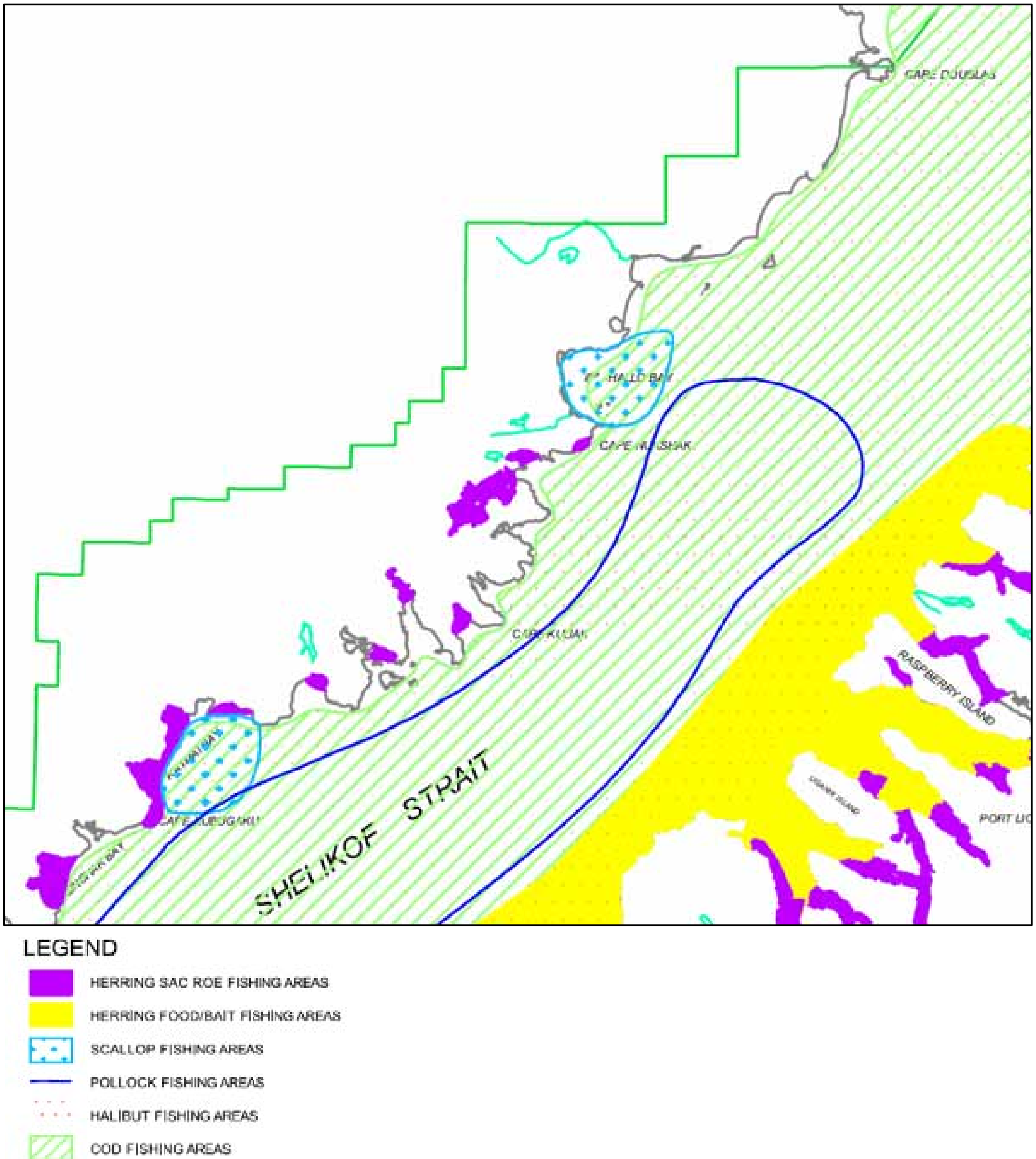

Figure 31. Excerpt of map of commercial fishing areas for herring, pollock, halibut, cod, and scallops in the Shelikof Strait area. Map available from the Alaska State Geospatial Clearinghouse website for the Kodiak region (at http://www.asgdc.state.ak.us/maps/cplans/subareas.html#kodiak). Map data are based on ADF&G and NOAA resources, with additional information by local communities, resource agencies, and resource focus groups.

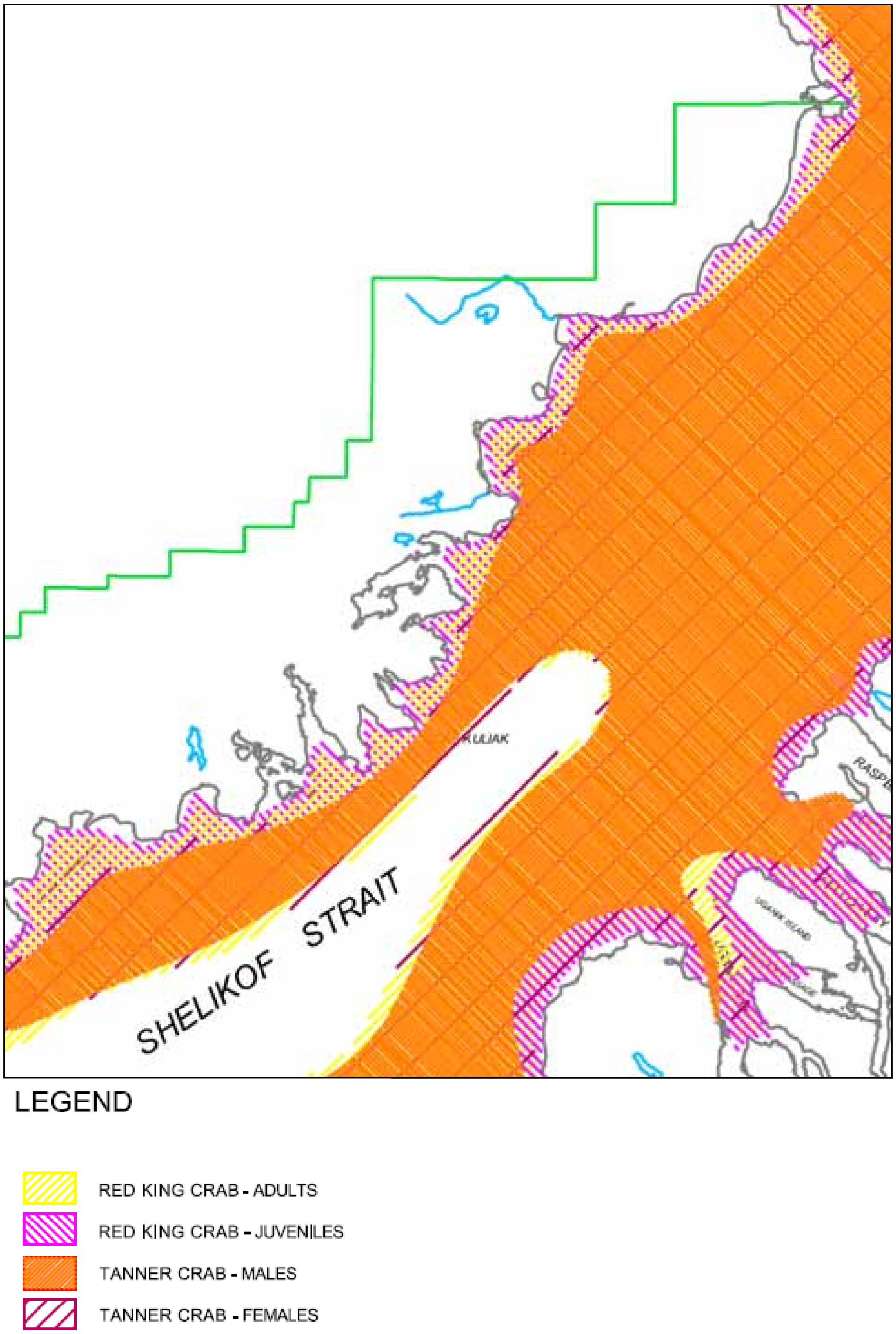

Figure 32. Excerpt of map of king and tanner crab fishery resources in the Shelikof Strait area. Map available from the Alaska State Geospatial Clearinghouse website for the Kodiak region (at http://www.asgdc.state.ak.us/maps/cplans/subareas.html#kodiak). Map data are based on NOAA resources, with additional information by local communities, resource agencies, and resource focus groups.

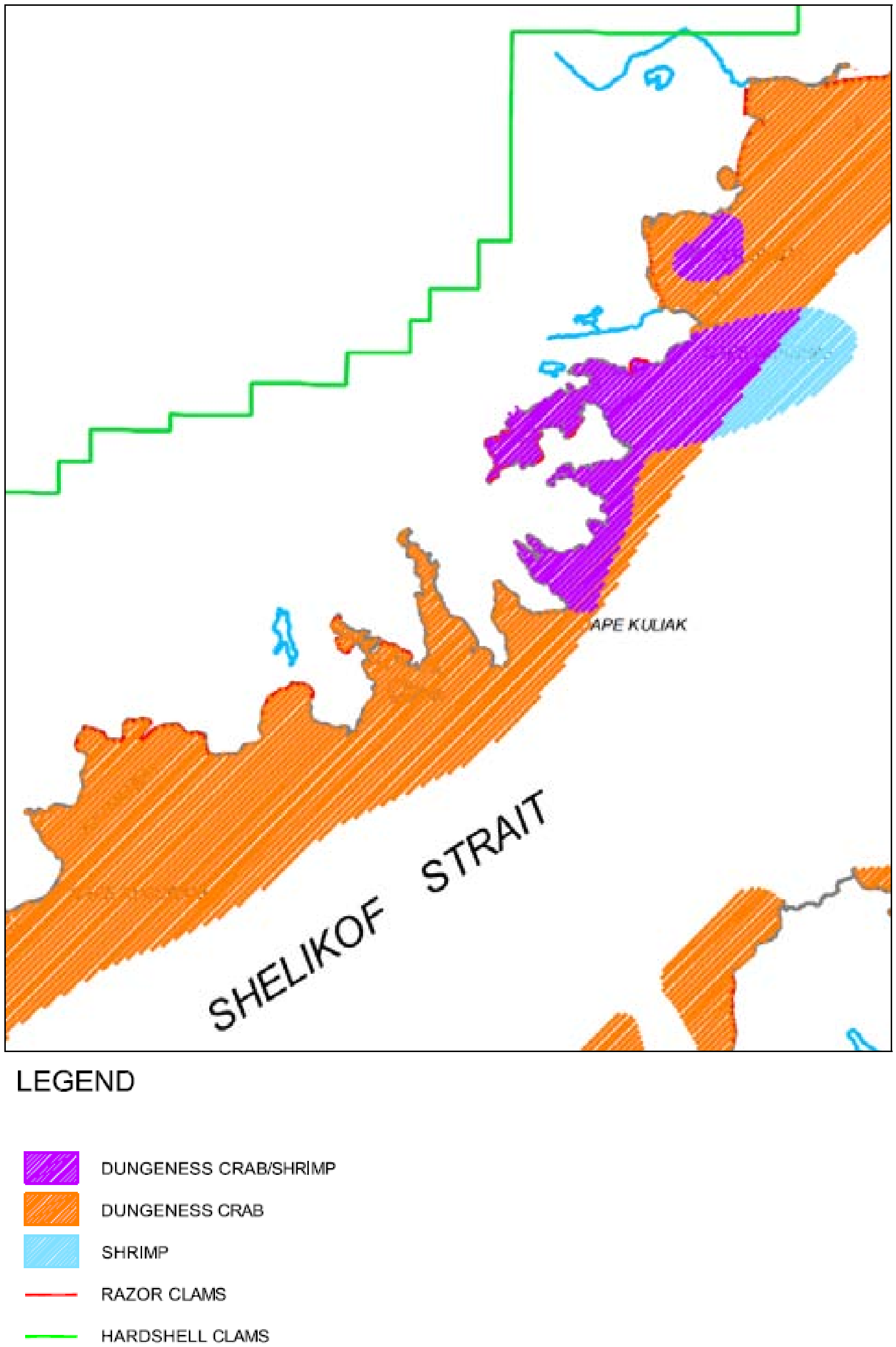

Figure 33. Excerpt of map of Dungeness crab, shrimp, razor clam, and hardshell clam fishery resources in the Shelikof Strait area. Map available from the Alaska State Geospatial Clearinghouse website for the Kodiak region (at http://www.asgdc.state.ak.us/maps/cplans/subareas.html#kodiak). Map data are based on ADF&G resources, with additional information by local communities, resource agencies, and resource focus groups.

C1c. Marine birds

Rock pinnacles and sea cliffs provide nesting sites, protected bays, lowland forage vegetation, intertidal invertebrates, and salmon-rich streams provide forage opportunities for a variety of marine and shorebird species (NPS, 2006b). Seventy-one shorebird species--one-third of the known shorebird species in the world-- occur along coastal Alaska (Andres and Gill, 2000). A bird list drafted by the USFWS and the NPS for the Alaska Peninsula region (Cape Douglas to Port Moller) indicates the presence/abundance of birds according to species and by habitat, including a separate category for the Pacific coast (U.S. Fish and Wildlife Service and NPS, 2006). In 1988 a coastal seabird inventory was conducted along the KATM coast in order to gather baseline data of species composition and density; a total of 11,500 breeding seabirds consisting of 11 species were observed (Litch and Blackie, 1988). Litch and Blackie (1988) identified another 42 species of birds in addition to the marine birds along the coast. A year later, another inventory was conducted in response to the Exxon Valdez Oil Spill (March, 1989) and found 15,834 marine birds representing at least 10 species (Martin, 1989). Seabirds are distributed all along the KATM coast (**Figure 34**). According to the NPS species list compiled as part of the I&M program, 254 bird species were reported to inhabit KATM, although the list is not exclusive to the coastal segment of KATM and not all species were confirmed as present (Lenz et al., 2002). Much of the marine bird research along the coastline from the past 1-2 decades has been motivated by the Exxon Valez oil spill, in which an estimated 300,000 to 645,000 birds were killed (Ford et al., 1996) (see section *V.A.1.a. Oil spills*).

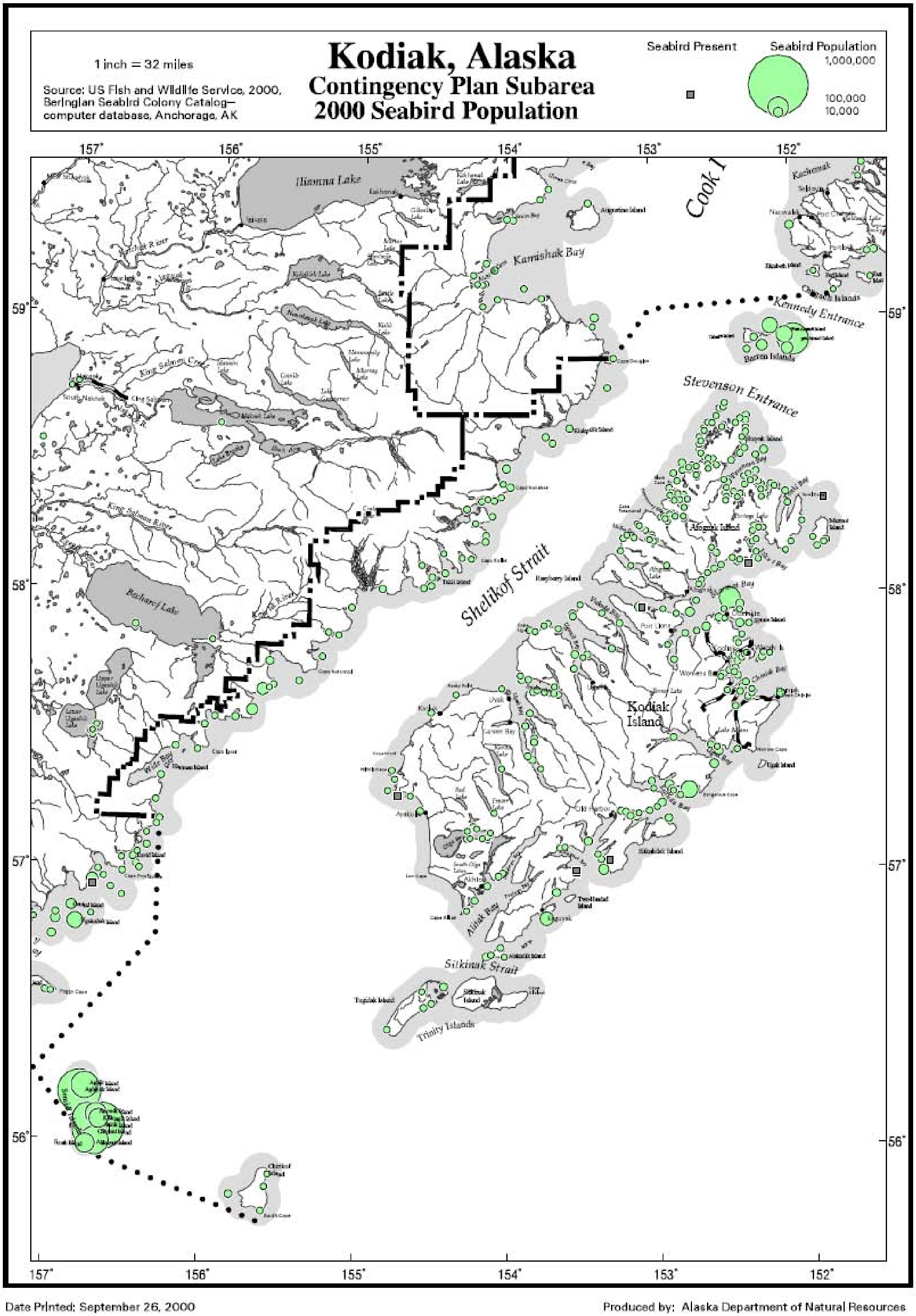

Figure 34. Seabird populations within the vicinity of KATM (from http://www.asgdc.state.ak.us/maps/cplans/kod/kod2seabird.pdf)

Further information on marine birds in coastal KATM or proximal/adjacent coasts include: documentation of marine birds along the coastline between Amber and Kamishak Bays (Bailey and Faust, 1984); marine bird survey of nearby ANIA, Becharof National Wildlife Refuge (NWR), and/or Alaska Peninsula NWR (Kaler et al., 2003; Savage, 2003); specific information on bald eagle distribution along the Alaska Peninsula (Dewhurst, 1991; Savage and Hodges, 2000; Savage et al., 1993); breeding trends and population trends of Alaska seabirds (Dragoo et al., 2000); harlequin duck (*Histrionicus histrionicus)* population genetics (Lanctot et al., 1999); distribution and abundance of marbled murrelets (*Brachyramphus marmoratus*) (Piatt and Ford, 1993); and population status of the Kittlitz's murrelets (*Brachyramphus brevirostris*), a candidate endangered species, along the southern coast of the Alaska Peninsula (Van Pelt and Piatt, 2005). The study of the rapidly declining Kittlitz's murrelets indicates a particularly important role of glaciated stream systems such as the Katmai River and streams draining from the Fourpeaked Glacier/ Mount Douglas massif in KATM in sustaining the populations of these birds, which appear to be sensitive to glacial thinning and retreat (Van Pelt and Piatt, 2005). Two of the 17 known Kittlitz's Murrelet nests in the world were located in KATM (Day, 1997). The federally-listed as threatened (USFWS, 2007) Steller's eider (*Polysticta stelleri*) occurs in/near Kamishak Bay in the winter (Sharon Kim, NPS-Anchorage, personal communication, 2007).

The most recent marine bird survey was conducted in June 2006 as a part of the SWAN I&M program (Bodkin et al., 2007). Twenty-five 200 m (656 ft) transects, ranging in length from 1.2 km to 16.4 km (0.8 to 10.2 mi) and averaging 6.4 km (4 mi) were surveyed, for a total of 159 km (98.8) or about 24.5% of the KATM shoreline. The most common birds, which were also uniformly distributed, were the glaucous-winged gull, the black-legged kittiwake, the black oystercatcher, and the harlequin duck (Table 4; Figures 35 to 44; Bodkin et al., 2007). Most other marine bird species were relatively abundant but aggregated in distribution (Table 4, Figures 35 to 44), except red-breasted mergansers, Pacific loons, and murrelets, which were rare (Table 4; Figures 35 to 44, Bodkin et al., 2007). Bodkin et al. (2007) note that because their survey was conducted in June, it can not reflect abundance of species that use KATM habitat in other seasons.

Table 4. Abundance and density of marine birds in the nearshore marine zone in KATM, June 2006. Approximately 25% of the total shoreline length was sampled. Min. and Max. are the minimum and maximum number of individuals per group and sum is the total number of individuals observed in all groups. Yellow shaded rows indicate focal species in the nearshore sampling protocol (Table 3.1 in Bodkin et al., 2007).

Species	# of groups observed	Min	Max	Sum	Average density (#/km^2)	SE
Arctic tern (*Sterna paradisaea*)	4	1	3	7	0.3	0.2
Auklets (*Alcidae sp.)*	1	24	24	24	0.5	0.5
Bald eagle (*Haliaeetus leucocephalus*)	60	1	2	68	2.2	0.3
Black-legged kittiwake (*Rissa tridactyla*)	46	1	275	1616	58.4	28.6
Black oystercatcher (*Haematopus bachmani*)	43	1	11	93	3.2	1.2
Unid. Murrelet (*Brachyramphus sp.*)	1	2	2	2	0.1	0.1
Cassin's Auklet (*Ptychoramphus aleuticus*)	4	2	15	28	0.8	0.8
Common eider (*Somateria mollissima*)	3	1	7	9	1.5	1.5
Common merganser (*Mergus merganser*)	14	1	124	179	5.1	3.5
Common Murre (*Uria aalge*)	2	1	5	6	0.2	0.2
Crested auklet (*Aethia cristatella*)	1	4	4	4	0.1	0.1
Double-crested cormorant (*Phalacrocorax auritus*)	10	1	9	29	1.1	0.8
Glaucous gull (*Larus hyperboreus*)	1	2	2	2	0.0	0.0
Glaucous-winged gull (*Larus glaucescens*)	172	1	280	2337	87.2	23.3
Harlequin duck (*Histrionicus histrionicus*)	81	1	40	502	16.9	3.4
Horned puffin (*Fratercula corniculata*)	24	1	75	203	20.0	17.3
Kittlitz's murrelet (*Brachyramphus brevirostris*)	1	2	2	2	0.1	0.1
Mallard (*Anas platyrhynchos*)	3	1	5	7	0.3	0.3
Marbled murrelet (*Brachyramphus marmoratus*)	4	1	2	7	0.3	0.2
Mew gull (*Larus canus*)	6	1	32	58	1.5	1.0
Northern crow (*Corvus caurinus*)	28	1	3	36	1.2	0.4
Pacific loon (*Gavia pacifica*)	2	1	3	4	0.1	0.1
Pelagic cormorant (*Phalacrocorax pelagicus*)	14	1	800	1014	31.0	27.8
Pigeon guillemot (*Cepphus columba*)	107	1	12	277	8.6	2.3
Red-breasted merganser (*Mergus serrator*)	3	1	4	9	0.3	0.2
Red-faced cormorant (*Phalacrocorax urile*)	26	1	121	581	18.2	11.5
Surf scoter (*Melanitta perspicillata*)	3	2	18	22	0.3	0.2
Tufted puffin (*Fratercula cirrhata*)	18	1	210	246	6.7	4.9
Unid. Cormorant (*Phalacrocoracidae sp.*)	5	1	240	324	19.1	14.9
Unid. Goldeneye (*Bucephala sp.*)	1	1	1	1	0.0	0.0
Unid. Gull (*Laridae sp.*)	22	1	9	35	1.3	0.5
Unid. Loon (*Gavia sp.*)	2	1	2	3	0.1	0.1
Unid. Scoter (*Melanitta sp.*)	2	1	4	5	0.2	0.2
White-winged scoter (*Melanitta fusca*)	7	1	108	176	20.9	19.3

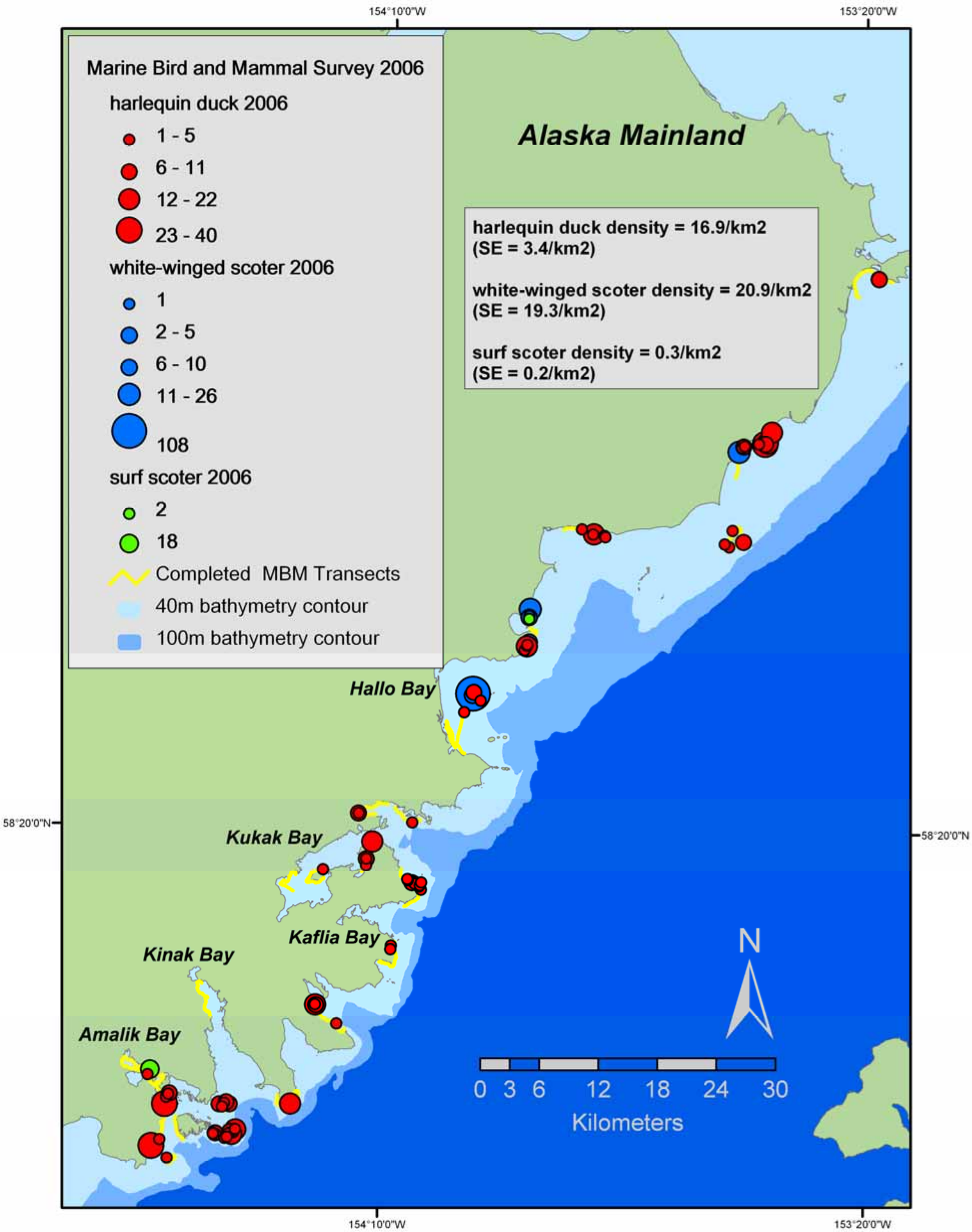

Figure 35. Distribution, abundance, and density of sea ducks (harlequin duck, white wing scoter and surf scoter) in KATM, June 2006 (Figure 3.2 in Bodkin et al. 2007).

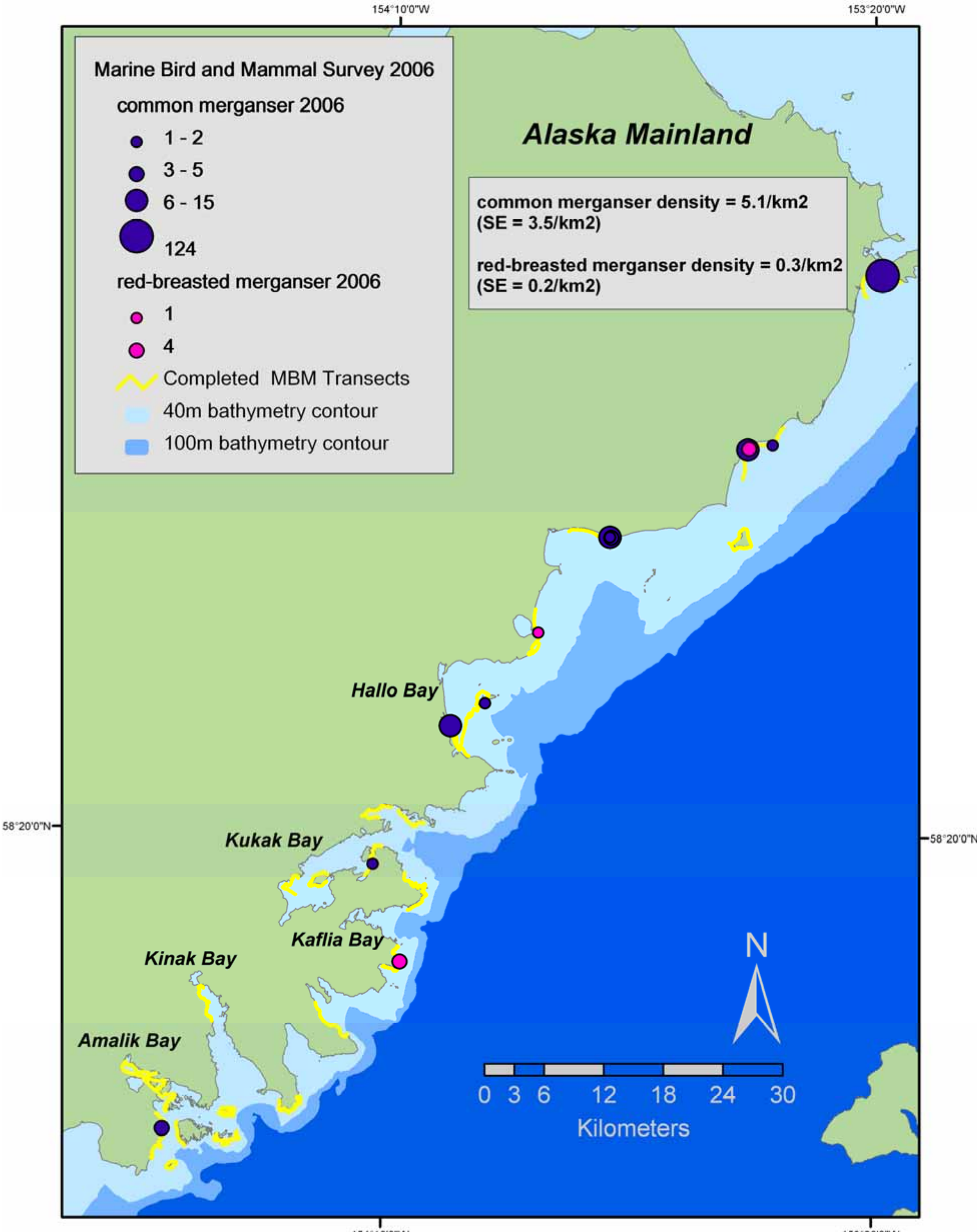

Figure 36. Distribution, abundance, and density of common and red-breasted mergansers in KATM, June 2006 (Figure 3.3 in Bodkin et al., 2007).

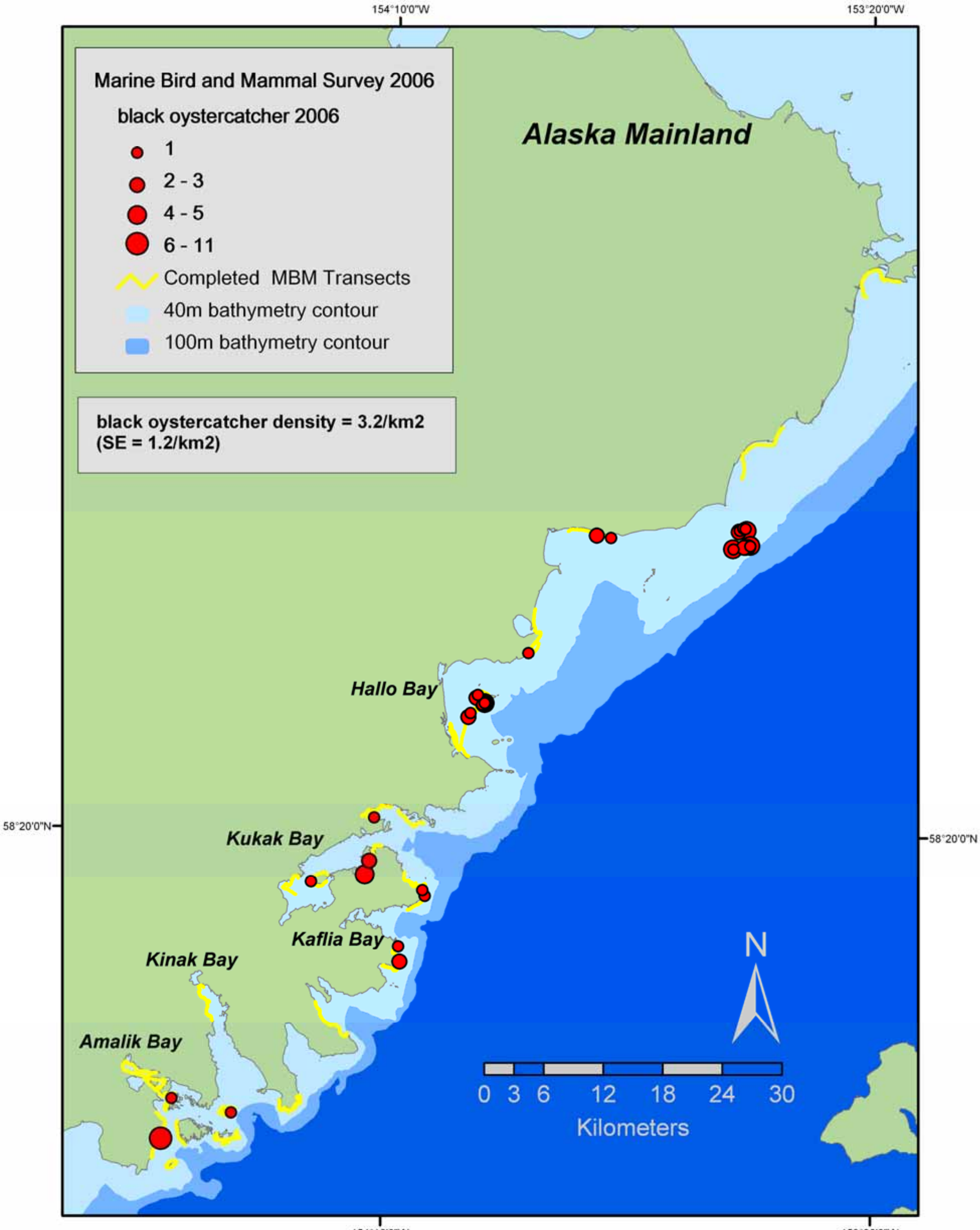

Figure 37. Distribution, abundance, and density of black oystercatchers in block 10 KATM, June 2006 (Figure 3.4 in Bodkin et al., 2007).

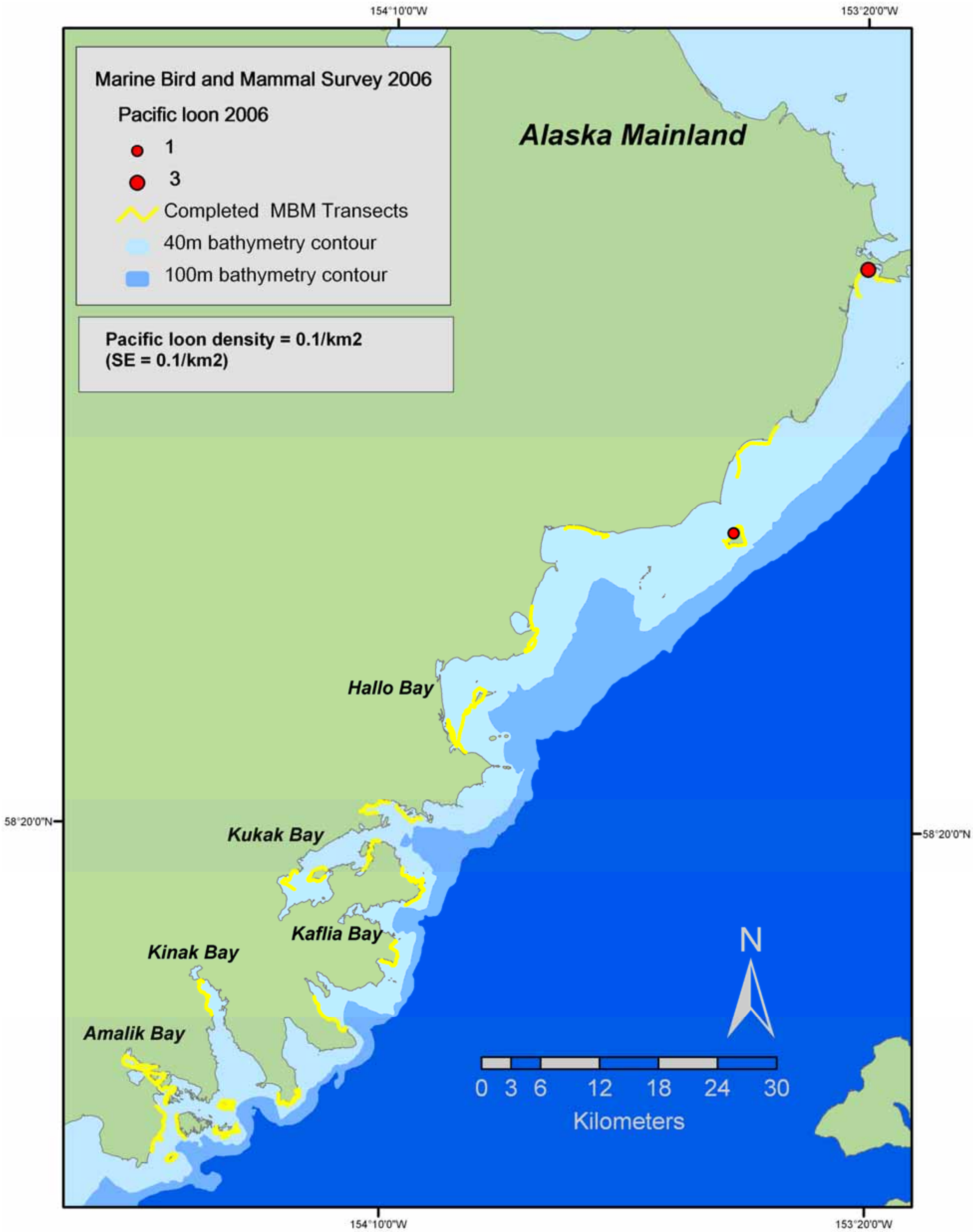

Figure 38. Distribution, abundance, and density of Pacific loons in KATM, June 2006 (Figure 3.5 in Bodkin et al., 2007).

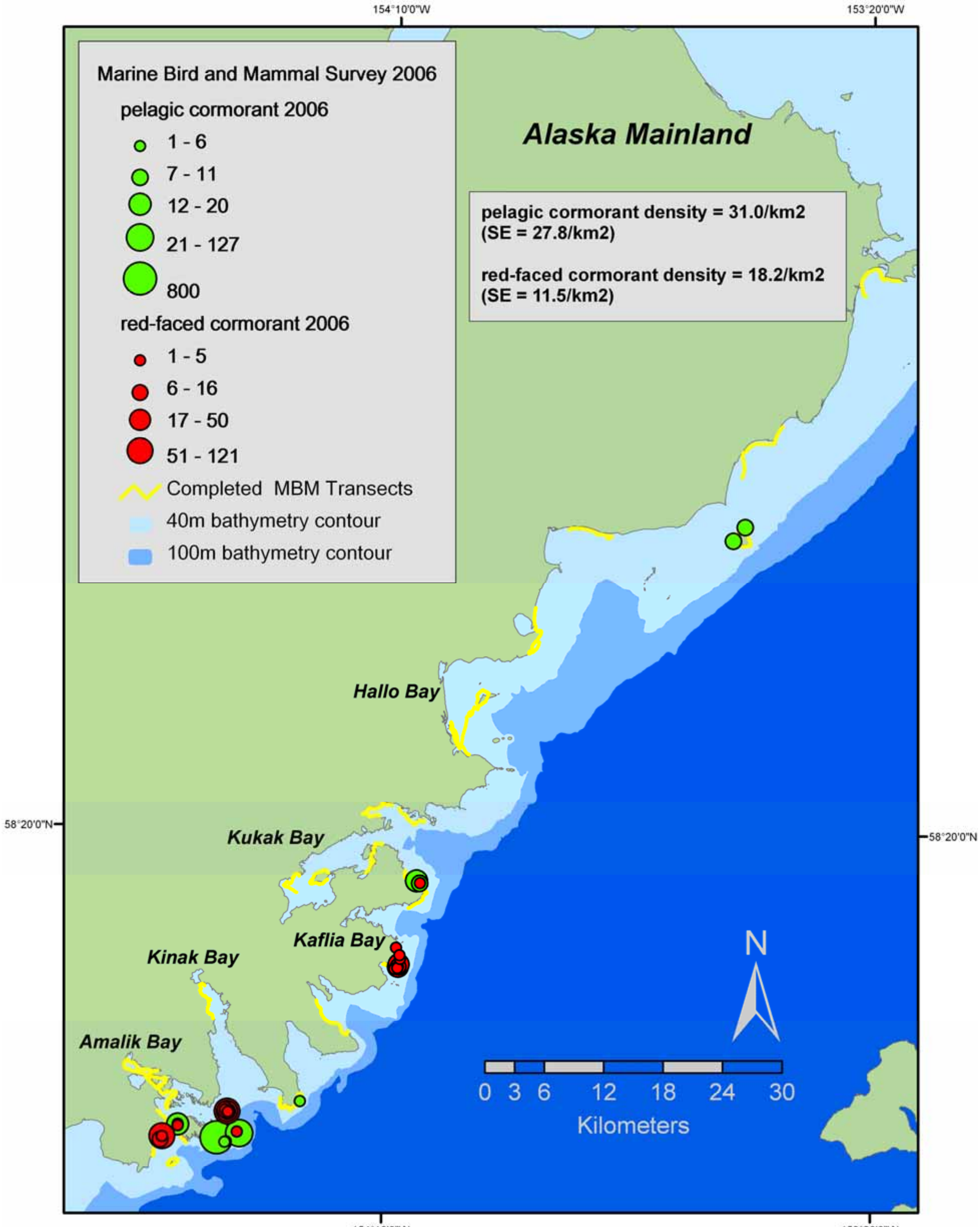

Figure 39. Distribution, abundance, and density of pelagic and red-faced cormorants in KATM, June 2006 (Figure 3.6 in Bodkin et al., 2007).

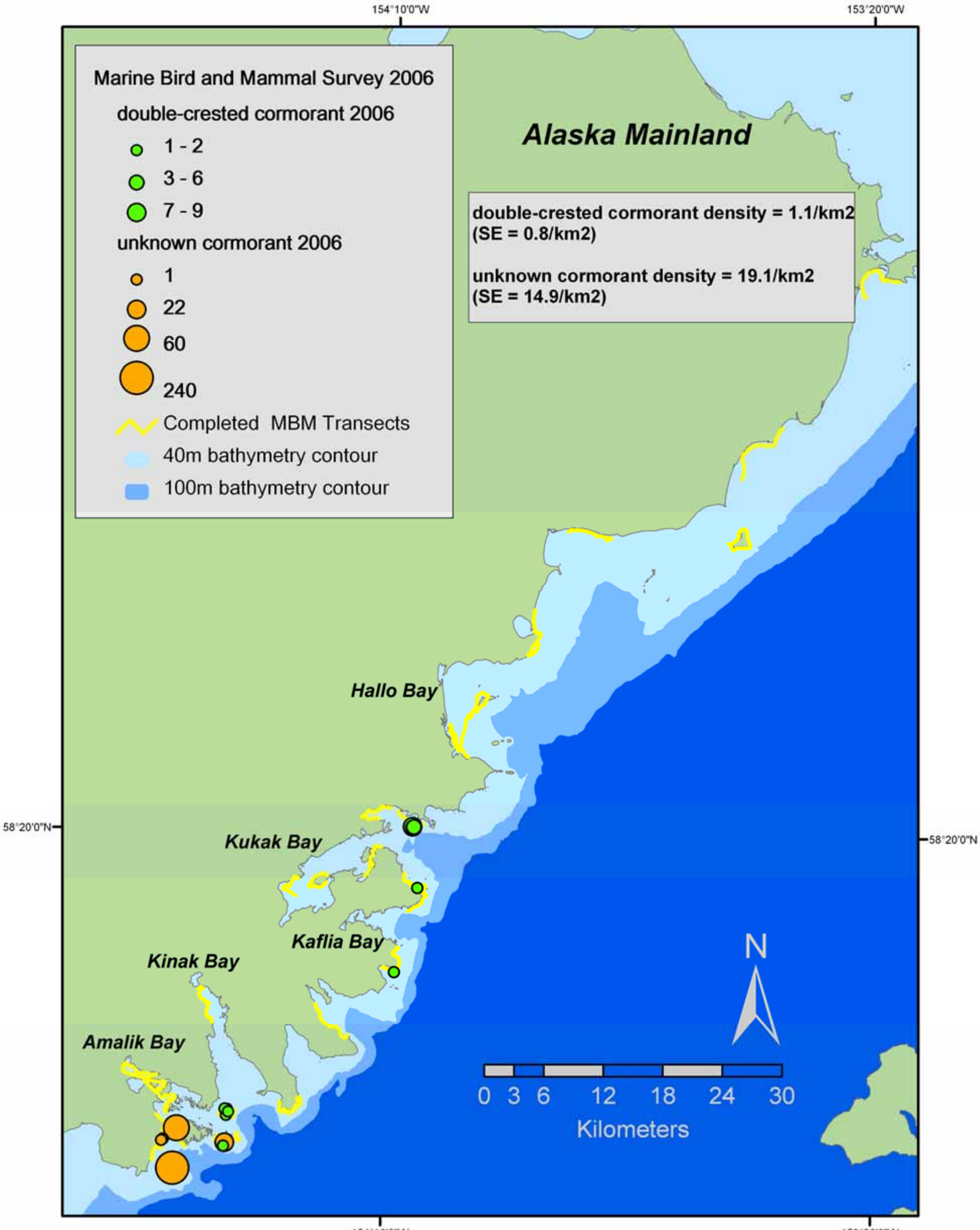

Figure 40. Distribution, abundance, and density of unidentified and double crested cormorants in KATM, June 2006 (Figure 3.7 in Bodkin et al., 2007)

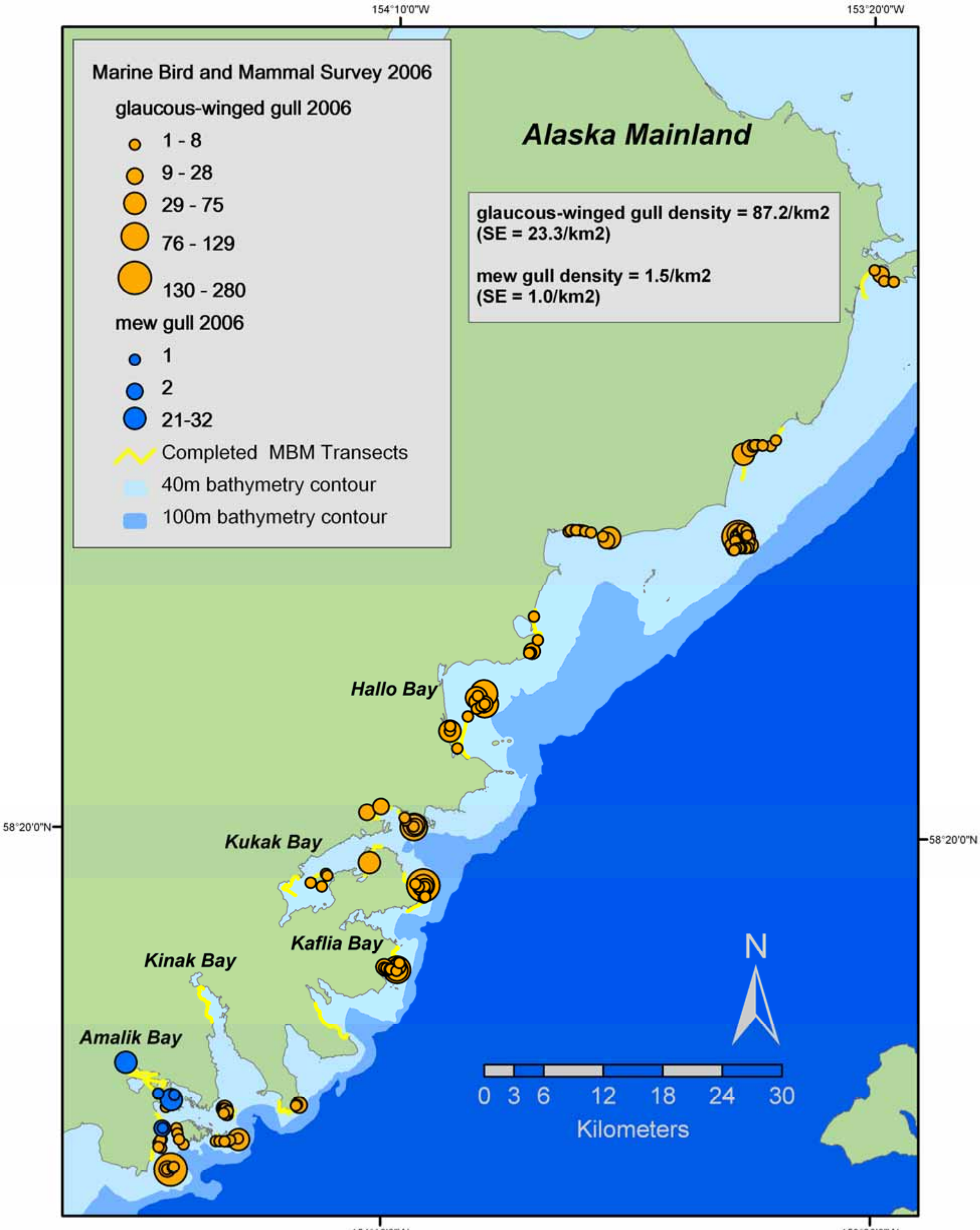

Figure 41. Distribution, abundance, and density of glaucous-winged and mew gulls in KATM, June 2006 (Figure 3.8 in Bodkin et al., 2007)

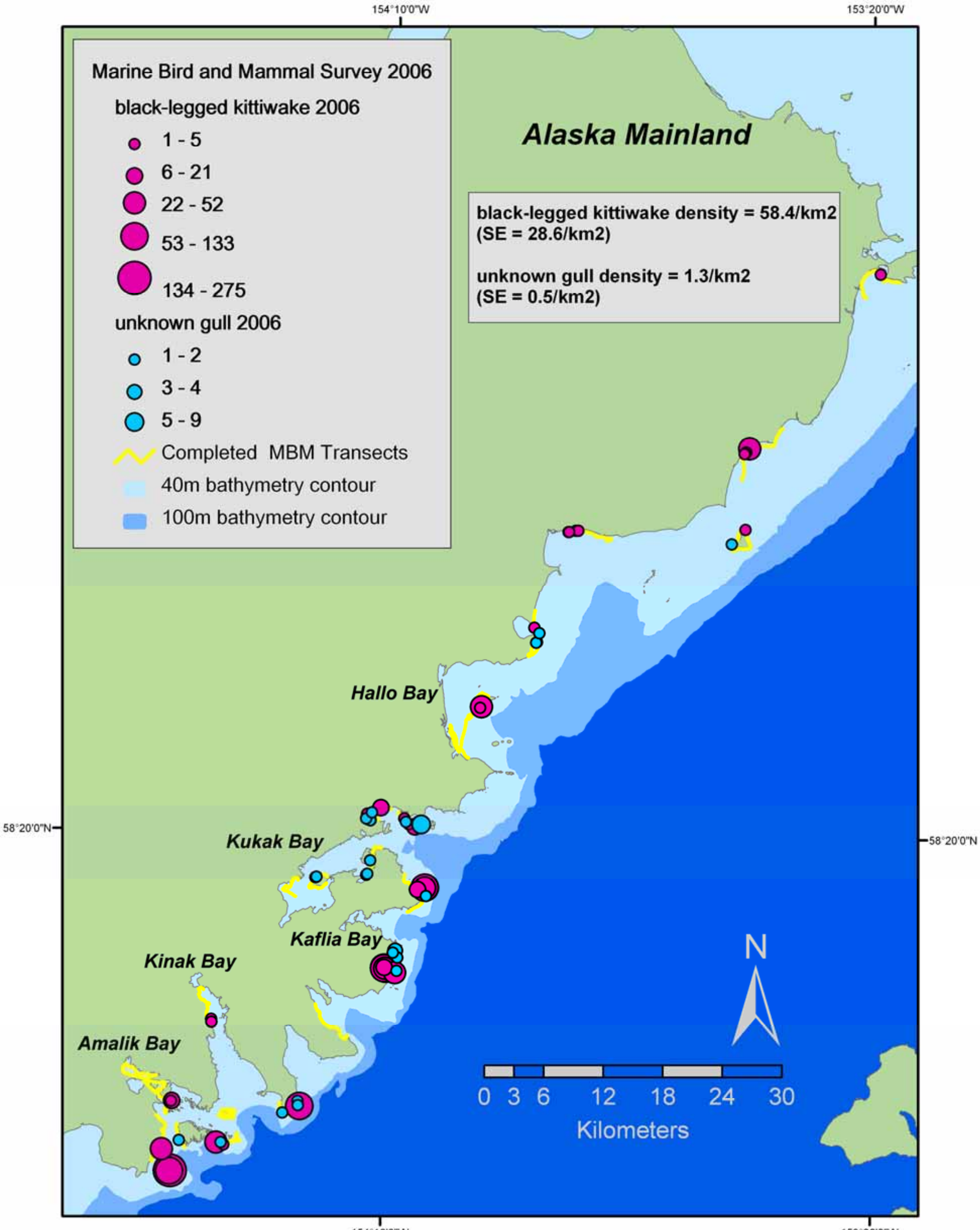

Figure 42. Distribution, abundance, and density of black-legged kittiwakes and unidentified gulls in KATM, June 2006 (Figure 3.9 in Bodkin et al., 2007).

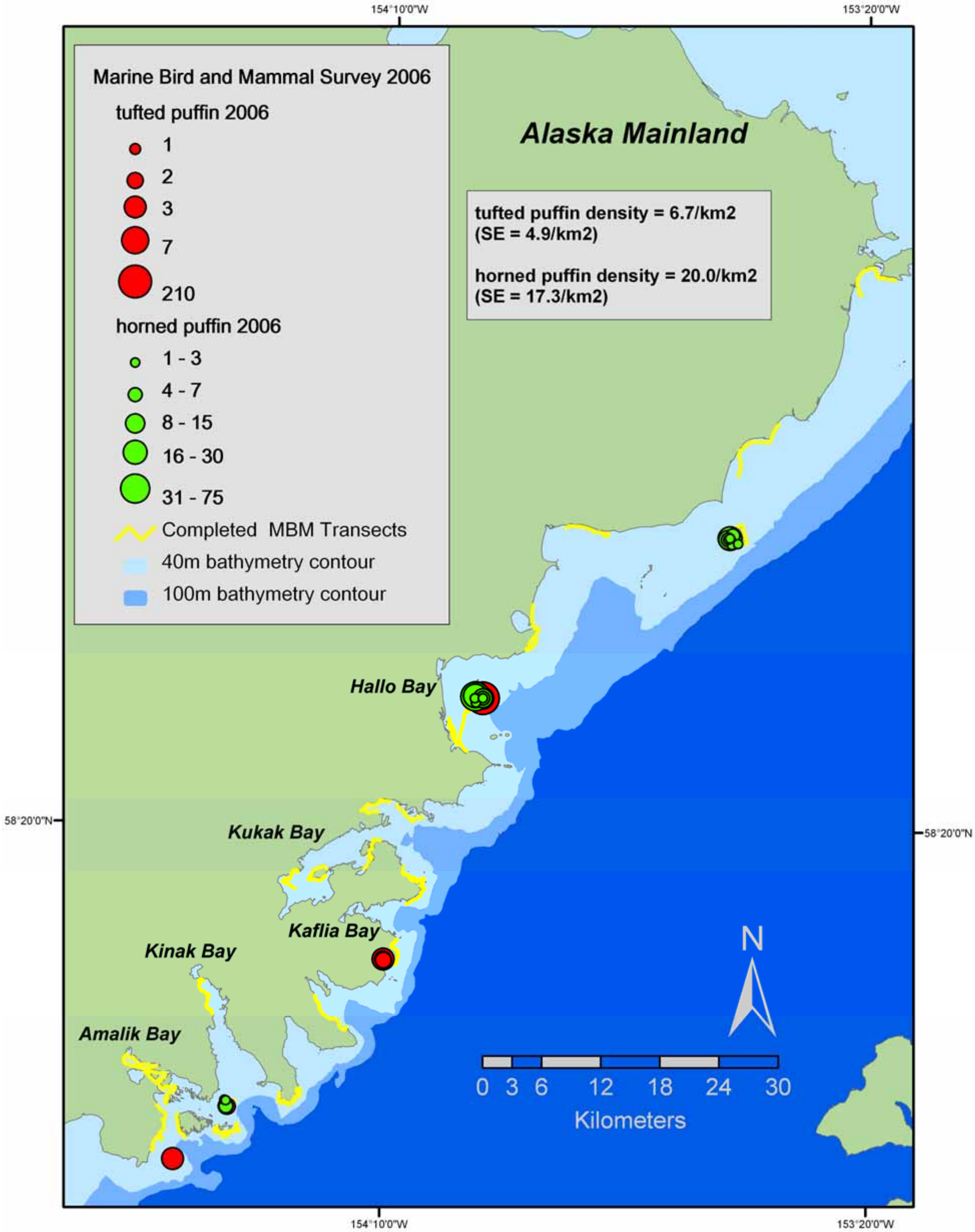

Figure 43. Distribution, abundance, and density of tufted and horned puffins in KATM, June 2006 (Figure 3.10 in Bodkin et al., 2007).

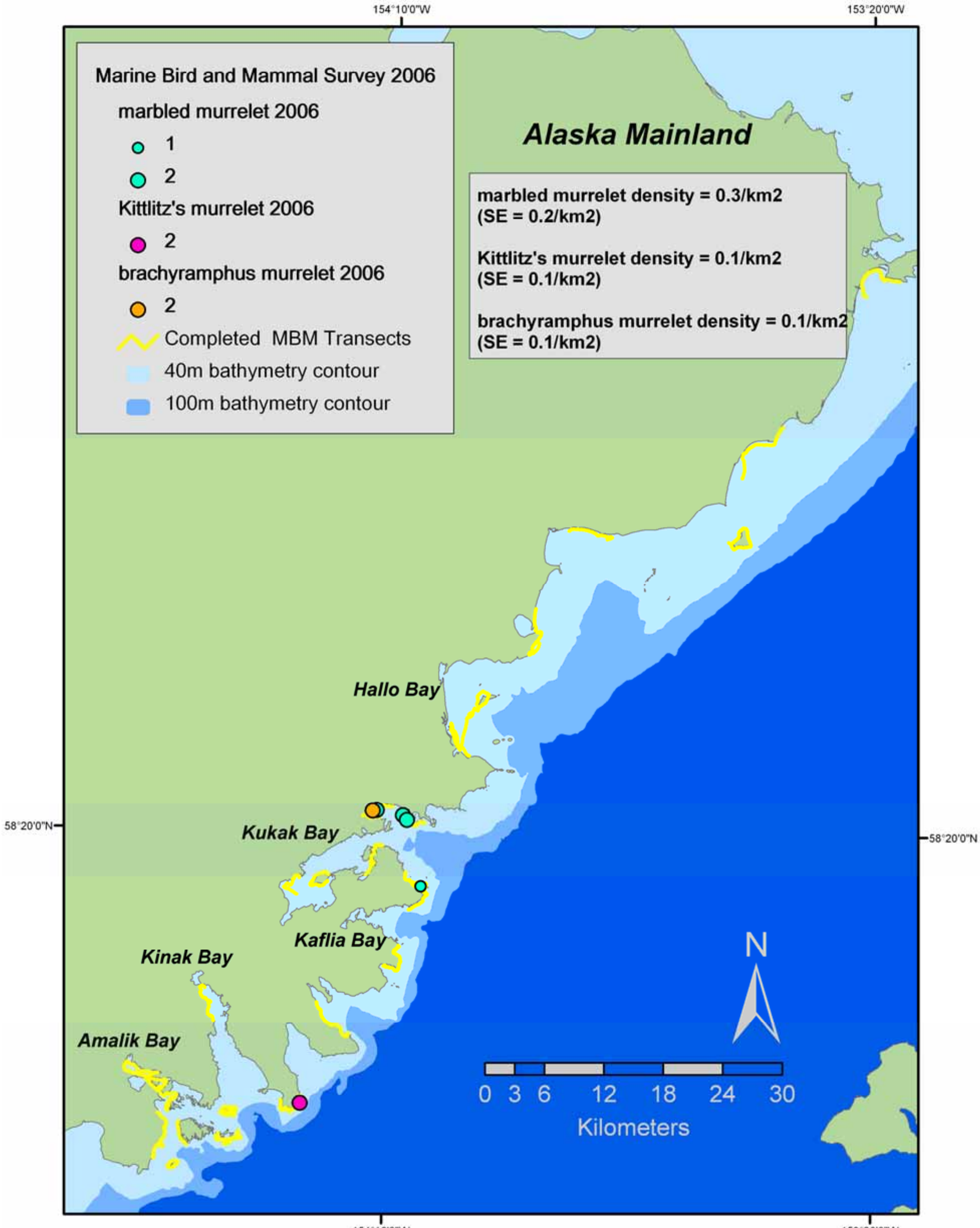

Figure 44. Distribution, abundance, and density of marbled, Kittlitz's, and unidentified branchyramphus murrelets in KATM, June 2006 (Figure 3.11 in Bodkin et al., 2007).

C1d. Marine intertidal resources

The KATM coastline is broad (average intertidal zone width is 209 m (686 ft), dominated by natural influences (less than 0.001% of the shoreline is modified [12.7 m (41.7 ft) by landfill and 15.6 m (51.2 ft) by rip rap at Kukak Bay]), and encompasses rich intertidal resources. The shoreline is composed of bedrock (9%), mixtures of bedrock and sediment (36%), sediment (35%), and wetland (20%) (**Figure 45**) (Harper and Morris, 2005). Of this shoreline, 2% is categorized as wave exposed, 37% is semi-exposed, 31% is semi-protected, 29% is protected, and 1% very protected (Harper, 2004).

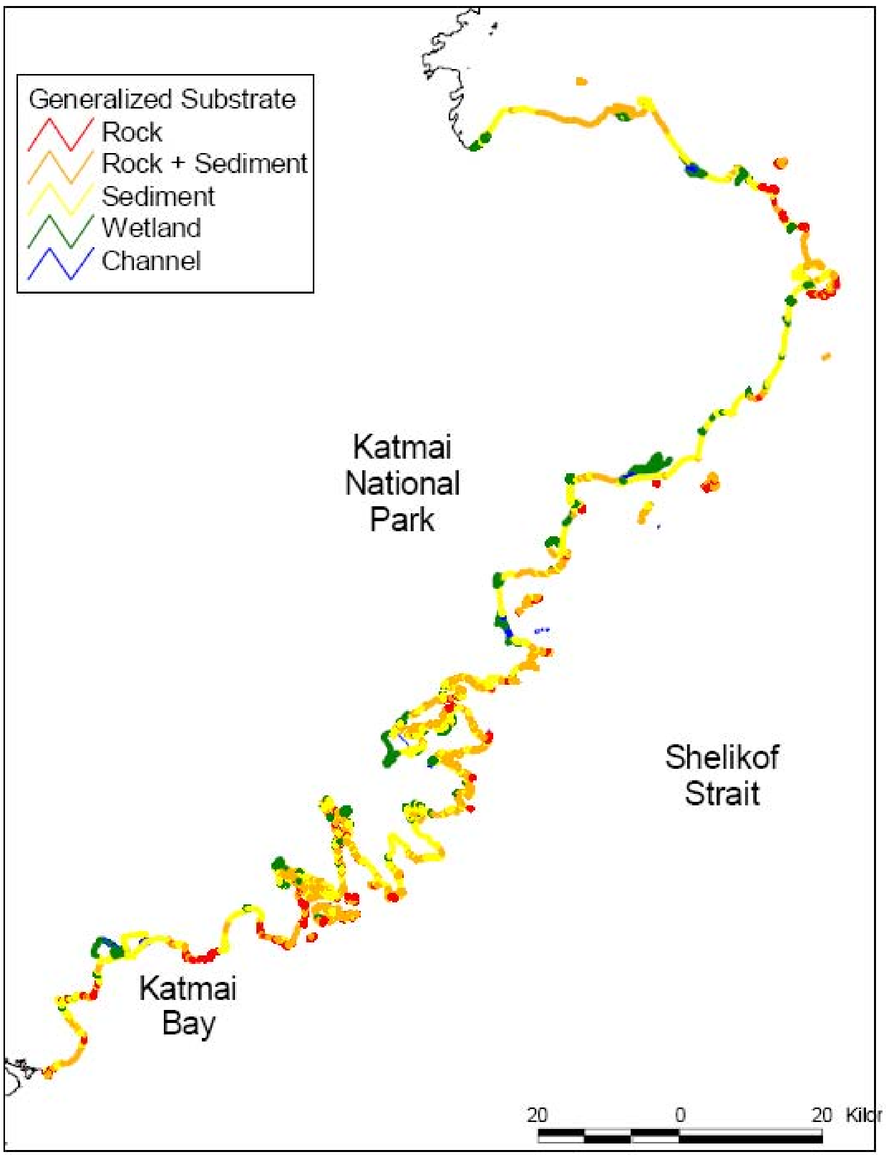

Figure 45. Distribution of general substrate types along the coast of KATM (Figure 20 in Harper and Morris, 2005).

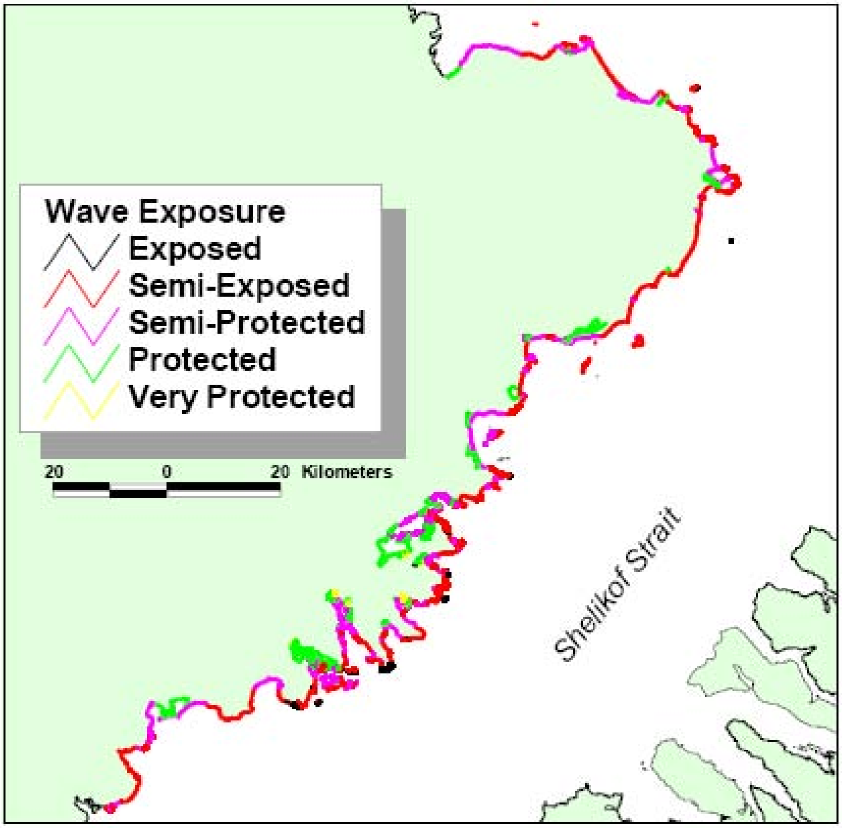

Figure 46. Wave exposure levels along the KATM coast (Figure 9 in Harper and Morris, 2005).

Figure 47. An example of the coastal environment on Cape Douglas, showing the steep, cliff-lined coast, seastack, and intertidal zone exposed at low tide with a brown bear at water's edge. August, 2005. Photo: S. Nagorski

ShoreZone is a coastal mapping project that provides a comprehensive and recent source of information on the KATM nearshore environments, descriptive overviews of coastal habitat, and classifications of physical and biological attributes (Harper, 2003; Harper and Morris, 2005; Morris, 2005). This project aerially surveyed intertidal and shallow subtidal areas of KATM during extremely low tides in the summer of 2003 for the purpose of identifying 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 KATM coastline. At the Gulf of Alaska Imagery website (http://imf.geocortex.net/mapping/cori/launch.html), one can activate the Katmai layer of the map provided and take a virtual flight of coastal KATM. One can generate maps of substrate types (**Figure 45**), as well as those of other many other coastal ecological and geological features (e.g. sediment type, splash zone, dune grasses, blue mussels, eelgrass) by turning on various layers available through the internet browser. In addition to the aerial flight surveys, ShoreZone included ground-truthing at 41 shore stations in order to collect detailed information on assemblages of intertidal species and their habitat. Additional information on the ShoreZone mapping program for coastal Alaska is available at www.coastalaska.net.

Rocky intertidal invertebrates and algae are monitored by the SWAN I&M program. They initiated an intertidal invertebrate and algae monitoring program in 2006 at five sites (**Figure 48**) that were predominantly rocky (**Table 5**) in which percent cover of sessile algae and invertebrates and counts of small mobile invertebrates were made in 12 evenly spaced 0.25 m^2 quadrats along a 100 m transect at 0.5m (low rocky intertidal) and 1.5 m (mid rocky intertidal) tidal heights (Bodkin et al., 2007). The dominant sessile algae and invertebrate species are listed for each site in Table 6 and Table 7, and the dominant small motile invertebrate species are listed for each site in Table 8.

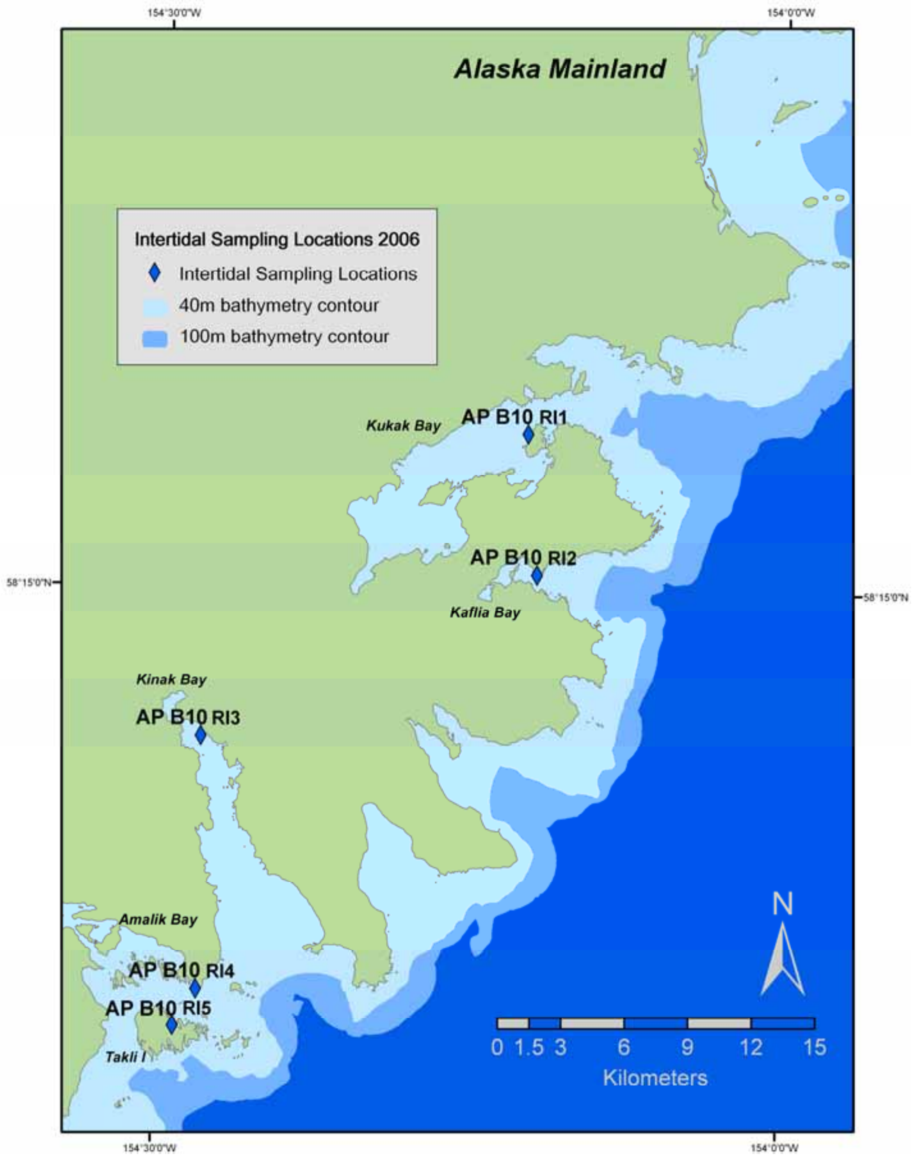

Figure 48. Locations of rocky intertidal sites established and sampled in KATM during 2006 (from Bodkin et al., 2007).

Table 5. Substratum type at intertidal sampling sites in KATM in 2006 (Table 2.2 in Bodkin et al. 2007).

Name	Site number	Elevation 0.5 m %Bedrock	0.5 m %Cobble/Boulder	1.5 m %Bedrock	1.5 m %Cobble/Boulder
Kukak	AP B10 RI1	90	10	83	17
Kaflia	AP B10 RI2	100	0	74	26
Kinak	AP B10 RI3	92	8	75	25
Amalik	AP B10 RI4	100	0	87	13
Takli	AP B10 RI5	45	55	50	50

Table 6. Dominant sessile algae and invertebrates in the low rocky intertidal (Table 2.4 in Bodkin et al. 2007).

Species	Common Name	Site: Kukak AP B10 RI1	Kinak AP B10 RI2	Kaflia AP B10 RI3	Amalik AP B10 RI4	Takli AP B10 RI5
Lower Intertidal (0.5 m MLLW)						
Acrosiphonia sp.	Red alga	0	x	x	x	x
Alaria marginata	Brown alga	x	x	x	x	x
Analipus japonicus	Brown alga	0	x	0	x	x
Balanophyllia elegans	Cup coral	0	x	0	x	0
Balanus / Semibalanus sp.	Barnacle	0	x	x	x	x
Balanus glandula	Barnacle	x	0	0	0	0
Chthamalus dalli	Barnacle	x	x	0	x	x
Clodophora/Rhizoclonium sp.	Green alga	0	0	x	0	x
Corallina sp.	Red alga	0	0	x	0	0
Cryptosiphonia woodii	Red alga	0	0	x	0	0
Elachista fucicola	Brown alga	0	0	0	0	x
Endocladia muricata	Red alga	0	0	0	0	x
Fucus gardneri	Brown alga	x	x	x	x	x
Gloiopeltis furcata	Red alga	0	0	0	x	x
Halosaccion glandiforme	Red alga	x	0	x	0	0
Laminaria saccharina	Brown alga	0	x	0	0	0
Lithothamnion sp.	Red alga	0	x	0	x	0
Mastocarpus papillatus	Red alga	x	x	x	0	0
Melanosiphon intestinalis	Brown alga	x	x	x	0	x
Microcladia borealis	Red alga	0	0	x	0	0
Mytilus trossulus	Mussel	0	x	0	x	x
Neorhodomela larix	Red alga	0	0	x	x	0
Neorhodomela oregona	Red alga	x	0	x	x	x
Odonthalia floccosa	Red alga	0	0	x	0	0
Palmaria collophylloides	Red alga	x	x	x	0	0
Palmaria hecatensis	Red alga	x	x	x	x	0
Palmaria sp.	Red alga	0	0	x	0	0
Pilayella littoralis	Brown alga	x	0	x	0	x
Polysiphonia sp.	Red alga	0	0	x	0	x
Porphyra sp.	Red alga	0	x	0	x	0
Pterosiphonia bipinnata	Red alga	x	x	x	x	x
Ralfsia sp.	Brown alga	0	0	x	0	0
Scytosiphon simplicissimus	Brown alga	0	0	x	x	x
Semibalanus balanoides	Barnacle	x	0	0	0	0
Stomachetosella cruenta	Bryozoan	0	x	0	0	0
Tokidadendron kurilensis	Red alga	x	0	0	0	0
Ulothrix flacca	Green alga	0	0	0	x	0
Ulva sp.	Green alga	x	x	x	x	x
Unidentified green algae	Green alga	0	0	x	0	0
Total No. Species		**15**	**18**	**24**	**18**	**18**

Table 7. Dominant sessile algae and invertebrates in the mid rocky intertidal (Table 2.4 in Bodkin et al. 2007).

		Site				
Species	**Common Name**	**Kukak AP B10 RI1**	**Kinak AP B10 RI2**	**Kaflia AP B10 RI3**	**Amalik AP B10 RI4**	**Takli AP B10 RI5**
Mid Intertidal (1.5 m MLLW)						
Acrosiphonia sp.	Green alga	x	x	x	x	x
Alaria marginata	Brown alga	x	x	0	x	x
Analipus japonicus	Brown alga	0	0	x	0	x
Anthopleura elegantissima	Sea anemone	0	0	0	x	0
Balanus / Semibalanus sp.	Barnacle	x	x	x	x	x
Balanus glandula	Barnacle	x	0	0	0	0
Chthamalus dalli	Barnacle	x	x	x	x	x
Clodophora/Rhizoclonium sp.	Green alga	0	0	x	x	0
Corallina sp.	Red alga	0	0	0	x	0
Cryptosiphonia woodii	Red alga	x	0	0	0	0
Elachista fucicola	Brown alga	0	0	0	0	x
Endocladia muricata	Red alga	0	x	x	x	x
Fucus gardneri	Brown alga	x	x	x	x	x
Gloiopeltis furcata	Red alga	x	x	x	x	x
Halosaccion glandiforme	Red alga	x	0	x	0	0
Lithothamnion sp.	Red alga	0	0	0	x	0
Mastocarpus papillatus	Red alga	x	0	x	x	0
Melanosiphon intestinalis	Brown alga	x	0	x	x	x
Mytilus trossulus	Mussel	x	x	x	x	x
Neorhodomela oregona	Red alga	x	0	x	x	x
Odonthalia floccosa	Red alga	0	x	0	0	0
Palmaria collophylloides	Red alga	x	0	x	x	0
Pilayella littoralis	Brown alga	x	0	x	0	x
Polysiphonia sp.	Red alga	x	0	0	x	x
Porphyra sp.	Red alga	x	x	x	x	x
Pterosiphonia bipinnata	Red alga	x	x	x	x	x
Ralfsia sp.	Red alga	0	0	x	0	0
Scytosiphon simplicissimus	Brown alga	0	x	0	x	0
Semibalanus cariosus	Barnacle	0	0	0	x	0
Ulva sp.	Green alga	x	x	x	x	x
unidentified brown algae	Brown alga	0	x	0	x	0
unidentified filamentous red algae	Red alga	x	x	0	0	0
Total No. Species		**20**	**15**	**19**	**23**	**17**

Table 8. Small motile invertebrates present at rocky intertidal sites in KATM in 2006 (Table 2.6 in Bodkin et al. 2007).

Species	Common Name	Kukak AP B10 RI1	Kaflia AP B10 RI2	Site Kinak AP B10 RI3	Amalik AP B10 RI4	Takli AP B10 RI5
Lower Intertidal (0.5 m MLLW)						
Amphiporus formidabalis	Ribbon worm	x	0	x	x	0
Buccinum baeri	Snail	x	0	0	0	0
Cancer orgegonensis	Crab	0	0	0	x	0
Cucumaria vegae	Sea cucumber	x	0	0	x	0
Emplectonema gracile	Ribbon worm	0	x	0	x	0
Haplogaster mertensii	Crab	0	0	0	x	0
Katharina tunicata	Chiton	0	0	x	0	0
Lepasterius epichlora	Sea star	x	0	0	x	0
Littorina scutulata	Snail	0	0	0	x	x
Littorina sitkana	Snail	x	x	x	x	x
Lottia digtalis	Limpet	0	x	0	0	0
Lottia pelta	Limpet	x	x	x	x	x
Margarites pupillus	Snail	0	x	x	x	x
Margurites helicinus	Snail	0	x	0	x	0
Mopalia sp.	Chiton	0	0	x	0	0
Neomolgus littoralis	Mite	0	0	x	0	0
Onchidella borealis	Unsheeled snail	0	0	0	x	0
Pagurus sp.	Crab	x	x	x	x	x
Paranemertes perigrina	Ribbon worm	0	x	0	x	0
Pentidotea wosnesenskii	Isopod	0	0	0	x	x
Phidiana crassicornis	Sea slug	0	x	0	0	0
Siphonaria thersites	Unsheeled snail	0	x	0	0	0
Tectura scutum	Limpet	x	x	0	x	x
Tonicella lineata	Chiton	0	0	0	x	0
Total number of species		**8**	**11**	**8**	**17**	**7**
Mid Intertidal (1.5 m MLLW)						
Amphiporus formidabalis		0	0	0	x	0
Anthopluera elagantissima	Sea Anemone	0	0	0	x	0
Buccinum baeri	Snail	0	x	0	0	0
Emplectonema gracile	Snail	0	0	0	x	x
Lepasterius epichlora	Sea star	0	0	0	x	0
Littorina scutulata	Snail	x	x	x	x	x
Littorina sitkana	Snail	x	x	x	x	x
Lottia digtalis	Limpet	0	0	0	0	x
Lottia pelta	Limpet	x	x	x	x	x
Margarites pupillus	Snail	0	0	0	x	0
Margurites helicinus	Snail	0	x	0	x	x
Neomolgus littoralis	Mite	0	0	x	0	x
Onchidella borealis	Unsheeled snail	0	x	0	x	x
Pagurus sp.	Crab	x	x	x	x	x
Paranemertes perigrina	Ribbon worm	0	0	0	x	0
Pentidotea wosnesenskii	Isopod	0	0	0	x	0
Siphonaria thersites	Unsheeled snail	0	x	0	x	0
Tectura persona	Limpet	x	x	0	0	0
Tectura scutum	Limpet	x	x	0	x	x
Tonicella lineata	Chiton	0	0	0	x	0
Total number of species		**6**	**10**	**5**	**16**	**10**

Numerous productive clam beds are located along the Shelikof Strait coastline, particularly from Hallo Bay to Cape Douglas and in Kashvik Bay (Norris, 1996). Razor clam digging and canning was particularly intense during the 1920s in Swikshak Bay, during the 1930s in Kashvik Bay, and commercial clamming operations in the KATM coastal region continued into the 1970s (Norris, 1996). Adult razor clams were not observed in 2005 in the vicinity of Swikshak Bay or Big River, which is surprising given the previous history of commercial operations in this area (Lees and Driskell, 2006). It is unknown if clam populations were destroyed by the 1964 earthquake or if populations declined from some other cause (Lees and Driskell, 2006).

Lees and Driskell (2006) conducted a reconnaissance survey of marine/estuarine bivalves in soft sediments in 2005 in KATM (**Figure 49**). Bivalves were surveyed using 0.25-m^2 (2.7 ft^2) and 0.0625-m^2 (0.67 ft^2) macrobivalve excavations and microinfaunal core samples. The northern and central regions of KATM were dominated by long stretches of very exposed sandy beaches, while the southern region of KATM contained large and small pocket beaches and protected lagoons with mud and sand flats (Lees and Driskell, 2006).

Figure 49. Sites visited by the soft-sediment intertidal reconnaissance survey in KATM in 2005 (Figure 5 in Lees and Driskell, 2006).

A variety of bivalve species were observed (**Table 9**) and examined to determine which species might serve as sentinel species in a monitoring program. In KATM, the potential sentinel species included butter clams (*Saxidomus giganteus*), two species of softshell clams (*Mya arenaria* and *M. pseudoarenaria*), foolish mussels (*Mytilus trossulus*), Alaska razor clams (*Silqua alta*), and Baltic macomas (*Macoma balthica*), which were chosen because they were abundant at multiple sites (**Table 9**; Lees and Driskell, 2006).

Table 9. 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	*Telliina 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 10. Major bivalve species, as a function of substrate, observed at soft-sediment intertidal reconnaissance 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

Intertidal and subtidal vegetation is very rich and 110 species were identified in KATM during an inventory in 2003 by a noted marine algal expert, S. Lindstrom (**Table 11**). Percent cover of sessile algae on rocky shores are described above (Table 9 and Table 10). Of particular importance are seagrasses such as eelgrass (*Zostera marina*) and surfgrass (*Phylospadix*) (**Figure 50**), which are important spawning and juvenile fish habitat; and kelp beds such as bull kelp (*Nereocystis luetkeana*) and dragon kelp (*Alaria fistulosa*) (**Figure 51**), which are highly valued fish habitat (Harper and Morris, 2005). Eelgrass is found either continuously or patchily distributed on about 22% of the coast (Harper and Morris, 2005).

Table 11. Species list of marine algae generated by S. Lindstrom in KATM in 2003.

Acrosiphonia arcta (Dillwyn) Gain
Acrosiphonia coalita (Ruprecht) Scagel, Garbary, Golden et M.W. Hawkes
Acrosiphonia duriuscula (Ruprecht) Yendo
Acrosiphonia saxatilis (Ruprecht) K.L. Vinogradova
Agarum clathratum Dumortier
Ahnfeltia fastigiata (Endlicher) Makienko
Alaria fistulosa Postels et Ruprecht
Alaria marginata Postels et Ruprecht
Analipus japonicus (Harvey) M.J. Wynne
Antithamnionella pacifica (Harvey) E.M. Wollaston
Bangia Lyngbye
Blidingia minima (Naegeli ex Kuetzing) Kylin

Callithamnion pikeanum   Harvey
Callophyllis flabellulata   Harvey
Capsosiphon groenlandica   (J. Agardh) K.L. Vinogradova
Chaetomorpha brachygona   Harvey
Chordaria chordaeformis   (Kjellman) Kawai et S.H. Kim in Kim & Kawai
Chordaria flagelliformis   (O. F. Mueller) C. Agardh
Chordaria gracilis   Setchell et N.L. Gardner
Cladophora sericea   (Hudson) Kuetzing
Clathromorphum circumscriptum   (Stroemfelt) Foslie
Clathromorphum reclinatum   (Foslie) Adey
Coilodesme bulligera   Stroemfelt
Coilodesme cystoseirae   (Ruprecht) Setchell et N.L. Gardner
Coilodesme fucicola   (Yendo) Nagai
colonial diatoms
Colpomenia peregrina   (Sauvageau) Hamel
Constantinea subulifera   Setchell
Corallina frondescens   Postels et Ruprecht
Costaria costata   (C. Agardh) Saunders
Cryptosiphonia woodii   (J. Agardh) J. Agardh
Cymathaere triplicata   (Postels et Ruprecht) J. Agardh
Cystoseira geminata   C. Agardh
Desmarestia aculeata   (Linnaeus) Lamouroux
Desmarestia viridis   (O.F. Mueller) Lamouroux
Devaleraea ramentacea   (Linnaeus) Guiry
Dictyosiphon foeniculaceus   (Hudson) Greville
Dilsea socialis   (Postels et Ruprecht) Perestenko ?
Dumontia alaskana   V. Tai, S.C. Lindstrom et G.W. Saunders
Dumontia simplex   Cotton
Elachista fucicola   (Velley) Areschoug
Endocladia muricata   (Endlicher) J. Agardh
Enteromorpha linza   (Linnaeus) J. Agardh
Eudesme virescens   (Carmichael in Berkeley) J. Agardh
Fucus distichus subsp. evanescens (C. Agardh) Powell
Gloiopeltis furcata   (Postels et Ruprecht) J. Agardh
Halosaccion firmum   (Postels et Ruprecht) Kuetzing
Halosaccion glandiforme   (S. G. Gmelin) Ruprecht
Hedophyllum sessile   (C. Agardh) Setchell ?
Kornmannia on Halosaccion/Palmaria
Kornmannia zostericola   (Tilden) Bliding
Laminaria groenlandica sensu Druehl
Laminaria longipes   Bory
Laminaria saccharina   (Linnaeus) Lamouroux
Laminaria yezoensis   Miyabe
Leathesia difformis   (Linnaeus) Areschoug
Mastocarpus Clade 1
Mastocarpus Clade 5
Mastocarpus Clade 7
Mazzaella parvula   nomen nudum
Mazzaella phyllocarpa   (Postels et Ruprecht) Selivanova et Zhigadlova
Meiodiscus spetbergensis   (Kjellman) G.W. Saunders et McLachlan
Melanosiphon intestinalis   (Saunders) M.J. Wynne
Membranoptera spinulosa   (Ruprecht) Kuntze
Microcladia borealis   Ruprecht
Mikamiella ruprechtiana   (Zinova) M.J. Wynne
Monostroma grevillei   (Thuret) Wittrock
Neoptilota asplenioides   (Esper) Kylin

Neorhodomela aculeata (Perestenko) Masuda
Neorhodomela oregona (Doty) Masuda
Nereocystis luetkeana (Mertens f.) Postels et Ruprecht
Odonthalia dentata (Linnaeus) Lyngbye
Odonthalia floccosa (Esper) Falkenberg
Odonthalia floccosa f. comosa Setchell et N.L. Gardner
Odonthalia lyallii (Harvey) J. Agardh or O. setacea (Ruprecht) Perestenko
Palmaria callophylloides Hawkes et Scagel
Palmaria hecatensis Hawkes
Palmaria mollis (Setchell et N.L. Gardner) van der Meer et C.J. Bird
Palmaria sp.
Petalonia fascia (O. F. Mueller) Kuntze
Phaeosaccion collinsii Farlow
Phycodrys riggii N.L. Gardner
Phyllospadix serrulatus Ruprecht ex Ascherson
Pilayella littoralis (Linnaeus) Kjellman
Pleonosporium kobayashii Okamura
Polysiphonia hendryi var. gardneri
Polysiphonia pacifica Hollenberg
Polysiphonia tongatensis Harvey ex Kuetzing
Porphyra abbottiae V. Krishnamurthy ?
Porphyra aestivalis S.C. Lindstrom et Fredericq
Porphyra cuneiformis (Setchell et Hus in Hus) V. Krishnamurthy
Porphyra fallax S.C. Lindstrom et K.M. Cole
Porphyra fucicola V. Krishnamurthy
Porphyra kurogii S.C. Lindstrom
Porphyra nereocystis C. L. Anderson in Blankinship et Keeler
Porphyra pseudolanceolata V. Krishnamurthy
Porphyra pseudolinearis Ueda
Porphyra schizophylla Hollenberg in Smith et Hollenberg
Porphyra torta V. Krishnamurthy
Porphyra variegata (Kjellman) Kjellman in Hus
Prasiola delicata Setchell et N.L. Gardner ?
Protomonostroma undulatum (Wittrock) K.L. Vinogradova
Pterosiphonia bipinnata (Postels et Ruprecht) Falkenberg
Ptilota serrata Kuetzing
Ptilota tenuis (Collins) Kylin
Punctaria tenuissima (C. Agardh) Greville
Ralfsia fungiformis (Gunnerus) Setchell et N.L. Gardner
Rhodochorton purpureum (Lightfoot) Rosenvinge
Rhodomela tenuissima (Ruprecht) Kjellman
Rosenvingiella polyrhiza (Rosenvinge) P.C. Silva
Scagelia occidentale (Kylin) E.M. Wollaston
Scytosiphon lomentarius (Lyngbye) Link
Soranthera ulvoidea Postels et Ruprecht
Sparlingia pertusa (Postels et Ruprecht) G.W. Saunders, Strachan et Kraft
Tokidadendron bullatum (N.L. Gardner) M.J. Wynne
Turnerella mertensiana (Postels et Ruprecht) Schmitz in Rosenvinge
Ulothrix flacca (Dillwyn) Thuret in LeJolis
Ulva californica Wille in Collins, Holden et Setchell
Ulva fenestrata Postels et Ruprecht
Ulvaria obscura var. blyttii (Areschoug) Bliding
Urospora neglecta (Kornmann) Lokhorst et Trask
Zostera marina Linnaeus

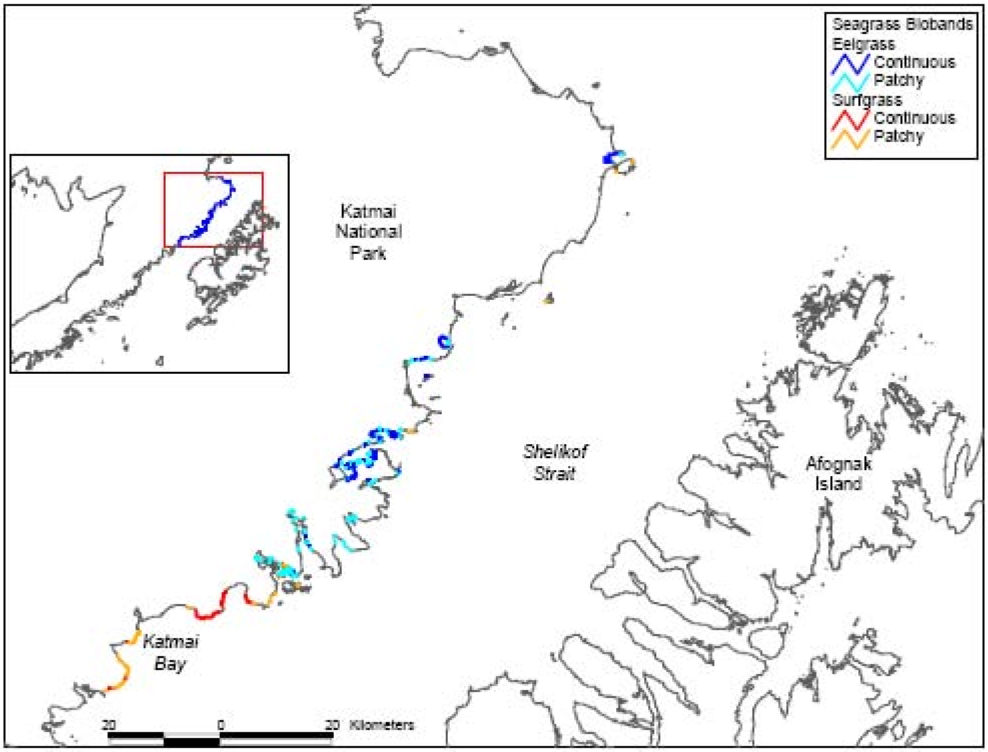

Figure 50. Distribution of eelgrass and surfgrass in KATM (Figure 42 in Harper and Morris, 2005)

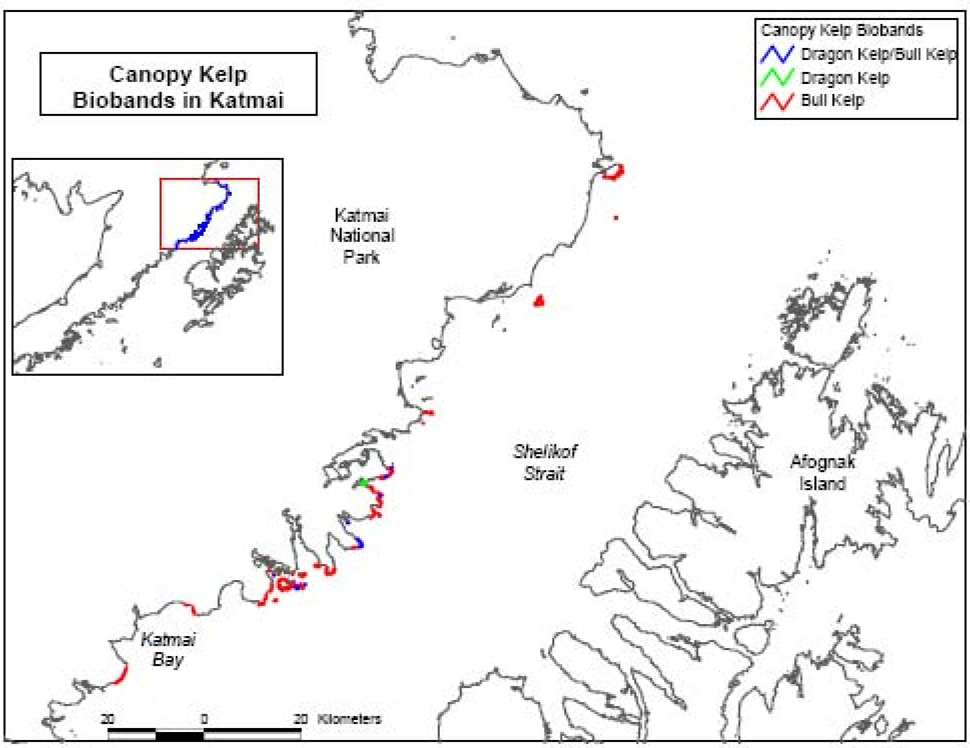

Figure 51. Distribution of canopy kelps in KATM (Figure 49 in Harper and Morris, 2005).

C2. Upland Resources

C2a. Plants and forest types

According to the ShoreZone mapping project, supratidal vegetation common along the shoreline are composed largely of marsh grasses, herbs and sedges (23%) and dune grasses (46%) (Harper and Morris, 2005). The 70 km (40 mi) of dunes that Harper and Morris (2005) mapped along the KATM coastline (**Figure 52**) provide habitat for dune grass (*Leymus mollis*) primarily. Coastal wetlands are spatially complex and wetland plant communities, which include dune grasses, *Leymus*- Herb Meadow, the Bluejoint (grass) *Leymus*- Herb Meadow, *Puccinellia* (alkali grass), and *Carex* (sedge species) are stratified along a gradient of salt tolerance (Harper and Morris, 2005).

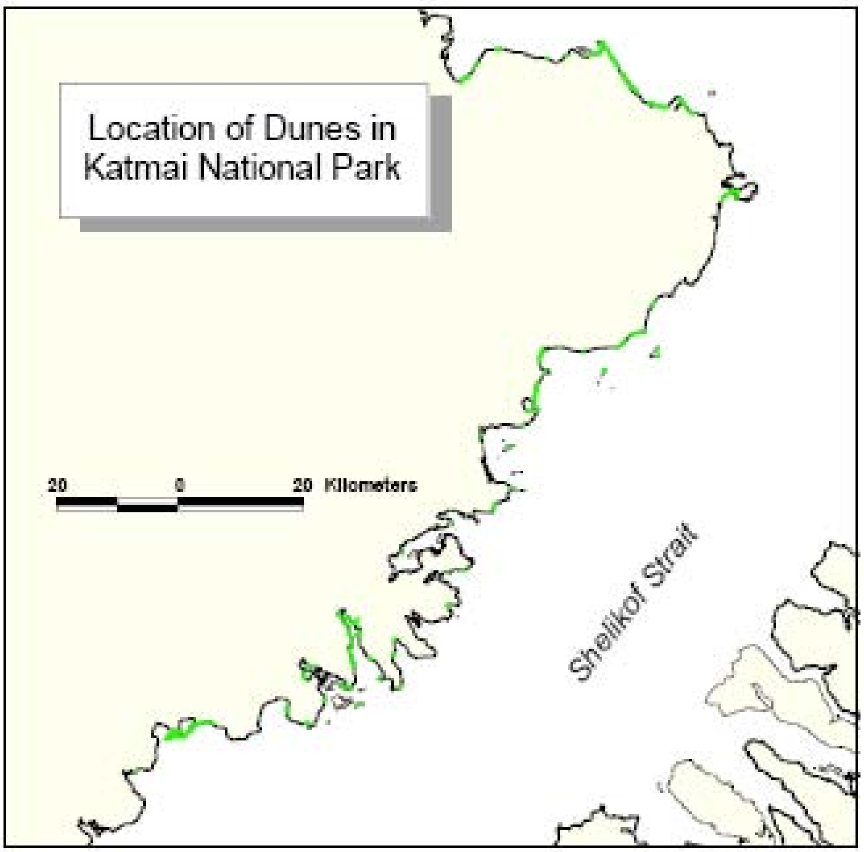

Figure 52. Occurrence of dunes along the KATM shoreline (Figure 28 in Harper & Morris, 2005).

Beyond the edge of the intertidal zone where soil conditions are suitable, tall alder shrub and tall willow shrub are the dominant land cover (**Figure 53**). Land coverage classification based on plant and forest types in KATM is shown in **Figure 53**.

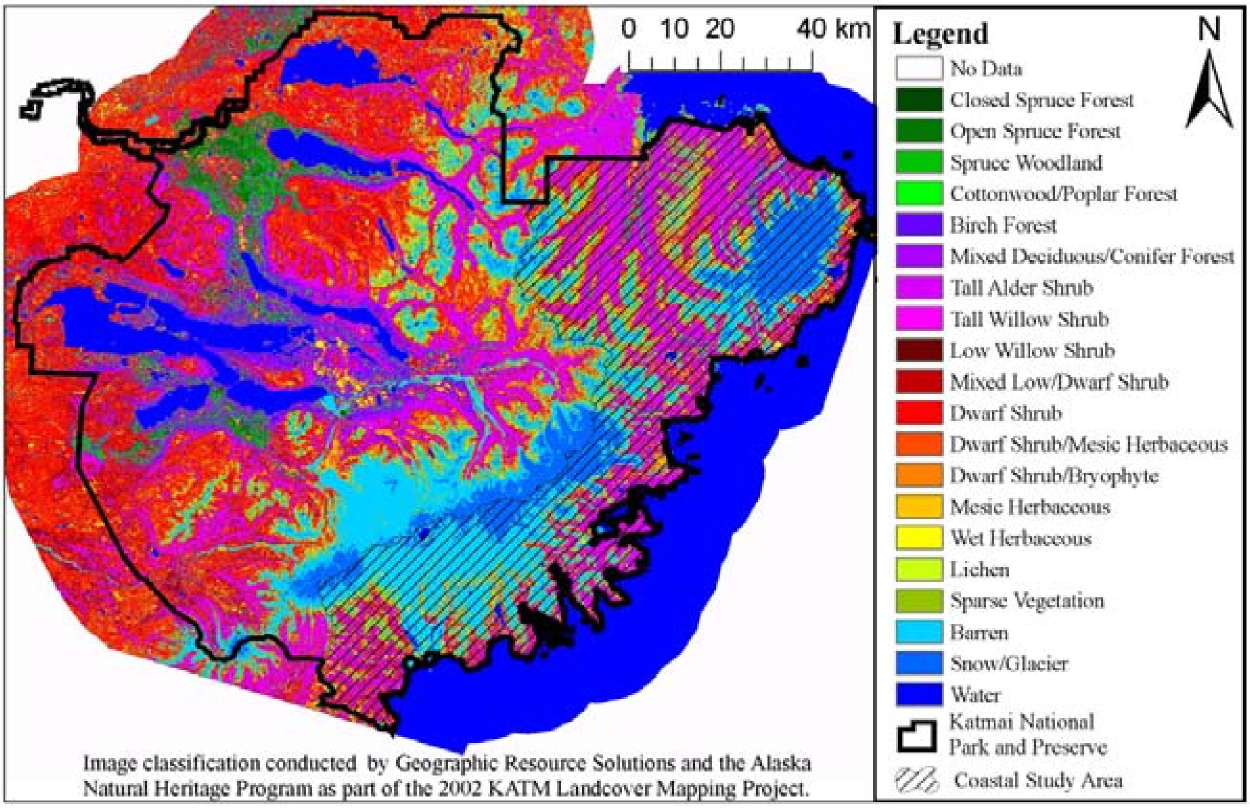

Figure 53. KATM land coverage classification based on plant and forest types.

A vascular plant inventory in KATM, conducted in 2002 as part of the NPS I&M Program, included an intensive evaluation of a coastal site at Swikshak Lagoon (Carlson and Lipkin, 2003). An important finding of the inventory was the discovery of a population of a tundra grass named *Dupontia fisheri* at this coastal site, extending its known range by about 300 km (200 mi). Carlson and Lipkin (2003) describe the lagoon's low elevation habitat as consisting of intertidal beach and halophytic-sedge habitats, forb-graminoid meadows, freshwater ponds and marshes, and alder and willow thickets. Higher elevations were characterized by wet, low shrub-edge meadows and fens, as well as a continuation of forb-graminoid meadows and alder/willow thickets. The highest elevations (450-900 m, 1500-3000 ft) were primarily composed of herbaceous-dwarf shrub tundra along exposed deflation and scree slopes. Each of these communities is described in detail, including species presence and names, in (Carlson and Lipkin, 2003).

C2b. Animal communities

A July, 2004 survey of mammals in Amalik Bay was conducted as part of the NPS I&M Program study of mammals within KATM (Cook and MacDonald, 2004). Five species (represented by 253 individuals) of small mammals were sampled at the site, and montane shrews, cinereus shrews, meadow jumping mice, and northern red-backed voles were more abundant at Amalik Bay compared to the other 4 study sites, all of which were in inland KATM. The report also documented the presence of red foxes (*Vulpes vulpes*), northern river otters (*Lontra canadensis*), brown bears (*Ursus arctos*), moose (*Alces alces*), and arctic ground squirrels (*Spermophilus parryii*) at Amalik Bay. Brown bear density in coastal KATM, specifically between Hallo Bay and Amalik Bay, is possibly the highest in the world, estimated recently at 551 bears of all ages (and 479 bears <2 years old) per 1000 km^2 (400 mi^2) (Sellers, 2005). Brown bear research in coastal KATM in the last 15 years at KATM was recently summarized in the 2005 Southwest Alaska Parks Science and Research Symposium (Smith, 2005).

C3. Freshwater Resources

C3a. Fishes

Although the western side of KATM includes well-studied and important habitat for the Bristol Bay salmon fishery, there have been no studies focusing on freshwater fishes and their habitat along the KATM coast (T. Hamon, NPS, *pers. comm.,* King Salmon, 2005).

Information on presence and types of anadromous fishes in the coastal area is contained in the 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 coastal KATM streams are summarized in Table 12 below.

Table 12. Anadromous Fish species present in coastal KATM streams according to Johnson and Weiss (2006).

Stream	Chinook salmon	Sockeye salmon	Coho salmon	Pink salmon	Chum salmon	Arctic char	Dolly varden
Little Kamishak River	X	X	X	X	X		
Strike Creek	X	X	X	X	X	X	
Kamishak River	X		X	X	X	X	
Douglas River		X	X	X	X	X	
Swikshak River		X	X	X	X		X
Big River				X	X		
Hallo Creek				X	X		
Katmai River				X	X		
Alagogshak Creek				X	X		

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

Various sources of information on fisheries in the entire KATM unit are available, some of which provide specific information on coastal KATM. For example, an early survey of fisheries resources in KATM identified salt-tolerant species (e.g. salmon, char, sticklebacks, and sculpins) in the drainages feeding into the Shelikof Strait and noted the absence of such principally freshwater fishes as whitefish, lake trout, grayling, blackfish, pike, suckers, and burbot, which occur in the interior art of the park (see Table 13 and Table 14 for scientific names) (Heard et al., 1969). In addition, a 1983 Fisheries management plan identifies eight species of fish in the Shelikof Strait and Kamishak Bay drainages (NPS, 1983). As for the lakes in coastal KATM, there are no fish within Katmai’s crater lake, which began developing only after the 1912 eruption of Novarupta. Kaguyak’s crater lake, where arctic char were introduced in 1956 but did not become established, contains only Dolly Varden (NPS, 1983).

The NPSpecies list for KATM includes 17 species of anadromous and 9 species of freshwater fishes (Table 13 and Table 14; no separation of coastal vs. inland species locations provided). The most recent baseline inventory of freshwater fish conducted as part of the I&M program verified that 24 freshwater fish species occurred within KATM (entire unit). As an added note, 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).   The researchers found no significant relationship between fish species diversity and physical characteristics such as stream elevation, but they detected a slight increase in diversity in lake systems, with diversity increasing in response to the combined factors of lake area and elevation (Jones et al., 2005).

Table 13. Anadromous fishes on the NPSpecies list for KATM (NPS 2004b).

Family	Species Name	Common Name
Gasterosteidae	*Gasterosteus aculeatus*	Threespine stickleback
Gasterosteidae	*Pungitius pungitius*	Ninespine stickleback
Osmeridae	*Hypomesus olidus*	Pond smelt
Osmeridae	*Hypomesus pretiosus*	Surf smelt
Osmeridae	*Osmerus mordax*	Arctic smelt
Osmeridae	*Thaleichthys pacificus*	Eulachon
Petromyzontidae	*Lampetra japonica*	Arctic lamprey
Salmonidae	*Coregonus clupeaformis*	Humpback whitefish
Salmonidae	*Coregonus sardinella*	Least cisco
Salmonidae	*Oncorhynchus gorbuscha*	Pink salmon
Salmonidae	*Oncorhynchus keta*	Chum salmon
Salmonidae	*Oncorhynchus kisutch*	Coho salmon
Salmonidae	*Oncorhynchus mykiss*	Steelhead
Salmonidae	*Oncorhynchus nerka*	Sockeye salmon
Salmonidae	*Oncorhynchus tshawytscha*	Chinook salmon
Salmonidae	*Salvelinus alpinus*	Arctic char
Salmonidae	*Salvelinus malma*	Dolly varden char

Table 14. Freshwater fishes on the NPSpecies list for KATM (NPS 2004b).

Family	Species Name	Common Name
Catostomidae	*Catostomus catostomus*	Longnose sucker
Cottidae	*Cottus cognatus*	Slimy sculpin
Esocidae	*Esox lucius*	Northern pike
Lotidae	*Lota lota*	Burbot
Salmonidae	*Prosopium coulteri*	Pygmy whitefish
Salmonidae	*Prosopium cylindraceum*	Round whitefish
Salmonidae	*Salvelinus namaycush*	Lake trout
Salmonidae	*Thymallus arcticus*	Arctic grayling
Umbridae	*Dallia pectoralis*	Alaska blackfish

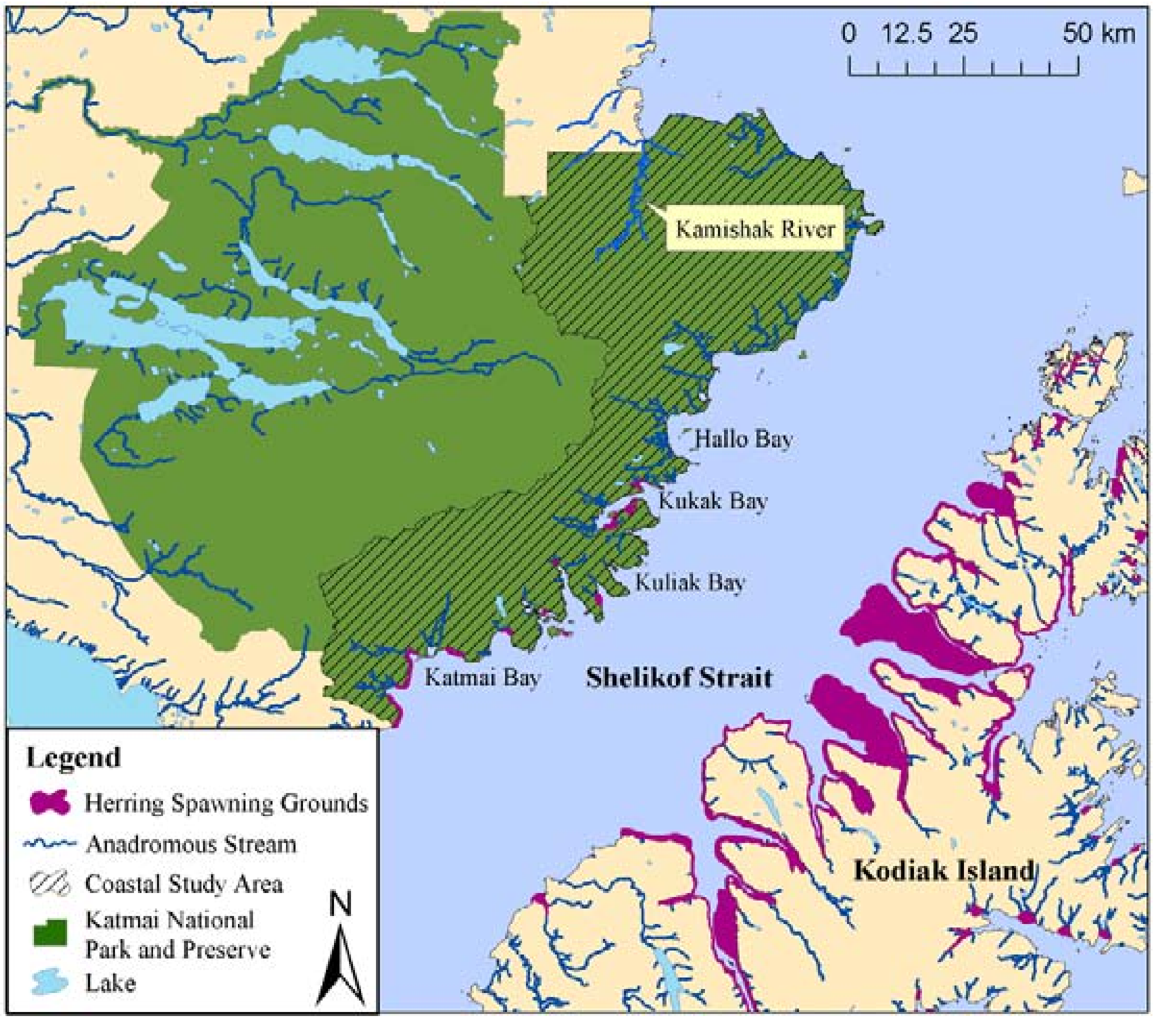

Figure 54. Anadromous streams and spawning grounds in and around KATM.

The most significant factor affecting salmon populations in KATM is the commercial fishing industry (NPS, 2004). Salmon purse and beach seining is allowed along most of the outer coast of KATM (Figure 55). Salmon populations spawning in drainages on the Shelikof coast are monitored by the Kodiak office of Commercial Fisheries; populations spawning in the Kamishak and Douglas drainages in Kamishak Bay are monitored by the Homer office of Commercial Fisheries (Weeks, 1999). Spawning salmon are an important resource for both terrestrial and aquatic ecosystems within KATM. When salmon return to their natal streams to spawn, they transport marine nutrients and energy across ecosystem boundaries and their carcasses release large quantities of "marine-derived nutrients" to freshwater and terrestrial ecosystems (Cederholm et al., 1999; Johnston et al., 2004; Willson et al., 1998). Salmon directly affect the ecology of consumers at many trophic levels, and thus their annual return has widespread effects on the food webs of coastal watersheds (Cederholm et al., 1999; Gende et al., 2002). The organic and inorganic nutrients (carbon, nitrogen, and phosphorus) released by spawning salmon are important to the overall health of these watersheds (Bryant and Everest, 1998) and can also strongly affect productivity in coastal streams (Chaloner and Wipfli, 2002; Wipfli et al., 1998). In particular, the seasonal pulse of salmon carcasses can dramatically elevate streamwater levels of limiting nutrients such as nitrogen and phosphorus (Mitchell and Lamberti, 2005)and thereby increase primary and secondary productivity in receiving streams. In addition, carcasses that end up in the riparian zone as a result of changes in stream discharge or bear activity provide a substantial input of nutrients such as nitrogen and phosphorus to riparian soils (Gende et al., 2002). These nutrients can be rapidly assimilated by microbial communities and vegetation in the riparian environment (Bilby et al., 1996)and have been hypothesized to increase the growth rate of trees in the riparian forest (Helfield and Naiman, 2002).

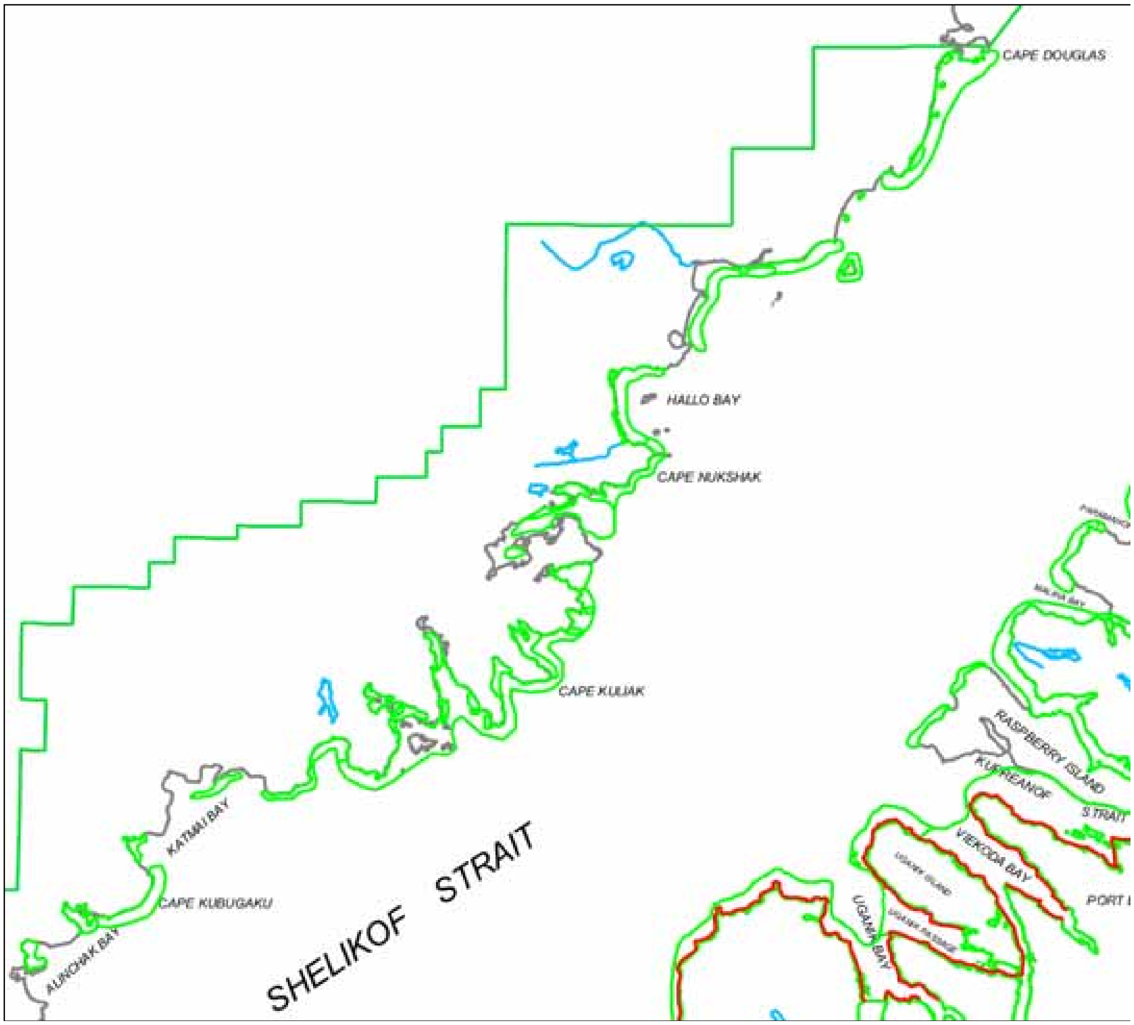

Figure 55. Excerpt of map of commercial fishing areas: salmon purse and beach seining (green lines) and set net areas (red lines) in the coastal KATM region. Map available from the Alaska State Geospatial Clearinghouse website for the Kodiak region (at http://www.asgdc.state.ak.us/maps/cplans/subareas.html#kodiak). Map data are based on Alaska Department of Fish and Game resources, with additional information by local communities, resource agencies, and resource focus groups.

C3b. Amphibians

Although there are no known formal surveys of amphibians in KATM, the wood frog (*Rana sylvatica*) is the only amphibian species that inhabits the park. This freeze tolerant species, which is observed elsewhere on 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). Park records include 1 unverified observation of wood frogs in KATM, east of Swikshak Bay (Anderson, 2004), and several specimens were collected 10-40 km (6-20 mi) northwest of the Park border and are currently held in the museum collections at the University of Alaska Fairbanks (**Figure 56**).

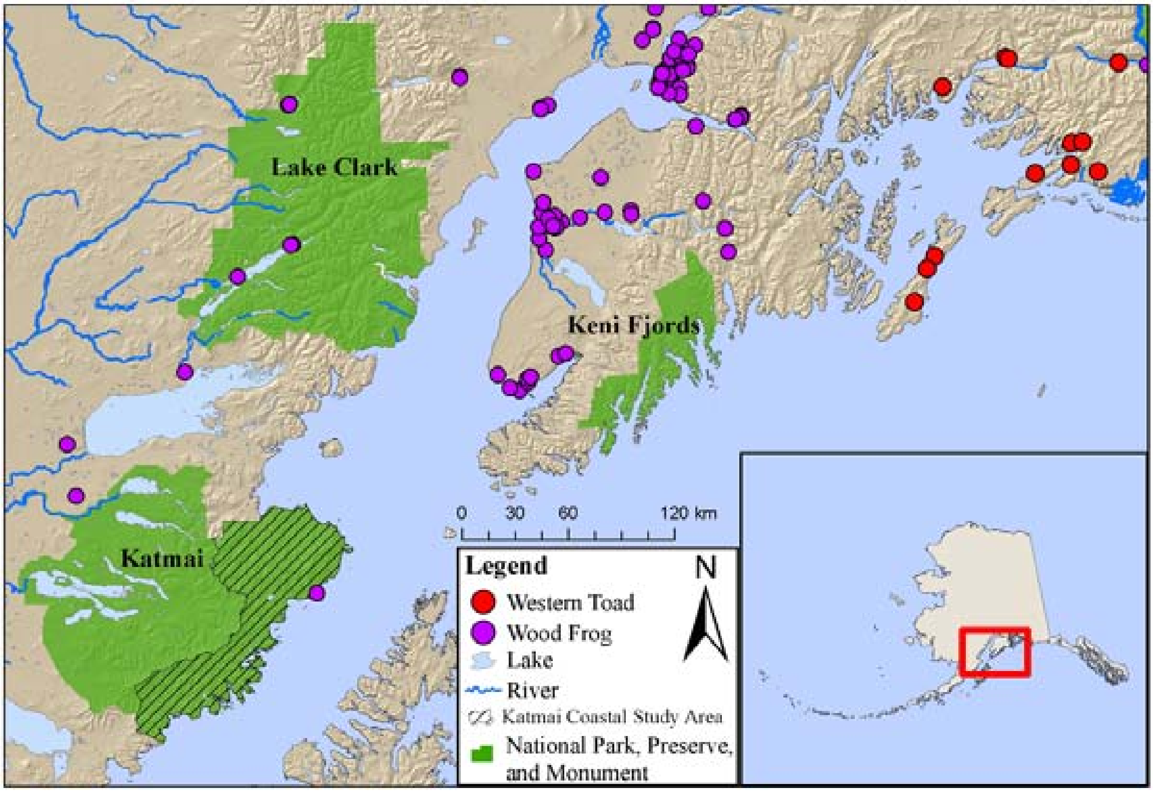

Figure 56. Location of amphibian reports in Southcentral Alaska. (Source: Alaska Natural Heritage Program).

C3c. Aquatic invertebrates, chlorophyll, phytoplankton, zooplankton

The only known information on aquatic invertebrates, chlorophyll, phytoplankton, and/or zooplankton comes from Cameron and Larson (1992), who conducted as study of the Aniakchak caldera and made some comparisons to Katmai's crater lake and the lake in Kagyuak crater (both in coastal KATM) and to Naknek and Brooks Lake in interior KATM. According to their study, harsh conditions in the acidic waters of the Katmai crater lake were reflected by the low phytoplankton and zooplankton community densities and only trace amounts of chlorophyll (chlorophyll was found to correlate with pH). The phytoplankton communities (dominated by *Synechocystis sp.*, a blue green algae) of Kaguyak Lake was similar to that of Surprise Lake in the Aniakchak crater (in ANIA), although Kaguyak had fewer zooplankton taxa (dominated by *Daphnia longiremis*, a large cladoceran grazer) (Cameron and Larson, 1992).

IV. Water Resources Assessment

A. Water and Sediment Quality

A1. Intertidal and Marine

A1a. EMAP in southcentral and southwestern Alaska

Water, sediment, and biologic quality in marine waters were surveyed in 2002 by the Environmental Monitoring and Assessment Program (EMAP, information available at: http://www.dec.state.ak.us/water/wqamp/emap.htm). Under this program, administered by the Alaska Department of Environmental Conservation (ADEC), samples were collected at 55 sites (at 3-352 m (10-1150 ft) depth) located throughout southcentral and southwest Alaska. Sites were located in Prince William Sound, Cook Inlet, Shelikof Strait, and along the Alaska Peninsula (**Figure 57**). They 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, histopathy specimens and external pathological anomalies in fish on the benthos.

Results from this sampling effort comprise the most comprehensive dataset available on the physical and biological conditions in the marine waters adjacent to KATM 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 in 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 study area. 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/Ll (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).

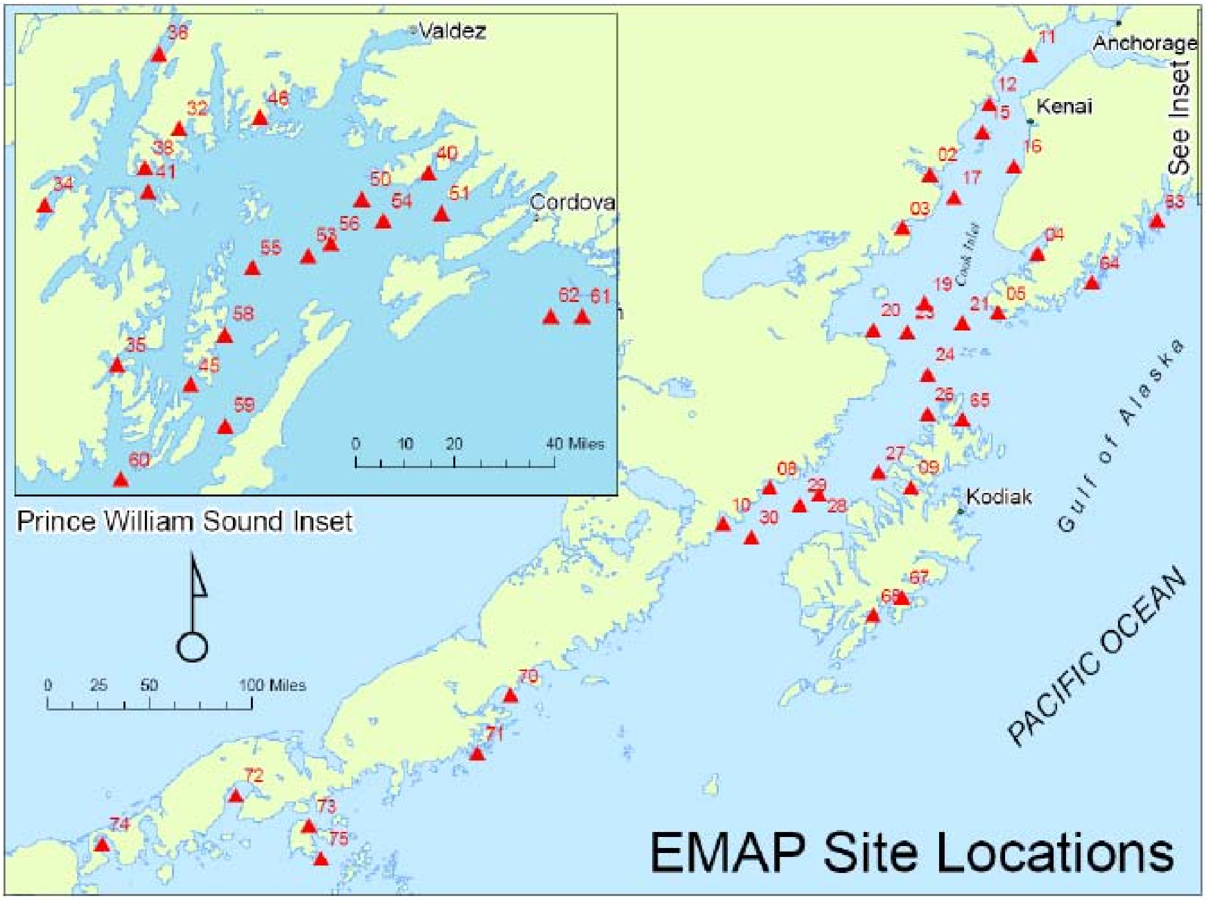

Figure 57. Sites sampled by EMAP in southcentral Alaska in 2002 (Saupe et al., 2005). The two-digit numbers reflect the last two numbers of each station. Prince William Sound is inset. Stations closest to KATM are (from north to south): #20, 23, 24, 26-30, 08, and 10.

In terms of contaminants, the EMAP project found few indications of levels of concern (Saupe et al., 2005). The EMAP 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. The concentrations of metals (Ag, Al, Cd, Cr, Cu, Hg, Fe, Pb, Mn, Ni, Se, Sb, Sn, Zn) and arsenic in the sediments collected off the KATM coast were all of acceptable quality, and almost all samples from the EMAP southcentral region were as well. 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 58**) (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 4020 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.

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 KATM coastal vicinity. Benthic infaunal communities in Shelikof Strait and throughout the study region were dominated by polychaetes (Saupe et al. 2005). Infaunal abundance was highest at one of the EMAP sites within the KATM region in Shelikof Strait (Saupe et al. 2005), however, little is known about spatial and temporal variation in benthic infauna in Alaska. Fish tissue analyses (95 samples from the 55 stations) of metals and organic pollutants showed that 100% of samples fell below the USEPA's Risk Guidelines for Recreational Fishers and also below the U.S. Food and Drug Administration's "Action Limits" for commercial fish.

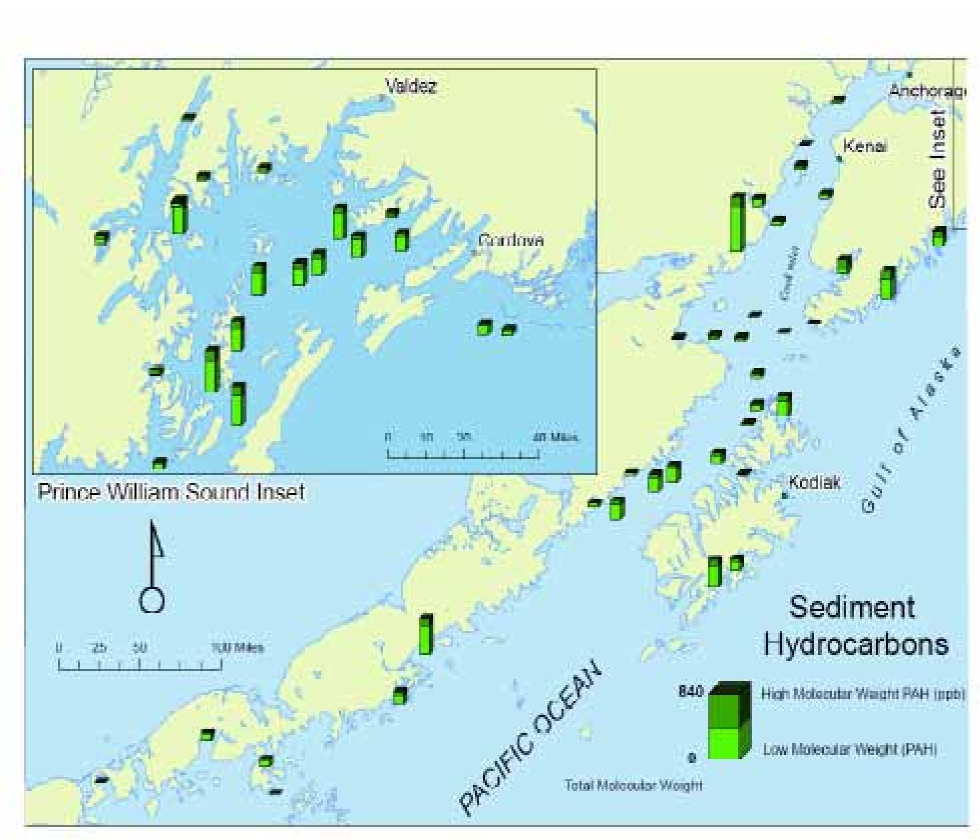

Figure 58. Sediment polynuclear aromatic hydrocarbon (PAH) concentrations (μg/g) at sampled stations across the EMAP study area, with low and high molecular weight PAHs shown as a fractrion of total PAH. From Saupe et al. (2005).

A1b. Other offshore sediment quality data

A baseline water quality retrieval effort by the NPS identified forty offshore stations (**Table 15**, **Figure 59**,60, 61) outside but adjacent to the NPS boundaries where sediment samples were collected between 1989 and 1994 in response to the Exxon Valdez Oil Spill in March 1989 (NPS, 2001). Samples were taken 1-4 times (but usually just once) between 1989-1994.

These sites were sampled for sediments only as part of a project funded by the Exxon Valdez Oil Spill Trustee Council and developed by the Alaska Department of Natural Resources and NOAA. The sediments were measured for oil-spill related parameters, such as C4,-, C3-, and C2-napththalene, perylene, C1-,C2-, and C3-fluorene, dibenzothiophene, C1-, C2-, C3-, and C4-chrysene, methylphenanthrene, and 2,6-dimethylnaphthalene. Median, mean, maximum, minimum, variance, and standard deviation values of the chemical concentrations are provided in site-specific tables in NPS (2001). While the NPS (2001) report says there are no EPA criteria to which these data can be compared, the samples comprise a baseline dataset to which future changes in hydrocarbon contamination levels can be compared

Table 15. Site code, locality, latitude, longitude, and sample date for sediment samples collected in the KATM coastal area, according to information compiles in NPS (2001).

ID	Locality	Latitude	Longitude	Sample Date
KATM 0001	Sukoi Bay	58.873892	-153.288892	7/30/1992
KATM 0002	Kiukpalik Island	58.596699	-153.553115	7/31/1992
KATM 0003	Kiukpalic Island	58.585615	-153.554199	8/8/1994
KATM 0004	Cape Chiniak	58.514280	-153.908700	9/28/1989
KATM 0005	Nukshak Island	58.391670	-153.908080	6/18/1993
KATM 0006	Nukshak Island	58.391698	-153.980809	8/6/1992
KATM 0007	Hallo Bay	58.436392	-153.981116	8/16/1989
KATM 0008	Niniagiak Island	58.454530	-153.997860	8/9/1994
KATM 0009	Niniagiak Island	58.454420	-153.998880	12/10/1989
KATM 0010	Niniagiak Island	58.453660	-154.000290	7/14/1994
KATM 0011	Niniagiak Island	58.453750	-154.000140	7/14/1994
KATM 0012	Niniagiak Island	58.458115	-154.003893	8/16/1989
KATM 0013	Niniagiak Island	58.454320	-154.009940	7/14/1994
KATM 0014	Hallo Bay	58.456893	-154.014699	8/16/1989
KATM 0015	Hallo Bay	58.456698	-154.018310	8/16/1989
KATM 0016	Hallo Bay	58.453615	-154.020616	7/14/1994
KATM 0017	Hallo Bay	58.455809	-154.023115	8/16/1989
KATM 0018	Hallo Bay	58.420004	-154.031116	8/16/1989
KATM 0019	Hallo Bay	58.449003	-154.048003	9/29/1989
KATM 0021	Kaflia Bay	58.235800	-154.148650	10/2/1989
KATM 0022	Kaflia Bay	58.235400	-154.152030	8/10/1994
KATM 0023	Kaflia Bay	58.235500	-154.152300	8/2/1992
KATM 0024	Kukak Bay	58.294670	-154.260430	9/29/1989
KATM 0026	Kaflia Bay	58.173360	-154.278060	5/15/1999
KATM 0027	Kaflia Bay	58.183780	-154.289800	5/15/1999
KATM 0028	Kaflia Bay	58.183260	-154.288660	5/15/1999
KATM 0029	Missak Bay	58.144809	-154.330030	9/27/1989
KATM 0030	Missak Bay	58.135000	-154.429500	9/27/1989
KATM 0031	Missak Bay	58.135000	-154.329500	9/27/1989
KATM 0032	Takli Island	58.067810	-154.488116	6/27/1990
KATM 0049	Katmail Bay	57.975004	-154.940040	8/17/1989
KATM 0050	Katmail Bay	57.954198	-154.941699	8/17/1989
KATM 0060	Katmail Bay	57.981698	-154.975809	8/17/1989
KATM 0061	Katmail Bay	57.956893	-154.975615	7/15/1994
KATM 0066	Btw Katmai, Kashvik Bays	57.970615	-155.016698	7/15/1994
KATM 0067	“ “	57.970615	-155.019698	7/15/1994
KATM 0070	“ “	57.971699	-155.026699	8/17/1989
KATM 0080	Kashvik Bay	57.907504	-155.070004	8/4/1992
KATM 0081	Kashvik Bay	57.907810	-155.070309	8/11/1994
KATM 0084	Kashvik Bay	57.911670	-155.083310	8/17/1989

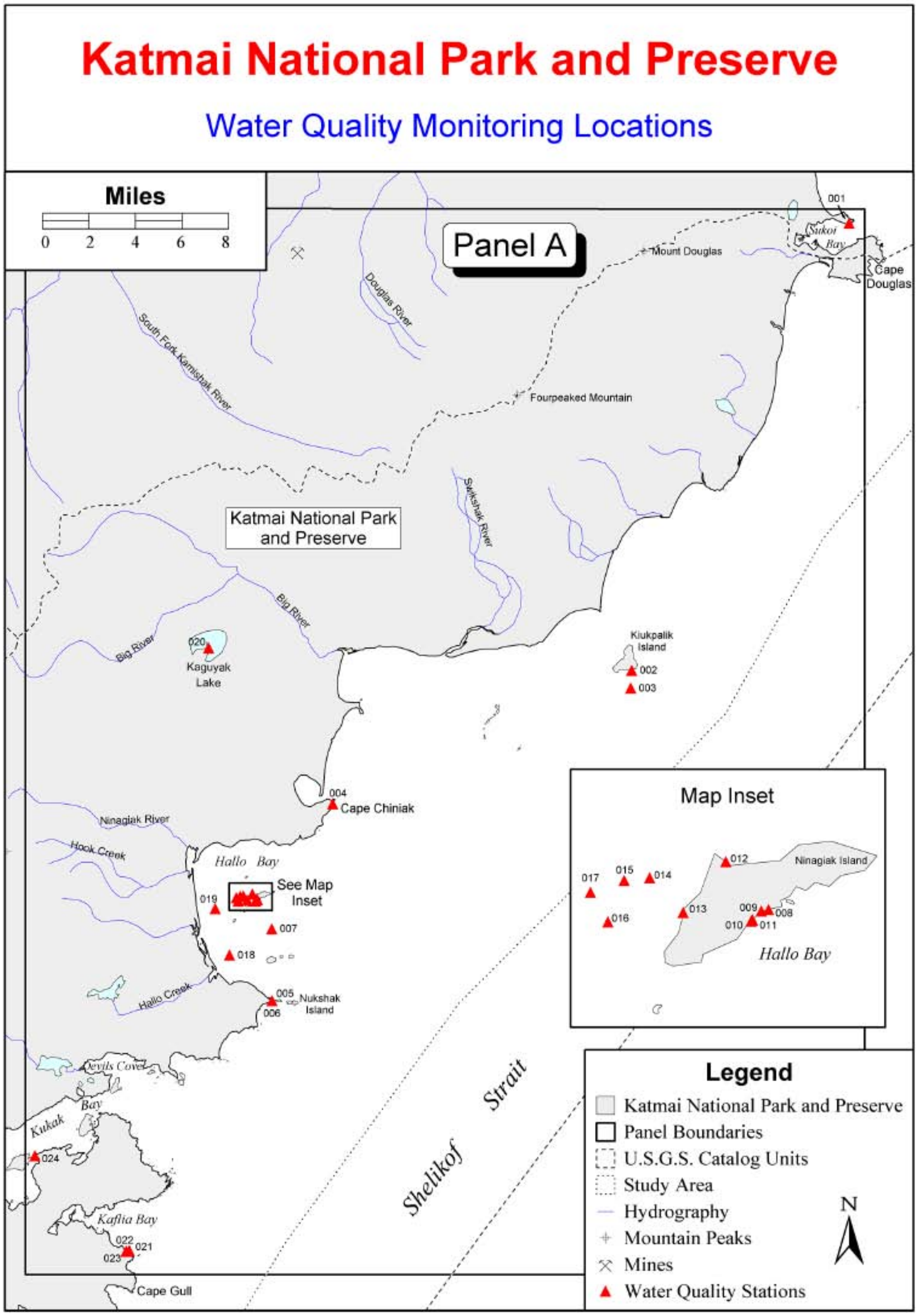

Figure 59. Sample location map of sites where water and/or sediment samples were collected between 1953 and 1997 in KATM by various research agencies (compiled in NPS, 2001). Sample sites in panels A are those where offshore sediments were collected following the Exxon Valdez Oil Spill between Cape Douglas and Kaflia Bay. Site codes correspond to listings of their latitude/longitude information in Table 15.

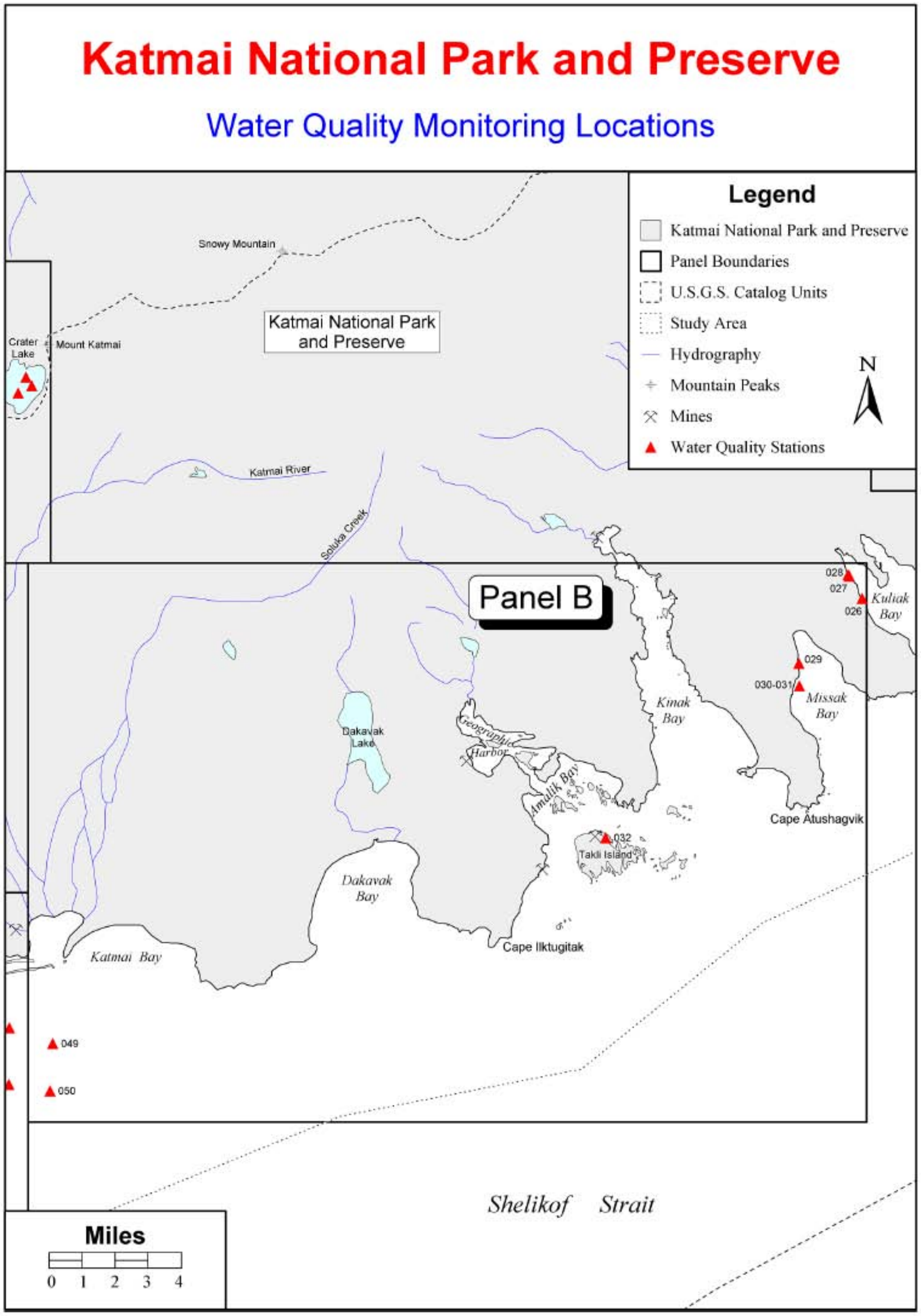

Figure 60. Sample location map of sites where water and/or sediment samples were collected between 1953 and 1997 in KATM by various research agencies between Missak and Katmai Bays (compiled in NPS, 2001). Site codes correspond to listings of their latitude/longitude information in Table 15.

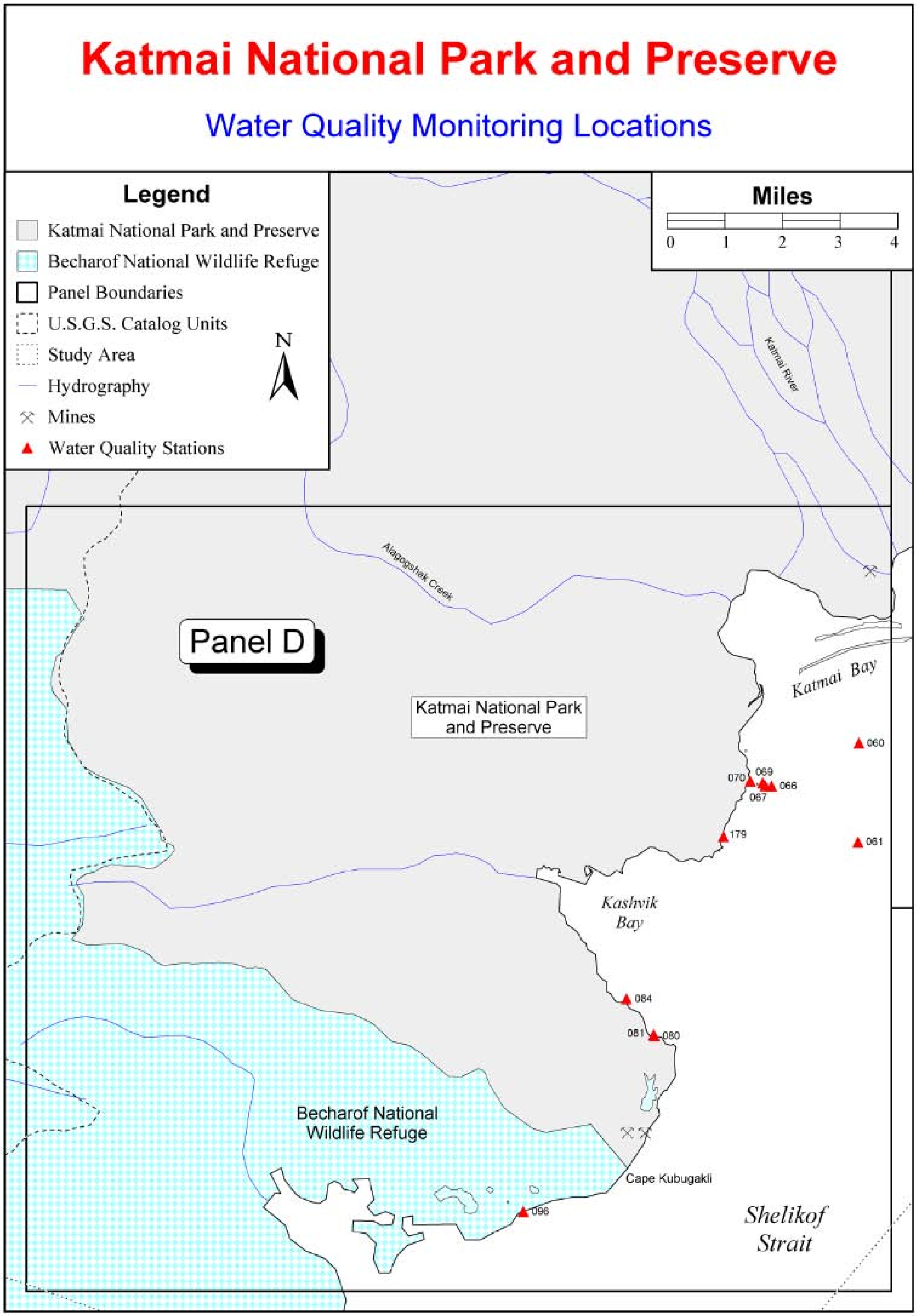

Figure 61. Sample location map of sites where water and/or sediment samples were collected between 1953 and 1997 in KATM by various research agencies between Katmai Bay and the KATM boundary (compiled in NPS, 2001). Site codes correspond to listings of their latitude/longitude information in Table 15.

A1c. 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, black oystercatcher, and sea otters, **Table 16**) 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 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). More information on the vital signs monitoring plan is provided in Bennett et al. (2006) and at the SWAN I&M website: http://www.nature.nps.gov/im/units/swan/index.cfm?theme=Overview.

Table 16. Nearshore marine vital signs and objectives of monitoring (Bodkin et al., 2007).

Marine Water Chemistry

- Acquire regional synoptic nearshore oceanographic data collected by the Alaska Ocean Observing System (AOOS) and incorporate into regional (SWAN) data sets.
- Document daily, seasonal, and annual variability and gradients in temperature and salinity at randomly selected shallow water (<20 m; 66 ft) nearshore sampling sites.
- Collect mussel (*Mytilus trossulus*) tissue for contaminant analysis.

Kelps and seagrasses

- Estimate long-term trends in abundance and distribution of kelps and seagrass.
- Estimate intertidal algal diversity.
- Estimate species composition and percent cover of intertidal algae at two tidal levels (+0.5 and +1.5 m).

Intertidal invertebrates

- Estimate percent cover of dominant sessile intertidal invertebrates (e.g. barnacles, mussels, snails, and limpets).
- Estimate densities of large intertidal invertebrates (e.g. stars, chitons, urchins).
- Document how the size distribution of limpets (*Tectura persona*) and mussels (*Mytilus trossulus*) is changing annually.
- Estimate long-term trends in abundance of littleneck clam (*Protothaca staminea*).
- Document how the size distributions and growth rates of littleneck clams are changing annually.
- Monitor status and trends in the concentration of metals, organochlorides, PCBs, and Hg in mussel tissue.

Marine Birds

- Estimate densities (se) of marine birds and mammals in coastal transects.
- Document change in populations of marine birds and mammals over time.

Black oystercatcher

- Estimate black oystercatcher density (se) in coastal transects.
- Estimate black oystercatcher nest density.
- Estimate number of eggs/chicks per nest.
- Estimate species composition and sizes of prey returned to nests.
- Document change in black oystercatcher density, productivity, and diet over time.

Sea Otter

- Estimate sea otter density (se) in coastal transects.
- Estimate prey species composition, prey number, and prey sizes.
- Estimate forage dive attributes (success, dive times, surface times).
- Estimate energy recovery rates of foraging sea otters.
- Estimate age class distribution of beach cast sea otters.
- Document change in sea otter density, diet, and survival over time.

A2. Streams and lakes

A2a. 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, and they include: surface water hydrology, freshwater chemistry, and landscape processes (including snow cover, lake and coastal ice, and suspended sediments)(Bennett et al., 2006). The water quality monitoring design components are fully integrated into the SWAN vital signs monitoring program (Bennett et al., 2006). To provide specialized guidance on the water quality monitoring component, a cooperative project was established between the NPS, SWAN, and University of Washington's School of Aquatic and Fishery Sciences (O'Keefe and Naiman, 2004). This collaborative effort developed an annotated bibliography of past and present freshwater research and monitoring in southwestern Alaska and summarized existing knowledge and identified ongoing data collection efforts that are relevant to aquatic monitoring in SWAN (O'Keefe, 2005). Results of the water quality monitoring project review found no 303(d) waters present with KATM (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 project developed a strategy for long-term monitoring of freshwater aquatic resources within the SWAN units. Streams and lakes were categorized into 3 tiers by using 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 are of medium priority, less accessible, and will be randomly subsampled 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 waterbodies. Vital sign metrics at Tier 2 and 3 waterbodies may also be collected by seasonal park staff on an opportunistic basis. In the coastal KATM area, no waterbodies were identified as Tier 1; the Hallo Lake system was designated as Tier 2; and Dakavak Lake was categorized as a Tier 3 waterbody (**Figure 62**).

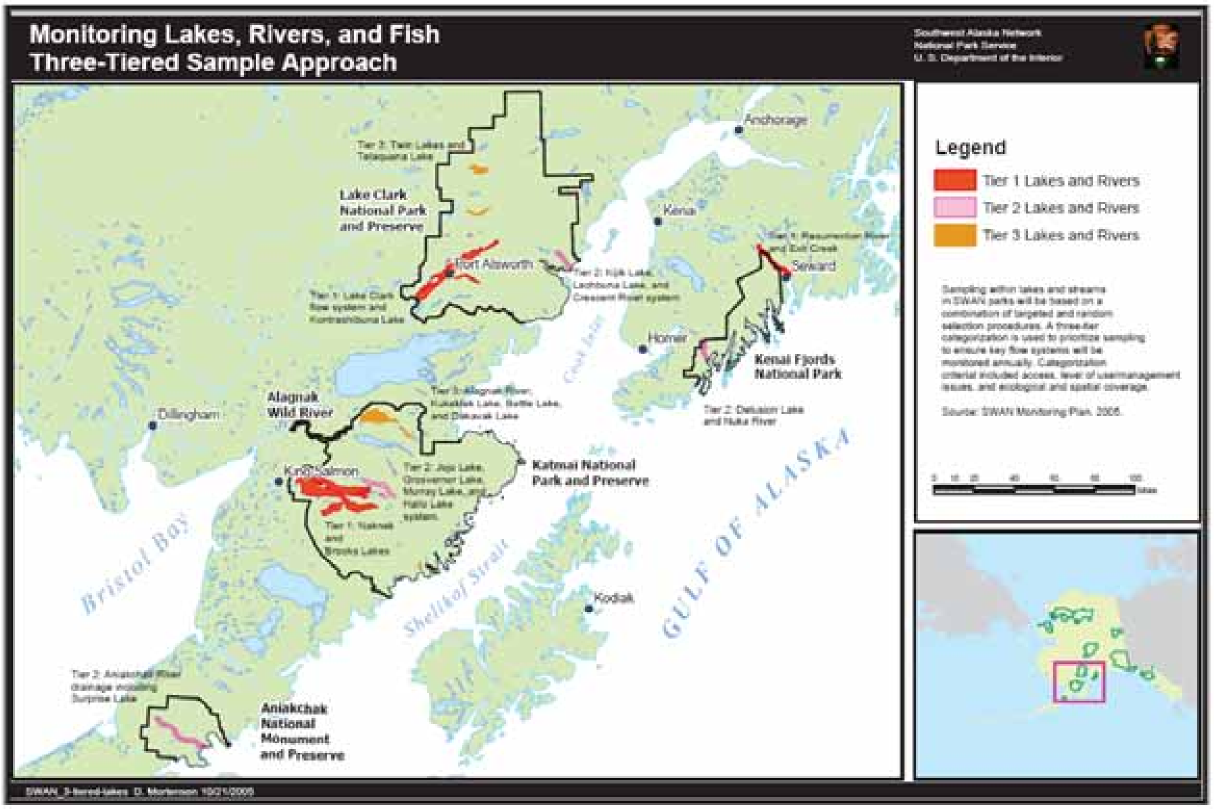

Figure 62. List and locations of proposed Tier 1,2, and 3 lakes and rivers for monitoring aquatic resources in SWAN units. Along the KATM coast, Hallo Lake system is ranked as Tier 2 and Dakavak Lake is ranked as Tier 3. (Bennett et al., 2006).

The surface hydrology and freshwater chemistry monitoring design calls for Tier 2 and 3 lakes and streams to be stratified by lake size, water type (clear, glacial, brown), and accessibility prior to selection using a GRTS design (Bennett et al., 2006; Stevens and Olsen, 2004).

A2b. Water quality of streams and lakes

For most water bodies in coastal KATM, water quality conditions are unknown. While scattered data exist on a few targeted streams and lakes (**Figure 63**), no studies have been designed and conducted specifically to survey water quality in the coastal watersheds of KATM. Without documented baseline information, it is not possible to make an assessment of their condition. However, due to their remoteness, lack of trails and human infrastructure, and near inaccessibility to humans it is fair to assume that their water quality conditions are almost entirely naturally influenced. There are no water bodies in coastal KATM that are listed as impaired under section 303(d) of the federal Clean Water Act (CWA). However, beaches along the Shelikof Strait and adjacent marine waters waters are listed under Tier III of Alaska's 303(d) list; that is, although they do not meet CWA Section 303(d) criteria, they are of concern and have a recovery plan. In the case of KATM's beaches and coastal waters, the concern stems from damage incurred by the Exxon Valdez Oil Spill (EVOS), and recovery is overseen by the Exxon Valdez Trustee Council, which aims to assess, restore, and enhance natural resources and shorelines impaired as a result of EVOS (see http://www.evostc.state.ak.us/). Other potential water quality concerns include the possible contamination by pollutants such as mercury and organic chemicals is discussed in section V.A.1. *Oceanographic sources* and 2. *Atmospheric sources* of this report. Additionally, disruption of nutrient cycling the streams may be caused by a decline in salmon migrations into the freshwater streams (see section III.C3a).

Water quality information is lacking not only in coastal KATM, but in much of the SWAN. A recent baseline inventory report of SWAN freshwater fishes emphasizes that the near absence of streamflow and water quality characteristics completely in the SWAN hinder needed ecological assessments for freshwater fishes as well (Jones et al., 2005). The few sources of information on water quality in coastal KATM lakes and streams are discussed below.

A baseline water quality inventory study of KATM and ALAG conducted by the NPS presents results of extensive data retrievals using six of the Environmental Protection Agency's (EPA) national databases: Storage and Retrieval (STORET) water quality database management system; River Reach File (RF3); Industrial Facilities Discharge (IFD); Drinking Water Supplies (DRINKS); Water Gages (GAGES); and Water Impoundments (DAMS) (NPS, 2001). The report concluded that the KATM and ALAG surface water bodies are generally of good quality, with some impacts from natural and human activities. In particular, the KATM coastal shores showed impact from the Exxon Valdez oil spill in 1989, based on offshore sediment quality (see section *IV.A.1.d. Offshore sediment quality*). The report identified potential anthropogenic sources of contaminants as: wastewater discharges, stormwater runoff, oil tanker and other marine traffic, floatplane traffic, commercial fishing operations, oil and gas exploration, military activities, landfill operations, recreational use, and atmospheric deposition (NPS, 2001). However, it is unlikely that some of these named threats (e.g. stormwater runoff, military activities, landfill operations) are relevant to coastal KATM.

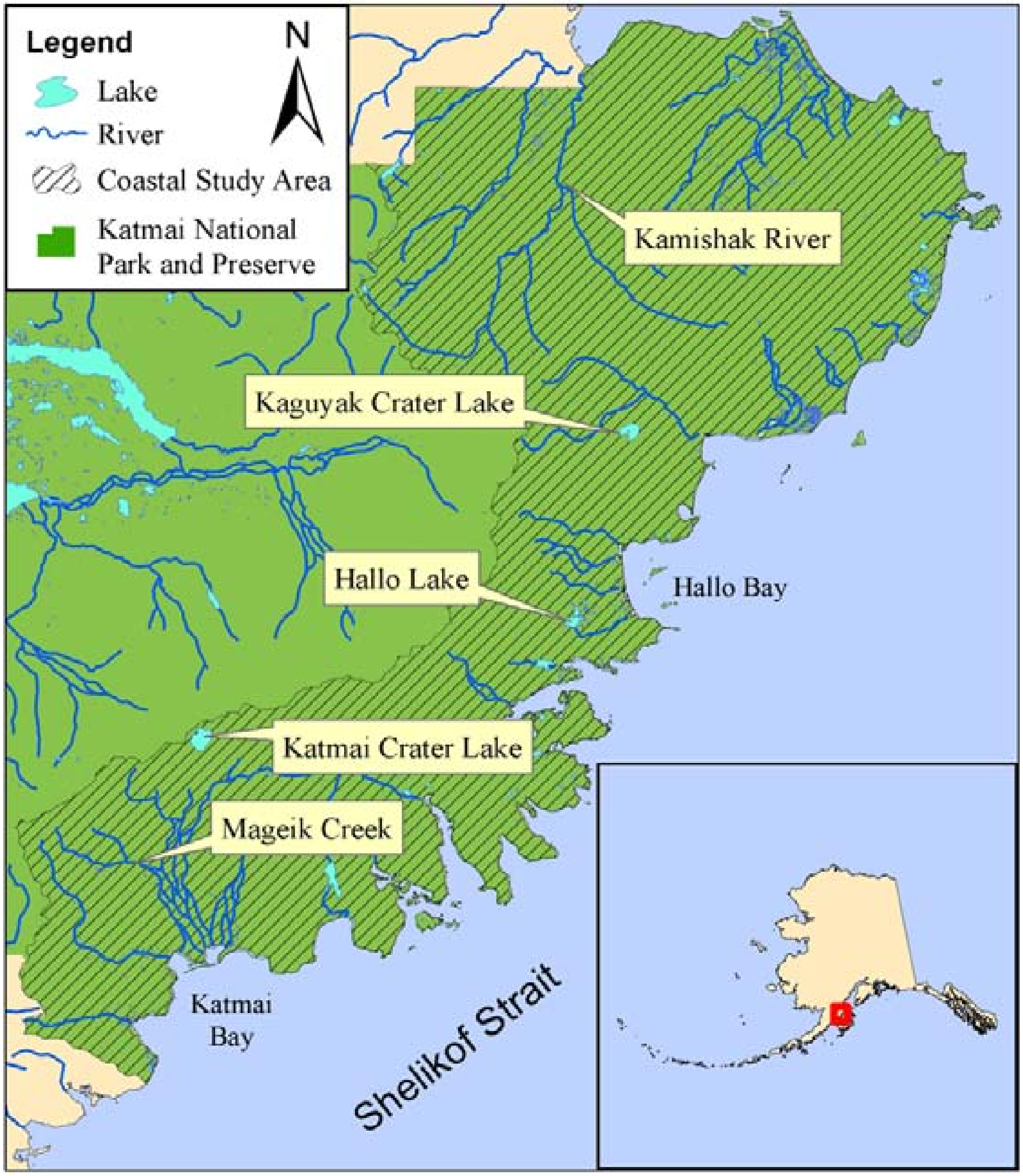

Figure 63. Sites within the coastal study area where water quality samples have been taken.

A2b 1) Water quality of crater lakes and geothermal springs

The NPS (2001) report yielded retrievals of 28,344 observations for 350 parameters collected at 248 monitoring stations in the study area between 1953-1997, mostly by the USGS, NPS, and EPA (**Figure 64**). However, aside from the 40 stations where offshore sediments were included, only 3 locations in the coastal KATM area had any freshwater chemistry data. These stations were at Kaguyak Lake (code: KATM 0020), at thermal springs near Mageik Creek (KATM 0098-0100, 102, 103), and in the crater lake of Mount Katmai (KATM 0055, 0057, 0062) (**Figure 64**). The NPS (2001) report determined that samples from these stations exceeded criteria-based water quality standards. However, it is very important to note that information on water quality standards are given here merely as a comparative reference for the conditions of these naturally-influenced water bodies and do not imply that these waters should be managed to meet criteria-based standards.

The NPS (2001) report flagged parameters and values that exceeded water quality standards, 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 (ADEC, 2006c). According to the NPS data compilation report, exceedences (relative to EPA water quality standards) were found in Katmai's crater lake and in the thermal springs near Mageik Creek (in the volcanic zone between Mount Katmai and Mount Mageik). Those "exceedences" are listed below and included the following (EPA standards cited below are for 2006 (EPA, 2006)):

- Low pH: the lowest pH, with a value of 1.9 standard pH units, was reported in Katmai's crater lake near the upwelling zone in July 1975.
- High chloride concentrations in Katmai's crater lake and at hot springs in Mageik Creek, in 1975 and 1982, respectively. Concentrations were 251-1750 mg/L, while the EPA secondary drinking water criterion is 250 mg/L and the acute freshwater aquatic criterion is 860 mg/L.
- High sulfate concentrations in Katmai's crater lake and at hot springs in Megeik Creek in 1975 and 1982, respectively. Concentrations were up to 1,250, while EPA's secondary drinking water criterion is 250 mg/L.
- High arsenic concentrations in Katmai's crater lake and Mageik Creek hot springs in 1982-1989. Concentrations were 230-1,340 μg/L, while the EPA drinking water criterion is 10 μg/L and the acute freshwater criterion is 340 μg/L
- High cadmium in Katmai's crater lake in 1989. Based on a single sample, with concentration of 16 μg/L, which exceeded the acute freshwater criterion of 2.0 μg/L and the drinking water limit of 5 μg/L.
- High selenium in Katmai's crater lake in 1989. Based on one sample, with concentrations of 108 μg/L, which exceeded the acute freshwater criterion of 20 μg/L (note: this standard is currently being modified) and drinking water criterion of 50 μg/L.

The results from the samples taken from the hot (*n*=3) and warm springs (*n*=1) near Mageik Creek were published by Keith et al. (1992). Additional chemical data available include temperature (15- 42ºC, 59-108ºF), pH (6.5-7.9 units), specific conductance (926-2280 μMhos/cm), deuterium/protium stable isotope ratio (-97), oxygen 18-oxygen 16 stable isotope ratio (-13.1), and dissolved ion (bicarbonate, Ca, Mg, Na, K, Cl, SO_4^{2-}, F, As, B, Fe, Mn, Sr, Ce, Li, Rb) concentrations (Keith et al., 1992). The high temperatures from the hot spring (40-42ºC, 104-108ºF) and from the warm spring (15ºC, 59ºF) exceeded state water quality limit of 13 ºC (55ºF) for spawning areas and egg and fry incubation, and of 15ºC for migration routes and rearing areas; however, again, these conditions are of natural origin and are not regulated the same way that human-caused water quality violations are (ADEC, 2006a).

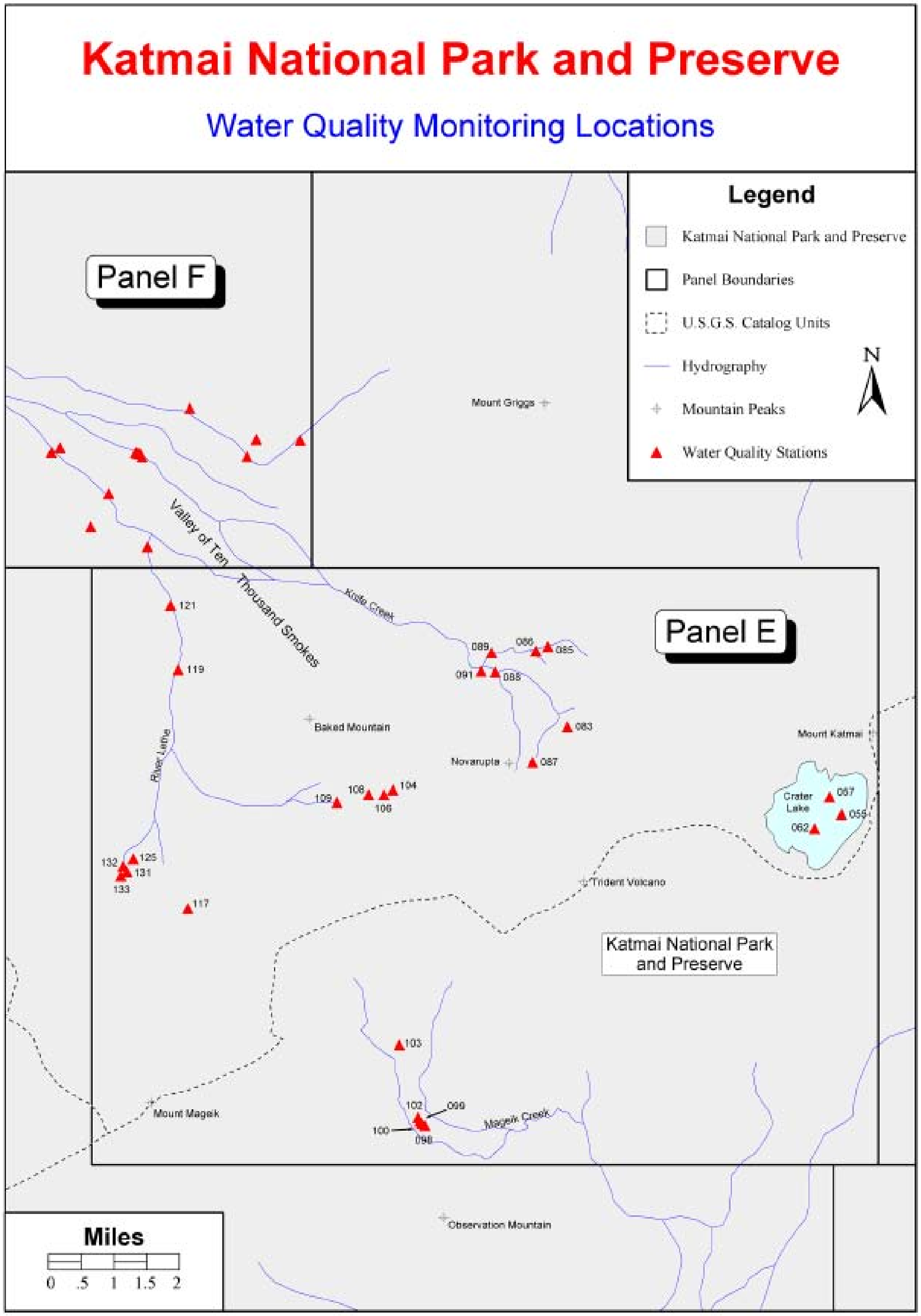

Figure 64. Location map of water quality samples collected in the Mageik Creek and Katmai's crater lake region of KATM, in the vicinity of Mount Katmai. From NPS (2001).

Samples from Katmai's crater lake were taken in 1975 (*n*=2) by Keith et al. (1992), and in 1989 (*n*=1) by Cameron and Larson (1992). The two samples from 1975, collected at an upwelling zone in the caldera lake, were measured for temperature (5.5ºC, 52ºF), specific conductance (6580 and 7580 µMhos/cm), pH (1.9-3 units), and dissolved Ca, Mg, Na, K, Cl, sulfate, F, Si, B, and Li. The single sample collected in 1989 included a larger suite of analytes, including some trace elements and planktonic structure. The chemical composition of the lake indicates that there is a large input of concentrated thermal waters and/or volcanic gases into the lake from below the caldera floor (Keith et al., 1992).

Table 17. Comparative water quality and chlorophyll data for three caldera lakes (Katmai, Kuguyak, and Katmai; sample depth 1 m (3.28 ft) on the Alaska peninsula and caldera lakes in general (Larson, 1989). From Cameron and Larson (1993).

Variable	Units	Katmai (8/13/89)	Kuguyak (8/13/89)	Surprise (8/31/88)	Surprise (7/30/89)	Caldera lakes-general (Larson, 1989)
pH	standard	2.5	7.4	7.3	7.5	2.8 - 10.5
Alkalinity	mg/l		30	162	180	-
Hardness	mg/l	-	105	126	132	10.2 - 4500
Cond.	µmhos/cm	473	312	380	391	39 - 28000
Turbidity	NTU	5560	0.7	2.6	3.2	-
TP	µg/l	3	5	25	19	-
TFP	µg/l	68	2	9	8	-
RFP	µg/l	679	10	24	6	-
TKN	µg/l	644	45	45	31	-
NH_3+NH_4	µg/l	5041	26	-	16	-
NO_3+NO_2	µg/l	457	25	-	-	-
Ca	mg/l	226	11	17	9	0.3 - 576
Mg	mg/l	56	7	15	16	1.9 - 744
K	mg/l	95	5	4	4	1.1 - 440
Na	mg/l	607	41	41	43	5.7 - 2340
S	mg/l	347	18	8	8	-
Si	mg/l	9	20	17	19	-
Fe	mg/l	43	<0.02	<0.01	<0.01	-
Cu	µg/l	30	<0.02	<0.01	<0.01	-
Mn	µg/l	4806	<3	71	6	-
Total chlorophyll	µg/l	0.01	2.5	2.3	1.7	-

The Kaguyak Lake sample and one of the 3 samples from Katmai's crater lake were collected in 1989 by Cameron and Larson (1992 and 1993) to supplement a larger study of water resources in ANIA. They compared the aquatic chemistry and biologic composition of the two KATM crater lakes with ANIA's Surprise Lake, which is another crater lake, 2 other small lakes in the Aniakchak Crater, and with Naknek and Brooks Lakes on the western side of KATM. Cameron and Larson (1992 and 1993) found that the 7 lakes represented a wide variety of water clarities and degree of hydrothermal influences, and that Katmai's crater lake had particularly harsh conditions compared with caldera lakes in general (**Table 17**). The ionic concentrations in Katmai's crater lake were generally an order of magnitude higher than in the other lakes, while the water quality of Kaguyak Lake was similar to that of Surprise Lake in the Aniakchak crater (in ANIA) (Cameron and Larson, 1992).

The above studies showed some extreme measurements of pH, temperature, and some dissolved ions; however, it must be noted that these studies specifically targeted crater lakes of recently active volcanoes and of thermal springs, which are known to have naturally high chemical concentrations.

A2b 2) Other water quality information

Very few data exist on water quality along streams and lakes specifically in the coastal watersheds of KATM. A search of the literature found physical, chemical, and biological information for the Kamishak River (NAWQA project, discussed below), a reconnaissance of drinking water supplies in KATM (Zenone, 1970), and a single measurement of temperature (1 ºC [34 ºF]) in mid-August, 1964) at Hallo Lakes (Heard et al., 1969). The 1970 water resources investigation report (Zenone, 1970) does not contain specific water quality information, but does state generally that small, freshwater streams could probably provide adequate and acceptable drinking water sources along the coast. In addition, a study of streambed geochemistry was conducted by the Alaska Mineral Resource Assessment Program (AMRAP) in the Katmai area (Church et al., 1994). Included in the study were samples from coastal KATM streams, whose streambed sediment chemistry was related to bedrock lithology, and six different mineral deposits were identified based on anomalous geochemical patterns. However, the development potential of the deposits is not known, and metal mining is prohibited within KATM nonetheless.

NAWQA study of the Kamishak River

As part of the U.S.G.S. National Water Quality Assessment (NAWQA) Program, the Cook Inlet region adjacent to KATM, and including the Kamishak River, was intensively studied between 1998 and 2001. The NAWQA Cook Inlet basin study is the closest area to KATM where a recently-conducted water assessment was conducted. An overview of the project and summary of major results is provided in (Glass et al., 2004). The reader is referred to the website: http://ak.water.usgs.gov/Projects/Nawqa/ for links and further information on results from the Cook Inlet Basin Study Unit.

Part of the USGS's NAWQA Cook Inlet Basin study included the collection and analysis of streamwater, streambed sediment, fish tissues, and macroinvertebrates at 15 sites for trace elements, organochlorines, and (SVOCs) (Brabets et al., 1999; Frenzel, 2000). Included in the study was one site from the Kamishak River, approximately 8 miles upstream from its mouth at Kamishak Bay, in KATM, where macroinvertebrates, water, streambed sediment, and fish samples were collected. Eight dipthera taxa were identified in the Kamishak. Field water quality properties (collected 7/21/1998) showed the river to be well oxygenated, cool, with low specific conductance (indicating few dissolved ions), and generally low concentrations of dissolved nutrients (Frenzel and Dorava, 1999). Water clarity was described initially as fair but became "very poor" during the site visit, when heavy rains lifted the river stage approximately 8 feet in one day. The authors ascribe the relatively large phosphorus concentration to the high (yet unquantified) turbidity level at the time. Data from the single sample are presented in **Table 18** below (Frenzel and Dorava, 1999).

Table 18. Field and analytical water quality results for the Kamishak River on July 20, 1998 (Frenzel and Dorava, 1999)

Water temperature (°C)	6.7
Specific conductance (μS/cm	68
Dissolved oxygen (mg/L)	12.2
pH	7.4
Phosphorus (P) total as P	0.357 mg/L
Orthophosphate (PO_4) dissolved as P	0.012 mg/L
Phosphorus (P) dissolved as P	<0.010 mg/L
Nitrite + nitrate, NO_2+NO_3, dissolved as N	0.088
Ammonia, NH_3, dissolved as N	0.027 mg/L
Ammonia + organic nitrogen, total as N	0.24 mg/L
Ammonia + organic nitrogen, dissolved as N	<0.10 mg/L

No detectable concentrations of semivolatile organic compounds (SVOCs) or organochlorines were found in the Kamishak River bed sediment (Frenzel, 2000). Median trace element (As, Cd, Cr, Cu, Ni, Pb, Hg, Se, and Zn) concentrations in streambed sediment were below the Probable Effects Levels (PELs) (Canadian Council of Ministers for the Environment, 1999) and placed within the second quartile (25-50%) of national median values, and trace element concentration in fish (slimy sculpin) were below any levels of concern (Frenzel, 2000). Fish from the Kamishak River were not analyzed for organochlorine compounds as were fish from other Cook Inlet streams

Water quality information for interior KATM:

The most extensive limnological studies in the KATM area characterized baseline water quality conditions (physical and chemical profiles, light penetration and Secchi depth), and phytoplankton productivity, and nutrient levels in 11 lakes (Battle, Brooks, Coville, Grosvenor, Kukaklek, Kulik, Murray, Naknek, Novianuk, Hammersly, Idavain); however none were in the KATM coastal region (LaPerriere, 1996; LaPerriere and Edmundson, 2000; LaPerriere and Jones, 2002). Other studies have focussed on the chemistry and biological productivity in lakes in interior KATM (Goldman, 1960; Gunther, 1992). Water quality studies of streams in interior KATM include: water quality in the Valley of Ten Thousand Smokes area (Keith et al., 1992; Lowell and Keith, 1991); and an investigation of potential drinking water sources throughout KATM (Zenone, 1970). Additionally, a 1983-1985 reconnaissance geochemical study of streambed sediment samples at 1243 sites in KATM and McNeil State Game Preserve provides information on chemical concentrations of 31 elements in streambed sediment samples (Bailey, 1986).

A3. Precipitation chemistry

A 1985 Annual Resource Management Report for KATM (Jope, 1985) suggests that a joint program with the University of California, Berkeley was begun to monitor rain chemistry, including acidity, over the course of a year at Brooks Camp (summer) and King Salmon (winter). However, subsequent reports provide no information about data collected through this program. 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 4 NADP sites in Alaska, two of which are administered by the National Park Service (Denali and Gates of the Arctic). The most representative NADP site for coastal KATM is the Juneau site located on the east coast of the Gulf of Alaska. Data from this 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. Data on precipitation chemistry in Alaska are available through the NADP website located at: http://nadp.sws.uiuc.edu/sites/ntnmap.asp?

B. Water quality stressors and effects on biological resources and human health issues

The KATM coastal area has no waterbodies listed as impaired under the 303d section of the Clean Water Act. As discussed above, extremely little data are available regarding water quality in KATM's coastal watersheds. Based on the limited data, threats to the health of fish, wildlife, and humans are centered in the hotsprings of the Mageik Creek area and in Katmai caldera lake, where drinking water and aquatic health standards are exceeded for several parameters such as pH, temperature, sulfate, chloride and some trace elements (see section IV.A.2.b.1) *Water quality of crater lakes and geothermal springs).* The rare visitor to this part of KATM should be cautioned against drinking water from these areas.

C. Available GIS data pertaining to water resources.

Only basic geospatial data pertaining to water resources are available in KATM – and these are primarily locations and extents for streams and water bodies (**Table 19**). Some related data, such as geology and landcover data sets are available but these are generally coarse and derived from statewide initiatives. One important hydrological GIS data source currently lacking are mapped wetland (e.g. NWI) boundaries and classifications. For base data, USGS topographic DRG's (1:63K and 1:250K scales), a 30-m (100 ft) Landsat scene, NOAA nautical charts, and georeferenced aerial photos are available for select parts of KATM are available for at least the entire KATM coastal zone.

Table 19. Available water resources- related geospatial data for KATM

Category	Data	Extent
Biological	Ecological Subsections	KATM
Biological	Landcover	KATM
Biological	Anadromous Waters Catalog	KATM
Index	Coastal Atlas Index	KATM
Cultural	Park Boundary	KATM
Physical	Elevation	KATM
Physical	Surficial Geology	KATM
Physical	Coastal bathymmetry (20-m)	Coastal KATM
Physical	Coastal Geomorphology	KATM
Physical	Hydrological features	KATM
Physical	Watershed boundaries (subbasin; 8-level code HUC)	KATM
Physical	Coastline 1:63K	KATM
Physical	Wisconsin glacial max and min extent	KATM
Base	Satellite Imagery- Color IR	KATM
Base	DRG Mosaic 1:250,000 & 63,360	KATM
Base	NOAA Nautical Charts	Coastal KATM
Base	Georeferenced aerial photos (AHAP)	Coastal KATM & Alagnak River

V. Threats to Water Resources

A. Sources of past, current, and potential future pollutants

Pollutants to KATM 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 airmasses that have the ability to deposit mercury (Hg) and persistent organic pollutants (POPs).

A1. Oceanographic sources

A1a. 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. The reader is referred to the KATM and ALAG Water Resources Management Plan (Kozlowski, in preparation), in which the oil spill risk to the KATM coast is extensively discussed.

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 65**). Two to four percent of the released oil came ashore on Shelikof Strait within KATM (Wolfe et al., 1994), resulting in the most extensive single human-caused disaster to strike a National Park (NPS 1990). Cape Chiniak and Chiniak Lagoon, Hallo Bay beach and lagoon, the south shore of Cape Gull and Kaflia Bay, offshore islands and Cape Douglas were the most impacted regions within KATM (NPS, 1990). Patches of unweathered oil mousse have persisted and retained their toxicity along exposed, rocky shorelines with boulder armored beaches in KATM (Irvine et al., 1999; Peterson et al., 2003). This monitoring of standed oil has continued through 2005 (A. Bennett, NPS-Anchorage, personal communication, 2007). In addition, mussel beds have retained oil and have not yet returned to background levels (Irvine et al., 2000). Ecological communities in Prince William Sound (and likely Shelikof Strait) have been slow to recover from this catastrophic disturbance, and even fourteen years after, many species and communities show limited signs of recovery relative to baseline conditions (see review by Peterson et al. 2003). The lingering effects of EVOS in KATM are now considered part of the baseline (T. Hamon, NPS-King Salmon, personal communication, 2005).

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 7 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, and steady or rising demands 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 potentially major pollution threats to the marine, estuarine, tidal and intertidal environments in the region, including along the KATM coast (Andres and Gill, 2000). The Valdez terminal receives approximately 24 billion gallons ($1.1x10^{11}$ 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 Divison of Oil and Gas, 2003; Andres and Gill, 2000; Chevron Corporation, 2006; Kozlowski, in preparation; Weeks, 1999). Not only are these activities subject to inevitable human error, but they are located along an extremely active volcanic and seismic area. Earthquakes, volcanoes, and tsunamis (see section V.C. for more information) may destabilize any of these petroleum-related infrastructure and cause massive spills.

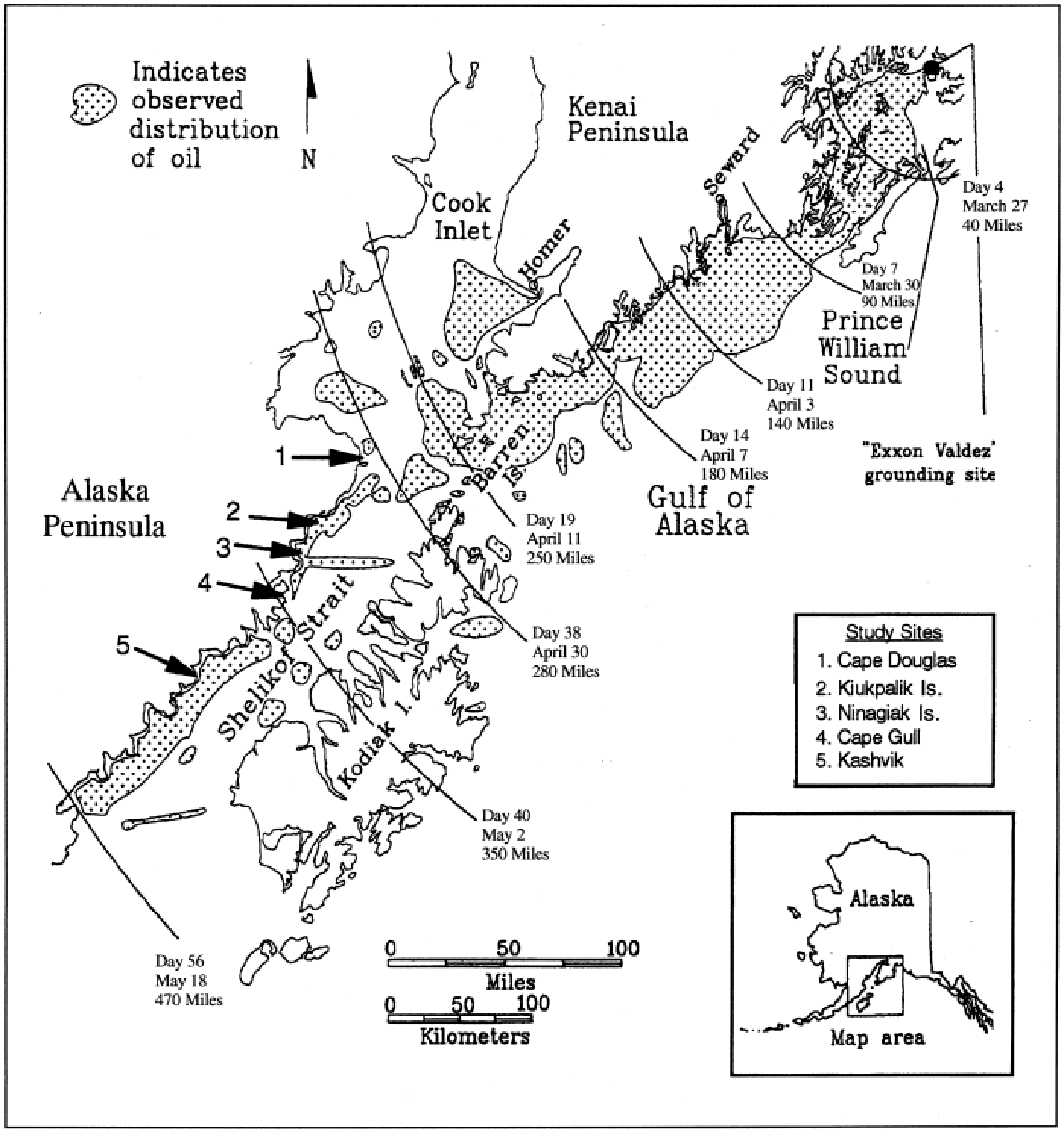

Figure 65. Geographical extent of the Exxon Valdez oil spill through time (24 March, 1989 to 20 June, 1989). Study sites from Irvine et al. (1999) are indicated. (Irvine et al. 1999).

Currently, Geographic Response Strategies (GRS) are in development for certain areas of KATM (Figure 66 and Figure 67). These spill response plans are tailored by a workgroup made up of local, state, and federal agencies (including NPS), 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. Proposed GRS locations in and on the boundary of KATM are shown as sites K48-K60 (from Swikshak Lagoon to Dakavak Bay) in **Figure 66** and sites 1-3 (Sukoi Bay, Douglas River, and Akumwarvik Bay/Kamishak River) in **Figure 67**, and were selected based on their levels of environmental sensitivity, risk of being impacted from a water borne spill, and feasibility of successfully protecting the site with existing technology. Site selection criteria are delimited in **Table 20**. Strategies for each site will be developed following GRS site selection finalization. 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, NPS, and others) are currently working with private industry (Alyeska Pipeline Service Company) and local groups (City of Kodiak, Cook Inlet Regional Advisory Council, and others) to develop Potential Places of Refuge (PPORs) (**Figure 68** and **Figure 69**). 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, 2006b). Information on the PPORs is available at http://www.info2.dec.state.ak.us/spar/perp/kppor/index.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.

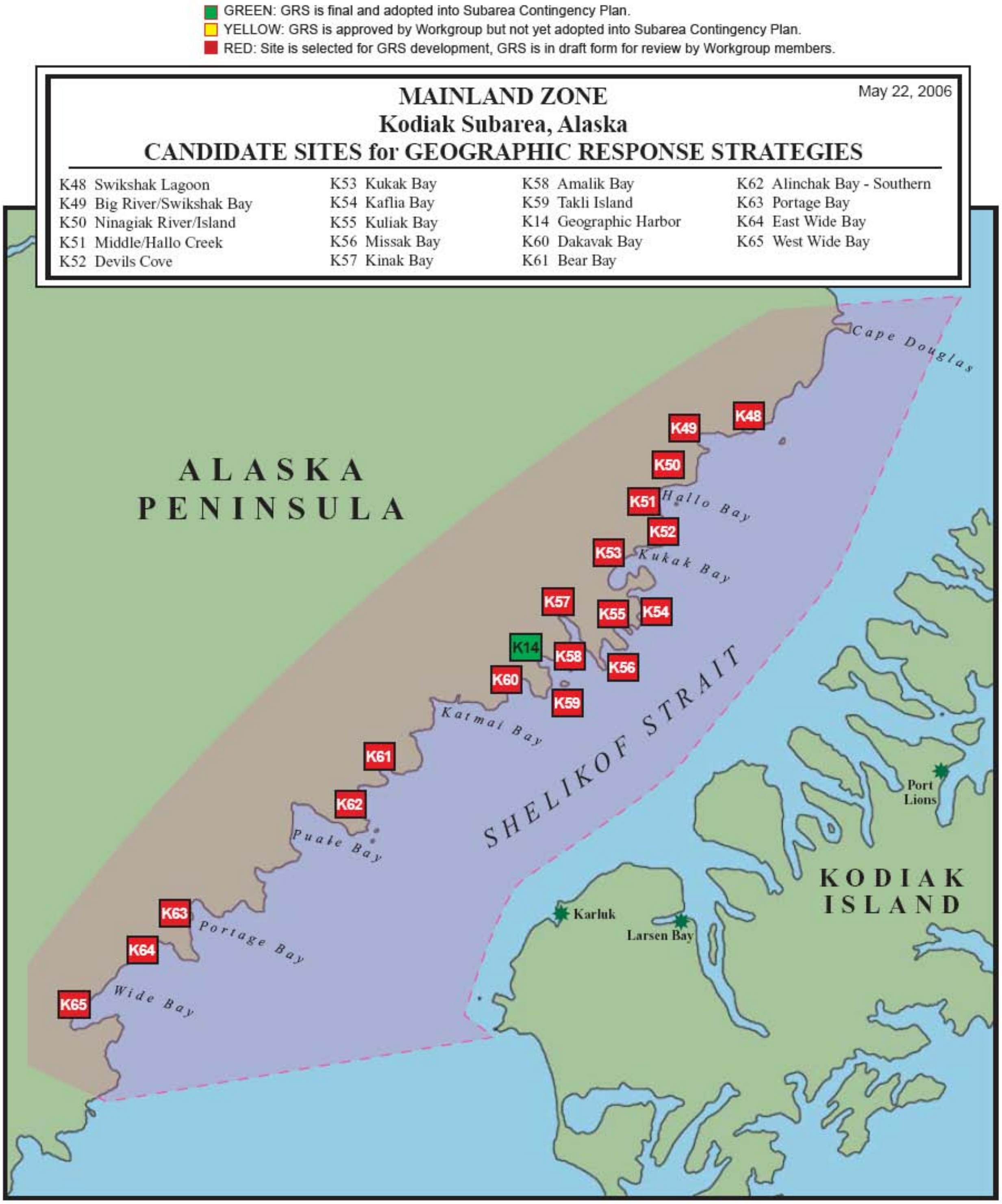

Figure 66. Geographic Response Strategies for the Shelikof Strait region of the KATM coast. Source: ADEC 2006, at http://www.dec.state.ak.us/spar/perp/grs/ki/mainland.htm

Table 20. Site selection criteria for GRS sites in/near KATM. Source ADEC, 2006 http://www.dec.state.ak.us/spar/perp/grs/ki/kgrsmainlandssm.pdf

Seletion #	Priority	GRS #	Site Name	Marine Mammals	Fish	Terrestrial Mammals	Intertidal	Subsistence	Cultural Resources	Birds	High Recreational Use	Commercia l Fishing	Land Mgt. Designations	Coast Habit
Mainland Zone														
148			South Cape Douglas	S,O	I,P					EN		CF	NP	M,ETF
149			Sacramento River	S	P,DV	B				En,WFc		CF	NP	SRS
150			Fourpeaked Glacier Streams	S,O	S,P,Co,Ch,DV	B				EN		CF	NP	ETF
151			Kiukpalik Island	S,O		B				EN,SBn	WV	CF	NP	ERS
152	H	K-48	Swikshak Lagoon	O	I,P,S,Ch,Co,DV	B	I			EN,Wfc		CF	NP	STF,M
153			Shakun Islets	SL,S,O						EN,SBn	SF	CF	NP	ERS
154	H	K-49	Big River/Swikshak Bay	S,O	I,P,Ch,Co	B	I			EN	SF+, WV	CF	NP	STF,M
155			Cape Chiniak Lagoon	S,O,SL	Ch,P	B	I			EN		CF	NP	M,ETF
156			Ninagiak Island	S						EN		CF	NP	STF,M
157	H	K-50	Ninagiak River	SL,S	I, Ch, P	B	I			EN,SBn	WV	CF	NP	M,ETF
158	H	K-51	Middle/Hallo Creek	SL,S	I, Ch, P	B	I			EN,SBn	WV	CF	NP	M,ETF
159			Cape Nukshak-KukakPt.		I,P,Ch	B				EN,SBn,WFc		CF	NP	STF,ERS
160	H	K-52	Devils Cove	O	I,H,Ch, P	B				EN,SBn,WFc	WV	CF	NP	STF,ERS
161	H	K-53	Kukak Bay	S,O	I,S,H,Ch, P	B				EN,SBn,WFc	WV	CF	NP	M,ETF
162			Cape Ugyak	SL,S		B				SBn		CF	NP	ERS
163	H	K-54	Kaflia Bay	S	Ch, P, S	B				SBn	WV	CF	NP	STF,SRS
164			Cape Gull	SL,S,O		B				EN,SBn		CF	NP	ERS
165	H	K-55	Kuliak Bay	S,O	Ch, P, DV	B				EN		CF	NP	STF,M
166			Cape Kuliak	SL		B				EN,SBn		CF	NP	ERS
167	H	K-56	Missak Bay	S,O	I, H,P,Ch	B				EN,SBn		CF	NP	STF,M
168	H	K-57	Kinak Bay	S,O	I, H,P,Ch	B				EN,SBn,WFc	WV	CF	NP	STF,M,ER
169	H	K-58	Amalik Bay	S,O	I,H,P	B				EN,WFc	WV	CF	NP	STF,ERS
170	H	K-59	Takli Island	SL,S,O	I,H,P	B				EN,SBn,WFc	WV	CF	NP	STF,ERS,
171	H	K-14	Geographic Hbr	S,O	P	B				EN,SBn,WFc	WV	CF	NP	STF,ERS,
172	H	K-60	Dakavak Bay	S,O	I,H,Ch,P,Co	B	I			EN,SBn		CF	NP	STF,ETF,
173			Katmai Bay	S,O	I,H,Ch,P	B	I			EN,SBn	WV	CF	NP	STF,ERS,
174			Kashvik Bay	S,O	I,H,Ch,P,DV	B				EN,SBn		CF	NP	STF,ERS
175	H	K-61	Bear Bay	S,O	I,H,P,S,CH,DV	B	I	I		EN,SBn		CF	NWR	STF,ERS,
176	H	K-62	Alinchak Bay-southern	S,O	I,H,P,CH, DV	B	I	I		EN,SBn			NWR	STF,ETF,
177			Puale Bay	SL,S,O	I,H, P, CH, CO, DV	B	I			EN,SBn,SBf		CF	NWR	STF,ERS,
178			Dry Bay	S,O	I, P, CH, DV	B	I			EN,SBn		CF	NWR	STF,ERS,
179			Island Bay	S,O	P, CH, DV	B	I			EN,SBn		CF	NWR	STF,ETF,
180	H	K-63	Portage Bay	S,O	S,P,Ch	B	I			EN,SBn		CF	NWR	STF,ETF,
181	H	K-64	East Wide Bay	S,O	CO,P,CH	B	I,EG			En,SBn,Wfc		CF	NWR	STF,ETF,
182	H	K-65	West Wide Bay	S,O	I,H,P,CH,CO	B	I			SBn,SBF,WFc, En		CF	NWR	STF,ETF,
183			Imuya Bay	O	P	B	I			SBn		CF	NWR	STF,ETF,

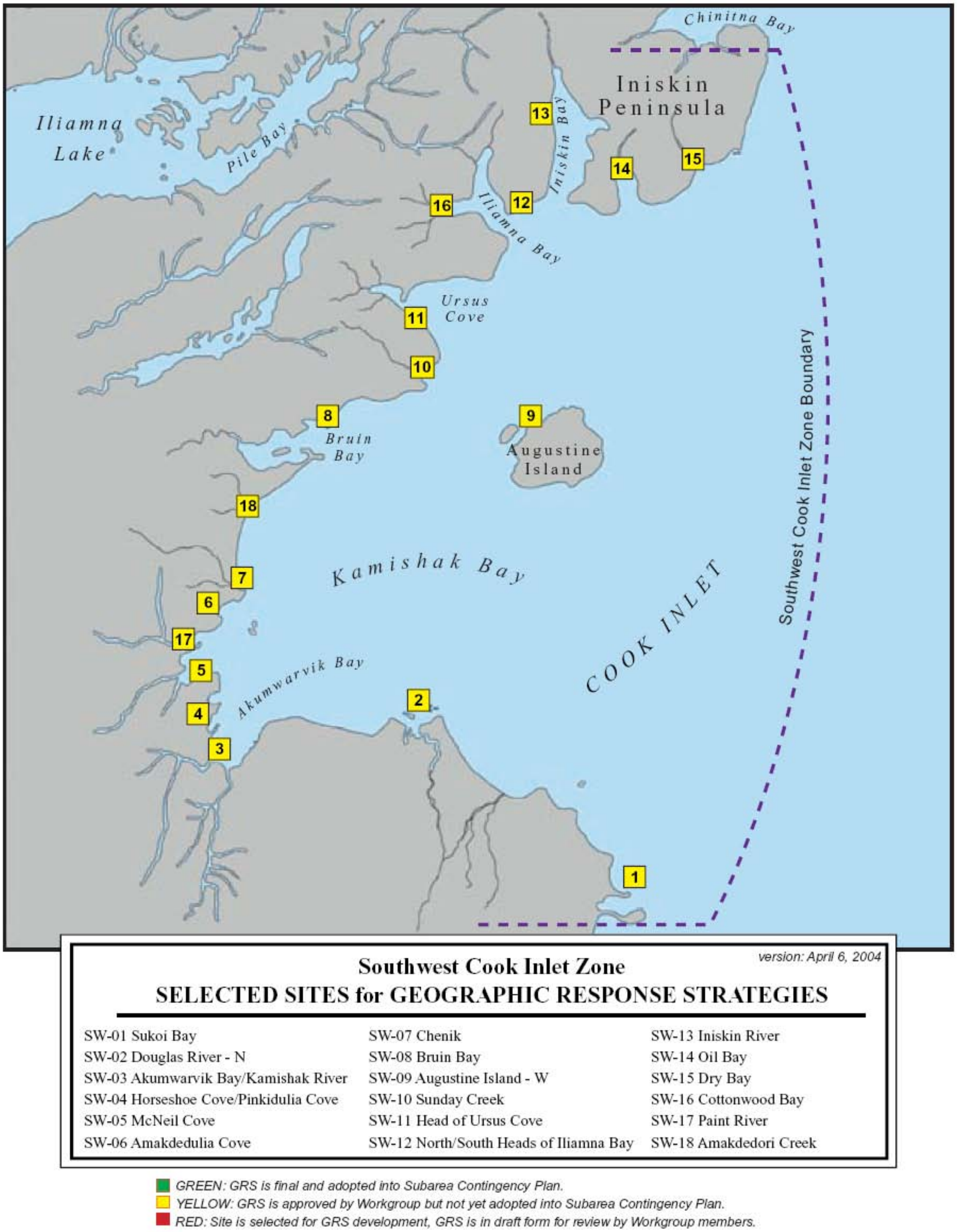

Figure 67. Geographic Response Strategies for the Cook Inlet region of the KATM coast and the area to its north. (KATM boundary ends at Kamishak River, near site 3). Source: ADEC 2006, at http://www.dec.state.ak.us/spar/perp/grs/ki/mainland.htm

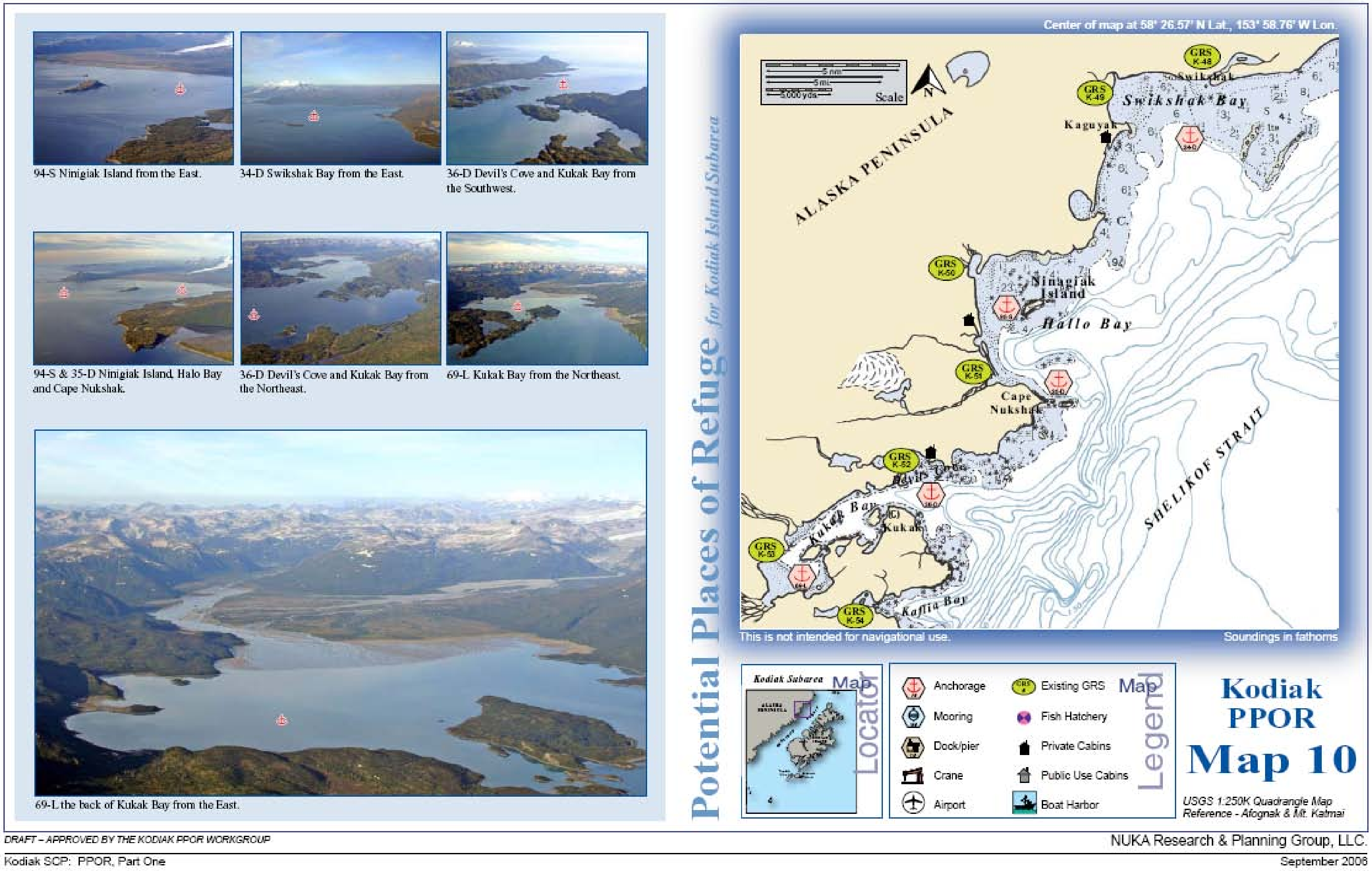

Figure 68. Draft Potential Places of Refuge along KATM for Kaflia Bay to Swikshak Bay in Kodiak Subarea- Mainland section. Source: ADEC, available at http://www.info2.dec.state.ak.us/spar/perp/kppor/index.htm

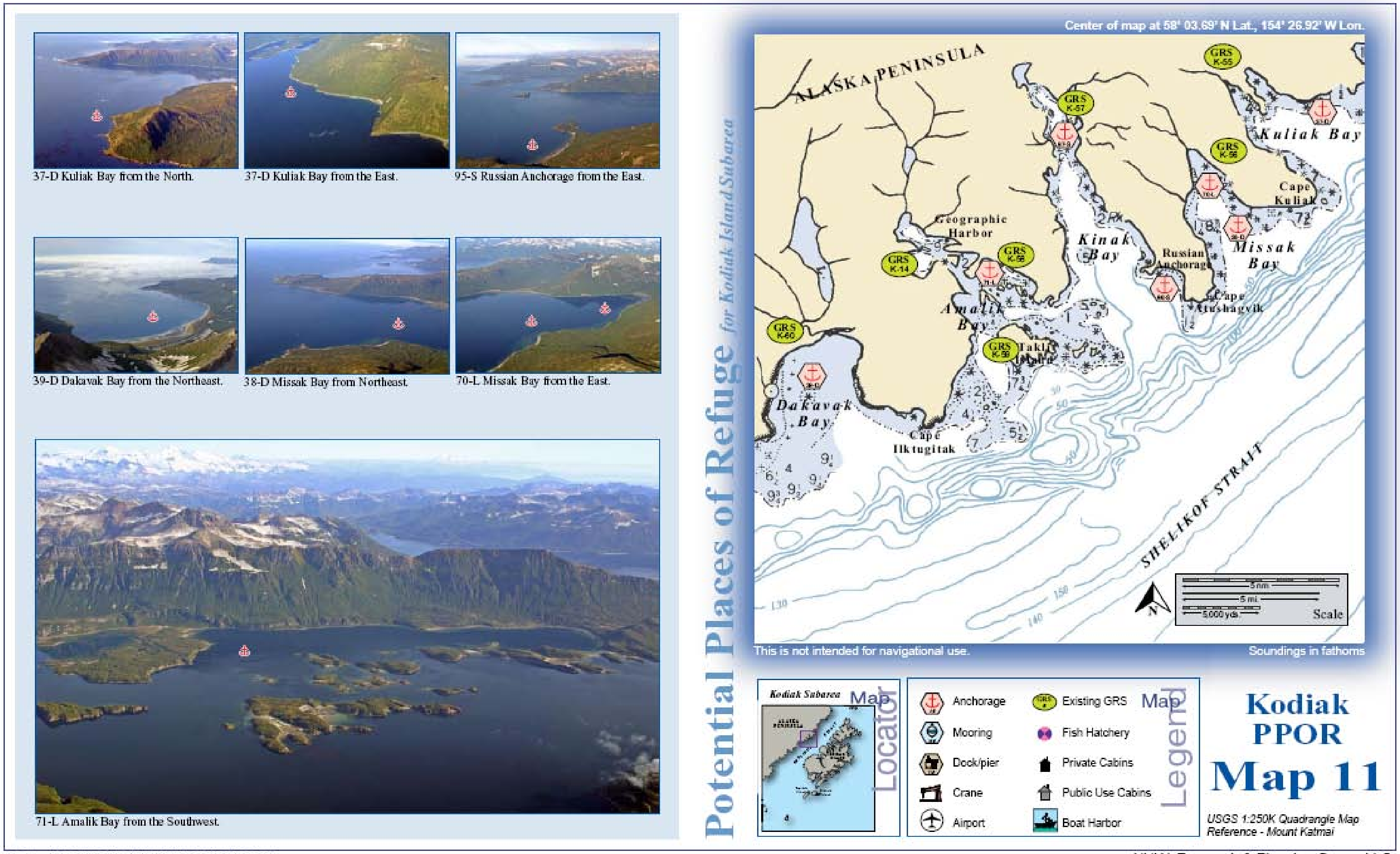

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Figure 69. Draft Potential Places of Refuge along KATM for Dakavak Bay to Kuliak Bay in Kodiak Subarea- Mainland section. Source: ADEC, available at http://www.info2.dec.state.ak.us/spar/perp/kppor/index.htm

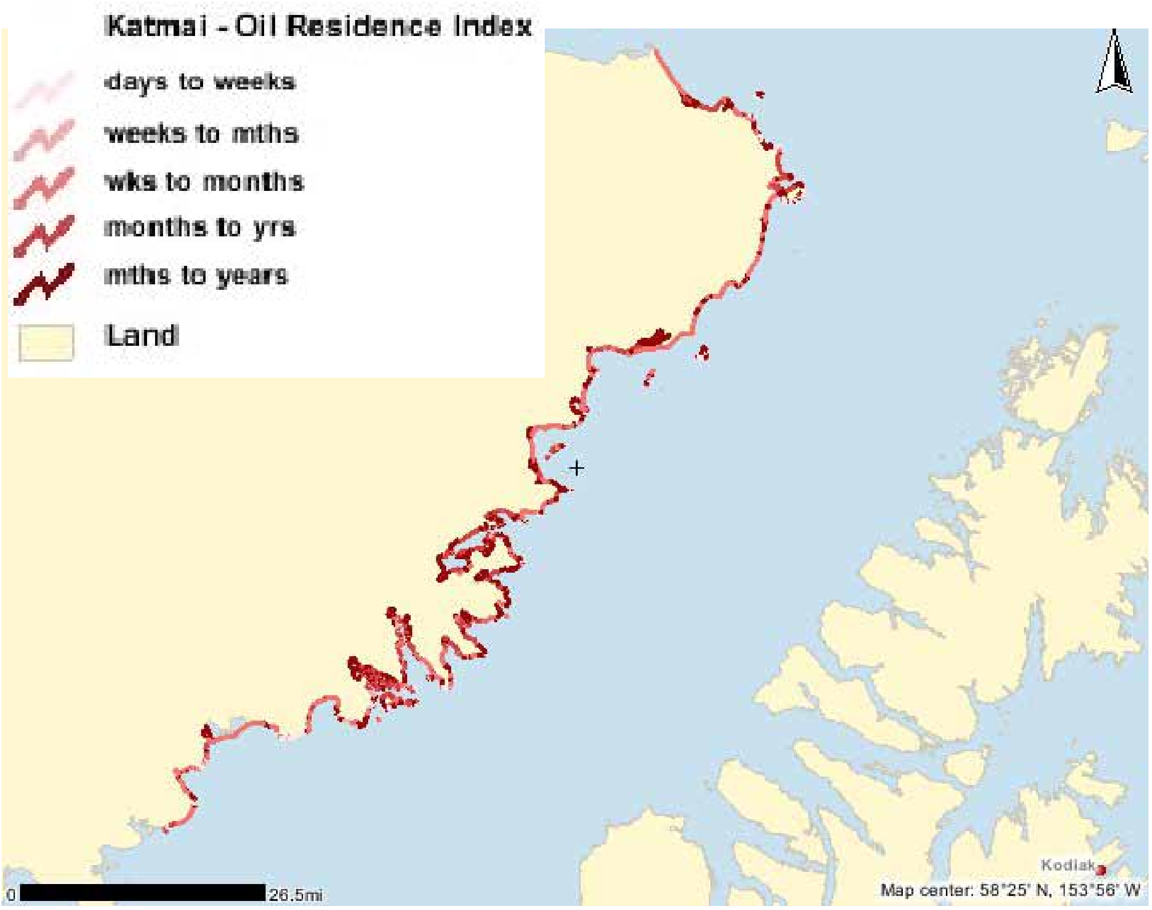

Figure 70. Map of the distribution of oil residence index determined by Harper and Morris (2005). Developed by activating the "oil residence index layer" at http://imf.geocortex.net/mapping/cori/launch.html)

The ShoreZone mapping program computed an "Oil Residence Index" (ORI) along coastal KATM based on data on wave exposure levels and substrate types (**Figure 70**). 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 processes removing stranded oil from shore (Harper, 2004). Through its imagery of physical attributes of the KATM coastline, Harper and Morris (2005) 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. They also note that cleanup in these areas is "difficult and can result in long-term damage is not conducted properly." According to their analyses, only 38% of the coastline had an ORI on the scale of days to months, and 62% had an ORI on the scale of months to years—indicating the strong potential for long term damage to the coast in the event of another oil spill (**Figure 70**, **Table 21**).

Table 21. Summary of Oil Residence Index along the KATM coastline (Harper, 2004).

Estimated Residence	ORI Code	Length (Km)	% of Mapping
DAYS to weeks	1	51.7	6%
WEEKS to months	2	16.1	2%
weeks to MONTHS	3	250.0	30%
MONTHS to years	4	190.3	23%
months to YEARS	5	328.6	39%

A1b. Marine vessel impacts

No analyses of marine vessel impacts have been conducted for the KATM coast, but based on an NPS study in Glacier Bay National Park in Preserve 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 by resuspension of sediments. Wastewater generated by marine vessels that may serve as a source of marine pollution includes 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 NPS (2003b) reports that because of the small volumes and large dilution factor, that 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 are not legally dumped within 5 km (3 mi) of the coast. Finally, vessels can affect water quality is 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(NPS, 2003). 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 KATM are most likely temporary and limited to the immediate area of vessel traffic. Most vessel traffic along the coast is relatively small in size compared to the large cruise ships that travel in southeast Alaska and up to the Kenai area. Most bear-viewing or fishing tour boats include 4-8 passenger visitors, a guide, and boat crew (T. Hamon, NPS, NPS-King Salmon, personal communication, 2005). Until recently, small (approximately 80 passenger) cruise ships would visit the KATM coast only every other year (T. Hamon, NPS-King Salmon, personal communication, 2005). However, in 2006 there were 3 or 4 cruise ships (with 80-100 person capacity) visiting from Kodiak and the same number are expected in 2007 (Sharon Kim, NPS-King Salmon, personal communication, 2007). Therefore, while impacts are likely minimal at the current time, they have the potential to grow with increased cruise ship travel. Of equal or greater importance are large fishing boats (e.g. 15-19 m (49-62 ft) purse seiners) that use the coastal region off of KATM; they pose water quality threats due to their fuel spill potential and waste discharges as well(T. Hamon, NPS-King Salmon, personal communication, 2005). Large fishing vessels are also known to utilize the KATM coast

to anchor up and wait out winter storms and to (illegally) store gear there for long time periods- sometimes up to a full year (Alan Bennett, NPS-Anchorage, personal communication, 2005).

A1c. Marine-derived biologic sources of pollutants

The benefits incurred by the contributions of salmon carcasses to the nutrient levels in aquatic systems (see section III.C.6.Freshwater habitat, a. Fishes) may be partially offset by another contribution by the salmon: marine derived contaminants such as 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 the 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 were studied; two of the lakes: Becharof and Ugashik Lakes are only 32 and 53 km (20 and 33 mi), respectively, southwest of KATM (**Figure 71**). 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- ca. 0 – 185 km (0 - 115 mi) from KATM) 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. A recent 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.

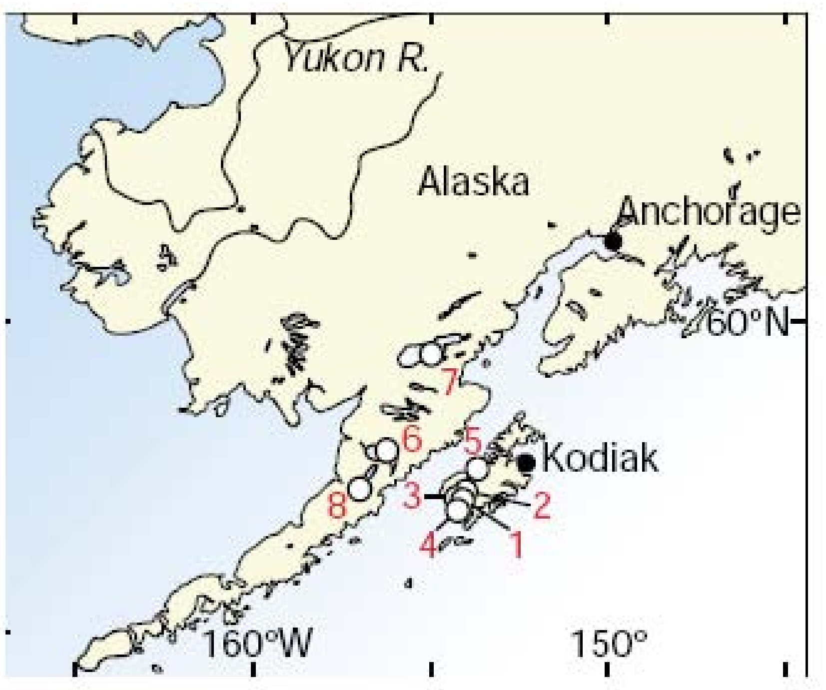

Figure 71. Sample locations of the 8 lakes surface sediments and sockeye salmon were collected for PCBs. Lake 1: Frazer; Lake 2: Karluk; Lake 3: Red; Lake 4: Olga; Lake 5: Spiridon; Lake 6: Becharof; Lake 7: Iliamna; Lake 8: Ugashik (Krümmel et al., 2003).

The available data indicate a strong likelihood that salmon are an important-- and possibly the dominant-- contributor to both the POPs and Hg budgets in streams where they spawn in areas such as KATM in southwest Alaska. These contaminants are not only are released into the waters where they spawn, but 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 vegetarian counterparts in inland areas (Christensen et al., 2005).

A2. Atmospheric sources of pollution

Mercury and POPs are the 2 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). Hg 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). Mercury and POPs in northern latitudes show significant concentration increases over the last few decades, and these trends are reflected in the extraordinarily high concentrations of some of these chemicals in the bodies of otters, whales, seals, bears, eagles, and indigenous peoples who rely on subsistence harvests (AMAP, 2004). Few studies on contaminants in southwest Alaska exist; however, the evidence available indicates that the region is accumulating many potentially toxic chemicals imported atmospherically from afar.

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 and high rates of oxidation (Schindler, 1999). Recent revelations of large Hg pollution events during polar springtime (known as Atmospheric Mercury Depletion Events) in regions of northern Alaska, other high Arctic regions, and even some sub-arctic regions such as the Hudson Bay area of Canada (at the same latitude as southwest Alaska) have drawn scientific attention to the subject of Hg pollution in remote, high latitude, coastal environments (Lindberg et al., 2002; Lu et al., 2001; Schroeder et al., 1998). Recently, U.S. Geological Survey researchers have found similar high rates of mercury deposition along the Gulf Coast (D. Krabbenhoft, USGS, personal communication, 2005), suggesting this phenomenon is more wide spread, and drawing additional concern for the extensive coastline of southwest Alaska. Although Hg and POPs have not been studied in KATM specifically, several studies in southern coastal Alaska indicate the region is being impacted by these contaminants.

Part of the NAWQA study of the Cook Inlet Basin in 1998-2001 included an evaluation of Hg concentrations in streambed sediments, fish tissues, and water in 5 watersheds as part of a national pilot study of Hg distribution (Frenzel, 2000). The researches report that the Deshka River, a remote, undeveloped basin in the upper Cook Inlet Basin and 320 km (200 mi) from KATM had some of the highest streambed sediment methylmercury concentrations found nationally. It also had one of the greatest percentages of wetlands in its drainage. Studies in North America and Europe have shown that the percentage of the landscape covered by wetlands is positively correlated with both the methylmercury concentrations in outflowing streams and the methylmercury accumulation in fish (Brumbaugh et al., 2000; Hurley et al., 1995; St.Louis et al., 1994; St.Louis et al., 1996). Based on these and other studies, wetlands are known to convert even low levels of inorganic Hg to highly toxic MeHg due to the wetlands' biogeochemical conditions that are highly favorable to methylating bacteria (typically sulfate-reducing bacteria). Wetland-generated methylmercury can readily be transported to nearshore marine systems by organic-rich outflowing streams, thereby making it bioavailable to freshwater and marine organisms. The presence of abundant wetland environments in coastal KATM increases the likelihood that methylmercury concentrations in the region may be of concern; however there are no known data investigating this potential problem.

Another 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, only 74 km (56 mi) from KATM coast) were significantly higher than in eggs from three colonies in the Bering Sea (Kucklick et al., 2002; Vander Pol et al., 2002a; Vander Pol et al., 2002b). Eggs from St. Lazaria (in Sitka Sound, southeast Alaska) had higher concentrations of SPCBs (sum of 46 congeners of PCBs) than eggs from any other Alaskan colonies (Kucklick et al., 2002; Vander Pol et al., 2002a; Vander Pol et al., 2002b). Geographic differences in POP concentrations are not understood, but may be products of global wind and ocean current patterns that result from variable deposition characteristics within Alaska. Mercury was also evaluated in the seabird egg studies (Christopher et al., 2002; Davis et al., 2004; Day et al., 2006) which indicated that mercury pollution may also be more of a concern in Gulf of Alaska compared to the Bering Sea region (**Figure 72**). Thick-billed and common murre eggs collected from islands in the Gulf of Alaska had mercury concentrations that were significantly higher ($p<0.0001$, based on two-way factorial ANOVA comparing geographic and species differences) than in eggs from islands in the Bering Sea. The highest mean concentrations of mercury were again from St Lazaria Island, and East Amatuli Island near KATM had the highest individual sample concentration (Figure **Figure 73**) (Christopher et al., 2002; 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 Southeast Alaska, and presence of estuaries—all factors that stimulate mercury methylation processes—as well as strong freshwater discharge and high erosion rates.

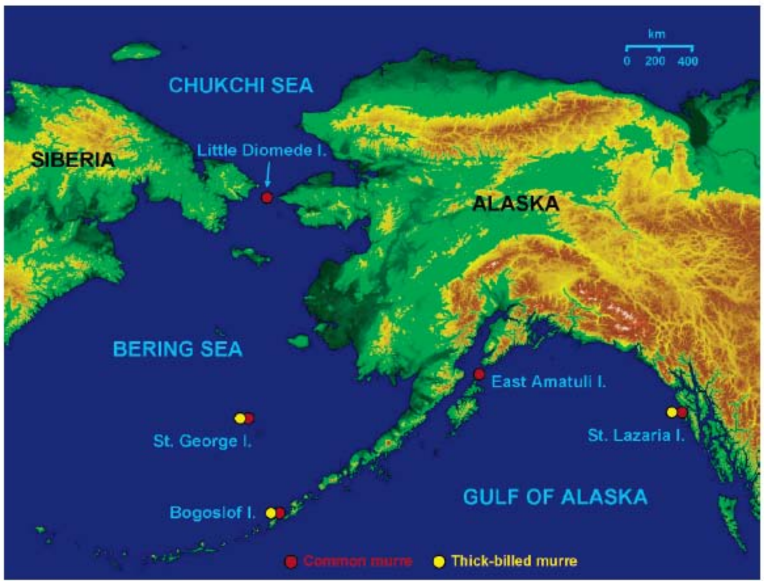

Figure 72. Map of the study area for Day et al (2006)'s research on Hg concentrations in eggs from five murre (Uria spp.) colonies.

Two studies of dated sediment cores collected in southeast Alaska-- from lakes in Glacier Bay National Park (GLBA) and in neighboring Chichagof Island-- show that modern Hg accumulation rates in sediments are 2-3 times preindustrial 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 U.S. where regional mercury emissions have been reduced. These results suggest that southern Alaska is being affected by mercury emissions from remote sources (e.g. in Asia), that are steadily increasing their output (Pacyna and Pacyna, 2002).

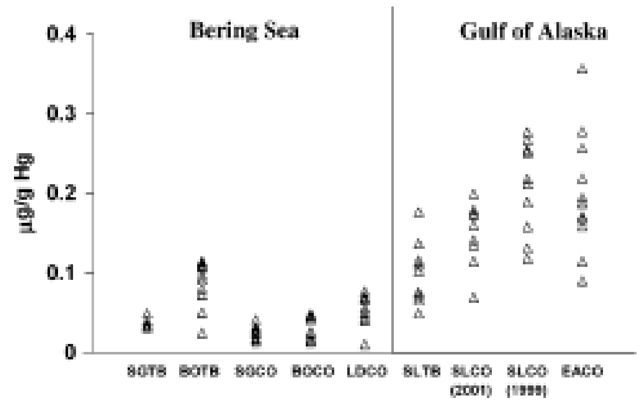

Figure 73. Total Hg concentrations (wet mass) for murre eggs for each collection event in the Day et al (2006) study. The first two letters of the four letter code indicate location (BO= Bogoslof, LD= Little Diomede, SG= St. George, EA= East Amatuli, SL= St. Lazaria) and the second two letters indicate species (CO= common murre, TB= thick-billed murre).

While mercury emissions in the USA have decreased in recent decades, global emissions continue to increase, particularly in Asia, a major source region for prevailing weather patterns that feed the northwest coast of North America (Pacyna and Pacyna, 2002). As a result, Alaska is predicted to be impacted by rising mercury contributions for decades to come. As for POPs, the Stockholm Convention, a global initiative to phase out 12 of the most dangerous POPs should reduce the threat that these pollutants pose to ecosystems such as those within KATM. However, numerous other forms of POPs are still being manufactured and released into the environment in large quantities with unknown consequences (Giles, 2004). In sum, the limited studies to date strongly suggest that the threats posed by mercury and POPs to ecosystems in Alaska are significant and deserve further evaluation and monitoring.

The NPS Air Resources Division, in cooperation with the EPA, USGS, US Forest Service, and several universities, has recently begun to address these issues through a project called the Western Airborne Contaminants Assessment Project (WACAP) that aims to characterize the extent of airbone pollution to remote NPS units in the western US and Alaska (NPS, 2005c). Snow, fish tissue, water, lake sediment, lichen, vegetation, and subsistence native foods are being collected by WACAP at eight NPS units, including 3 in Alaska: Denali National Park and Preserve; Gates of the Arctic National Park and Preserve; and Noatak National Preserve. Samples are being analyzed for a group of semi-volative organic compounds, which include a variety of POPs, and mercury and other trace metals (but not all sample media are receiving full analyses). KATM was selected for inclusion in the WACAP study as well, although contaminant analyses are restricted to vegetation only. Information from KATM, as well as from the 3 NPS units elsewhere in the state will provide important indications of the extent and magnitude of the contaminants' threats to park ecosystems. Analyses are expected to be completed in 2006 and results published in 2007.

Additionally, the state of Alaska Department of Environmental Conservation (DEC) will begin monitoring wet deposition of Hg to coastal southern Alaska in the summer of 2006 by establishing two Mercury Deposition Network stations: in Dutch Harbor and in Kodiak (Heidi

Strader, Alaska DEC-Anchorage, personal communication, 2006). The data generated by these future studies will be instrumental in tracking Hg levels in southern Alaska. To date, wet deposition information is limited to one year of data collected in GLBA by (Fitzgerald et al., 2006), who provide data on Hg concentrations in precipitation (mean: 2.6 ng Hg/L) and estimated atmospheric wet deposition rates (mean: 4.6 µg m^{-2} y^{-1}) (Fitzgerald et al., 2006).

A3. Point sources of pollutants

There are no known point sources of pollutants along coastal KATM.

B. Visitor impacts

Visitor use along coastal KATM is driven by bear-watching tours and fishing trips, and main destinations are Geographic Harbor, Hallo Bay, Big River, Swikshak Lagoon, Kaflia Bay, and Kamishak Bay. Bear viewing is concentrated mainly in Swishak Lagoon (May and June), Hallo Bay (June and July), Geographic Harbor (July and August), and to a lesser extent in Kaflia Bay (late August, September, and October), where extreme gradient streams with leaping salmon attract particularly high densities of bears (T. Hamon, NPS-King Salmon, personal communication, 2005). Human- bear interaction is a major management concern for the NPS in KATM (NPS, 2005a); however, there are no permanent or consistently-present seasonal rangers or other NPS staff on site to actively manage the issue. Two private inholdings respectively contain the only two tourist lodges along the KATM coast: the Katmai Wilderness Lodge in Kukak Bay and the Hallo Bay Bear Lodge in Swikshak Bay. Katmai Wilderness Lodge has a 12-guest capacity and provides guided bear-viewing excursions and charter fishing trips. Hallo Bay Bear Lodge has 5 cabins that are available to visitors for 2-7 day-long visits and also provides bear-viewing excursions.

Kamishak River is relatively heavily visited in August for silver salmon fishing (T. Hamon, NPS-King Salmon, personal communication, 2005). Big River is also fished for silver salmon, although fish cleaning there is restricted due to problems in 1999 in which bears were tearing apart boats, and has been the site of many bear- human interaction management issues (NPS, 1985). Bear management issues have also forced the closure of overnight camping in Hallo Bay and have led to increased efforts by the NPS to educate the air taxis bringing visitors to the area (NPS, 2005b). Geographic Harbor is a favorite spot for halibut fishing by residents of King Salmon. Geographic Harbor has seen a particularly striking increase in visitor use; estimated at approximately 21 visitor days in 1995 to up to 700 in 2002 (T. Hamon, NPS-King Salmon, personal communication, 2005). Other areas that are known to receive some use, but of an unknown magnitude, are Kukak, Kuliak, Missak, Kinak, Dakavak, Katmai, and Kashvik Bays (T. Hamon, NPS-King Salmon, personal communication, 2005). **Table 22**and **Table 23** list outfitters that bring tourists to the KATM coastal region for bearviewing and fishing tours. The large numbers of outfitters is reflective of the large (yet unquantified) number of visitors who utilize the coastal region.

Bear-viewing tours along coastal KATM increased in popularity particularly after the McNeil River State Game Sanctuary greatly restricted hunting and photographing of bears to a very small number of lottery winners, and after coastal KATM received a lot of attention following the EVOS (Kizzia, 1993). Charter hunting and fishing trips—both fly-in and boat-accessed--have been growing rapidly in the last two decades, and even the occasional cruise ship has been known to launch a series of zodiacs in search of bear viewing along the coast (Kizzia, 1993). Most of KATM's management resources are directed to Brooks Camp, however, and as pointed out in a recent visitor impact monitoring report for SWAN, use levels along the KATM (and LACL) have been increasing but to an undetermined extent and receive little management (Monz, 2005). Visitor use to coastal KATM is not monitored, and permits are not required, and as a result, there are no accurate data on the number of visitors to the area.

Sport hunting is allowed in the Preserve portion of KATM, but not in the Park areas; hence the coastal watersheds are not open to this activity (T. Hamon, NPS-King Salmon, personal communication, 2005). One exception to this is the Kamishak Special Use Area, which is a state-owned area north of Cape Douglas, immediately adjacent to the McNeil River State Game Sanctuary. This area has been closed to hunting since 1985, and efforts to reopen it to hunting in 2007 were blocked by a unanimous vote by the Alaska Board of Game in March, 2007. However, poaching of wildlife has been known to occur throughout the Park, although also to an unknown extent due to the near absence of law enforcement along the coast (NPS, 1994). Although KATM is not a subsistence-authorized unit, KATM identified 3 areas where "traditional-use" fisheries are authorized, although to the NPS's knowledge, this fishing has never occurred. In other areas, legal sport fishing is a major tourist attraction to all parts of KATM, coastal and inland. Off-road vehicle use is not known to occur along the coast, and there are no designated ORV trails within KATM (NPS, 2005a).

Impacts of coastal tourism to water and biologic resources include wildlife disturbance, harassment, and displacement; human waste and garbage; vegetation trampling and loss; stream bank erosion, fire rings; and tree damage (Monz, 2005). Various reports over the years have noted other impacts as well, such as the illegal storage of crab pots and skiffs along the shore and the discharging of firearms (NPS, 1985, 1994). The extent of these impacts is largely unknown, although their existence and the need for more information on them is well-recognized by NPS staff (T. Hamon, NPS-King Salmon, personal communication, 2005). What is clear however, is that fly-in charter tours and boat-based tours continue to be on the rise (Kozlowski, 2006, in preparation; Weeks, 1999)– a trend that is now facilitated by the recent securing by the State of Alaska of mooring buoy permits that will accommodate commercial tour operators (T. Hamon, NPS-King Salmon, personal communication, 2005). An increase in marine vessel traffic will raise the risk of fuel spills and potentially harmful wastewater discharge (see section V.A.1.c. above) and increase disturbance to marine and coastal biological communities.

Table 22. List of bear-viewing outfitters that use the KATM coast. List compiled based on internet search in May, 2006, and may not necessarily include all outfitters.

Bear-viewing outfitter	Address	Travel Locations	Trip Duration	Operation Seasonality
Alaska Air Taxi	Anchorage, AK	Various, including Swikshak Bay	6-8 hr tour	June-Sept
Alaska Alpine Adventures, LLC	Port Alsworth, AK	Brooks Camp and throught KATM and LACL	5 day trip	June-Sept
Alaska Bear Tours	Homer, AK	Homer to Katmai	All day	June-Sept
Alaska Bear Quest, LLC	Fritz Creek, AK	Throughout Katmai and Brooks Falls	5 days	June-Sept
Alaska's Fishing Unlimited Lodge	Port Alsworth, AK	Throughout Katmai	3-7 days	June-August
Bald Mountain Air Service	Homer, AK	Homer to Katmai	9-10 hr tour	May-October
Bear Quest Aviation, Inc	Kodiak, AK	Kodiak to Katmai Coast	4 hr trip	May-Sept
Dolly Varden Alaska	N/A	Katmai	10 hr	N/A
Emerald Air Service, Inc	Homer, AK	Katmai	All day	June-Sept
Euro Alaska Tours	N/A	Anchorage to Katmai	4 day trip	May-Sept
Go Alaska Tours	N/A	Homer to Katmai	1-4 days	July-August
Hallo Bay Wilderness Camps	Homer, AK	Homer to Katmai NP	5 hr- 7 days	May-Sept
Insight Wildlife Management	Bellingham, WA	Kodiak to Katmai	4 day/3 night	August-September
Katmai Coastal Bear Tours	Homer, AK	Homer to Katmai	4 day/3 night	June-Sept
Katmai Wilderness Lodge, LLC	Kodiak, AK	Kukak Bay	4-8 days	May-October
Kingfisher Aviation	Kodiak, AK	Kukak Bay	4 hours	May-October
Lifetime Adventures	Palmer, AK	Katmai	6 days	May-Sept
Raspberry Island Remote Camps	Kodiak, AK	Katmai coast	2-7 days	N/A
Sea Hawk Air, Inc	Kodiak, AK	Katmai	4-5 hours	June-August
True North Adventures, LLC	Kodiak, AK	Katmai	5 days	August
West Canada Tours	N/A	Kodiak to Katmai	1-4 days	June-Sept

Table 23. List of fishing outfitters that use the KATM coast. List compiled based on internet search in May, 2006, and may not necessarily include all outfitters.

Fishing Outfitter	Address	Travel Locations	Trip Duration	Operation Seasonality
4 W Air	Soldotna, AK	will do whatever customer wants	Custom length	June-September
Alaska's Fishing Unlimited Lodge	Port Alsworth, AK	Throughout Katmai	3-7 days	June-August
Air Madura, LLC	Anchorage, AK	Katmai	6 days/5 nights	June-September
Crystal Creek Lodge	Wasilla, AK	Throughout Katmai	6 days	June-September
Katmai Wilderness Lodge	Office in Kodiak, AK	Kukak Bay	4-8 days	May-October
Rainbow Point Lodge, LLC	Anchorage, AK	Kamishak and 13 other rivers	4-6 days	May-September
Sea Hawk Air, Inc	Kodiak, AK	Katmai	N/A	March-October
Katmai Wilderness Lodge	Office in Kodiak, AK	Kukak Bay	4-8 days	May-October

C. Climate change

Climate change is an important natural resource issue for national parks in Alaska, and recent research suggests that changes in climate may dramatically impact water resources in these parks. On a global scale, mean surface air temperature has risen by about 0.6 ºC (1.1 ºF) in the last century and the best estimate of the International Panel on Climate Change is that temperatures will rise by another 1.7 to 4.0 ºC (3.1 to 7.2 ºF) by 2100 (IPCC, 2001). 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 re-radiate outgoing terrestrial longwave radiation.

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 (Roots, 1989). Over the past fifty years, Siberia, Alaska and northern Canada, and the Antarctic Peninsula have warmed more than any other regions on Earth, and the 20th century arctic is the warmest of the past 400 years (Overpeck, 1997; Serreze et al., 2000). Alaska's climate has warmed by approximately 4ºF since the 1950s and is projected to rise an additional 3-10º F (5-18ºF) by 2100 (Parson et al., 2000). The reasons for the larger temperature increases at high latitudes are not fully understood, but are thought to involve cyospheric 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).

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). KATM contains substantial area of glaciers and permanent snowfields are common in north and northeast facing basins in the Aleutian mountains within the park. 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 KATM, winter temperatures are typically close to the freezing point of water (**Figure 74**). 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.

At present, there are no long term hydrologic data available for KATM to evaluate climate driven shifts in streamflow. However, long-term discharge data from the Kadushan River near Tenakee Springs, Alaska suggest that climate warming can increase winter streamflows and decrease streamflow in the summer and fall (**Figure 74**). The Kadushan River may be an appropriate analog for seasonally snow covered watersheds in coastal KATM because it is located at a similar latitude (57˚N) and has a comparable climate. A decrease in seasonal snowcover and associated lower summer streamflows may 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˚C, which is the State of Alaska standard for egg and fry incubation (Mauger, 2005). These findings suggest that climate warming and shifts in the timing of streamflow within KATM have the potential to influence the spawning success of salmon within the park.

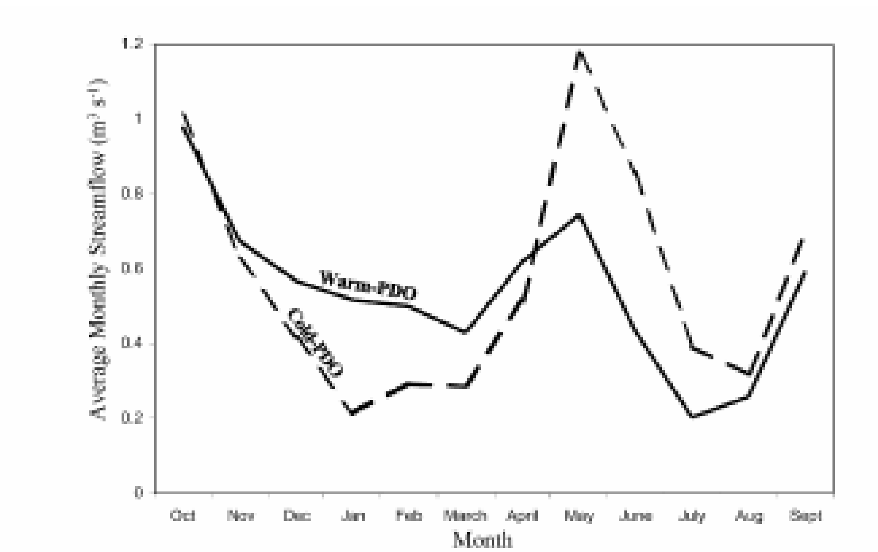

Figure 74. Annual streamflow patterns for the Kadashan River near Tenakee, Alaska during warm and cold periods of the Pacific Decadal Oscillation (Neal et al., 2002). Climate warming results in an increase in winter streamflow and a decrease in summer streamflow.

In addition to snowcover, climate warming is also affecting the dynamics of KATM glaciers. Glaciers in coastal KATM have been retreating since the end of the Little Ice Age in the late 1700s. Hildreth et al. (2000, 2001) suggest that despite the advances of several ash-insulated glacier tongues, the ice budget for most glaciers in KATM has clearly been negative during the last century. Moreover, geomorphologic investigations on several peaks in the coastal KATM including Snowy, Trident, and Mageik have shown that glaciers have retreated on the order of 1.5 to 3.5 km (0.9-2.2 mi) from their Little Ice Age maxima (Hildreth et al., 2000, 2001a, b). In recent decades, glaciers in both maritime and continental regions of Alaska are thinning and retreating at increasingly rapid rates. To the northest of KATM along the Alaska Peninsula, laser altimetry surveys on seven glaciers in and around Lake Clark National Park have measured relatively high thinning rates (0.5 to 1.0 m/yr [1.6-3.3 ft/yr]) over the surface area of the glaciers) during the period from the mid-1950s to 2001 (Arendt et al., 2002).

An important hydrologic effect of increased glacier melt is an increase in the volume of runoff from glaciers. 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). Reduced stream temperatures from increased glacial runoff can also decrease 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 KATM may produce less runoff as glacier mass decreases significantly.

Climate warming within KATM 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 in the reduction of surface water area as well as the number of 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). Like lakes and ponds, wetlands in KATM 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 KATM 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. Presumably, longer residence times will increase concentrations of conservative weathering products and decrease levels of biologically important solutes such as nitrogen and phosphorus. 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 and moisture, 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 KATM because the productivity of these systems is partially controlled by the input of nutrients from coastal watersheds.

D. Physical hazards

D1. Volcanic activity

The string of Aleutian Mountain volcanoes running parallel to the Shelikof Strait in KATM form one of the world's most active volcanic areas and is the site of the highest density of young volcanic centers in Alaska (Neal, 2005; NPS, 2006d). The active volcanoes are: Katmai, Novarupta, Fourpeaked, Trident, Mageik, and Martin; while those that have not erupted in the last 250 years are: Cerberus, Falling Mountain, Griggs, Snowy, Denison, Kukak, Devils Desk, Kaguyak, Douglas, and Kejulik (NPS, 2006d) (**Figure 75**). Although not in a current state of unrest, these Aleutian volcanoes in KATM are all still in a highly active volcanic zone, along the Pacific "Ring of Fire." Subduction of the Pacific plate under the Alaska section of the North American plate generates frequent earthquakes and volcanic activity throughout the Aleutian chain (**Figure 76** and **Figure 77**). Since 1990, 1-2 volcanoes in Alaska have erupted each year; most notably: Novarupta (1912), Redoubt (1989), Mount Spurr (1992), Pavlof (1996), Okmok (1997), and most recently, Augustine and Fourpeaked (2006) (Alaska Volcano Observatory, 1998, 2006). At this report writing, Fourpeaked volcano is categorized under an "advisory" volcanic activity alert level. At least 10 major eruptions have occurred in the KATM area in the last 7000 years, and approximately 140 km^3 of magma have been released from volcanoes in the region in the last 150,000 years (Dumond, 1979; Hildreth, 1991). Relatively small-volume volcanic eruptions are common as well, as exemplified by the activity on Trident volcano, which released 0.5 km^3 of andesite and dacite magma between 1953 and 1974 (Coombs and Eichelberger).

The June 6, 1912 eruption of Novarupta (although originally thought to be Mt. Katmai) was the largest 20th century eruption in the world and the largest rhyolite eruption in recorded history. During the first 60 hours of the eruption, massive volumes magma (12 km^3, 2.9 mi^3) inflated to 30 km^3 (7 mi^3) of tephra, which in turn deposited as ashfall and filled an adjacent valley with 213 m (699 ft) of ash (forming the Valley of Ten Thousand Smokes); furthermore, the village of Katmai and Kaflia Bay were blanketed with ~1 m (3 ft) of ash, and areas as far as Kodiak (170 km away) were covered with 30 cm (10 in) of ash (Eichelberger, 1991; Griggs, 1922; Hildreth, 1991; Hildreth and Fierstein, 2000; Kienle, 1991; Norris, 1996). Within hours of Novarupta's explosion, 2-3 summits of Mt Katmai (10 km, 6 mi away) began to collapse due to the withdrawal of subterranean magmatic support, forming the 3 km (2 mi)- wide and 1 km (0.6 mi) deep caldera still present today (Hildreth, 1991; Miller and Smith, 1987). The sound of the blast was heard as far away as in Juneau (1200 km, 750 mi east) and the decrease in solar radiation produced by the thick dust and aerosols lowered mean global temperatures by 0.2ºC (0.4ºF) for the last 6 months of 1912 (Norris, 1996; Rampino and Self, 1984).

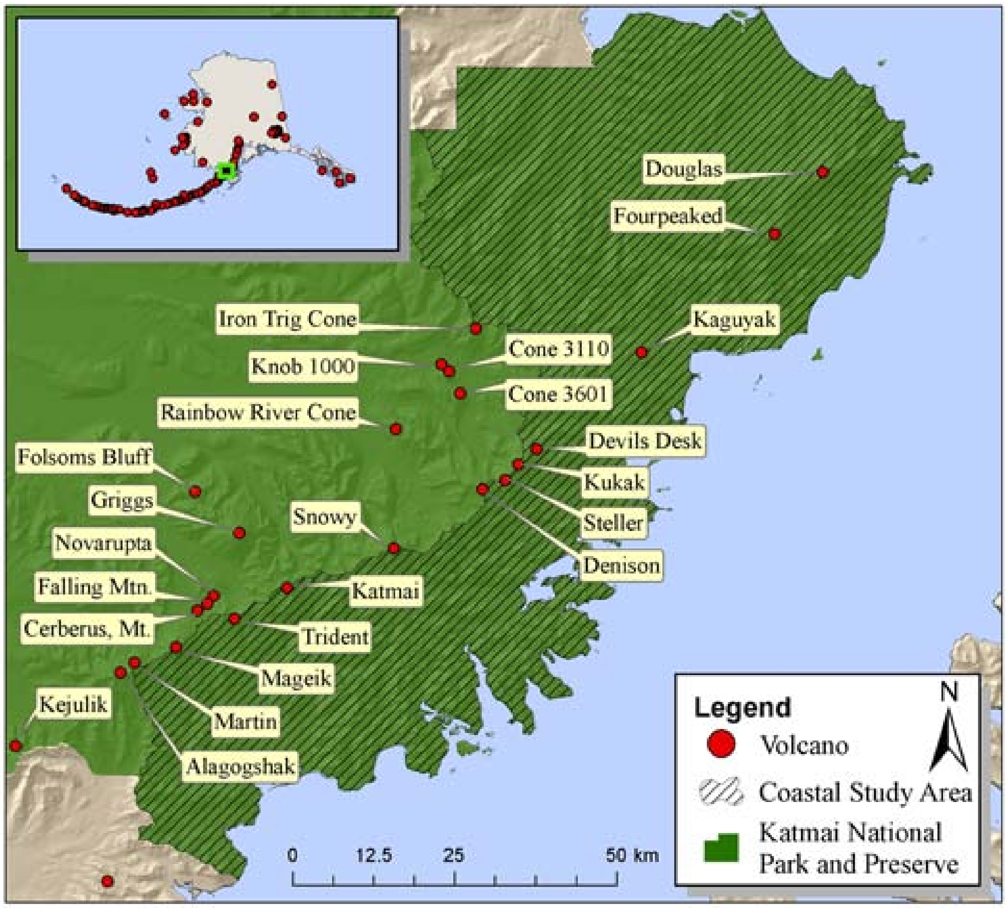

Figure 75. Location of volcanoes in KATM and the coastal study area.

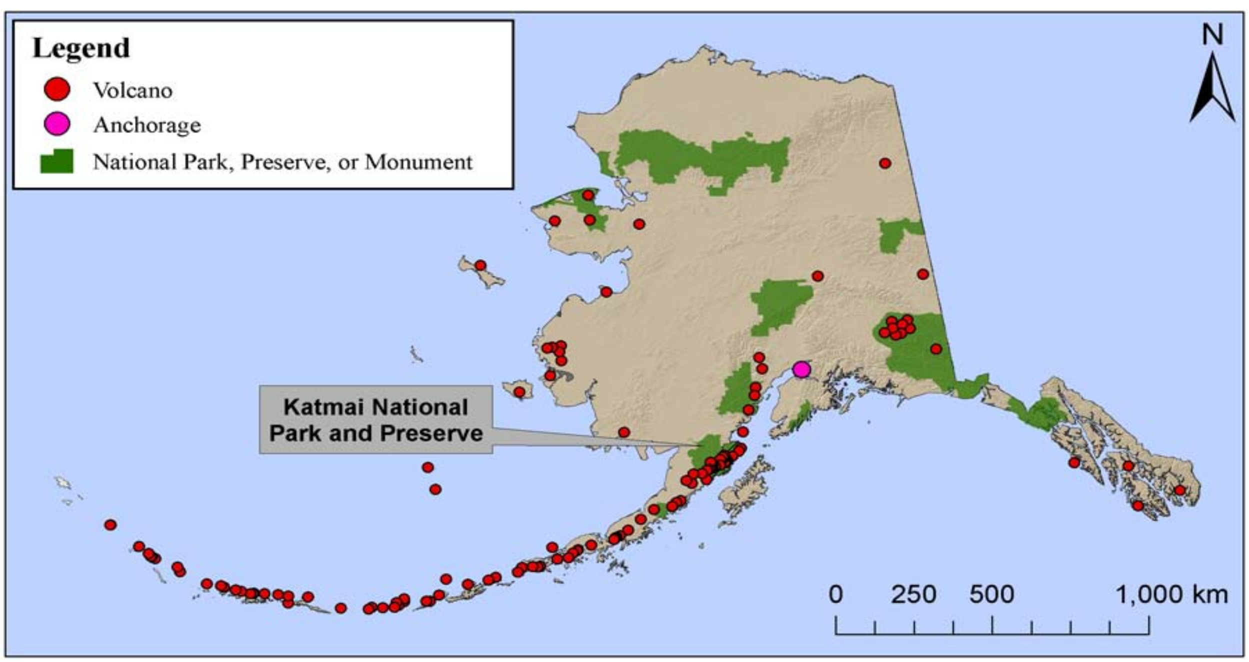

Figure 76. Location of volcanoes in Alaska.

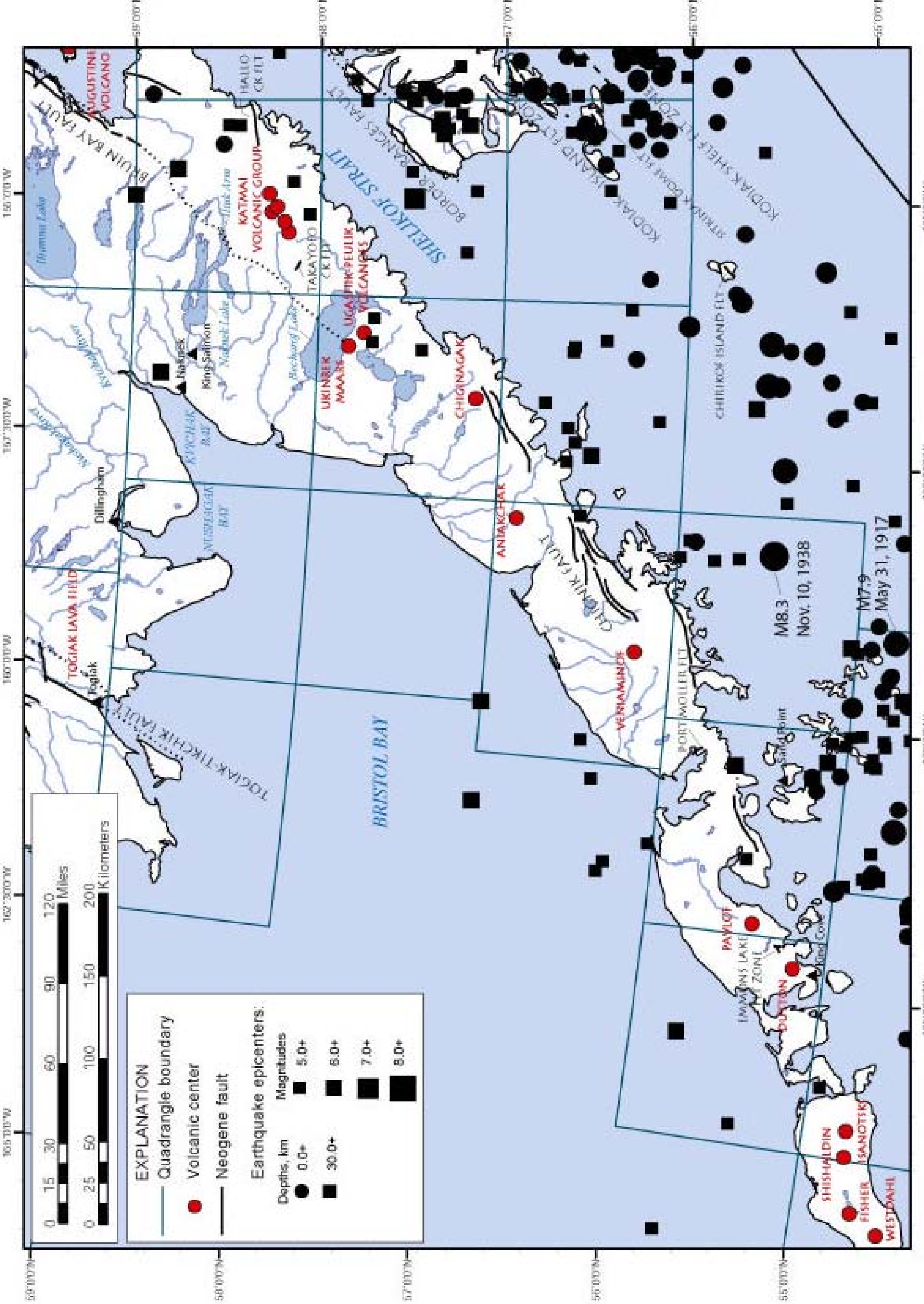

Figure 77. Volcanic centers, faults, and epicenters of earthquakes with magnitudes >5.0 in the Alaska Peninsula Region. Epicenters from the Alaska Earthquake Information Center. (Stevens and Craw, 2004)

The KATM coastal zone was directly downwind of the eruption and sustained major damage to plant and animal life as a result (Dumond, 1979). A team of National Geographic Society researchers visited the area in 1915 and described it as largely denuded of vegetation (Griggs, 1922). However, recovery from the blast was rapid and survival by flora and fauna was found to have been better than expected (Griggs, 1933), and within a few years trapping cabins were in use along the coast, followed a few years later by the start of clamming operations (Dumond, 1979). Even the sockeye salmon catch was depressed for only a few years and rebounded strongly afterwards (Dumond, 1979; Eicher and Rounsefell, 1957). A 1959 NPS biological survey of KATM reported that with the exception of the Valley of Ten Thousand Smokes and few nearby areas, post-volcanic recovery was largely or entirely complete (Cahalane, 1959) The aftermath of eruption has initiated much geologic interest in the area, and investigations of the volcanic events and related geologic structure and geochemistry have been published in major scientific journals (Eichelberger et al., 1986; Fenner, 1920; Hildreth and Fierstein, 2000; Kasameyer et al., 1991; Ward et al., 1991; Westrich et al., 1991). Notably, a major interdisciplinary surface and drilling investigation occurred in the late 1980s and 1990s as part of the Continental Scientific Drilling Program (Eichelberger, 1991; Eichelberger and Hildreth, 1986; Eichelberger et al., 1990; Sattler, 1990).

Future volcanic eruptions releasing ash clouds and lava flows in the KATM area and adjacent regions are certain and unavoidable (Neal). According to a recent USGS assessment of volcano hazards for the Katmai volcanic cluster, the areas/infrastructres at greatest risk of being impacted by these future eruptions are (1) air-traffic corridors of the North Pacific, including those approaching Anchorage, one of the Pacific’s busiest international airports, (2) several regional airports and military air bases, (3) fisheries and navigation on the Naknek Lake system and Shelikof Strait, (4) pristine wildlife habitat, particularly that of the Alaskan brown bear, and (5) tourist facilities in and near Katmai National Park (Fierstein and Hildreth, 2000). Due to these risks 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 in KATM are actively monitored at 19 stations by the AVO (visit http://www.avo.alaska.edu/ for more information). The AVO is conducting detailed volcanic hazard assessments for many of Alaska’s potentially active volcanoes. Most hazards are identified as ash clouds, ash fall, pyroclastic flows and surges, mudflows (lahars) (which are of special concern in Alaska due to the risk of rapid melting of snow and ice, as demonstrated by the 1989-90 eruption of Redoubt), lava flows, and volcanic gases (Neal, 2005).

The influence of chronic low-level volcanic activity on water resources in KATM is most directly related to the water quality conditions of hydrothermal springs within volcanic craters and surrounding areas. Hydrothermal springs are generally less supportive of fisheries due to their high temperatures, low dissolved oxygen concentrations, and high dissolved loads. Changing volcanic conditions within the Katmai and Kaguyak calderas may alter the scale and location of contributions from thermal springs to the lakes. However, because neither crater lake has an outlet stream, effects would likely be confined to the local area. However, in the Mageik Creek region, variations in the scale and content of volcanic contributions to surface waters would likely have watershed-scale effects.

The types of impacts of volcanic eruptions on water quality varies from the catastrophic lahars of rapidly melting of snow and ice, which may result in mud-choked streams and major changes in streambed morphology, to more subtle and longer-time positive 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 (50 km (30 mi) from coastal KATM) 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 KATM region (although no data were derived specifically from coastal KATM). It is notable that some of the world's richest salmon runs are in the Bristol Bay region adjacent to Katmai, and this region is regularly impacted by ashfall from volcanic events along the Aleutian chain.

D2. Earthquakes and tsunamis

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) (**Figure 77**). The "Shumagin" segment of the volcanic zone, located along the southwestern Alaska Peninsula, has been predicted by (Nishenko and Jacob, 1990) to have a 74-84% chance of a magnitude 7.4 earthquake between 1988 and 2008, and many other scientists believe this zone is due for a major earthquake in the next few decades (Stevens and Craw, 2004). An earthquake in the Shumagin seismic gap may generate extensive tsunamis along the southern coast of the Alaska Peninsula and Aleutian Islands (Kowalik and Murty, 1989).

In 1964, the largest earthquake in North America- and the second largest earthquake ever recorded- occurred in the northern Prince William Sound (Sokolowski, 2006). The earthquake raised some land areas up to 10 m (30 ft), 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). While 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 in and around the Katmai volcanoes themselves, particularly during a build-up to a volcanic eruption (Fierstein and Hildreth, 2000; Moran, 2003; Ward et al., 1991).

Tsunamis striking coastal KATM 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 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, Hawai'i (http://www.prh.noaa.gov/ptwc/). The AVO also operates seismic networks throughout the Aleutian chain and has recorded more than 5000 earthquakes in the Katmai volcanic group since 1989 (Moran et al., 2005)

D3. Uplift

The complex interplay of tectonic, isostatic, and global eustatic effects in the Gulf of Alaska results in highly spatially variable sea level histories along the southcentral and southwestern Alaska coast. Overall, the KATM coastal region has tended toward net uplift than by subsidence in its recent geologic past (Crowell and Mann, 1996; Kozlowski, in preparation). Earthquakes leading to sudden coastal uplift events are common along the tectonic setting of the Alaska Peninsula coast. The subduction of the Pacific plate under the North American plate tends to cause the continental plate to be uplifted, sometimes very suddenly as occurred during the 9.2 magnitude Good Friday earthquake in 1964. During this earthquake earthquake, for example, some portions of the coastal southcentral Alaska were uplifted over 8m, while other areas subsided up to 2.25 m (7.40 ft) (Harper and Morris, 2005). Uplift of the land due to tectonic activity is superimposed upon isostatic rebound from deglaciation, a process which raises the land and reshuffles successional processes on a much more gradual time scale (Bennett et al., 2006; Mann et al., 1998). Changes in relative sea level has been shown to cause dramatic changes in fisheries and wildlife habitat in southeast Alaska's Wrangell-St. Elias National Park and Preserve (Mills and Firman, 1986). Uplift may also cause changes in the composition and location of key vegetative types, and in the distribution of birds and wildlife along the coastline. For example, in some areas of southeast Alaska, high marsh communities dominated by grasses have replaced the sedge-dominated low marsh communities (Armstrong et al., 2004). Migrating birds such as pipits and longspur favor high marsh communities, while low marsh communities are nutritionally crucial for waterfowl such as Vancouver Canada Geese (Armstrong et al., 2004). In addition to changes in habitat, these ongoing shifts in the elevation of the land surface also have implications for the hydrology of small coastal streams, many of which support salmon populations. As water tables drop in response to uplift events, it is possible that coastal streams fed by groundwater may experience reduced seasonal or perennial flows and become impassable for fish, limiting the range of certain anadramous stocks.

E. Exotic/invasive species and disease

Nonindigenous aquatic invasive species 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 likely to be invaded by nonindigenous 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 or due to negligence, and 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 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.)

The presence and scale of exotic species in KATM's coastal watersheds is not known or documented, as no studies have been directed at this issue (T. Hamon, NPS-King Salmon, personal communication, 2005; Jim Larson, USFWS-King Salmon, personal communication, 2005). Exotic plant species have been documented in the Brooks Camp area of interior KATM and areas in KATM's backcountry include: shepherd's purse *(Capsella bursa-pastoris*), clover (*Trifolium repens*) and pineapple weed (*Matricaria matricarioides*), bluegrass (*Poa pratensis*) and knotweed (*Polygonum aviculare*), but have not been targeted for study in the coastal zone (Densmore et al., 2001). However, the increase in visitor use along the coast may result in the import of exotic species to the area in the near future. The tourism, fishing, and hunting-related anchorings along the KATM coast greatly increase the likelihood of invasive species introductions to the area (Alan Bennett, NPS-Anchorage, personal communication, 2005).

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 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 recoveries in both British Columbia and Alaska, with the first catches of Atlantic salmon in Southeast Alaska in 1991 (ADFG, 2002b). While ADFG has documented over 700 recoveries of Atlantic salmon in Alaskan waters, representing an estimated 3,000 immigrants per year, no Atlantic salmon have been documented in southcentral/southwestern Alaska in the coastal KATM area (T. Hamon, NPS-King Salmon, personal communication, 2005). The risk posed by Northern Pike to SWAN watersheds 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; however, their possible survival in brackish lagoons such as in Swikshak and Hallo Bays and/or the deliberate planting by people flying into coastal lakes may provide means of their introduction into coastal watersheds (T. Hamon, NPS-King Salmon, personal communication, 2005).

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 1990's, and has since become established in estuaries as far north as British Columbia. Bacteria, viruses, and parasites are also a threat to Alaskan waters because these can be easily introduced through nonindigenous species.

Disease concerns include high intensity spruce bark beetle (*Dendroctonus rufipennis*) outbreaks and potential arrival of the avian influenza (H5N1) virus in Alaska. Spruce bark beetle conditions have been examined in the Brooks Camp area, but not in the coastal zone (Manski, 1986). Spruce bark beetles are native, and at endemic levels they 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). As part of the Vital Signs monitoring activities, a tree-ring study is being conducted in KATM and LACL to determine the extent of historic vs modern bark beetle outbreaks (more information at: http://www.nature.nps.gov/im/units/swan/index.cfm?theme=insect_outbreak). While spruce beetle- caused tree mortality is high on parts of the LACL coastline northeast of coastal KATM, the scale of this potential issue in coastal KATM is largely unknown. Resultant large-scale tree mortality would affect 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.

The avian flu 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 to closely monitor wild birds, primarily in western Alaska, for the presence of the virus (State of Alaska, 2006). An outbreak of the virus has the potential to decimate bird populations in the KATM 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. As a result, the extensive coastal wetlands and ponds in KATM may be potential breeding grounds and source areas of the virus if they were to become infected by carrier birds.

Chytridiomycosis is an emerging infectious disease caused by a waterborne fungus that, alone or in consort with other environmental stressors, has caused amphibian declines globally (Skerrat at al., 2007). This disease probably does pose a threat to resident wood frog populations in KATM, but the prevalence of the fungus in ANIA is currently unknown. It has, however, been detected on the Kenai National Wildlife Refuge and many other remote parts of Southeast Alaska (Reeves and Green, 2006; S. Pyare, personal communication).

F. Salmon populations

The maintenance of healthy salmon stocks and appropriate fish passage in coastal streams and rivers in KATM is important not only for fisheries resources but also because spawning salmonids have significant impacts on biological resources in both terrestrial and freshwater aquatic ecosystems (see Gende et al., 2002 for a review). The ecological importance of salmon in coastal ecosystems suggests that fisheries management decisions related to salmon populations and salmon returns have the potential to affect biological resources within KATM. For a description of the role of salmon-derived nutrients in KATM watersheds, see *section C4a*. KATM contains all five species of Pacific salmon, however relatively little research has been done on salmon populations in the park and, to our knowledge, there has been no research in KATM on the ecosystem function of salmon-derived nutrients. While studies on this subject have been done elsewhere in southwestern Alaska, findings from these studies may not be directly applicable to KATM because the relative importance of salmon-derived nutrients to watershed nutrient stocks and productivity varies by watershed because of differences in lithology, hydrologic regime, and landcover.

G. 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 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 they cause a variety of human illnesses that vary by type of toxic phytoplankton or diatom. Some cause respiratory problems in humans in certain geographic regions. Southwest Florida, for example, now issues health alerts and suggests that people with certain health problems stay inside and away from beaches during certain blooms. HABs are known to cause a variety of shellfish poisoning (SP), including paralytic (PSP), diarrhetic (DSP), neurotoxic (NSP), and A fifth human illness, caused by finfish and not shellfish, is Ciguatera Fish Poisoning (CFP).

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 is 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 78. 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 KATM. The Alaska Department of Environmental Conservation (ADEC) is responsible for testing shellfish for PSP. Due to the geographic extent of Alaska (over 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 KATM. Any unusual incidences of mass mortalities of marine bird, mammal, and fish populations should be suspected as possible HAB-related events. NPS should advise against non-commercial harvests of shellfish because of the risks associated with PSP.

H. Abandoned structures

A 1999 historic properties study identified a list of known and suspected structures of potential historical/archeological interest along the Shelikof coast drainge of KATM (Clemens and Norris, 1999). Almost all structures associated with historical canneries and clamming industry infrastructure no longer remain along KATM's coastline. Nine trapping/subsistence cabins were present historically along the coast, at locations along the mouth of the Kamishak River, Cape Douglas, Chiniak Lagoon, Hallo Bay (2 cabins), Kukak Bay, Kuliak Bay, Takli Island, and Kashvik Bay; but little evidence remains of their presence (Norris, 1996). Some of the cannery, clamming industry, and trapping/subsistence cabins and buildings were destroyed or damaged by fire and earthquakes (e.g. in Kukak Bay); some were razed by NPS personnel following closure of the sites (e.g. at Swikshak Bay); and others were buried by volcanic ash (i.e. Kaflia Bay). Partial structures remain from the canneries in Kukak Bay and Swikshak Bay, and of an individual small shack along the northern coast of Kukak Bay (Norris, 1996). One intact cabin still remains in Swikchak Bay, and it was characterized by Jennifer Tobey, an NPS staffer who conducted an investigation of cabins along KATM's coast in 2005, as clean, still used by visitors, in moderately good shape, and containing only small amounts of stove fuel (Jennifer Tobey, NPS-Anchorage, personal communication, 2006). In contrast, a book on the Kukak Bay clam cannery described its current condition as a safety hazard and "a heap of corrugated metal, buckled boardwalk, and scattered machines. Most structures are collapsed, exposing retorts, boilers, and other cannery apparatus" (Johnson, 2002). Nonetheless, the historic cannery site is valued by the NPS, which is mandated by the National Historic Preservation Act to protect significant places, and considers the cannery a cultural resource that deserves protection (Johnson, 2002).

The NPS survey of cabins along the KATM coast mentioned above found insignificant evidence of environmental risk associated with abandoned structures and their waste, although this risk level was qualitative and not quantitative (Jennifer Tobey, NPS-Anchorage, personal communication, 2006). Yet, localized threats to water quality may still exist from untreated or unremoved hazardous materials associated with the abandoned structures. For example, in 1994, a group of NPS seabird surveyors found a hazardous materials site associate with "a small abandoned military facility or USCG [United States Coast Guard] aid to navigation site" on Nukshak Island, on the south cape of Hallo Bay that consisted of an old generator shack, cabin sub-floor, at least 4 decomposing diesel starter batteries, approximately 1 cubic yard of unidentified yellow powder, 3 empty 55-gallon drums, 1 partial and leaking 55 gallon drum assuming to be diesel, an outhouse or other dump pit, various cable deadmen/anchors, two decomposing 5-gallow grease cans, and miscellanous garbage (NPS, 1994). The report recommended an in-depth survey and assessment. However, NPS staff were not aware of this issue in 2006 (Jennifer Tobey, NPS-Anchorage, personal communication, 2006), and it remains unclear whether the Nukshak Island site has undergone any clean-up.

I. Coastal debris and garbage

From a flight tour over coastal KATM in August, 2005, we observed the undeveloped, wild landscape regularly interrupted by high tide lines clearly delineated by garbage and debris from human activities. This issue extends at least as far back as 1989, when a coastal survey of the damage from EVOS on Kamishak and McNeil River area made note of the problem (Kavanagh, 1989). The report described "the incredible amount of beach debris present at the high tide line among the driftwood… In many places you couldn't go 15 feet *[4.6 m]* without seeing plastic of one kind or another—everything from pails, jerry cans, buoys, nets, floats, bottles, to very large items like rubber bumpers for boats" (Kavanagh, 1989). A marine debris and carcass survey several years later reported household garbage (probably cast-offs from ships), fish nets, crab fish refuse, and timber industry refuse as the most frequently found items (NPS, 1994). Bottom trawl webbing was the most common fisheries refuse, followed closely by high-seas drift gillnets. To describe the scale of the debris issue, the report authors commented: "if the amount of trawl webbing found on park shorelines is a valid indicator of effort in nearby waters, the park marine ecosystem is being severely pounded by this industry. How this relates to seabird and marine mammal declines is of concern" (NPS, 1994). Drift gillnets and much of the garbage was of foreign origin, including Chile, Canada, the "U.S.S.R", and to the largest extent, Japan. By contrast, the Cook Inlet petrochemical industry received positive marks for the fact that relatively little off-shore oil industry refuse was found. Bodkin et al. (2007) conducted a debris survey at 10 randomly selected 100m sections of KATM coastline. The most commonly found debris, in order of abundance, was fishing/boat debris, plastic containers, metal containers (predominantly metal drums), glass containers, and dimensional lumber (**Table 24**). Bodkin et al. (2007) recommended that costs in terms of personnel and vessel time were high and that coastline surveys be conducted once every 10 years. No studies have been conducted to evaluate the impact of coastal debris (e.g. entanglement) on KATM's natural resources and there are no known efforts by the NPS to rid the coastline of collected debris and garbage.

Table 24. Estimated abundance of beach cast debris of human origin on ten randomly selected 100 m long beaches in block 10, KATM, surveyed in April (Segment 1, and Segment 4 beaches 1,2, and 3), or June and July (Segment 4 beaches 4 and 5, and Segment Z). Numbers refer to the estimated number of 33 gallon trash bags that the visible debris would fill. (Table 6.2 in Bodkin et al. 2007).

	Segment 1				**Segment 4**						**Segment Z**	
# of 33 gal. bags	#1	#2	# 3		# 1	# 2	# 3	# 4	# 5		# 1	# 2
Fishing/boat gear	<1	1	2		5	8	26	2	1			
Glass containers						<1	1	<1	1			
Plastic containers	<1	<1	1		<1	<1	1	1	<1		<1	
Metal containers		<1	<1		2			2			1	
Misc. containers								<1	<1			
Other			1 wood		<1			3 wood	2 wood		<1 plastic/ rubber	

VI. Condition overview and recommendations

A. Condition overview

Based on our research of available data and our best professional judgment, we summarize the potential and existing stressors of aquatic resources in KATM in the following table (**Table 25**).

Table 25. Water resources-related indicators and current/potential stressors of aquatic resources in Katmai National Park and Preserve.

Indicator	Freshwater	Intertidal, Bays & Estuaries	Coastal waters
Water Quality			
Nutrients/ Eutrophication	OK	OK	OK
Contaminants	PP	PP	PP
Hypoxia	OK	OK	OK
Turbidity	OK	OK	OK
Pathogens	PP	OK	OK
Habitat Disruption			
Coastal development	OK	OK	OK
Water quantity/ withdrawals	OK	OK	OK
Coastal erosion/shoreline modification by humans	OK	OK	OK
Natural geologic hazards	IP	IP	IP
Recreational usage			
Tourism (Bear viewing)	PP	PP	OK
Other Indicators			
Oil spills	NA	EP	PP
Harmful algal blooms	NA	PP	PP
Aquatic invasive species	PP	PP	PP
Climate change	PP	PP	PP

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

Freshwater and marine ecosystems in and adjacent to KATM are dominated by natural influences with few potential problems of concern; however, in many cases, few data are available (**Table 25**). Our rationale for assignments is described below.

Freshwater – Water quality in freshwater areas is likely to be high and unaltered by humans due to the remoteness and inaccessibility of much of the region. However, extremely little information exists to support or counter this assessment. Very few studies of stream, lake or groundwater water quality have been conducted. Water quality stressors of natural (volcanic) origin are known to exist in crater lakes and geothermal springs. Atmospheric deposition and biologic transport of contaminants from the marine environment pose threats to freshwater water quality, particularly in wetland-rich areas where atmospherically derived mercury may be transformed to highly toxic methylmercury. Habitat disruption is generally very limited, although increasing pressures from fishing, hunting, and other recreational uses are sharply rising and may lead to localized areas of disturbance to wildlife, pollution from small boats, fuel leaks, human waste, and garbage. Large-scale freshwater habitat disruption may occur due to natural geologic hazards such as volcanic eruptions, earthquakes, tsunamis, and uplift. No sampling has been done to evaluate the presence of aquatic invasive species. Climate change effects are largely unknown but could be significant at high latitudes and greatly influence the hydrologic, sediment, and nutrient budgets in glacier-fed KATM streams. As glaciers recede, land surfaces will create shifting hydrological patterns.

Marine Coastal Waters and Bays & Estuaries

Based on very limited data, water quality in marine and intertidal areas is high. The largest threat to intertidal and marine water quality is posed by oil spills from marine vessels (including oil tankers), accidents in the proposed and ongoing oil drill platforms, oil refineries, storage areas, and transfer facilities in Cook Inlet Shelikof Strait and Prince William Sound, all of which are upstream from KATM and which could suffer a human-caused error or be compromised from earthquakes, volcanic eruptions, and/or tsunamis. Lingering effects of the Exxon Valdez Oil Spill in 1989 persist along the KATM coast and are now part of the baseline. Atmospheric deposition of global contaminants such as Hg and POPs poses a chronic threat to marine water quality. Habitat disruption is generally very limited except for localized impacts by tourists arriving by boat and mooring near bays and beaches, although no studies have evaluated such impacts. Recreation and tourism usage is low in the nearshore area, and these impacts are likely minimal. Sudden and massive disturbances that have occurred or are likely to occur in the future due to natural physical hazards (volcanoes, earthquakes, tsunamis) may dramatically affect intertidal communities, which may be subject to sudden, meter-scale uplift or subsidence events. No sampling has been done to evaluate the presence of harmful algal blooms or aquatic invasive species, although the release of farmed Atlantic salmon and/or the expansion of the Northern Pike's range near KATM pose dangers to native salmon stocks. Climate change effects are unknown but could be significant. As glaciers recede locally and as ice caps melt globally, the interplay between land surface uplift and rising sea level could affect intertidal communities.

B. 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 on the current level of understanding of water (and other) resources in the network. We highly commend the SWAN I&M team for their efforts. 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. 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 described below and listed in Table 26.

Table 26. List of recommendations.

<u>Data access/management</u>
1. Online archives of NPS publications and reports
2. Data mining and integration and development of information into centralized and web-accessible GIS
3. Derivation of of key GIS layers, including wetland boundary and classification

<u>Water quality</u>
1. Oil spill response planning
2. Assess threat from atmospheric and marine-derived contaminants
3. Continue and expand on efforts to establish baseline freshwater water quality and watershed condition
4. Evaluate and monitor impacts of tourism and recreation on coastal water quality.

<u>Biological resources and habitats</u>
1. Wetlands inventory
2. Invasive species survey
3. Planning for natural hazards

<u>Hydrology/Oceanography</u>
1. Physical scientist hire for KATM
2. Climate/weather stations
3. Streamflow gaging

B1. Data access/management

1. Online archives of NPS publications and reports

A large number of NPS-related documents are available in electronic format online through NatureBib, an excellent searchable database. However, while almost 2700 citations are listed for KATM, only a small minority have downloadable files attached to the citation information. In light of this, access to the NPS files was greatly facilitated by our site visit to King Salmon, where we did manual searches through the office filing cabinets, and files were also available from the SWAN Data Manager.

2. Data mining and integration and development of information into centralized and web-accessible GIS

There are a number of data sources that have relevance to coastal watershed stressors and condition including EVOS, GRS, EMAP, EVO, and the DNR, as well as numerous inventory and survey efforts. Many of these sources do not reside in a public, GIS-ready repository, however nearly all of these data are geographically referenced. Through a concerted data-mining effort and/or cooperative data sharing agreements with other agencies, much of these data could be converted to a GIS format and unified for more effective analysis. In addition, Shorezone GIS data and imagery is likely an important source of baseline information for shoreline morphology, substrate, wave exposure, and biota of intertidal and nearshore habitats. This new resource should be more fully explored to evaluate its potential applicability for monitoring of structural and biological characteristics of coastal water resources in KATM. Collectively, these data could all be integrated into a centralized and web-accessible format, and potentially integrated with the current web-accessible NPS GIS clearinghouse (http://www.nps.gov/akso/gis/).

3. Derivation of key GIS layers, including wetland boundaries and classification

Several important GIS data sources are currently lacking. One example is wetland (e.g. NWI) boundary and classification data. This and other useful classified products for water resource monitoring could be derived through a combination of existing hydrological feature data sets, interpretation of existing aerial photos wherever these are available (e.g. AHAP products), and acquisition and classification of relatively inexpensive, moderate resolution, multispectral remote sensing imagery (e.g. 4-10 m IKONOS or SPOT) that encompasses all of KATM. Imagery could be acquired by cooperating with other interested agencies (e.g. NOAA, AVO, DNR) with jurisdiction adjacent or near KATM. In addition, this imagery could be useful for monitoring other hydrologic parameters within the park such as the extent of permanent snowfields and the number and aerial coverage of lakes and ponds.

B2. Water quality

1. Oil spill response planning

The NPS should continue their partnership with other responsible agencies, Coast Guard, ADEC, etc., to further develop and maintain GRS and oil spill response plans, for the KATM coast. NPS and their partners may want to collaborate with organizations developing circulation models for Cook Inlet and Shelikof Strait to predict potential oil spill trajectories. NPS may want to monitor future expansion of oil and gas facilities in Cook Inlet and Shelikof Strait.

2. Assess threat from atmospheric and marine-derived contaminants

KATM should partner with other parks in the SWAN network 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 potential impacts in the other parks. However, data specifically from KATM would be best, as distances and landscape differences among park units are large. In particular, SWAN should monitor future results from the ongoing WACAP project by the NPS Air Resources Division and the planned Mercury Deposition Network sites (to be funded by the Alaska DEC) in southcentral and southwestern Alaska. While the WACAP study does include vegetation samples from KATM, SWAN should consider sampling other parameters (snow, lake water, sediment, lichens, fish and other subsistence foods) in KATM, as is done in the "core" WACAP park units. More studies on the influence of salmon carcasses on contaminants loads in KATM streams, as well as studies on the role of wetlands in converting atmospheric mercury to methylmercury would greatly assist in evaluating the scale and magnitude of the problem.

3. Continue and expand on efforts to establish baseline freshwater water quality and watershed condition

The vital signs monitoring plan for the SWAN will greatly enhance the understanding of baseline freshwater water quality in KATM, but no water bodies in the coastal KATM zone have been categorized as “Tier 1,” which would receive annual monitoring. The Hallo Lake system, identified as Tier 2 (sampling every 2-5 years), and Dakavak Lake as Tier 3 (sampling every ~10 years if at all) should be considered for additional funding support in order to increase the likelihood of monitoring them over the long term. In addition, a water quality survey of a subset of coastal streams should be conducted. Physical, chemical, and biological parameters would include: turbidity (streams), Secchi depth (lakes), temperature, conductivity, total dissolved solids (TDS), dissolved oxygen (DO), pH, organic and inorganic nitrogen and phosphorus, sulfate, dissolved organic carbon (DOC), DOC quality, trace elements including mercury, organic pollutants, and inventories of macroinvertebrate communities (the current plan does not call for sampling of contaminants in water bodies). Streams draining a variety of environments, such as glacial, volcanic, non-glacial, wetland-rich, and wetland-poor should be measured for the above water quality parameters. Many of the watersheds in KATM are highly dynamic, thus the condition of watersheds within the park should be monitored on an ongoing basis using aerial photography to assess parameters such as: channel morphology, lake presence and size, shifting wetland habitats, and the extent of riparian vegetation. All of this information should be stored in a database as a way to facilitate data access.

4. Evaluate and monitor impacts of tourism and recreation on coastal water quality

It is clear that the popularity of bear-viewing and charter fishing trips to the KATM coast has been increasing at a rapid pace in the recent decade, yet there have been no studies evaluating the impacts of these uses on the water and biological resources. We recommend that the NPS conduct studies to identify the location and density of recreational and tourism visits to the coastal area, and investigate potential water quality impairments due to disposal of garbage and human waste, oil spills and leaks from boats and float planes, use of (unmaintained) camping sites and trails along stream corridors, and accelerated streambank erosion due to fly-fishing activities. The few rangers that work along the KATM coast are seasonal and work inland as needed. We recommend that at least one park ranger be consistently staffed during the summer tourist season along the heavily used areas along the coast, and that the ranger(s) have access to (and probably be stationed on) a marine vessel to patrol the coastal region. Our recommendation of staffing a boat-based coastal ranger is consistent with recommendations made back in 1990 by the Katmai Shoreline Assessment Team (Schoch et al., 1990), who strongly emphasized the urgent need for a coastal ranger who could monitor use, communicate with boaters, and educate visitors on how to protect coastal resources.

B3. Biological resources and habitats

1. Wetlands inventory

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

2. Invasive species survey

Aquatic and marine environments should be surveyed for invasive species. Standard protocols, such as PVC settling plates as passive collectors in subtidal marine environments (Ruiz et al. 1997), should be used whenever possible to survey invasive species. Freshwater streams should be monitored for the presence of potential invasive species such as Northern pike or Atlantic salmon. As part of the Vital Signs Monitoring Plan, invasive/exotic species surveys are planned with a strong focus on vegetative invasive species. We recommend that invasive/exotic species surveys are sure to include not only areas of relatively dense human use, but also the more remote, inaccessible areas of KATM.

3. Planning for natural hazards

Future tectonic activity is inevitable in and near KATM, and the likely effects of a large eruption, earthquake, tsunami, and/or catastrophic flood may have devastating short-term consequences to its resources despite some long-term benefits (e.g. nutrients in volcanic ash). While 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. However, considering that coastal KATM has no human infrastructure within its boundaries or in its immediate vicinity, there is little that can be done to protect its aquatic and biologic resources from the natural outcome of a large volcanic eruption, earthquake, tsunami, or catastrophic flood. Probably the most immediate actions that could prevent potential anthropogenic damage to the park resources include the rerouting of marine and air traffic away from the geologically active area, so that these vessels and any hazardous materials they may contain will not injure KATM resources in the event of their destruction. In particular, the NPS should continue to work with the AVO regarding volcanic hazards and response strategies.

B4. Hydrology/Oceanography

1. Physical scientist hire for KATM

KATM should consider hiring a physical scientist to oversee monitoring of hydrologic and oceanographic resources as well as park climatology.

2. Climate/weather stations

Climate change is one of the major threats to water resources in Alaskan parks. Streamflow in coastal parks such as KATM is particularly sensitive to climate change because during the winter the air temperature near sea level in southwestern Alaska is close to the freezing point of water. As a result, a relatively small increase in temperature can shift precipitation from snow to rain which, in turn, shifts the annual pattern of streamflow in coastal watersheds. Basic climate parameters in KATM should be monitored, ideally at both a coastal and an interior location because of the strong climate gradient within the park. Data collection should be automated, continuous, and archived with transmittal of information to national databases (i.e. NOAA, USGS). Physical parameters that should be monitored include: air temperature, precipitation, wind speed, wind direction, and other weather and oceanographic factors.

3. Streamflow gaging

There are currently no gaging stations operating within KATM, although streamflow is a key parameter in any water quality monitoring effort. Information on seasonal discharge patterns as well as longer-term variations in streamflow along one or more KATM coastal streams would be highly useful for evaluating the effects of climate change on surface water hydrology. If possible, gages should be established on one glacial and one non-glacial stream.

VII. References

ADEC, 2002, Science Advisory Panel, Commercial Passenger Vessel Environmental Compliance Program. The Impact of Cruise Ship Wastewater Discharge on Alaska Waters.: Alaska Department of Environmental Conservation.

-, 2006a, 18 AAC 70 Water Quality Standards as amended through March 23, 2006. .

-, 2006b, Geographic Response Strategies for Alaska, available at http://www.dec.state.ak.us/spar/perp/grs/home.htm.

-, 2006c, Guidance for the implementation of natural condition-based water quality standards. November 15, 2006.: ADEC report available at: http://www.dec.state.ak.us/water/wqsar/wqs/pdfs/natural_conditions_guidance_nov_15_re-adopt_v_11-27-06.pdf.

ADF&G, 1999, Division of Commercial Fisheries annual management report- Bristol Bay area. Alaska Department of Fish and Game, Anchorage, Alaska. .

ADFG, 2002b, Atlantic Salmon - A White Paper: Alaska Department of Fish and Game, Commissioner's Office, Juneau.

Alaska Divison of Oil and Gas, 2003, 2003 Annual Report, Section Six: Alaska Refining Sales and Consumption. http://www.dog.dnr.state.ak.us/oil/products/publications/annual/2003_annual_report/section6.pdf.

Alaska Volcano Observatory, 1998, Volcanoes of Alaska: information circular 38.

-, 2006, Augustine current activity, http://www.avo.alaska.edu/activity/Augustine.php.

AMAP, 2004, AMAP Assessment Report: Arctic Pollution Issues: Persistent Organic Pollutants, Heavy Metals, Radioactivity, Human Health, Changing Pathways: Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Anderson, B. C., 2004, An opportunistic amphibian inventory in Alaska's national parks 2001-2003: final report: National Park Service.

Anderson, D. M., 1995, ECOHAB: The Ecology and Oceanography of Harmful Algal Blooms - A National Research Agenda: WHOI.

Anderson, D. M., Hoagland, P., Kaoru, Y., and White, A. W., 2000, Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States: Woods Hole Sea Grant, WHOI-2000-11.

Andres, B. A., and Gill, R. E. J., 2000, U. S. Shorebird Conservation Plan: a conservation plan for Alaska shorebirds: U. S. Fish and Wildlife Service, Migratory Bird Management.

Angliss, R. P., and Outlaw, R. B., 2005, Alaska Marine Mammal Stock Assessments, 2005, *in* US Department of Commerce, ed., NOAA, p. 261 pp.

Arendt, A. A., Echelmeyer, K. A., Harrison, W. D., Lingle, C. S., and Valentine, V. B., 2002, Rapid wastage of Alaska Glaciers and Their Contribution to Rising Sea Level: Science, v. 29, p. 382-386.

Bailey, E. A., 1986, Analytical results and sample locality map of stream-sediment and heavy-mineral-concentrate samples from the Mt Katmai quadrangle, and portions of the Naknek, Afognak, and Iliamna quadrangles, Alaska.: United States Geological Survey.

Bailey, E. P., and Faust, N. H., 1984, Distribution and abudance of marine birds breeding between Amber and Kamishak Bays, Alaska, with notes on interactions with bears: Waterbirds, v. 15, p. 161-174.

Barsdate, R. J., and Dungdale, R. C., 1972, Effects of volcanic ashfalls on chemical and sediment characteristics of two Alaskan lakes: J. Fish. Res. Bd. Canada, v. 29, p. 229-236.

Beget, J. E., and Kowalik, Z., 2006, Confirmation and calibration of computer modeling of tsunamis produced by Augustine volcano, Alaska: Science of Tsunami Hazards, v. 24, no. 4, p. 257.

Bennett, A., Thompson, R., and Mortenson, D. C., 2006, Vital Signs Monitoring Plan: National Park Service Southwest Alaska Network. Anchorage, AK.

Bilby, R. E., Fransen, B. R., and Bisson, P. A., 1996, Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes Canadian Journal of Fisheries and Aquatic Sciences v. 53, p. 164-173.

Bograd, S. J., Stabeno, P. J., and Schumacher, J. D., 1994, A census of mesoscale eddies in Shelikof Strait, Alaska, during 1989: Journal of Geophysical Research, v. 99, p. 18,243-18,254.

Brabets, T. P., Nelson, G. L., Dorava, J. M., and Milner, A. M., 1999, Water-quality assessment of the Cook Inlet Basin, Alaska- environmental setting: U.S. Geological Survey.

Bricker, S. B., Clement, C. G., Pirhalla, D. E., Orlando, S. P., and Farrow, D. R. G., 1999, National Estuarine Eutrophication Assessment: Effects of nutrient enrichment in the nation's estuaries.

Brumbaugh, W. G., Krabbenhoft, D. P., Helsel, D. R., and Wiener, J. G., 2000, A national pilot study of mercury contamination of aquatic ecosystems along multiple gradients--bioaccumulation in fishes, *in* 21st annual meeting of the Society of Environmental Toxicology and Chemistry (SETAC), Nashville, TN, November 12-16, 2000.

Bryant, M. D., and Everest, F. H., 1998, Management and Condition of Watersheds in Southeast Alaska: The Persistence of Anadromous Salmon: Northwest Science, v. 72, no. 4, p. 249.

Burke, L., Kura, Y., Kassem, K., Revenga, C., Spaulding, M., and McAllister, D., 2000, Pilot Analysis of Global Ecosystems (PAGE): Coastal Ecosystems: World Resources Institute.

Burn, D. M., and Doroff, A. M., 2005, Decline in sea otter (Enhydra lutris) populations along the Alaska Peninsula, 1986-2001: Fishery Bulletin, v. 103, no. 2, p. 270-279.

Cahalane, V. H., 1959, A biological survey of Katmai National Monument: Smithsonian Miscellaneous Collections, v. 138, no. 5, p. 134.

Calkins, D. G., D. C. McAllister, K. W. Pitcher, and G. W. Pendleton, 1999, Steller sea lion status and trend in Southeast Alaska: 1979-1997: Marine Mammal Science v. 15, p. 462-477.

Cameron, W. A., and Larson, G. L., 1992, Baseline inventory of the aquatic resources of Aniakchak National Monument: National Park Service, Pacific Northwest Region.

-, 1993, Limnology of a caldera lake influenced by hydrothermal processes: Archives of Hydrobiology, v. 128, no. 1, p. 13-38.

Canadian Council of Ministers for the Environment, 1999, Canadian sediment quality guidelines for the protection of aquatic life-- Summary tables, *in* Canadian Council of Ministers of the Environment, ed., Canadian environmental quality guidelines: Winnipeg, Canada.

Carlson, M. L., and Lipkin, R., 2003, Alagnak Wild River and Katmai National Park Vascular Plant Inventory Annual Technical Report: National Park Service Alaska Region Inventory and Monitoring Program.

Cederholm, C. J., Kunze, M. D., Murota, T., and Sibatani, A., 1999, Pacific salmon carcasses: Essential contributions of nutrients and energy for aquatic and terrestrial ecosystems: Fisheries, v. 24, no. 10, p. 6-15.

Chaloner, D. T., and Wipfli, M. S., 2002, Influence of Decomposing Pacific Salmon Carcasses and Macroinvertebrate Growth and Standing Stock in Southeastern Alaska Streams: Journal of the North American Benthological Society, v. 21, no. 3, p. 430-442.

Chevron Corporation, 2006, Cook Inlet Pipeline & Terminal (website). http://www.chevron-pipeline.com/cookinlet.asp.

Christensen, J. R., MacDuffee, M., Macdonald, R. W., Whiticar, M., and Ross, P. S., 2005, Persistent organic pollutants in British Columbia grizzly bears: Consequence of divergent diets: Environmental Science and Technology, v. 39, no. 18, p. 6952-6960.

Christopher, S. J., S. S. Vander Pol, Pugh, R. S., Day, D., and Becker, P. R., 2002, Determination of mercury in the eggs of common murres (Uria aalge) for the seabird tissue archival and monitoring project: Journal of Analytical Atmoic Spectrometry v. 17, p. 780-785.

Church, S. E., Riehle, J. R., and Goldfarb, R. J., 1994, Interpretation of exploration geochemical data for the Mt. Katmai quadrangle and adjacent parts of the Afognak and Naknek quadrangles, Alaska. .

Clark, G. H., 1974, Prehistory of the Pacific coast of the Katmai National Monument, Alaska [Dissertation thesis]: University of Oregon, 343 p.

Clemens, J., and Norris, F. B., 1999, Building in an Ashen Land: Historical Resource Study of Katmai National Park and Preserve: Anchorage, AK.

Cook, J. A., and MacDonald, S. O., 2004, Mammal Inventory of Alaska's National Parks and Preserves: Katmai National Park and Preserve, Annual Report 2004: National Park Service: National Park Service.

Coombs, M., and Eichelberger, J., The 1953-1974 eruption of Mount Trident: return to business as usual for Katmai National Park's volcanoes, *in* Southwest Alaska Parks Science and Research Symposium.

Crawford, W. R., Cherniawsky, J. Y., and Foreman, M. G. G., 2000, Multi-year meanders and eddies in the Alaskan Stream as observed by TOPEX/Poseidon altimeter: Geophysical Research Letters, v. 27, no. 7, p. 1025-1028.

Crawford, W. R., Cherniawsky, J. Y., Foreman, M. G. G., and Gower, J. F. R., 2002, Formation of the Haida-1998 oceanic eddy: Journal Of Geophysical Research-Oceans, v. 107, no. C7.

Crowell, A. L., and Mann, D. H., 1996, Sea level dynamics, glaciers, and archeology along the central Gulf of Alaska coast: Arctic Anthropology, v. 33, no. 2, p. 16-37.

Crowell, A. L., Steffian, A. F., and Pullar, G. L., 2001, Looking both ways: hertiage and identity of the Alutiiq people: Fairbanks, Alaska, University of Alaska Press, 265 p.

Davis, W. C., Pol, S. S. V., Schantz, M. M., Long, S. E., Day, R. D., and Christopher., S. J., 2004, An accurate and sensitive method for the determination of methylmercury in biological specimens using GC-ICP-MS with solid phase microextraction: Journal of Analytical Atmoic Spectrometry v. 19, p. 1546-1551.

Day, R. D., Vander Pol, S. S., Christopher, S. J., Davis, W. C., Pugh, R. S., Simac, K., Roseneau, D. G., and Becker, P. R., 2006, Muure eggs (Uria aalge and Uria Iomvia) as indicators of mercury contamination in the Alaskan marine environment: Environmental Science and Technology, v. 40, no. 3, p. 659-665.

Densmore, R. V., McKee, P. C., and Roland, C., 2001, Exotic plants in Alaskan national park units: National Park Service.

Dewhurst, D. A., 1991, History and status of bald eagle population and productivity studies on the Alaska Peninsula, Alaska: U. S. Wildlife Service, King Salmon. 31p.

Dragoo, D. E., Byrd, G. V., and Irons, D. B., 2000, Breeding status and population trends of seabirds in Alaska in 1999: U. S. Wildlife Service, Report AMNWR 2000/02.
Dumond, D., 1979, People and Pumice on the Alaska Peninsula., *in* Grayson, S. a., ed., Volcanic activity and Human Ecology: New York, Academic Press, p. 373-392.
Dyurgerov, M. B., and Meier, M. F., 2000, Twentieth century climate change: Evidence from small glaciers: Proceedings of the National Academy of Science, v. 97, no. 4, p. 1406-1411.
Eichelberger, J. C., 1991, The Katmai Scientific Drilling Project, surface phase: investigation of an exceptional igneous system: Geophysical Research Letters, v. 18, no. 8, p. 1513-1516.
Eichelberger, J. C., Carrigan, C. R., Westrich, H. R., and Price, R. H., 1986, Non-explosive silicic volcanism: Nature, v. 323, p. 598-602.
Eichelberger, J. C., and Hildreth, W., 1986, Research drilling at Katmai, Alaska: EOS, v. 67, no. 41, p. 778-780.
Eichelberger, J. C., Neal, C. A., Paskievitch, J. F., Papike, J. J., and Hildreth, W., 1990, Geophysical expedition to Novarupta II, *in* Eichelberger, H., Papike, ed., Compilation of abstracts on the Katmai Drilling Project, USGS.
Eicher, G. J., and Rounsefell, G. A., 1957, Effects of lake fertilization by volcanic activity on abundance of salmon: Limnology and Oceanography, v. II, no. 2, p. 70-76.
Engstrom, D. R., and Swain, E. B., 1997, Recent declines in atmospheric mercury deposition in the upper midwest: Environmental Science and Technology, v. 31, p. 960-967.
EPA, 2002, Persistent Organic Pollutants: A Global Issue, A Global Response. Website: http://www.epa.gov/oiamount/toxics/pop.htm#pops, no. July 15, 2005.
-, 2006, Water Quality Criteria: http://www.epa.gov/waterscience/criteria/.
Ewald, G., Larsson, P., Linge, H., Okla, L., and Szarzi, N., 1998, Biotransport of organic pollutants to an inland Alaska lake by migrating sockeye salmon (O. nerka): Artic, v. 51, p. 40-47.
Fechhelm, R. G., Wilson, W., Griffiths, W., and Stables, T. B., 1999, Forage Fish Assessment in Cook Inlet Oil and Gas Development Areas, 1997-1998, *in* LGL Alaska Research Associates Inc., ed., Department of the Interior Minerals Management Service.
Fenner, C. N., 1920, The Katmai region, Alaska, and the Great Eruption of 1912: Journal of Geology, v. 28, no. 7, p. 569-606.
Fierstein, J., and Hildreth, W., 2000, Preliminary volcano-hazard assessment for the Katmai Volcanic cluster, Alaska: United States Geological Survey, 00-489.
Fitzgerald, W. F., Engstrom, D. R., Lamborg, C. H., and Balcom, P. H., 2006, 2006 Progress Report: Natural and anthropogenic sources of mercury to the atmosphere: Global and regional contributions: Submitted to: STAR Program, National Center for Environmental Reserach, Office of Research and Development, U.S. Environmental Protection Agency, Washington D.C.
Fitzgerald, W. F., Engstrom, D. R., Mason, R. P., and Nater, E. A., 1998, The case for atmospheric mercury contamination in remote areas: Environmental Science and Technology v. 32, p. 1-7.
Fountain, A. G., Schlicting, R. B., Jacobel, R. W., and Jansson, P., 2005, Fractures as main pathways of water flow in temperate glaciers: Nature, v. 433, p. 618-621.
Frenzel, S. A., 2000, Trace elements in streambed sediments and fish tissues, Cook Inlet Basin, Alaska: U.S. Geological Survey Water-Resources Investigations Report 00-4004, p. 46.

Frenzel, S. A., and Dorava, J. M., 1999, Water-quality data for the Talkeetna River and Four Streams in national parks, Cook Inlet Basin, Alaska, 1998: National Park Service, Open-File Report 99-459.
Fritz, L. W., and Stinchcomb, C., 2005, Aerial, ship and land-based surveys of Steller sea lions (*Eumetopias jubatus*) in the western stock in Alaska, June and July 2003 and 2004, *in* US Department of Commerce, ed., NOAA Tech. Memo, p. 56 pp.
Garshelis, D. L., 1997, Sea otter mortality estimated from carcasses collected after the Exxon Valdez oil spill: Conservation Biology, v. 11, no. 4, p. 905-916.
Garshelis, D. L., and Johnson, C. B., 2001, Sea otter population dynamics and the Exxon Valdez oil spill: disentangling the confounding effects: Journal of Applied Ecology, v. 38, no. 1, p. 19-35.
Gelatt, T., Trites, K., Pitcher, Hastings, K., and Jemison, L., 2004, Steller sea lion population trends, diet, and brand-resighting observations in Glacier Bay, *in* Glacier Bay Science Symposium, Juneau, AK.
Gende, S. M., Edwards, R. T., Willson, M. F., and Wipfli., M. S., 2002, Pacific salmon in aquatic and terretrial ecosystems: BioScience, v. 52, p. 917 - 926.
Gessner, B. D., 1996, Epidemiology of paralytic shellfish poisoning outbreaks in Alaska: Alaska's Marine Resources, v. 8, no. 2, p. 16-17.
Gessner, B. D., and Schloss, M., 1996, A population-based study of paralytic shell fish poisoning in Alaska: Alaska Medicine, v. 38, no. 2, p. 54-58.
Giles, J., 2004, Treaty calls time on long term pollutants. : Nature v. 247, p. 768.
Glass, R. L., Brabets, T. P., Frenzel, S. A., Whitman, M. S., and Ourso, R. T., 2001, Ground water quality in the Cook Inlet Basin Alaska, 1998-2001: USGS.
-, 2004, Water quality in the Cook Inlet Basin Alaska, 1998-2001: USGS.
Goatcher, B., 1993, Harbor seal (Phoca vitulina): National Park Service.
-, 1994, Sea otter (Enhydra lutris): National Park Service.
Goldman, C. R., 1960, Primary productivity and limiting factors in three lakes of the Alaska Peninsula: Ecological Monographs, v. 30, no. 2, p. 207-230.
Griggs, R. F., 1922, The Valley of Ten Thousand Smokes: Washington DC, National Geographic Society, 340 p.
-, 1933, The colonization of the Katmai ash, a new and inorganic "soil": American Journal of Botany, v. 20, no. 2, p. 92-113.
Gunther, A. J., 1992, A Chemical survey of remote lakes of the Alagnak and Naknek River Systems, southwest Alaska, USA. : Arctic and Alpine Reserch, v. 24, no. 1, p. 64-68.
Hall, D. K., 1988, Assessment of climate change using satellite technology: Reviews of Geophysics, v. 26, p. 26-39.
Hamilton, T. D., 1973, Geomorphic role of snow and ice during the Katmai 1912 eruption: Abstracts with Programs: Geological Society of America, v. 5, p. 48-49.
Hare, S. R., Mantua, N. J., and Francis, R. C., 1999, Inverse production regimes: Alaska and west coast Pacific salmon: Fisheries, v. 24, no. 1, p. 6-15.
Harper, J., 2003, 2003 aerial video imaging survey, Katmai National Park and Aniakchak National Preserve, Alaska (12-16, June 2003): Coastal & Ocean Resources INC.
-, 2004, ShoreZone mapping data, Katmai, Alaska - draft: Coastal & Ocean Resources Inc. and Archipelago Marine Research Ltd., for the National Park Service.

Harper, J., and Morris, M., 2005, The Katmai Coast: a guide to coastal biophysical features and ecological processes: Southwest Alaska Network, National Park Service. Report Number: NPS/AKRSWAN/NRTR-2005/03.

Heard, W. R., Wallace, R. L., and Hartman, W. L., 1969, Distributions of fishes in fresh water of Katmai National Monument, Alaska, and their zoogeographical implications: U. S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 590.

Helfield, J. M., and Naiman, R. J., 2002, Salmon and alder as nitrogen sources to riparian forests in a boreal Alaskan watershed: Oecologia, v. 133, no. 4, p. 573-582.

Hildreth, W., 1991, The timing of caldera collapse at Mount Katmai in repsonse to magma withdrawl toward Novarupta: Geophysical Research Letters, v. 18, no. 8, p. 1541-1544.

Hildreth, W., and Fierstein, J., 2000, Katmai volcanic cluster and the great eruption of 1912 GSA Bulletin, v. 112, no. 10, p. 1594-1620.

Hildreth, W., Fierstein, J., Lanphere, M. A., and Siems, D. F., 2000, Mount Mageik: A compound stratovolcano in Katmai National Park, *in* Kelley, K. D., and Gough, L. P., eds., Geologic studies in Alaska. U.S. Geological Survey Professional Paper 1615, U.S. Geological Survey, p. 23-41.

-, 2001a, Snowy Mountain: a pair of small andesite-dacite stratovolcanoes in Katmai National Park, *in* Gough, L. P., and Wilson, F. H., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1998: U.S. Geological Survey Professional Paper 1633, p. 13-34.

-, 2001b, Trident volcano: Four contiguous stratocones adjacent to Katmai Pass, Alaska Peninsula: US Geological Survey Professional Paper, v. 1678.

Hilton, M. R., 2000, Environment and Archaeology on the Upper Alaska Peninsula: Toward a Better Understanding of Human Ecology: National Park Service.

Hodge, R. P., 1976, Amphibians and Reptiles in Alaska, the Yukon, and the Northwest Territories.: Anchorage, AK, Alaska Northwest Publishing Co., 55 p.

Hood, D. W., and Zimmerman, S. T., 1986, Gulf of Alaska: Physical Environment and Biological Resources: Washington, D.C., NOAA Ocean Assessment Division, Alaska Office.

Hurley, J. P., Benoit, J. M., Babiarz, C. L., Shafer, M. M., Sullivan, J. R., Hammond, R., and Webb, D. A., 1995, Influences of watershed characteristics on mercury levels in Wisconsin rivers: Environmental Science and Technology, v. 29, no. 7, p. 1867-1875.

Hyland, J., Balthis, L., Karakassis, I., Magni, P., Petrov, A., Shine, J., Vestergaard, O., and Warwick, R., 2005, Organic carbon content of sediments as an indicator of stress in marine benthos: Marine Ecology Progress Series, v. 295, p. 91-103.

Incze, L. S., Kendall, A. W., Schumacher, J. D., and Reed, R. K., 1989, Interactions of a mesoscale patch of larval fish (Theragra chalcogramma) with the Alaska Coastal Current: Continental Shelf Research, v. 9, p. 269-284.

IPCC, 2001, IPCC Third Assessment Report-Climate Change 2001: The Scientific Basis.

Irvine, G. V., Mann, D. H., and Short, J. W., 1999, Multi-year persistence of oil mousse on high energy beaches distant from the Exxon Valdez spill origin: Marine Pollution Bulletin, v. 38, no. 7, p. 572-584.

-, 2000, Residual Oiling of Armored Beaches and Mussel Beds in the Gulf of Alaska. Restoration Project 00459 Draft Final Report: Exxon Valdez Oil Spill Trustee Council.

Johnson, K., 2002, Buried dreams: the rise and fall of the clam cannery on the Katmai coast: Anchorage, Alaska, National Park Service, 124 p.

Johnston, N. T., MacIsaac, E. A., Tschaplinski, P. J., and Hall, K. J., 2004, Effects of the abundance of spawning sockeye salmon (Oncorhynchus nerka) on nutrients and algal biomass in forested streams: Canadian Journal of Fisheries and Aquatic Sciences, v. 61, no. 3, p. 384-403.

Jones, T. M., Bennett, L., and Hamon, T. R., 2005, Baseline Inventory of Freshwater Fishes of the Southwest Alaska Inventory and Monitoring Network: Alagnak Wild River, Aniakchak NM and Preserve, Katmai NP and Preserve, Kenai Fjords NP, and Lake Clark NP: National Park Service.

Jope, K. L., 1985, Annual Resource Management Report, Katmai National Park and Preserve, 1985: National Park Service.

Kaler, R., Savage, S., and Leppold, A., 2003, Populations and productivity of seabirds on the Pacific coast of Becharof National Wildlife Refuge, Alaska Peninsula, Alaska June-September 2002: U. S. Fish and Wildlife Service.

Karl, T. R., and Trenberth., K. E., 2003, Modern global climate change: Science, v. 302, p. 1719-1723.

Kasameyer, P., Wilt, M., Daily, W., and Felske, D., 1991, Time-domain electromagnetic soundings in the vicinity of Novarupta, Katmai National Park, Alaska: Geophysical Research Letters, v. 18, no. 8, p. 1525-1528.

Kavanagh, R. C., 1989, Fisheries report - Kittiwake II - area surveyed - McNeil River to Cape Douglas - 4/15-22/89.: National Park Service.

Keith, T. E. C., Thompson, J. M., Hutchinson, R. A., and White, L. D., 1992, Geochemistry of waters in the Valley of Ten Thousand Smokes region, Alaska. : Journal of Volcanology and Geothermal Research, v. 49, p. 209-231.

Kienle, J., 1991, Depth of the ash flow deposit in the Valley of Ten Thousand Smokes, Katmai National Park, Alaska: Geophysical Research Letters, v. 18, no. 8, p. 1533-1536.

Kizzia, T., 1993, Shelikof grizzlies: Tourists discover Katmai coast, Anchorage Daily News: Anchorage, Alaska.

Kowalik, Z., and Murty, T. S., 1989, On some future tsunamis in the Pacific Ocean: Natural Hazards v. 1, p. 349-369.

Kozlowski, J., 2006, in preparation, Katmai National Park and Preserve and Alagnak Wild River Water Resources Managment Plan.

-, in preparation, Katmai National Park and Preserve and Alagnak Wild River Water Resources Managment Plan.

Krümmel, E. M., Macdonald, R. W., Kimpe, L. E., Gregory-Eaves, I., Demers, M. J., Smol, J. P., Finney, B., and Blais, J. M., 2003, Delivery of pollutants by spawning salmon: Nature, v. 425, p. 255-256.

Kucklick, J. R., Pol, S. S. V., Becker, P. R., Pugh, R. S., Simac, K., York, G. W., and Roseneau, D. G., 2002, Persistent organic pollutants in murre eggs from the Gulf of Alaska and Bering Sea.: Organohalogen Compounds v. 59, p. 13-16.

Lanctot, R., Goatcher, B., Scribner, K., and Talbot, S., 1999, Harlegquin duck recovery from the Exxon Valdez oil spill: a population genetics perspective: The Auk, v. 116, no. 3, p. 781-791.

LaPerriere, J. D., 1996, Water quality inventory and monitoring- Katmai National Park and Preserve: National Park Service.

LaPerriere, J. D., and Edmundson, J. A., 2000, Limnology of two lake systems of Katmai National Park and Preserve, Alaska: Part II. Light penetration and Secchi depth: Hydrobiologia, v. 418, p. 209-216.

LaPerriere, J. D., and Jones, J. R., 2002, Limnology of lakes in Katmai National Park and Preserve, Alaska: nutrients and plankton: Verh. Internat. Verein. Limnol., v. 28, p. 1010-1016.

Larson, G. L., 1989, Geographical distribution, morphology and water quality of caldera lakes: A review: Hydrobiologia, v. 171, p. 24-32.

Lawson, D. E., 1993, Glaciohydrologic and glaciohydraulic effects on runoff and sediment yield in glacierized basins, CREEL Monograph 93-2, 108 pp. p.

Lenz, J., Gotthardt, T., Kelly, M., and Lipkin, R., 2001, A bibliography of vascular plant and vertebrate species references for Katmai National Park and Preserve. A supplemental report to the Final Report- Compilation of Existing Species Data in Alaska's National Parks: Alaska Natural Heritage Program, For the National Park Service.

Lenz, J., Gotthardt, T., Lipkin, R., and Kelly, M., 2002, Final Report: Compilation of existing species data in Alaska's National Parks: Alaska Natural Heritage Program for National Park Service Inventory and Monitoring Program, Alaska Region.

Lindberg, S. E., Brooks, S., Lin, C.-J., Scott, K. J., Landis, M. S., Stevens, R. K., Goodsite, M., and Richter., A., 2002, Dynamic oxidation of gaseous mercury in the arctic troposphere at polar sunrise. : Environmental Science and Technology, v. 36, p. 1245-1256.

Litch, J. A., and Blackie, B. A., 1988, 1988 coastal seabird colony monitoring program-Katmai National Park and Preserve: National Park Service.

Lloyd, D. S., 1987, Turbidity as a water quality standard for salmonid habitats in Alaska: North American Journal of Fisheries Management, v. 7, p. 34-45.

Lloyd, D. S., Koenings, J. P., and LaPerriere, J. D., 1987, Effects of turbidity in fresh waters of Alaska: North American Journal of Fisheries Management, v. 7, p. 18-33.

Long, E. R., MacDonald, D. D., Smith, S. L., and Calder, F. D., 1995, Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. : Environmental Management, v. 19, no. 1, p. 81-97.

Lowell, R. P., and Keith, T. E. C., 1991, Chemical and thermal constraints on models of thermal springs Valley of Ten Thousand Smokes, Alaska: Geophysical Research Letters, v. 18, no. 8, p. 1553-1556.

Lu, J. Y., Schroeder, W. H., Barrie, L. A., Steffen, A., Welch, H. E., Martin, K., Lockhart, L., Hunt, R. V., Boila, G., and Richter, A., 2001, Magnification of atmospheric mercury deposition to polar regions in springtime: the link to tropospheric ozone depletion chemistry: Geophysical Research Letters v. 28, p. 3219-3222.

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

Manski, D., 1986, Spruce beetles in Katmai National park and Preserve: a survey of baseline conditions: National Park Service.

Martin, C. J., 1989, Inventory of coastal seabirds in Katmai National Park and Preserve during 1989: National Park Service.

Mauger, S., 2005, Lower Kenai Peninsula's salmon streams: annual water quality assessment: Homer Soil and Water Conservation District and Cook Inlet Keepers.

Meyer, J. L., and Pulliam, W. M., 1992, Modification of terrestrial-aquatic interactions by a changing climate, *in* Firth, P., and Fisher, S. G., eds., Global Climate Change and Freshwater Ecosystems: New York, Springer-Verlag, p. 177-191.

Miller, T. P., and Smith, R. L., 1987, Late Quaternary caldera-forming eruptions in the eastern Aleutian arc, Alaska: Geology, v. 15, p. 434-438.

Mitchell, N. L., and Lamberti, G. A., 2005, Responses in dissolved nutrients and epilithon abundance to spawning salmon in Southeast Alaska streams: Limnology and Oceanography v. 50, p. 217-227.

Molnia, B., and Sfraga, M., 1999, Measuring and monitoring changes in Alaska's glaciers with ground, aerial, and space photography: A history, *in* 50th Arctic Science Conference, Science in the North: 50 Years of Change, Denali National Park and Preserve, Alaska, p. 78-79.

Monz, C., 2005, Monitoring visitor use and associated impacts in the Southwest Alaska Network Parks: National Park Service, NPS/AKRSWAN/NRTR-2005/01.

Moran, S. C., 2003, Multiple seismogenic processes for high-frequency earthquakes at Katmai National Park, Alaska: evidence from stress tensors inversions of fault-plane solutions: Bulletin of Seismological Society of America, v. 93, no. 1, p. 94-108.

Moran, S. C., Paskievitch, J. F., Power, J. A., Tytgat, G., McNutt, S. R., and Estes, S., 2005, Seismicity from a decade of recordings by Alaska Volcano Observatory Seismic Networks in Alaskan national parks, *in* Southwest Alaska Parks Science and Research Symposium-Research abstracts.

Morris, M., 2005, Coastal ShoreZone Mapping of Katmai and Aniakchak, Presentation given at Southwest Alaska Network Science Symposium 2005. http://www.nature.nps.gov/im/units/swan/index.cfm?theme=science_symposium#Coastal

Motyka, R. J., 1977, Katmai caldera: glacier growth, lake rise, and geothermal activity: Short Notes On Alaskan Geology, v. Geologic Report 55, p. 17-21.

-, 1978, Surveillance of Katmai caldera and Crater Lake, Alaska : 1977 Final report. : University of Alaska, Geophysical Institute.

Motyka, R. J., Liss, S. A., Nye, C. J., and Moorman, M. A., 1993, Geothermal resources of the Aleutian Arc: Geological and Geophysical Surveys Professional Report v. 114, p. 17.

Muller, E. H., and Coulter, H. W., 1957, Incipient glacier development within Katmai caldera, Alaska: Journal of Glaciology, v. 3, no. 21, p. 13-17.

Mundy, P. R., and Olsson, P., 2005, Climate and Weather, *in* Mundy, P. R., ed., The Gulf of Alaska: Biology and Oceanography: Fairbanks, AK, Alaska Sea Grant College Program.

Murray, T. L., 2005, The case for studying volcanoes in Alaska and Alaskan National Parks, *in* Southwest Alaska Parks Science and Research Symposium-Research Abstracts.

Neal, C. A., 2005, Hazard assessments for Redoubt, Iliamna, Aniakchak, and the Katmai Volcanoes, *in* Southwest Alaska Parks Science and Research Symposium.

Neal, E. G., Walter, M. T., and Coffeen, C., 2002, Linking the Pacific Decadal Oscillation to seasonal stream discharge patterns in southeast Alaska: Journal of Hydrology, v. 263, p. 188-197.

Niebauer, H. J., 1988, Effects of El Nino-Southern Oscillation and North Pacific weather patterns on interannual variability in the subarctic Bering Sea: Journal of Geophysical Research, v. 93, p. 5051-5068.

Nishenko, S. P., and Jacob, K., 1990, Seismic potential of the Queen Charlotte-Alaska-Aleutian seismic zone: Journal of Geophysical Research, v. 95, no. B3, p. 2511-2532.
Norris, F. B., 1996, An Administrative History of the Katmai and Aniakchak NPS units, Alaska, http://www.nps.gov/katm/adhi/adhit.htm: Anchorage, Alaska, National Park Service, Alaska System support Office.
NPS, 1983, Fishery management plan: Katmai National Park and Preserve.
-, 1985, An assessment of management alternatives for Big River: National Park Service.
-, 1990, NPS 1989 Response, *Exxon Valdez* Oil Spill.: Alaska Regional Office. .
-, 1994, Draft coastal natural resources monitoring and management report, 1994: National Park Service.
-, 2001, Baseline water quality data inventory and analysis: Katmai National Park and Preserve and Alagnak Wild River: Technical Report NPS/NRWRD/NRTR-2000/258.
-, 2003, Glacier Bay National Park and Preserve, Alaska, Vessel Quotas and Operating Requirements Final Environmental Impact Statement: National Park Service, Alaska Region, United States Department of the Interior.
-, 2004a, NPSpecies Report Park-Fish Species List- Draft.
-, 2004b, NPSpecies Report Park-Mammals Species List- Draft

-, 2004c, NPSpecies Report Park-Vascular Plants Species List- Draft, p. 123.
-, 2005a, Preamble to the Superintendent's Compendium 2005. Katmai National Park and Preserve, Aniakchak National Monument and Preserve, Alagnak Wild River, p. 29.
-, 2005b, Strategic plan for Katmai National Park and Preserve, Aniakchak National Monument and Preserve, and Alagnak Wild River, p. 61.
-, 2005c, Western Airborn Contaminants Assessment Project: NPS Fact Sheet January 2005 Available at http://www2.nature.nps.gov/air/Studies/air_toxics/wacap.cfm, p. 4.
-, 2006a, Katmai National Park & Preserve, Nature & Science, Coasts/Shorelines: http://www.nps.gov/katm/pphtml/subnaturalfeatures10.html.
-, 2006b, Katmai National Park and Preserve, Nature & Science, Birds: http://www.nps.gov/katm/pphtml/subanimals2.html.
-, 2006c, Katmai National Park and Preserve, Nature & Science, Environmental Factors: http://www.nps.gov/katm/pphtml/subenvironmentalfactors14.html.
-, 2006d, Katmai National Park and Preserve, Nature & Science, Volcanoes/Lava Flows: http://www.nps.gov/katm/pphtml/subnaturalfeatures39.html.
-, 2007, Southwest Alaska Network Inventory and Monitoring Program: Glacial Extent Change. http://www.nature.nps.gov/im/units/swan/index.cfm?theme=glacial_extent. February 2007.
Nriagu, J. G., and Pacyna, J. M., 1988, Quantitative assessment of worldwide contamination of air, water, and soils with trace metals: Nature, v. 333, p. 134-139.
O'Keefe, T. C., 2005, Freshwater research and monitoring in Southwest Alaska: National Park Service.
O'Keefe, T. C., and Naiman, R. J., 2004, Aquatic monitoring of large lakes and rivers- a conceptual framework and process for making reasoned decisions: National Park Service.
Oswood, M. W., Milner, A. M., and Irons, J. G. I., 1992, Climate change and Alaskan rivers and streams, *in* Firth, P., and Fisher, S. G., eds., Global Climate Change and Freshwater Ecosystems: New York, Springer-Verlag, p. 192-210.

Overpeck, J., 1997, Arctic environmental change of the last four centuries: Science, v. 278, no. 5341, p. 1251-1256.
Pacyna, E. G., and Pacyna, J. M., 2002, Global emission of mercury from anthropogenic sources in 1995: Water, Air, and Soil Pollution, v. 137, p. 149-165.
Parson, E. A., Carter, L., Anderson, P., Wang, B., and Weller, G., 2000, Chapter 10: Potential Consequences of Climate Variability and Change for Alaska. , *in* Team, N. A. S., ed., U.S. national Assessment of the Potential Consequences of Climate Variability and Change, p. 283-312.
Peterson, C. H., Rice, S. D., Short, J. W., Esler, D., Bodkin, J. L., Ballachey, B. E., and Irons, D. B., 2003, Long-term ecosystem response to the Exxon Valdez oil spill: Science, v. 302, no. 5653, p. 2082-2086.
Piatt, J. F., and Ford, R. G., 1993, Distribution and abundance of Marbled Murrelets in Alaska: The Condor, v. 95, no. 3, p. 662-669.
Powell, J., D'Amore, D., Thompson, R., Brock, T., Huberth, P., Bigelow, B., and Walter, M. T., 2003, Functional HGM wetland assessment guidebook., State of Alaska Department of Environmental Conservation: Juneau, AK, State of Alaska Department of Environmental Conservation

Power, J. A., Moran, S. C., McNutt, S. R., Stihler, S. D., and Sanchez, J. J., 2005, Triggered seismicity beneath the Katmai volcanoes following the December 6, 1999 magnitude 7.0 Karluk Lake Earthquake, Alaska, *in* Southwest Alaska Parks Science and Research Symposium.
Prasil, R., 1971, Sea and coastline surveys : Katmai National Monument, Alaska, July 1969 through June 26, 1971.: National Park Service.
Prasil, R. G., and Blaisdell, J. A., 1968, Katmai coast sea mammal survey: National Park Service.
Prentki, R., 1997, Sediment Quality in Depositional Areas of Shelikof Strait and Outermost Cook Inlet: Year 1 Study Design and Preliminary Results, *in* Alaska OCS Region at the Watersheds ’97: Cook Inlet Symposium, Anchorage.
Rampino, M. R., and Self, S., 1984, Sulfur-rich volcanic eruptions and stratopsheric aerosols: Nature, v. 310, p. 677-679.
Reed, R. K., and Schumacher, J. D., 1986, Physical oceanography, *in* Hood, D. W., and Zimmerman, S. T., eds., The Gulf of Alaska: Physical Environment and Biological Resources: Washington, D.C., NOAA Ocean Assessment Division, Alaska Office, p. 57-75.
Reed, R. K., Schumacher, J. D., and Incze, L. S., 1987, Circulation in Shelikof Strait, Alaska: Journal of Physical Oceanography, v. 17, no. 9, p. 1546-1554.
Riordan, B., Verbyla, D., and McGuire, A. D., 2006, Shrinking ponds in subarctic Alaska based on 1950-2002 remotely sensed images: Journal of Geophysical Research, v. 111, p. G04002, doi:10.1029/2005JG000150.
Roots, E. F., 1989, Climate Change: High latitude regions: Climate Change, v. 15, p. 223-253.
Royer, T. C., 1998, Coastal Processes in the northern North Pacific, *in* Robinson, A. R., and Brink, K. H., eds., The Sea: NY, John Wiley and Sons, p. 395 - 414.
Saleeby, B. M., 2002, Out of place bones: beyond the study of prehistoric subsistence: Arctic Research of the United States, v. 16, p. 55-62.

Sarica, J., Amyot, M., Hare, L., Doyon, M.-R., and Stanfield, L. W., 2004, Salmon-derived mercury and nutrients in a Lake Ontario spawning stream: Limnology and Oceanography, v. 49, no. 4, p. 891-899.
Sattler, A. R., 1990, Operations plan for the Katmai drilling project: Sandia National Laboratories.
Saupe, S. M., Gendron, J., and Dasher, D., 2005, The condition of southcentral Alaska coastal bays and estuaries. A statistical summary for the National Coastal Assessment Program.
Savage, S., 2003, Pilot survey: waterbirds and sea mammals-Pacific coast, Alaska Peninsula, October 2003: National Park Service.
Savage, S., and Hodges, J., 2000, Bald eagle survey, Pacific coast of the Alaska Peninsula, Alaska: National Park Service.
Savage, S., Smith, T., and Dewhurst, D. A., 1993, Bald Eagle Nesting and Productivity, Katmai National Park and Preserve: National Park Service.
Schindler, D., 1999, From acid rain to toxic snow: Ambio, v. 28, p. 352-355.
Schoch, C., Leach, H., and Tear, L., 1990, General recommendations by Katmai Shoreline Assessment Team: National Park Service.
Schroeder, W. H., Anlauf, K. G., Barrie, L. A., Lu, J. Y., Steffen, A., Schneeberger, D. R., and Berg, T., 1998, Arctic springtime depletion of mercury: Nature, v. 394, p. 331-332.
Schroeder, W. H., and Munthe, J., 1998, Atmospheric mercury - An overview: Atmospheric Environment, v. 32, p. 809-822.
Schumacher, J. D., Stabeno, P. J., and Bograd, S. J., 1993, Characteristics of an eddy over the continental shelf: Shelikof Strait, Alaska: Journal of Geophysical Research, v. 98, p. 8,395-8,404.
Sease, J. L., and Loughlin, R. L., 1997, Status and population trends of Steller sea lions, *in* Stone, G., Goebel, J., and Webster, S., eds., Pinniped populations, eastern North Pacific: status, trends and issues. American Fisheries Society, Montery, CA., U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-122, Seattle, WA, p. 22-30.
Sellers, R. A., 2005, Population dynamics of a naturally regulated brown bear population on the coast of Katmai National Park, *in* Southwest Alaska Parks Science and Research Symposium.
Senkowsky, S., 2004, Fear of fish: The contaminant controversy: BioScience, v. 54, no. 11, p. 986-988.
Serreze, M. C., Walsh, J. E., F.S. Chapin III, Osterkamp, T., Dyergerov, M., Romanovsky, V., Oechel, W. C., Morison, J., Zhang, T., and Barry, R. G., 2000, Observational evidence of recent change in the northern high latitude environment: Climate Change, v. 46, p. 159-207.
Sinclair, A. F., and Crawford, W. R., 2005, Incorporating an environmental stock-recruitment relationship in the assessment of Pacific cod (Gadus macrocephalus): Fisheries Oceanography, v. 14, no. 2, p. 138-150.
Smith, T., 2005, Brown bears at Katmai National Park- 9 years of research investigations, *in* Southwest Alaska Parks Science and Research Symposium.
Sokolowski, 2006, The great Alaskan Earthquake and tsunamis of 1964, http://wcatwc.arh.noaa.gov/64quake.htm: Palmer, Alaska, West Coast & Alaska Tsunami Warning Center.

St.Louis, V. L., Rudd, J. W. M., Kelly, C. A., Beaty, K. G., Bloom, N. S., and Flett, R. J., 1994, Importance of wetlands as sources of methyl mercury to boreal forest ecosystems: Canadian Journal of Fisheries and Aquatic Sciences, v. 51, p. 1065-1076.

St.Louis, V. L., Rudd, J. W. M., Kelly, C. A., Beaty, K. G., Flett, R. J., and Roulet, N. P., 1996, Production and loss of methylmercury and loss of total mercury from boreal forest catchments containing different types of wetlands: Environmental Science and Technology, v. 30, p. 2719-2729.

Stabeno, P. J., Bond, N. A., Hermann, A. J., Kachel, N. B., Mordy, C. W., and Overland, J. E., 2004, Meteorology and oceanography of the Northern Gulf of Alaska: Continental Shelf Research, v. 24, no. 7-8, p. 859-897.

Starr, F., and Starr, P., 1991, Katmai National Park and Preserve Resource Management Plan: National Park Service, Alaska Region.

State of Alaska, 2006, Alaska Departments of Health & Social Services, Fish & Game, and Environmental Conservation News Release March 29, 2006: http://www.pandemicflu.alaska.gov/PDFs/pr32906avian-flu-briefing.pdf.

Stevens, D. L., Jr., and Olsen, A. R., 2004, Spatially balanced sampling of natural resources: Journal of the American Statistical Association, v. 99, p. 262-278.

Stevens, D. S. P., and Craw, P. A., 2004, Geologic hazards on and near the northern coast of the Alaska Peninsula, *in* Surveys, A. D. o. G. a. G., ed., State of Alaska Department of Natural Resources, p. 20.

Strand, A., and Hov, O., 1996, A model strategy for the simulation of chlorinated hydrocarbon distribution in the global environment. : Water, Air, Soil Pollution, v. 86, p. 283-316.

Sturm, M., Douglas, T., Racine, C., and Liston, G. E., 2005, Changing snow and shrub conditions affect albedo with global implications: Journal of Geophysical Research, v. 110, p. G01004, doi:10.1029/2005KG000013.

Sweeney, B. W., Jackson, J. K., Newbold, D., and Funk, D. H., 1992, Climate change and the life histories and biogeography of aquatic insects in eastern North America, *in* Firth, P., and Fisher, S. G., eds., Global Climate Change and Freshwater Ecosystems: New York, Springer-Verlag, p. 143-176.

Thompson, T. S., 2004, Oceanic and nearshore research and monitoring in northern Gulf of Alaska: National park Service, NPS/AKRSWAN/NRTR-2004/01.

U.S. Fish and Wildlife Service, and NPS, 2006, Birds of the Alaska Peninsula, Cape Douglas to Port Moller. : Jamestown, ND: Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/othrdata/chekbird/r7/akpenin.htm

Van Pelt, T. I., and Piatt, J. F., 2005, Population status of Kittlitz's Murrelet *Brachyramphus brevirostris* along the southern coast of the Alaska Peninsula, USGS Science Support Program, Final report for the U.S. Fish and Wildlife Service, USGS Alaska Science Center: Anchorage, Alaska, p. 63.

Vander Pol, S. S., Becker, P. R., Kucklick, J. R., Pugh, R. S., Roseneau, D. G., Simac, K., and York, G. W., 2002a, Trends in concentrations of persistent organic pollutants in eggs from Alaskan murre colonies *in* Second AMAP International Symposium on Environmental Pollution of the Arctic, Rovaniemi, Finland, October 1-4, 2002. Extended abstract 0-025. AMAP Report 2002.2, Arctic Monitoring and Assessment Program (AMAP), Oslo, Norway.

Vander Pol, S. S., Christopher, S. J., Day, R., Pugh, R. S., Becker, P. R., Roseneau, D. G., Simac, K., and York., G. W., 2002b, Trends in concentrations of mercury in eggs from

Alaskan murre colonies. , *in* Second AMAP International Symposium on Environmental Pollution of the Arctic, Rovaniemi, Finland, October 1-4, 2002. Extended abstract P-M40. AMAP Report 2002.2, Arctic Monitoring and Assessment Program (AMAP), Oslo, Norway.

Wania, F., and Mackay, D., 1996, Tracking the distribution of persistent organic pollutants: Environmental Science and Technology, v. 30, p. 390A-396A.

Ward, P. L., Pitt, A. M., and Endo, E., 1991, Seismic evidence for magma in the vicinity of Mt. Katmai, Alaska: Geophysical Research Letters, v. 18, no. 8, p. 1537-1540.

Waythomas, C. F., and Neal, C. A., 1998, Tsunami generation by pyroclastic flow during the 3500-year B.P. caldera-forming eruption of Aniakchak Volcano, Alaska: Bulletin of Volcanology, v. 60, p. 110-124.

Waythomas, C. F., and Watts, P., 2003, Numerical simulation of tsunami generation by pryoclastic flow at Aniakchak Volcano, Alaska: Geophysical Research Letters, v. 30, no. 14, p. 1751.

Weeks, D. P., 1999, Katmai National Park and Preserve Alaska water resources scoping report: National Park Service.

Weingartner, T., Danielson, J. S., and Royer, T. C., 2005, Freshwater variability and predictability in the Alaska Coastal Current: Deep-Sea Res II, v. 52, p. 169-191.

Weller, G., and Anderson, P. A., 1997, Implications of global change in Alaska and the Bering Sea region, Proceedings of a Workshop, June 3-6, 1997, Center for Global Change and Arctic System Research, University of Alaska Fairbanks.

Weller, G., Lynch, A., Osterkamp, T., and Wendler, G., 1997, Climate trends and scenarios, *in* Implications of Global Climate Change in Alaska and the Bering Sea Region: Proceedings of a Workshop, June 3-6, 1997, Center for Global Change and Arctic System Reserach, Univeristy of Alaska Fairbanks, Alaska.

Westrich, H. R., Eichelberger, J. C., and Hervig, R. L., 1991, Degassing of the 1912 Katmai magmas: Geophysical Research Letters, v. 18, no. 8, p. 1561-1564.

Williams, P., 1989, Adapting water resources management to global climate change: Climate Change, v. 15, no. 83-93.

Willson, M. F., Gende, S. M., and Marston, B. H., 1998, Fishes and the forest: expanding perspectives on fish-wildlife interactions: Bio Science, p. 445-462.

Wilson, J. G., and Overland, J. E., 1986, Meteorology, *in* Hood, D. W., and Zimmerman, S. T., eds., The Gulf of Alaska: Physical Environment and Biological Resources: Washington, D.C., NOAA Ocean Assessment Division, Alaska Office, p. 31-54.

Wipfli, M. S., Hudson, J., and Caouette, J., 1998, Influence of salmon carcasses on stream productivity: response of biofilm and benthic macroinvertebrates in southeastern Alaska, USA: Canadian Journal of Fisheries and Aquatic Sciences, v. 55, no. 6, p. 1503-1511.

Wolfe, D. A., Hameedi, M. J., Galt, J. A., Watabayashi, G., Short, J., O'Claire, C., Rice, S., Michel, J., Payne, J. R., Braddock, J., Hanna, S., and Sale, D., 1994, The fate of the oil spilled from the Exxon Valdez: Environmental Science & Technology, v. 28, no. 13, p. 560A-568A.

Zenone, C., 1970, Water-resources investigations at Katmai National Monument, Alaska: National Park Service.

Zhang, X., Naidu, A. S., Kelley, J. J., Jewett, S. C., Dasher, D., and Duffy, L. K., 2001, Baseline concentrations of total mercury and methylmercury in salmon returning via the Bering Sea (1999-2000): Marine Pollution Bulletin, v. 42, no. 10, p. 993-997.

Appendix A. Southwest Alaska Network vital signs in the context of the program-wide vital signs organization framework of the National Park Service. (Table 3-1 in SWAN Vital Signs Monitoring Plan, Bennett et al., 2006).

Level 1	Level 2	Level 3	SWAN Vital Sign	ALAG	ANIA	KATM	KEFJ	LACL
Air and Climate	Air Quality	Visibility and particulate matter	Visibility and particulate matter	-	●	-	-	●
	Weather and Climate	Weather and Climate	**Weather and Climate**	-	-	X	X	X
Geology and Soils	Geomorphology	Glacial features and processes	**Glacier Extent**	-	-	X	X	X
		Coastal / oceanographic features and processes	**Geomorphic coastal change**	-	-	X	X	X
	Subsurface Geologic Processes	Volcanic and Seismic Activity	Volcanic and Earthquake activity	●	●	●	●	●
Water	Hydrology	Surface water dynamics	**Surface hydrology**	X	X	X	X	X
	Water Quality	Water chemistry	Marine Water Chemistry			X	X	X
			Freshwater Chemistry	X	X	X	X	X
Biological Integrity	Invasive Species	Invasive/Exotic plants and animals	Invasive/Exotic plants	●	●	●	●	●
	Infestations and Disease	Insect pests	Insect outbreaks	-	-	●	●	●
	Focal Species or Communities	Marine communities	Kelp and eelgrass	-	-	X	X	X
		Marine invertebrates	Marine intertidal invertebrates	-	-	X	X	X
		Fishes	**ResidentLake Fish**	X	X	X	X	X
			Salmon	●	●	●	●	●
		Birds	**Black oystercatcher**	-	-	X	X	-
			Bald eagle	X	X	X	X	X
			Seabirds	-	-	X	X	X

Level 1	Level 2	Level 3	SWAN Vital Sign	ALAG	ANIA	KATM	KEFJ	LACL
		Mammals	**River otter (coastal)**	-	-	X	X	X
			Brown bear	X	X	X	-	X
			Wolf	X	X	X	X	X
			Wolverine	X	X	X	X	X
			Moose	X	X	X	-	X
			Caribou	●	●	●	-	●
			Sea otter	-	-	X	X	X
			Harbor seal	-	-	●	●	●
		Vegetation complex	**Vegetation Composition and Structure**	X	X	X	X	X
			Sensitive Vegetation Communities	X	X	X	X	X
Human use	Consumptive Use	Consumptive use	Resource harvest for subsistence and sport	●	●	●	-	●
	Visitor and Recreation Use	Visitor usage	Visitor use	●	●	●	●	●
Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land cover and use	**Land Cover/Land Use**	X	X	X	X	X
			Landscape Processes	X	X	X	X	X

X = Vital signs that the SWAN is working independently or jointly with a Network park, federal, state, or private partner to develop and implement monitoring protocols using funding from the vital signs or water quality monitoring programs

● Vital signs that are monitored independently of SWAN by a Network park, another NPS program, or another federal, state, or private agency. (category 2, information is obtained and used by SWAN)

- Vital sign will not be monitored in that park.

Appendix B. 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 ADFG (2002a).

Species	**Originally from…**	**Now located in…**	**Why it is a concern**
Fish:			
Northern Pike	Alaska	Spreading to other areas of Alaska	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.
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	Hydrilla is a noxious water weed that can quickly spread to become an impenetrable mat. Fills lakes and rivers completely until it

		Washington	"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 and Alaska Also found in Canada.	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 US including Alaska. Also found in Canada.	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
Salt marsh cordgrass	Eastern seaboard of the US from Maine to Texas	Has spread to Canada and western US includi 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 o bottom-dwelling algae, changes bottom-dwelling invertebrate populations, and loss o 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 slo the flow of water and increase sedimentation (raising the wetland).
Swollen bladderwort	Southeastern US	Western Washington	Grows in still or slow-moving water and forms dense beds of floating plants. Impacts native plants and animals and water quality.

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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