National Park Service
U.S. Department of the Interior

Water Resources Division
Natural Resource Program Center

Technical Report NPS/NRWRD/NRTR-2006/353

ASSESSMENT OF COASTAL WATER RESOURCES AND WATERSHED CONDITIONS AT GLACIER BAY NATIONAL PARK AND PRESERVE, ALASKA

Ginny Eckert, Eran Hood, Sonia Nagorski, and Carrie Talus





The National Park Service Water Resources Division is responsible for providing water resources management policy and guidelines, planning, technical assistance, training, and operational support to units of the National Park System. Program areas include water rights, water resources planning, marine resource management, regulatory guidance and review, hydrology, water quality, watershed management, watershed studies, and aquatic ecology.

Technical Reports

The National Park Service disseminates the results of biological, physical, and social research through the Natural Resources Technical Report Series. Natural resources inventories and monitoring activities, scientific literature reviews, bibliographies, and proceedings of technical workshops and conferences are also disseminated through this series.

Copies of this report are available from the following:

National Park Service (970) 225-3500
Water Resources Division
1201 Oak Ridge Drive, Suite 250
Fort Collins, CO 80525

National Park Service (303) 969-2130
Technical Information Center
Denver Service Center
P.O. Box 25287
Denver, CO 80225-0287

Cover photos:

Top left: Chad Soiseth
Top right: NPS photo
Bottom left: NPS photo
Bottom right: Cliff McCreedy
Bottom middle: Cliff McCreedy

Assessment of Coastal Water Resources and Watershed Conditions at Glacier Bay National Park and Preserve, Alaska

Dr. Ginny Eckert[1], Dr. Eran Hood[2], Dr. Sonia Nagorski[2], Ms. Carrie Talus[1]

Technical Report NPS/NRWRD/NRTR-2006/353

[1]Biology Program
[2]Environmental Science Program
University of Alaska Southeast
Juneau, AK 99801

July 2006

This report was prepared under Task Order J9W88 04 0016
of the Pacific Northwest Cooperative Ecosystem Studies Unit (agreement CA90880008)

WATER RESOURCES DIVISION

National Park Service - Department of the Interior
Fort Collins - Denver - Washington

TABLE OF CONTENTS

Executive Summary 9
A. Park Description 16
  A1. Background 16
    A1a. Setting 16
    A1b. History and Human Utilization 19
  A2. Hydrologic Information 22
    A2a. Climatic Setting 22
    A2b. Streamflow 23
    A2c. Water Resources 24
    A2d. Oceanography 34
  A3. Biological Resources 40
    A3a. Marine 40
    A3b. Intertidal 46
    A3c. Upland 49
    A3d. Freshwater 50
B. Water Resources Assessment 52
  B1. Water Quality 52
    B1a. Surface Water 56
    B1b. Groundwater 60
    B1c. Lakes 61
    B1d. Precipitation 61
  B2. Water Quality Impairments 62
    B2a. Ptarmigan Creek 62
    B2b. Bartlett Cove 62
    B2c. Kahtaheena River (Falls Creek) 65
    B2d. Alsek River and Dry Bay 66
  B3. Pollutants 69
    B3a. Point Source 69
    B3b. Nonpoint Source Pollutants 73
C. Other Areas of Concern 77
  C1. Marine Vessel Impacts on Water Quality 77
  C2. Harmful Algal Blooms 78
  C3. Invasive or Nuisance Species 79
  C4. Future Development 80
    C4a. Brady Mining Claim 80
  C5. Physical impacts 81
    C5a. Land Surface Uplift 81
    C5b. Landslide-induced Wave Hazards in Tidal Inlet 84
    C5c. Glacial Outburst Floods 85
  C6. Climate Change 86
D. Recommendations 91
  D1. Condition overview 91
  D2. Recommendations 92
    D2a. Data access/management 93

D2b. Water quality 93
D2c. Biological resources and habitats 94
D2d. Hydrology/Oceanography 95
References Cited 97
Appendices 118

List of Figures

Figure 1. Southeast Alaska National Parks 16
Figure 2. Boundaries and major features of GLBA. 17
Figure 3. Landsat TM image of Glacier Bay (1 August 1999) 19
Figure 4. Areas designated for commercial fishing, as of July, 2004. 21
Figure 5. Mean monthly temperature and precipitation in Bartlett Cove 22
Figure 6. Location of climate stations in Cold Regions Research and Engineering Lab meteorological network. 23
Figure 7. Location of the two USGS Hydrologic Units contained within GLBA boundaries. 24
Figure 8. Location of active stream gages on the Alsek and Kahtaheena Rivers. 25
Figure 9. Mean daily streamflow of the Alsek River stream gage 26
Figure 10. Location of major rivers and streams in the western portion of GLBA. 27
Figure 11. Location of major rivers and streams in the eastern portion of GLBA. 28
Figure 12. Glacial ice ephemeral pond on remnant of the Fairweather Glacier. 30
Figure 13. Location of major glaciers in the western portion of GLBA. 32
Figure 14. Location of major glaciers in the eastern portion of GLBA. 33
Figure 15. Wetland areas in and around GLBA 35
Figure 16. USGS Oceanographic monitoring stations. 37
Figure 17. A. Temperature (ºC) and B. chlorophyll a (µg per L) in late June and July 2004 39
Figure 18. Humpback whale distribution and abundance in Glacier Bay in 2004 41
Figure 19. Number of individual whales in Glacier Bay and Icy Strait, 1985-2004 41
Figure 20. Harbor seal population decline in GLBA. 43
Figure 21. Distribution and abundance of sea otters in lower Glacier Bay 44
Figure 22. Biomass (g dry wt) of clams per 0.25 m^2 in GLBA 46
Figure 23. Locations of sites in intertidal monitoring program. 48
Figure 24. Sample distribution maps from the Coastal Resources Inventory and Mapping Program 49
Figure 25 Offshore kelp distribution (left) and locations where streams are present (right) From Sharman et al. (2003) 49
Figure 26. Location and chronosequence of glacial retreat along the east arm of Glacier Bay ... 50
Figure 27. Turbidity increases with discharge on the Alsek River 59
Figure 28. Dixon Harbor. 60
Figure 29. Park headquarters, housing and visitor facilities are based in Bartlett Cove. 65
Figure 30. Designated ATV trails near the mouth of the Alsek River in the Dry Bay preserve. The use of ATVs for commercial fishing purposes is allowed inside the boundary of the designated Temporary Fish Camp Zone identified on the map. Source NPS (2006b). ... 68
Figure 31. Geographic Response Strategies for zone 6 of Southeast Alaska. 70
Figure 32. Hg accumulation rates for individual lake sediment strata 74

Figure 33. Mean values (±1 standard error bar) of primary POPs in murre *(Uria spp.)* eggs...... 75
Figure 34. *Alexandrium* sp.,.. 79
Figure 35. Location of PSP outbreaks 79
Figure 36. Land surface uplift rates in southeast Alaska from GPS measurements.................... 83
Figure 37. Relative sea level change (m) in southeastern Alaska near GLBA............................ 83
Figure 38. Location of Tidal Inlet in GLBA.. 84
Figure 39. Detached landslide mass perched above the northern shore of Tidal Inlet................ 85
Figure 40. Abyss Lake in August 2002. This image clearly shows the "bathub ring" indicator of previous higher lake levels. Photo provided by Bill Eichenlaub, NPS-GLBA. 86
Figure 41. Glacier Bay ice field reconstruction... 87
Figure 42. Changes in glacier ice thickness in GLBA since 1750.. 88
Figure 43. Current rates of glacier ice thinning in southeastern Alaska as measured by laser altimetry. FWF depicts the location of the Fairweather Fault. 89

List of Tables

Table 1. Water quality on the Alsek River 58
Table 2. Chemical concentration of bed sediments (<2 mm) and suspended sediment 59
Table 3. Analytical concentration of samples in the Burroughs Glacier area. 61
Table 5. Presence of fish in the vicinity of the Falls Creek Hydroelectric Project....................... 66
Table 6. Potential for impairment of GLBA water resources... 91
Table 7. List of recommendations. 92

List of Appendices

Appendix 1. Species list of fishes for GLBA 118
Appendix 2. List of birds observed in GLBA during Robards et al. (2003) surveys. 121
Appendix 3. Selected water quality standards for the State of Alaska (ADEC 2003).............. 123
Appendix 4. Non-indigenous invasive species that have invaded or could soon invade Alaska. 126

Acknowledgements

We would like to thank numerous people for their help in the preparation of this report. Chad Soiseth, Susan Boudreau, Bill Eichenlaub, Lewis Sharman, Arch Thompson, Mark Foster, Jim Capra and other GLBA staff were very helpful and provided information about the park. Other agency personnel provided useful information, including Lisa Eisner, NOAA; Mayumi Armitsu & Gail Irvine, USGS; Jim Gendron & Barbara Smith, ADEC; Wilf Schofield, UBC; Tara Martich & Elizabeth Kim, US EPA; Edward Neal, USGS. Mark Flora, Chad Soiseth, Chuck Young, David Nemeth, Whitney Rapp, Janet Neilson, Susan Boudreau, Barry Long, Chuck Pettee, Cliff McCreedy, and Kristen Keteles provided extensive comments on the draft report, which improved the final product. Edwin Knuth at UAS created original maps for the report.

Commonly used abbreviations

ADEC – Alaska Department of Environmental Conservation
ADFG – Alaska Department of Fish and Game
ADNR – Alaska Department of Natural Resources
ANILCA – Alaska National Interest Land Conservation Act
EMAP – Environmental Monitoring and Assessment Program (of the US Environmental Protection Agency)
EPA – US Environmental Protection Agency
GOA – Gulf of Alaska
GLBA – Glacier Bay National Park and Preserve (National Park Service Designation)
HAB – Harmful Algal Bloom
LIA – Little Ice Age
NADP – National Atmospheric Deposition Program
NOAA – National Oceanic and Atmospheric Administration (US Department of Commerce)
NPDES – National Pollutant Discharge Elimination System (of the US Environmental Protection Agency)
NPS – National Park Service (US Department of Interior)
NWI – National Wetlands Inventory (of the US Fish and Wildlife Service)
POPs – Persistent Organic Pollutants
PSP – Paralytic Shellfish Poisoning
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)

Executive Summary

The purpose of this report is to provide a comprehensive inventory and assessment of the current condition and possible impairments, both natural and anthropogenic, of water resources in the coastal region of Glacier Bay National Park and Preserve (GLBA), based on currently available data and information. In addition, the report identifies gaps in data and information that hinder the assessment of water resources and provides recommendations for future monitoring and mapping of coastal water resources. The diversity and quality of freshwater and marine habitats affects plants and animals and provides aesthetic and recreational opportunities for park users.

Currently, the coastal watersheds in GLBA are more affected by natural changes than by anthropogenic impacts. However, it is important to understand current and historical impacts to water quality, since it is possible that there will be increased anthropogenic impacts in the future in areas such as Gustavus and Dry Bay. Our consensus is that the quality of both the fresh and marine waters of GLBA is in good condition. Many of the past events that have affected water quality in GLBA have been remediated and regularly monitored and are no longer an issue today.

GLBA is located in northern Southeast Alaska and is bordered by the Pacific Ocean to the west, Icy Strait to the south, Tongass National Forest to the west and northwest, Tatshenshini-Alsek Provincial Park (Canada) to the north, and Tongass National Forest to the northeast. Glaciers have been carving the park for more than seven million years, and today approximately 27 percent (356,136 ha [880,000 acres]) of GLBA is covered by glacial ice. In 1794, Captain George Vancouver documented that Glacier Bay was only 5 miles long due to a massive glacier occupying the bay with its terminus located just south of Sitakaday Narrows. At that time, this large glacier, which is now called the Grand Pacific Glacier, measured more than 1,200 m (4,000 ft) thick, 32 km (20 mi) wide, and more than 161 km (100 mi) long. By 1916, the Grand Pacific Glacier had retreated 100 km (60 mi) to the present Tarr Inlet. This dramatic glacial retreat provides an outstanding opportunity to study glacial retreat, ecological succession, the effects of climate change, and other physical and biological dynamics of the area. Glacial retreat has caused and is continuing to cause tremendous physical changes to GLBA, and as a result, its freshwater and marine ecosystems are dynamic and challenging to understand.

On February 26, 1925, President Calvin Coolidge created Glacier Bay National Monument to preserve the majestic beauty and scientific opportunities. The area of the Monument doubled in size in 1936, and the boundaries were modified in 1955, excluding Gustavus and the east side of Excursion Inlet. Gold mining was permitted from 1936 until 1976. Glacier Bay became a National Park through the Alaska National Interest Lands Conservation Act (ANILCA) of 1980, which extended the park boundary to the Alsek River and Dry Bay for a total area of over 1.33 million ha (3.28 million acres) including 23,426 ha (57,884 acre) in the preserve. We use the term GLBA hereafter to indicate the entire park and preserve. GLBA was designated an International Biosphere Reserve in 1986 and a World Heritage Site in 1992. In 2005, the National Park Service won a Supreme Court case filed by the State of Alaska, resulting in NPS jurisdiction over submerged lands and tidelands within GLBA boundaries. This decision made GLBA one of the few protected areas in the world that includes submerged marine habitat within its jurisdiction.

Climate in fall, winter, and spring is dominated by the strong Aleutian Low in the northern Gulf of Alaska and by weak high pressure systems in the summer. As a result, GLBA experiences a wet and moderate marine climate. Records from the only NOAA weather station located within GLBA, at Bartlett Cove, has records going back to 1966 and shows an average temperature of 4.9ºC (40.9ºF), average rainfall of 92 cm (36 in), and average snowfall of 132 cm (52 in). July is the warmest month with an average temperature of 12.8ºC (55 ºF), and the coolest conditions occur in January, when the average temperature is -2.8ºC (27 ºF). Given the geographic and topographic heterogeneity within GLBA, data from this weather station does not represent the diversity of conditions within GLBA.

Freshwater resources in GLBA are vast and dynamic, poorly understood, and include: rivers and streams, lakes and ponds, snow and glaciers, wetlands, frost (which includes seasonal ground ice and permafrost), and groundwater. The majority of GLBA streams are relatively short (<20 km [12 mi]) and steep (average gradient 5-20%), and occur in small catchments (1-100 km^2 [0.38-38 mi^2]). For many streams in GLBA, variations in discharge are dominated by snowmelt and precipitation events. High precipitation combined with peak glacier melting result in maximal freshwater discharge during autumn. Freshwater lakes and ponds are typical features of recently deglaciated landscapes and, as a result, are abundant in GLBA. Two notable freshwater systems in GLBA are glacial ice ephemeral ponds and glacier-dammed lakes. Glacial ice is the dominant landform in GLBA, and covers approximately 27 percent of GLBA. Most of the glaciers have been retreating since the end of the Little Ice Age ~250 years ago, which opened the inlets and bays, including Glacier Bay, that characterize GLBA. The majority of wetlands in Glacier Bay are coastal intertidal wetlands and palustrine and riverine wetlands located along valley bottoms. Groundwater systems in glacial outwash deposits are characterized by broad, extensive systems that are well connected through highly conductive sands and gravels. In contrast, till deposits and lenses of fine-grained clays may produce perched aquifers and regions of low hydraulic conductivity. Groundwater flow in the steep, high mountainous areas of GLBA is likely limited to relatively shallow soil zones and fraction flow through faults and fissures in the bedrock.

GLBA encompasses marine areas along the outer coast, Cross Sound, Icy Strait, Glacier Bay, and smaller bays including Dundas Bay, Lituya Bay, Torch Bay and Dry Bay. Multiple sills, embayments, tidewater glaciers, islands and other topographic features characterize Glacier Bay’s complex bathymetry. Glacier Bay has mixed semi-diurnal tides and a large tidal range, averaging 3.7 m (12 ft) near the mouth to greater than 4.2 m (14 ft) at the heads.

Since 1992, the National Park Service (NPS) and US Geological Survey (USGS) have monitored physical conditions, including temperature, salinity, turbidity, photosynthetically active radiation (PAR), and in situ fluorometric measurements at 24 stations distributed throughout the Bay. Salinities range from 8 to 31.9, with least saline waters found in narrow surface lenses near tidewater glaciers, and the most saline were found at depth near the mouth of the Bay. Density fluctuations are primarily driven by salinity. Sea water temperatures range from 1.9 to 12.2 ºC (35 to 54 ºF), with the coldest temperatures at the heads of the two arms and the warmest observed near the mouth. Light penetration is reduced by sedimentation resulting from glacial runoff and by increases in phytoplankton biomass. The factors driving reductions in light penetration are important to understand because the amount of light available impacts phytoplankton production. Zooplankton surveys indicate rich productivity in a variety of locations within Glacier Bay, particularly in upper inlets with and without tidewater glaciers and near river and stream outlets.

Biological marine resources include a rich diversity and high abundance of marine mammals, including humpback whales (*Megaptera novaeangliae*), killer whales (*Orcinus orca*), harbor seals (*Phoca vitulina*), Steller sea lions (*Eumetopias jubatus*), sea otters (*Enhydra lutris*), harbor porpoise (*Phocoena phocoena*), minke whales (*Balaenoptera acutorostrata*), and rarely Dall's porpoises (*Phocoenoides dalli*). Since monitoring began in the mid-1980s there has been inter-annual variability in the number of humpback whales documented in Glacier Bay, but in general the population is increasing.. Harbor seals, however, have undergone a drastic decline, up to 10% per year on average from 1992-2002. Sea otters have undergone a dramatic increase since they began recolonizing Glacier Bay in 1993, with over 1200 individuals recorded in 2002.

Fish and bird diversity in GLBA are very high. Glacier Bay is an important nursery area for fishes and is probably a spawning location for many species. Glacier Bay provides important habitat for many marine birds, with species composition shifting from predominantly seabirds in the summer to predominantly waterfowl in the winter. Some species of marine birds have been declining in Glacier Bay, including Kittlitz's and marbled murrelets, which have been declining throughout Alaska. Marine invertebrate resources are diverse and include Tanner (*Chionoecetes bairdi*), Dungeness (*Cancer magister*), and king crabs (*Paralithodes* spp.), which are abundant and either were or still are commercially fished in GLBA.

An intertidal monitoring program was established by USGS and NPS in 1997 in recognition of the potential for natural and human-induced changes to intertidal communities. Twenty-five intertidal segments of bedrock and/or cobble/boulder substrates were sampled four times over a five year spread (1997-1999, 2001). ShoreZone is a project sponsored by multiple agencies and organizations that conducted aerial surveys of the outer coast of GLBA in 2005 and surveyed other areas of Southeast Alaska in 2004-2005. This project aerially surveyed intertidal and shallow subtidal areas to identify shoreline morphology, substrate, wave exposure, and biota of intertidal and nearshore habitats. The National Park Service implemented a predecessor to ShoreZone, called the Coastal Resources Inventory and Mapping Program, which collected baseline data on over 1545 km (960 mi) of intertidal coast in GLBA. The area inventoried and mapped includes the continuous shoreline from Taylor Bay to the Park boundary in Excursion Inlet, including all of Glacier Bay proper and Dundas Bay, plus the shoreline of Lituya Bay, Dixon Harbor, Torch Bay, Graves Harbor, and Dicks Arm, including all islands within the Park in these areas. This protocol and its resulting GIS layers are used to collect, analyze, and display biological and physical shoreline data.

Glacier Bay is well known as a natural laboratory, and starting with John Muir and William S. Cooper, classic studies of ecological succession began in the late 1800s and early 1900s. Vegetation changes along the gradient of glacier recession are well-documented and are textbook examples of ecological succession. In streams, the successional development of plant and animal communities is closely connected with the growth and maturation of adjacent terrestrial plant communities. Stream invertebrates colonize streams after dissolved organic carbon inputs by colonizing stream bank vegetation reach adequate levels. As plant succession continues, woody debris may accumulate in streams, providing shelter for fish and promoting the colonization by anadromous salmonids. Amphibians are rare in GLBA, and only the western toad (*Bufo boreas*) has been inventoried in GLBA, although the northwestern salamander and wood frog have each been spotted once.

Water quality within GLBA has been studied in few locations and with little temporal consistency. Based on these limited data sources, water quality in GLBA is generally considered to be of high quality and conforms to state and federal water quality standards, with only minimal and highly localized areas of impairment. Water quality studies, some quite dated, have been conducted in Alder Creek, Wolf Creek, tributary to Wolf Creek, Sandy Cove Creek, Alsek River, East Alsek River, Berg Bay South and Berg Bay North streams, Wolf Point Creek, Ice Valley, Nunatak Creek, Dundas River, Old Dundas River, Dog Salmon River, Reid Stream, Ptarmigan Creek, Justice Creek, Echo Creek, Steelhead Creek, Topsy Creek, Crillon River, Dagelet Rivers, and the Kahtaheena River. High turbidity values have been identified in glacial streams such as the Alsek River and Wolf Point Creek, but they are products of natural processes relating to glacial melt. The water quality studies conducted in GLBA to date provide valuable baseline data. However the available studies lack the spatial and temporal resolution, and in some cases appropriate quality assurance and quality control procedures, to allow for conclusive evaluation of water quality condition in the park.

There are no 303d impaired water bodies in GLBA. Current and potential sources of impairments to water quality in GLBA include mining claims and historic mining pollution; development of human facilities and associated fuel spills, sewage, and other waste pollution; construction of a hydroelectric facility; and degradation of streams by all-terrain vehicle (ATV) use. Sampling in Ptarmigan Creek in 1984 found high concentrations of lead and cadmium at this historic site of a gold mine that was active from 1938 to 1945. No recent water quality sampling of this region is available. Bartlett Cove is the major site of human interaction in GLBA and the only location in the park that is human-occupied year-round. Groundwater was contaminated in 1989 by a leaking underground heating oil storage tank. The leaking tank has been replaced, all existing tanks have been upgraded, and based on limited data from only 3 monitoring wells, the contamination is unlikely impacting nearby surface waters.

In March 2006, the State of Alaska and the NPS traded GLBA land to allow for the construction of a hydroelectric facility that will serve the town of Gustavus, which currently relies on expensive diesel power generation. NPS traded 418 ha (1,034 acres) along the Kahtaheena River (also known as Falls Creek) in exchange for 421 ha (1,040 acres) of land along the Chilkoot Trail in Klodike Gold Rush National Historic Park (KLGO). In order to offset the loss of federal wilderness in the NPS system, the NPS also gained federal wilderness protection of an unnamed small island in Blue Mouse Cove and of Cenotaph Island in Lituya Bay. Discrepancies in land values cost the NPS $66,000, which was paid to the State of Alaska. Within days of the trade agreement, construction of the $5 million, 800- kilowatt project began.

All-terrain vehicles (ATVs) in the Dry Bay fish camp area on the lower Alsek River could potentially impact water quality in this region. These ATVs are allowed, with restrictions, to access commercial and subsistence fishing in a designated “Temporary Fish Camp Zone” located near the lower East Alsek River, from Alsek Lake to the Dry Bay estuary. However, NPS staff have noted that users have failed to limit their traffic to existing trails, and new ATV tracks cross numerous streams and other sensitive habitats. When impacted areas are sandy, gravelly, and/or unvegetated, the impact may be ephemeral; however, impacts in grasslands, forests, and wetlands are likely persistent.

Petroleum spills present a clear environmental risk to coastal water resources in GLBA. Currently, Geographic Response Strategies (GRS), which are spill response plans tailored by ADEC and other agencies to protect specific sensitive areas from oil impacts following a spill. Specific areas within the park for which GRS exist include Pt. Carolus, Bartlett Cove, Berg Bay, Hugh Miller Inlet, N Beardslee Island, S Marble Island, and Sandy Cove.

Human waste is a point source pollutant when not treated properly. The Bartlett Cove waste treatment plant, operated by the NPS, provides secondary waste treatment that is discharged into the deep waters of Bartlett Cove approximately 30-40 m (33-43 yds) seaward from low tide. Overall, the waste treatment facility appears to have minimal impact on water quality in Bartlett Cove.

Gustavus lacks municipal sewage waste treatment, and private sewage waste treatment systems range from outhouses, composting toilets, cesspools, and septic tanks with leach fields. The high elevation of the water table in Gustavus renders it susceptible to contamination from surface and near-surface sources. Backcountry use in GLBA has not generated human sewage problems, except along the Alsek River. All river rafters are now required to collect and pack out all human waste. In 2004 the NPS built a new human waste dump station at the Alsek River rafter take-out area and installed a septic system at the ranger station because of the failure of the previous dump station and ranger station outhouse to meet ADEC standards. This improvement is expected to prevent any future coliform contamination in the area and along the Alsek River.

GLBA, like many pristine high-latitude areas, is currently at risk from atmospherically derived contaminants. Mercury (Hg) and a group of chemicals known as Persistent Organic Pollutants (POPs) are the two primary contaminants of concern for Alaska. Sediment cores collected in GLBA indicate that rates of mercury deposition in the area have been rising consistently since the Industrial Revolution. In addition, a study of sea bird eggs in the Gulf of Alaska found elevated levels of POPs. These contaminants may also enter the freshwater and terrestrial environments via biological vectors. As salmon grow (≥95% of their biomass is developed in the marine environment), they incorporate marine contaminants such as Hg and POPs and transport them into watersheds where they spawn. 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 the Gulf of Alaska, with GLBA as no exception. However, atmospheric deposition of these contaminants and their import into watersheds by anadromous fishes are not being measured in GLBA or its vicinity.

Harmful algal blooms (HABs) are known to cause paralytic shellfish poisoning (PSP) and Alaska has one of the highest incidences of reported PSP in the world. Since 1973, there have been 176 incidences of PSP in Alaska from 66 outbreaks, with the majority in Southeast Alaska. Little is known about the distribution or abundance of PSPs in coastal areas of GLBA. The Alaska Department of Environmental Conservation (ADEC) is responsible for testing shellfish for PSP, however shellfish are only tested for PSP in association with a commercial harvest or mariculture facility. More information is needed in order to evaluate if HABs are an issue of concern in GLBA, and any unusual incidences of mass mortalities of marine bird, mammal, and fish populations should be suspected as possible HAB-related events.

Non-indigenous aquatic invasive species that have been introduced or are moving into Alaskan waters include multiple species of fish, plants, and invertebrates. Pathways of introduction that could affect GLBA include: fish farms or other aquaculture, transport on or in ballast water from ships or fishing vessels, live seafood or aquarium trade, and sport fishing gear. There has not been a comprehensive survey of aquatic invasive species in GLBA, although inventories of a few groups, including fishes, have not detected any persistent reproducing populations.

The number of people who visit and reside in the Glacier Bay region is growing each year. This increase in human presence means there will need to be a corresponding increase in support infrastructure. With increasing visitation to GLBA, Bartlett Cove will likely need improvements in visitor accommodations, utilities, Park housing and concessions, and Park administrative and science facilities. Relatad growth in Gustavus and Excursion Inlet may spur an increase in development and roads in these areas. Already, hundreds of miles of logging roads have been built through nearly every watershed on northeast Chichagof Island and south of Excursion Inlet during the last two decades. Another future development issue includes the possibility of the Brady Mine operation proceeding. In addition, it is possible, but not likely, that logging and development may occur in any of the private land holdings in GLBA. Any such future development is likely to become an important resource management issue for GLBA.

Hazards associated with natural hydrological processes are found throughout GLBA. Potential hazards include: outburst floods, landslides, land surface uplift (isostatic rebound), snow avalanches, advancing glacial systems, and seismic activity. Of these hazards, landslides, seismic activity, and isostatic rebound present relatively well documented threats to coastal water resources. Current rates of land surface uplift in southeastern Alaska are among the highest ever recorded. GPS measurements have recorded rebound rates of up to 28 mm (1.1 in) per year in Glacier Bay. This uplift will change shorelines and intertidal communities and alter the hydrology of coastal streams and lakes.

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. 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, which in turn will influence vegetation dynamics and ecosystem community composition. Currently, glaciers in coastal GLBA are thinning at rates as high as 4 m (13 ft) per year. An important hydrologic effect of increased glacier melt is an increase in runoff from glaciers, which can lead to the creation of new streams, and alter sediment, streamflow, and temperature regimes in surrounding streams. Climate warming may impact the hydrology of terrestrial systems in GLBA by causing areas of permafrost to thaw and dry out. Increasing air temperatures also have the potential to impact waterbodies such as high-altitude muskeg ponds and glacier-dammed lakes. The effects of climate change on the chemistry of lakes and streams are unknown.

Specific recommendations for management and monitoring of both freshwater and marine water resources in GLBA are provided in Table i and detailed in *D. Recommendations*.

Table i. Potential for impairment of GLBA water resources.

Indicator	Freshwater	Marine Outer Coast	Marine Bays & Estuaries
Water Quality			
Eutrophication	OK	OK	OK
Contaminants	PP	PP	PP
Hypoxia	OK	OK	OK
Turbidity	OK	OK	OK
Pathogens	OK	OK	OK
Water Quantity	OK	NA	NA
Habitat Disruption			
Physical benthic impacts	OK	OK	OK
Coastal development	PP	OK	OK
Altered flow	OK	OK	OK
Erosion/Sedimentation	OK	OK	OK
Altered salinity	OK	OK	OK
Recreation/Tourism usage	OK	OK	OK
Other Indicators			
Harmful algal blooms	NA	PP	PP
Aquatic invasive species	PP	PP	PP
Impacts from fish/shellfish harvesting	OK	PP	OK
Climate change	PP	PP	PP

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

A. Park Description

A1. Background

A1a. Setting

Glacier Bay National Park and Preserve (GLBA) is located in northern Southeast Alaska and is one of four coastal national parks in this region of Alaska (Figure 1). GLBA is bordered by the Pacific Ocean to the west, Icy Strait to the south, Tongass National Forest to the west and northwest, Tatshenshini-Alsek Provincial Park (Canada) to the north, and Tongass National Forest to the northeast (Figure 2). The National Park Service (NPS) manages over 1.33 million ha (3.28 million acres) within GLBA. Park lands are comprised of Glacier Bay National Park with 1,305,272 ha (3,225,284 acres), which consists of 1,305,132 ha (3,224,938 acres) federal land and 140 ha (346 acres) nonfederal land and the smaller Glacier Bay National Preserve with 23,426 ha (57,884 acres), which consists of 22,436 ha (55,439 acres) federal land and 989 ha (2,445 acres) nonfederal land (NPS 2006b).

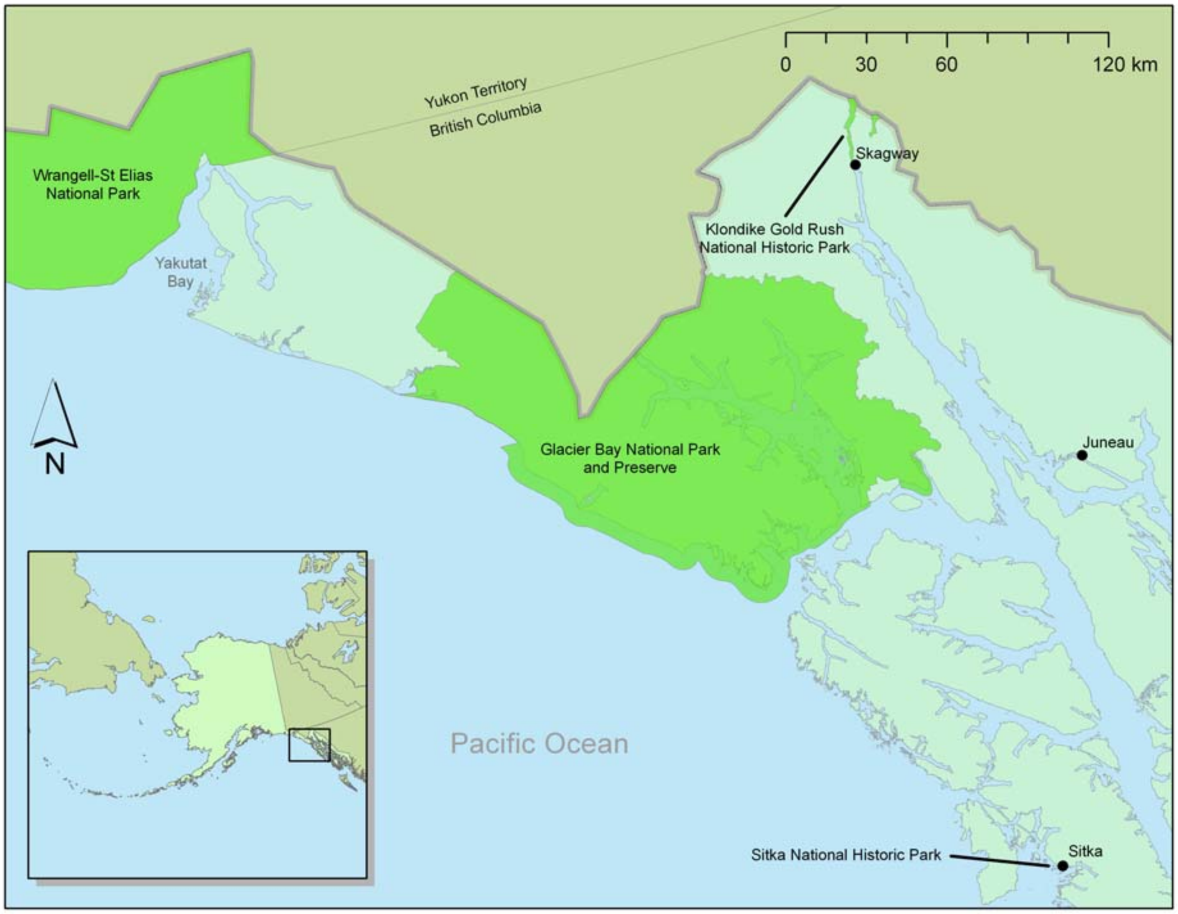

Figure 1. Southeast Alaska National Parks

Much of GLBA at low elevation is dominated by temperate rainforest with mild temperatures and high precipitation. The park contains diverse habitats including the world's highest coastal mountain range, coastal and estuarine areas, wetlands, deep fjords, tidewater glaciers,

Figure 2. Boundaries and major features of GLBA. Source NPS (2005b).

and freshwater streams and lakes. This landscape hosts a variety of aquatic and terrestrial plant communities that range from mature communities in older coastal and alpine ecosystems to pioneer species in areas that have been recently exposed by receding glaciers. Mature vegetative communities in GLBA are subdivided into eight categories: salt marsh, beach meadows, lowland forest, upland forest, shrub lands, bog communities, subalpine meadows and alpine meadows. These diverse habitats support a variety of wildlife including marine wildlife, terrestrial wildlife, birds, and fish.

Glaciers have been carving the park for more than seven million years, and today approximately 27 percent (356,136 ha [880,000 acres]) of GLBA is covered by glacial ice (Figure 2). In 1794, Captain George Vancouver documented that Glacier Bay was only 5 miles long beyond the terminus of a massive glacier that once occupied much of the bay. At that time, this large glacier, which is now called the Grand Pacific Glacier, reached more than 1,200 m (4,000 ft) thick, 32 km (20 mi) wide, and more than 161 km (100 mi) long (Conner and O'Haire 1988). By 1916, the glacier had retreated 100 km (60 mi) to the present Tarr Inlet, providing an opportunity to study glacial retreat, ecological succession, the effects of climate change, and other physical and biological dynamics of the area.

Glacial retreat has caused and is continuing to cause tremendous physical changes to GLBA, and as a result, its freshwater and marine ecosystems are dynamic and challenging to understand. Besides the glacial ice that covers much of GLBA, there are numerous lakes, ponds and muskeg on both mature terrain and in recently deglaciated areas. GLBA has about 300 streams within its boundaries and a total of 3,380 km (2,100 mi) of streams and rivers (National Park Service 2005a). Numerous watersheds have developed after deglaciation. In fact, about one third of GLBA's streams have been created by glacial retreat since 1750. These new streams are undergoing primary succession. As the glaciers retreat, water flowing from the glaciers feeds new streams, and physical transitions and succession occur.

GLBA is unusual compared with other coastal parks in that the NPS has jurisdiction over submerged lands and tidelands, including those within 5 km (3 mi) of shore. Such areas are normally under state jurisdiction (see *History* below). Glacier Bay, the dominant geomorphic feature of GLBA, is a geologically young fjord that stretches approximately 100 km (62 mi) from north to south, with a total area of 1,255 km^2 (310,000 acres), with two main tributary arms: the West Arm and the East Arm (Figure 3, Hooge and Hooge 2002). Glacier Bay is a recently deglaciated, tidally mixed, fjord estuarine system with multiple underwater sills. The Glacier Bay region is extremely biologically productive because of numerous tidewater glaciers, freshwater mountain streams, and snowmelt that contribute vast quantifies of freshwater and nutrients and mix with marine water from the Pacific Ocean.

NPS (2005a) identifies three major marine ecosystems in the Park: continental shelf, wave-beaten coasts, and fjord estuaries. The continental shelf is the offshore zone to a depth of 200 m (650 ft), and these waters are used for fishing, travel, freighting and boat recreation (NPS 2005a). Wave-beaten coasts consist of 200 km (125 mi) of sandy and gravel beaches from Dry Bay to Icy Point and rocky coasts from Icy Point to Cape Spencer (NPS 2005a). Fjord estuaries, including Dundas Bay and Glacier Bay, are usually highly productive and often used for fishing. Fjords are protected from direct wave action and have a high rate of silt deposited annually(NPS 2005a). The high productivity and marine life diversity in these systems is a result of high nutrient levels and consistent vertical mixing.

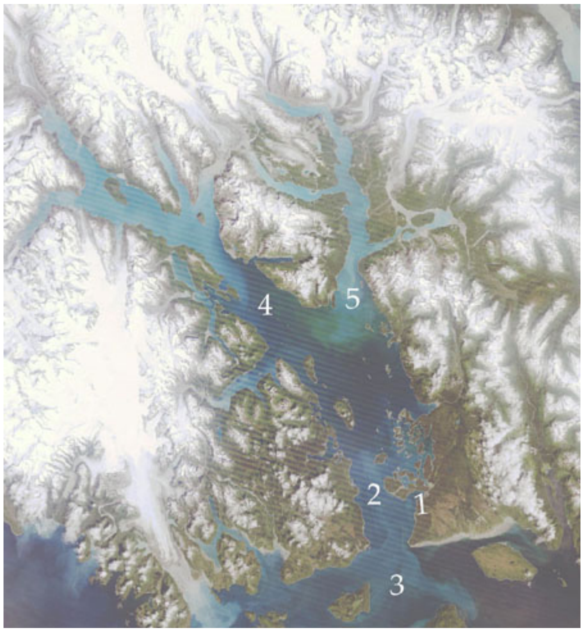

Figure 3. Landsat TM image of Glacier Bay (1 August 1999)
1 – Bartlett Cove; 2 – Sitakaday Narrows;
3 – Sill at mouth; 4 – West Arm; 5 – East Arm (courtesy of P. Hooge).

A1b. History and Human Utilization

Prehistoric people occupied the Glacier Bay area for at least the last 9,000 years (Schroeder 1993). These people were likely ancestors of the modern Tlingit, however the archaeological record does not identify the group, and it is not known how or when Tlingit groups migrated to northern Southeast Alaska (Schroeder 1993). Advancing glaciers during the Little Ice Age (450 years ago) forced the Tlingits out of Glacier Bay proper, and they relocated to Hoonah. Still based in Hoonah today, many Tlingit regard Glacier Bay as their ancestral home. Tlingit clans historically used the bay for traditional harvest of salmon, halibut, shellfish, goats, seals, and bird eggs (Bosworth 1988, Hunn et al. 2004). The end of the Little Ice Age in the mid-1700s marks the beginning of European exploration of the area. In 1796 Jean Francois Galoup de LaPerouse, a French explorer, was the first white man to land in the park (near Lituya Bay); he observed the activity of Tlingit fish camps in the Glacier Bay area (Taylor and Perry 1988). Captain George Vancouver from the HMS Discovery charted the waters around Glacier Bay in 1794. Two years later, Russian fur hunters, under direction from Alexander Baranov, collected 1800 sea otter skins from Lituya Bay (Catton 1995). John Muir recorded his “discovery” of Glacier Bay in 1879 and continued studying the region on subsequent visits in 1880, 1890, and 1899. After viewing Captain George Vancouver’s charts of the Glacier Bay area, Muir observed that the Grand Pacific Glacier had retreated 30 miles since Vancouver’s 1794 visit and that a bay was present where the large glacier had retreated. In 1899, Muir and other prominent naturalists on the famous Harriman Alaska Expedition visited Glacier Bay and Lituya Bay, documenting biological and geological features. An earthquake of magnitude 8.4 struck in the fall of 1899 and choked the waterways with icebergs from shattered glaciers.

William S. Cooper, an ecologist from the University of Minnesota began studying plant succession in Glacier Bay in 1916. He suggested to the Ecological Society of America in 1924 that Glacier Bay be designated as a National Monument. Subsequently, on February 26, 1925, President Calvin Coolidge created Glacier Bay National Monument to preserve the majestic beauty and scientific opportunities. The area of the Monument doubled in size in 1936, and the boundaries were modified in 1955, excluding Gustavus and the east side of Excursion Inlet. Once the park became a Monument, collections of most natural resources were banned with a few exceptions. Gold mining was permitted in the park from 1936 until

1976. Glacier Bay became a National Park through the Alaska National Interest Lands Conservation Act (ANILCA) of 1980, which extended the park boundary to the Alsek River and Dry Bay for a total of 1.33 million ha (3.28 million acres) including the 23,426 ha (57,884 acre) Dry Bay Preserve (Figure 1). GLBA was designated an International Biosphere Reserve in 1986 and a World Heritage Site in 1992. In 2005, the National Park Service won a Supreme Court case filed by the State of Alaska, resulting in NPS jurisdiction over submerged lands and tidelands within GLBA boundaries. This decision made GLBA one of the few national parks that includes submerged marine habitat within its jurisdiction.

Shortly after Muir's first visit, a commercial fishery was established in Glacier Bay in the late 1880's (Schroeder 1993). A salmon cannery at Dundas Bay opened in 1900 and heavily relied upon native, white, and Chinese labor (Catton 1995). The cannery closed in 1931 due to low prices generated during the Great Depression. Another short-lived cannery operated in Bartlett Cove from 1882-1894 (Cobb 1930 cited in Schroeder 1993). Historically, the commercial fishing industry consisted of king crab (*Paralithodes* sp.), Dungeness crab (*Cancer magister*), Tanner crab (*Chionoecetes bairdi*), shrimp (*Panadalus* sp.), Pacific halibut (*Hippoglossis stenolepis*) and salmon (*Oncorhynchus* spp.) (Taylor and Perry 1988). Trawling was banned in 1980, and in 1999, king and Dungeness crab fisheries were closed throughout Glacier Bay proper. Tanner crab, halibut and salmon fisheries were allowed to continue in certain portions of the bay and will be phased out over time with no new permits or transfer of permits (Figure 4). Existing fisheries in GLBA include longline fishing for halibut, pot and ring fishing for Tanner crab, and winter trolling for king salmon. Gustavus residents subsistence fish in GLBA for salmon, halibut, cod (*Gadus macrocephalus)*, rockfish (*Sebastes* spp.), trout, Dolly Varden (*Salvelinus malma***)**, Dungeness crab, Tanner crab, clams (various spp.), and cockles (*Clinocardium nuttallii)* (Betts et al. 1998).

GLBA is used recreationally and in 2003-2004 received approximately 390,000 visitors (NPS 2005b). Wildlife viewing of humpback whales, seals, sea lions, moose, and bears are a large attraction to visitors. Bird watchers can find over 240 bird species (gulls, guillemots, puffins, cormorants, loons, murrelets, sea ducks, and bald eagles). Other activities within the park include backpacking, fishing, hiking, kayaking, whitewater rafting in the Tatshenshini and Alsek Rivers, and commercially-guided mountaineering trips east of the Fairweather mountain range. Hunting is only allowed in the Glacier Bay Preserve. Most visitors access Glacier Bay proper by boat, aboard a cruise ship, tour vessel, charter boat, or private vessel. Cruise ships have been entering Glacier Bay seasonally (May-September) since the late 1960's. Today, a maximum of three tour boats and two cruise ships are permitted per day year-round, with a seasonal cruise ship quota of 139 cruise ship entries in June, July and August (NPS 2005c), and these boats transport most of the park visitors to the upper Bay to view tidewater glaciers. The Superintendent recently increased this seasonal cruise ship quota 10% in 2007 to 153 vessels (NPS 2006a). The number of private vessels and charter vessels entering Glacier Bay proper are limited from June 1 and August 31, and during this period, only 25 private vessels and 6 charter vessels are permitted per day so that the maximum number of motorized vessels does not exceed 36 (NPS 2005b). Backcountry camping in GLBA is predominantly limited to low elevations and coastal areas due to the steep topography and logistical complexities. The numbers of backcountry visitors are increasing in recent years. According to guidelines in the park's Wilderness Visitor Use Management

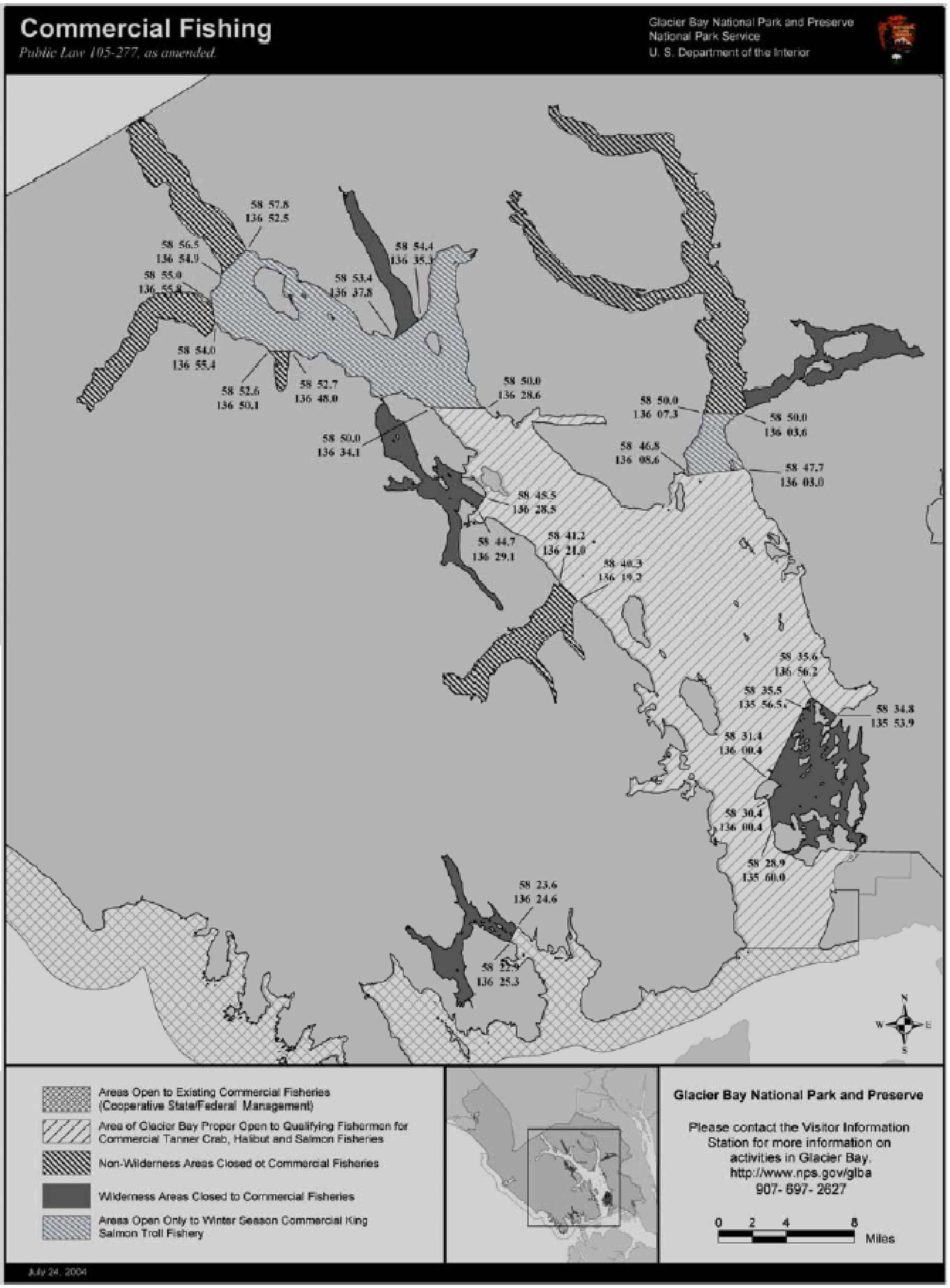

Figure 4. Areas designated for commercial fishing, as of July, 2004.
Source NPS (2006b)

Plan, any individual backcountry campsite should be occupied only 25% of the time between June 1 and August 31 to minimize environmental impact (NPS 1989b). However, a visitor use survey from 1996-1999 indicated that some popular backcountry campsites were being occupied 40-60% of the time (NPS 2005d). In 1998 GLBA instituted a cap of 2,200 backcountry camper visits per year and required free permits for backcountry camping to track the number of campers. The cap has since been removed, however camping regulations including group size, length of stay, group spacing and resource protection closures remain in effect today. The Resource Management division surveys camping impacts to advise management regarding future restrictions (NPS 2005d).

A2. Hydrologic Information

A2a. Climatic Setting

Climate in fall, winter, and spring is dominated by the strong Aleutian Low in the northern Gulf of Alaska and by weak high pressure systems in the summer. As a result, GLBA experiences a wet and moderate marine climate. Records from the only NOAA weather station located within GLBA, at Bartlett Cove, has records going back to 1966 and shows an average temperature of 4.9ºC (40.9ºF), average rainfall of 92 cm (36 in), and average snowfall of 132 cm (52 in) (Figure 5; NOAA 2005). July is the warmest month with an average temperature of 12.8ºC (55 ºF), and the coolest conditions occur in January, when the average temperature is -2.8ºC (27 ºF). Given the geographic and topographic heterogeneity within GLBA, data from this weather station cannot accurately represent all conditions within GLBA. The outer coast of GLBA is influenced by the northward flowing Alaska Current and has milder temperatures, more rainfall, and less snow than Bartlett Cove. Areas closer to glaciers and at higher elevations are colder with resultant greater snowfall than Bartlett Cove. The area has intermittent snowpack near sea level and continuous snow cover at elevations above 300m (1000 ft) during winter and early spring.

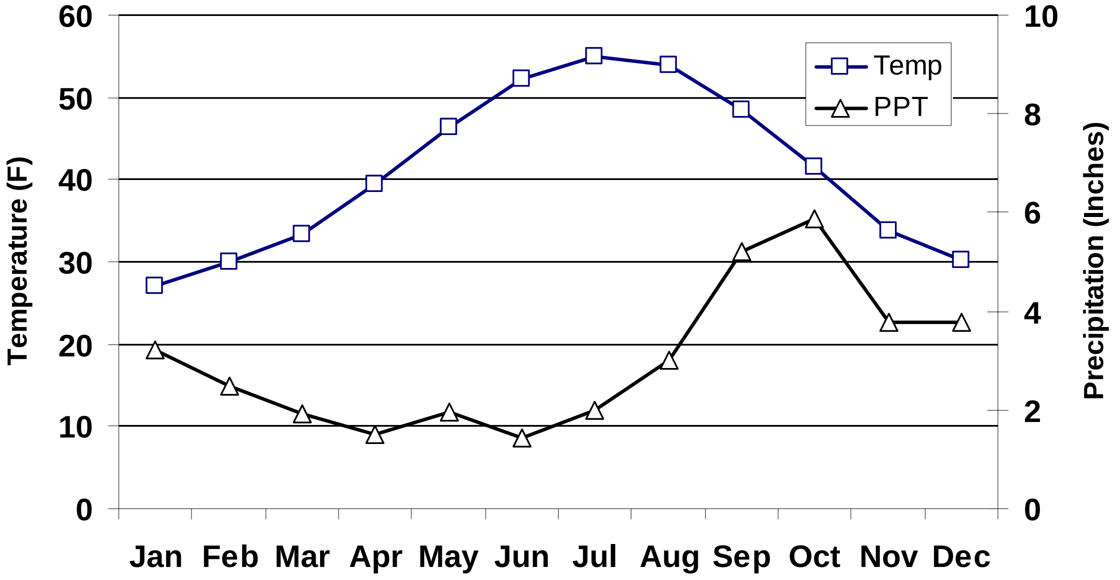

Figure 5. Mean monthly temperature and precipitation in Bartlett Cove

(NWS station “Glacier Bay”), based on data from 1966-2005, available from NOAA’s National Weather Service (http://weather.gov/).

In order to better understand how climate varies across Glacier Bay a network of 24 meteorological stations has been installed across Glacier Bay (Figure 6). Basic climate parameters such as temperature, wind speed, relative humidity as well as the isotopic composition ($\delta^{18}O$ and δD) of precipitation are being measured at these stations. The data collected at these sites will provide valuable information about storm patterns and glacier responses to climate forcing (Finnegan et al. 2004).

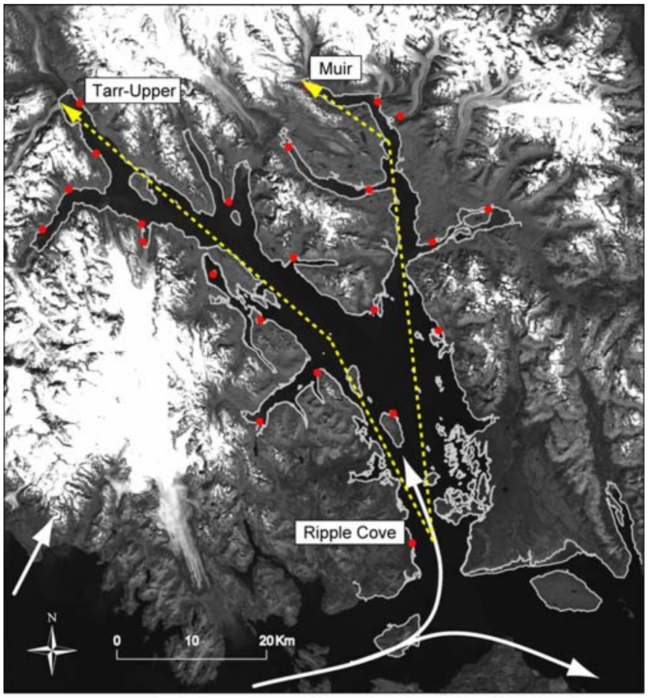

Figure 6. Location of climate stations in Cold Regions Research and Engineering Lab meteorological network.
From Finnegan et al. 2004.

A2b. Streamflow

For many streams in GLBA, variations in discharge are dominated by snowmelt and precipitation events. High precipitation combined with peak glacier melting result in maximal freshwater discharge during autumn (Royer 1982). The US Geological Survey, which delineates hydrologic resources in the United States, defines two hydrologic units within the boundaries of GLBA: Yakutat Bay (USGS Hydrologic Unit 19010401) and Glacier Bay (USGS Hydrologic Unit 19010302, Figure 7). The USGS has measured flow in two rivers within the GLBA boundaries: the Alsek River and the Kahtaheena River. Current streamflow measurements are available only for the Alsek River, where the USGS has had continuous flow records since 1991 (at gage no.15129000; “Alsek R nr Yakutat AK”). Discharge from the Kahtaheena River was measured from 1998 to 2004 at two gaging stations (Figure 8). The upper gage (gage no. 15057580; "Kahtaheena River R ab Upper Falls nr Gustavus AK"), located 2.7 km (1.7 mi) from the river's mouth, collected discharge information between August, 1999 through September, 2004. The lower gage ("Kahtaheena R nr Gustavus AK"; no. 15057590), located less than 0.3 km (0.2 mi) from the river's mouth, recorded streamflow between October, 1998 and April, 2001. Flow data from the gages on these two rivers indicate that high flows occur in the spring, during periods of snowmelt at higher elevations, and again in the fall, when heavy precipitation is common. Low flows commonly occur during the winter months when much of the watershed is under ice and snow. The Alsek River provides a representative hydrograph for glacial rivers in GLBA. Discharge on the Alsek is closely correlated with air temperature and demonstrates more than a 2000% change in discharge between winter low flows and peak flow during mid-summer months (Figure 9).

A2c. Water Resources

Freshwater resources in GLBA are vast and dynamic, and their hydrology is poorly understood. There are thousands of small lakes and ponds in forested, high elevation, and muskeg (bog characterized by poorly-drained, acidic, organic soils) areas; over 416 of the lakes are larger than 1 ha (2.5 acres) and five lakes are larger than 405 ha (1,000 acres) (NPS 2005a). GLBA has more than 310 streams, 100 of which have been created since about 1750 by glacial retreat, with a total inventory of over 3,380 km (2,100 mi) of streams and rivers that discharge along 1,500 km (931 mi) of shoreline (Soiseth and Milner 1993, NPS 2005a). Glacial retreat in the Park has opened up an extensive fjord system and adjacent uplands. Freshwater resources within GLBA include: rivers and streams, lakes and ponds, snow and glaciers, wetlands, frost (which includes seasonal ground ice and permafrost), and groundwater.

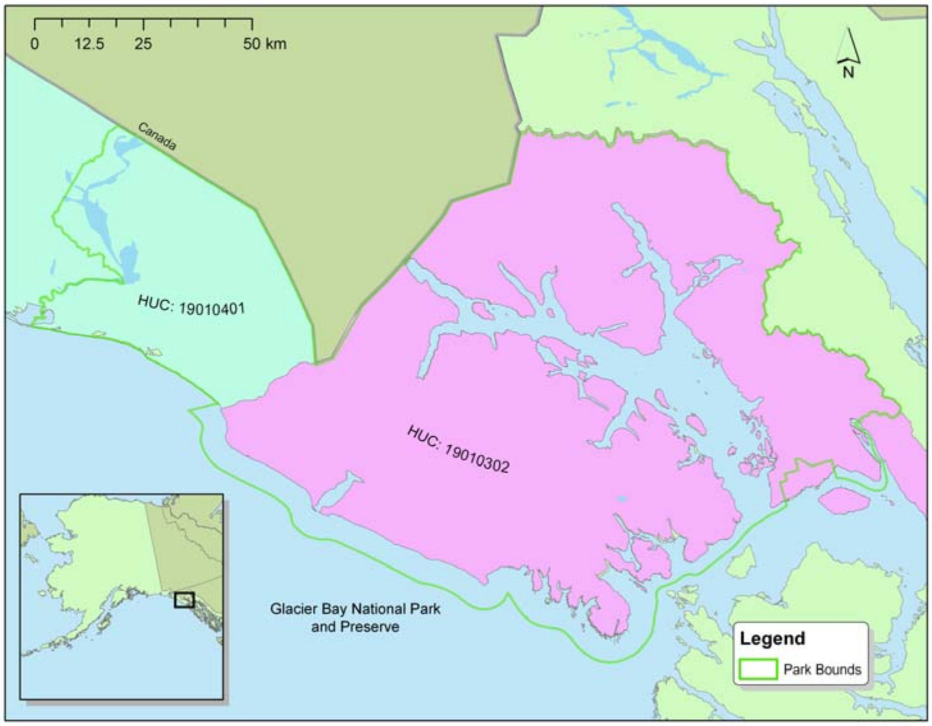

Figure 7. Location of the two USGS Hydrologic Units contained within GLBA boundaries. Hydrologic Unit Code #19010401 is Yakutat Bay and Hydrologic Unit Code #19010302 is Glacier Bay.

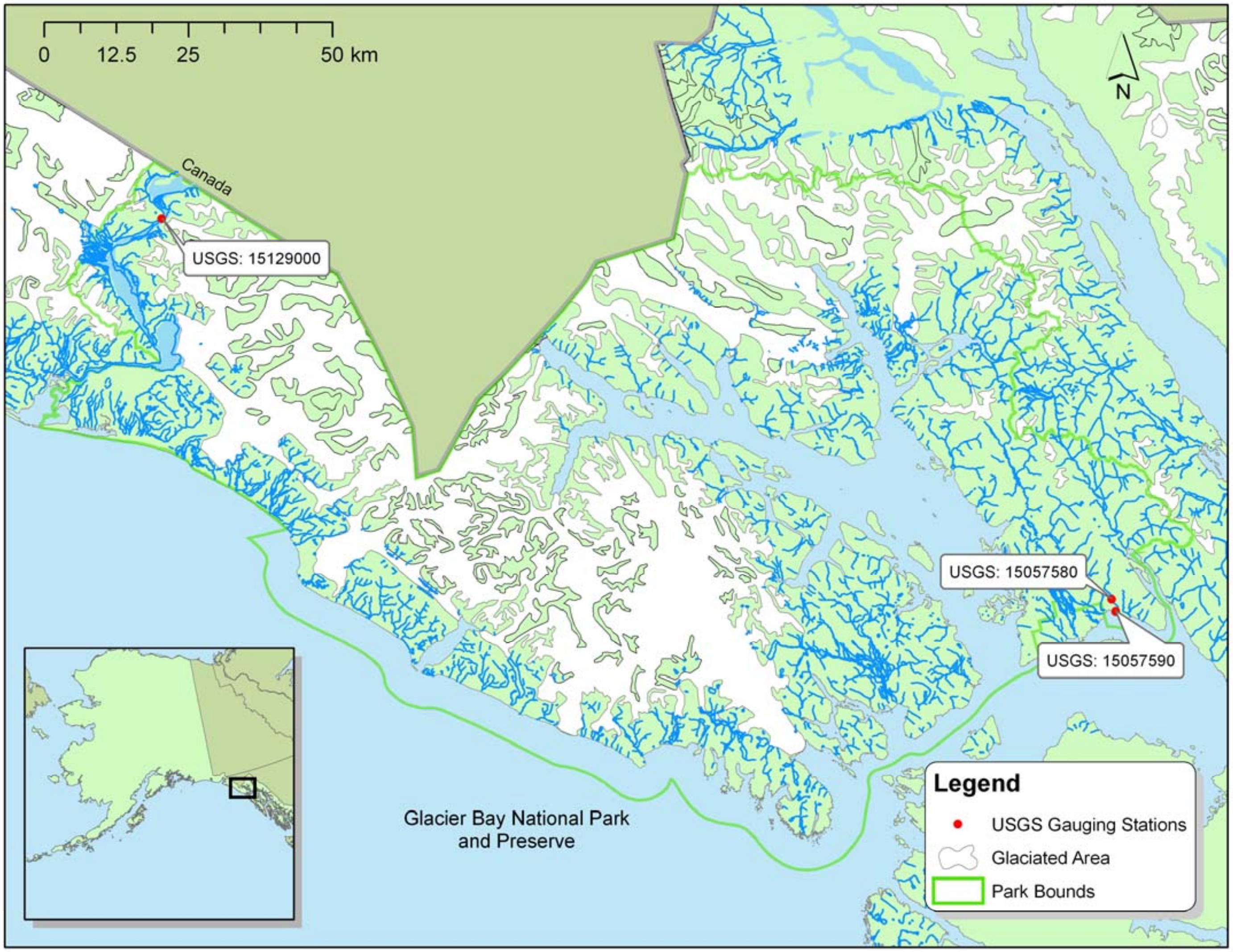

Figure 8. Location of active stream gages on the Alsek and Kahtaheena Rivers.
Alsek River gage (USGS #15129000) is active and Kataheena River gages (USGS #'s 15057580 and 15057590) were recently active from 1998-2004.

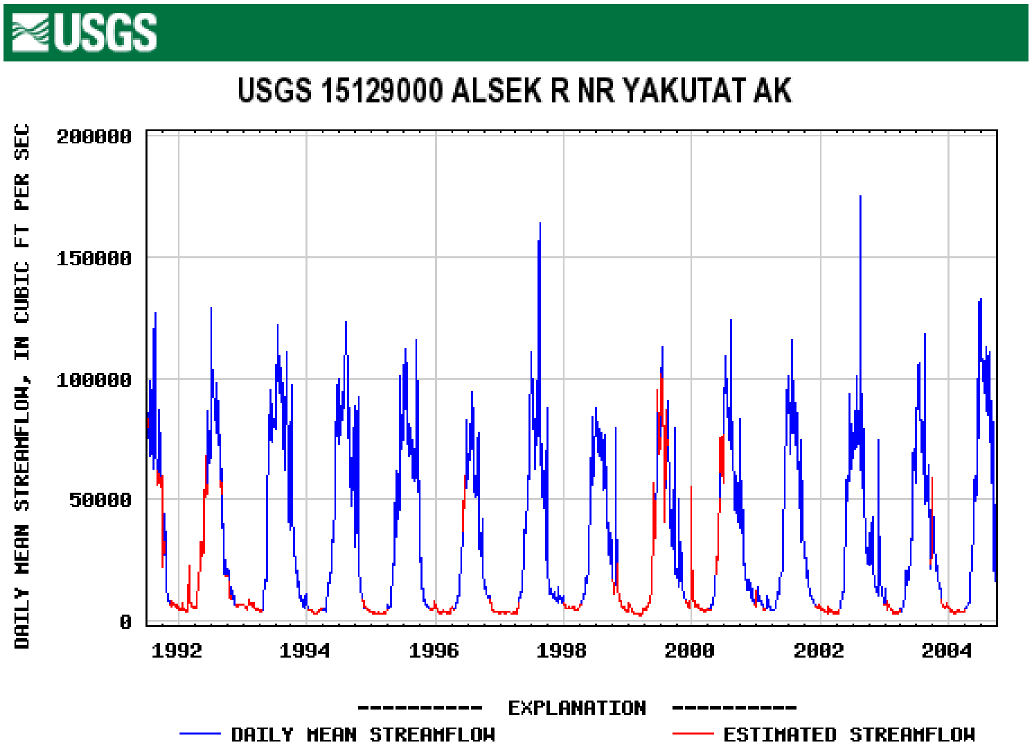

Figure 9. Mean daily streamflow of the Alsek River stream gage
(USGS gage no. 15129000) for July 1991-September 2004. Data from USGS (2006).

A2c1. Rivers and Streams

The major river system on the west coast of GLBA is the Alsek River (Figure 10), which collects water from the Alsek Range via the Tatshenshini River in British Columbia, enters the US as it flows through the St. Elias Mountains, drains Alsek Lake, and forms a portion of the northwest boundary of GLBA before emptying into Dry Bay. There are a multitude of small glacial and clearwater streams along the forelands between Dry Bay and Lituya Bay to the east (Figure 10). The Brady Icefield is a major source area for streams such as the Crillon River, Kaknau Creek, Dundas River, and Dixon River, which drain into bays and harbors (e.g. Liuya Bay, Palma Bay, Dixon Harbor, Taylor Bay, and Dundas Bay) in the west and southwest regions of GLBA (Figure 11). Numerous short, steep, and unnamed glacial streams flow into the many inlets that ring the boundary of Glacier Bay. Along much of the West Arm of Glacier Bay, glaciers are ubiquitous and extend to sea level, thereby greatly limiting the number of freshwater streams to a few, extremely short and steep drainages. The East Arm is flanked by tidewater glaciers only in the northernmost portions and therefore has more extensive stream systems. While there are few large river systems in the northeastern portion of GLBA, the longest streams (Granite Canyon, Berg Creek) are those that drain the Chilkat Mountains and empty into Adams Inlet. Midway between Adams Inlet and the town of Gustavus, Beartrack River flows south for more than 20 km (12.4 miles), a relatively long distance for a GLBA stream, into Beartrack Cove. North of Gustavus, the Bartlett River and Salmon River flow southeast and south, toward Park Headquarters in Bartlett Cove and through Gustavus, respectively. The Excursion River is the longest river in GLBA at approximately 22 km (13.7 miles) and its watershed forms the southeast corner of GLBA, just east of Gustavus. A hydrologic survey in the Lituya Bay region provides information on watershed size, lithology, typography, flow characteristics, streambed characteristics, and sediment load for drainages in the Lituya Bay region: Justice, Echo, Steelhead, and Topsy Creeks; Fish Lake; and the Crillon and Dagelet Rivers (Bishop, 1980).

The majority of GLBA streams are relatively short (<20 km [12 mi]) and steep (average gradient 5-20%), and occur in small catchments (1-100 km^2 [0.38-38 mi^2]) (Soiseth and Milner 1993, Soiseth 1995). Streams in GLBA are generated by surface runoff from snowmelt or precipitation, by lakes fed by surface runoff, or by glacial sources. Milner (1987) characterized streams in Glacier Bay as one of five types: turbid meltwater streams, clearwater streams without lakes, or clearwater streams with lakes, brownwater streams draining wetland dominated landscapes, and karst influenced streams. The numerous rivers and streams fed by glacial meltwater in GLBA have turbid waters and are typified by high gradients, large sediment loads, low levels of biotic productivity and small resident fish populations. The less abundant clearwater streams are characterized by relatively low suspended sediment loads and higher biological productivity and, consequently, are important habitat for spawning fish. An overview of studies relating to the evolution of streams following deglaciation is provided in section *A3d. Freshwater*.

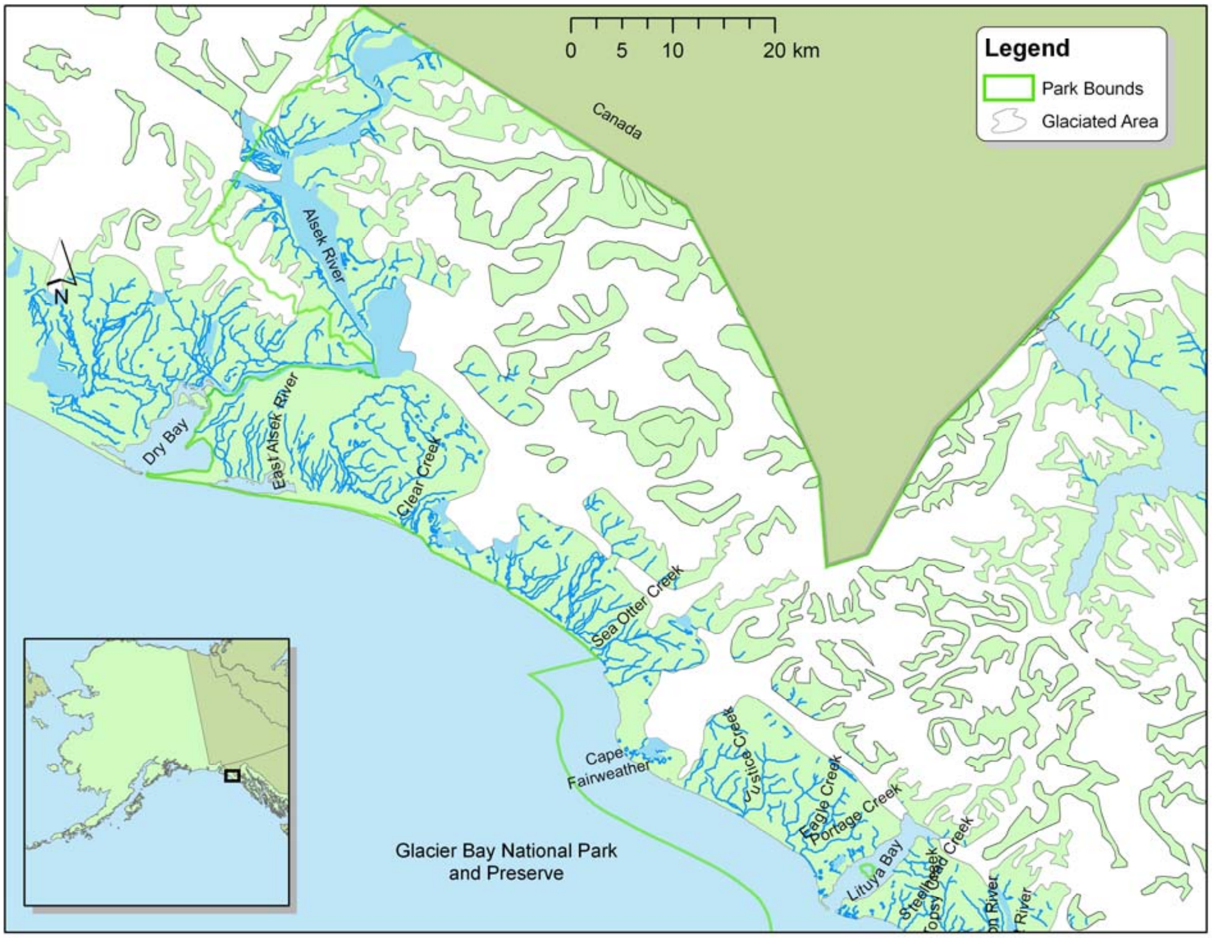

Figure 10. Location of major rivers and streams in the western portion of GLBA.

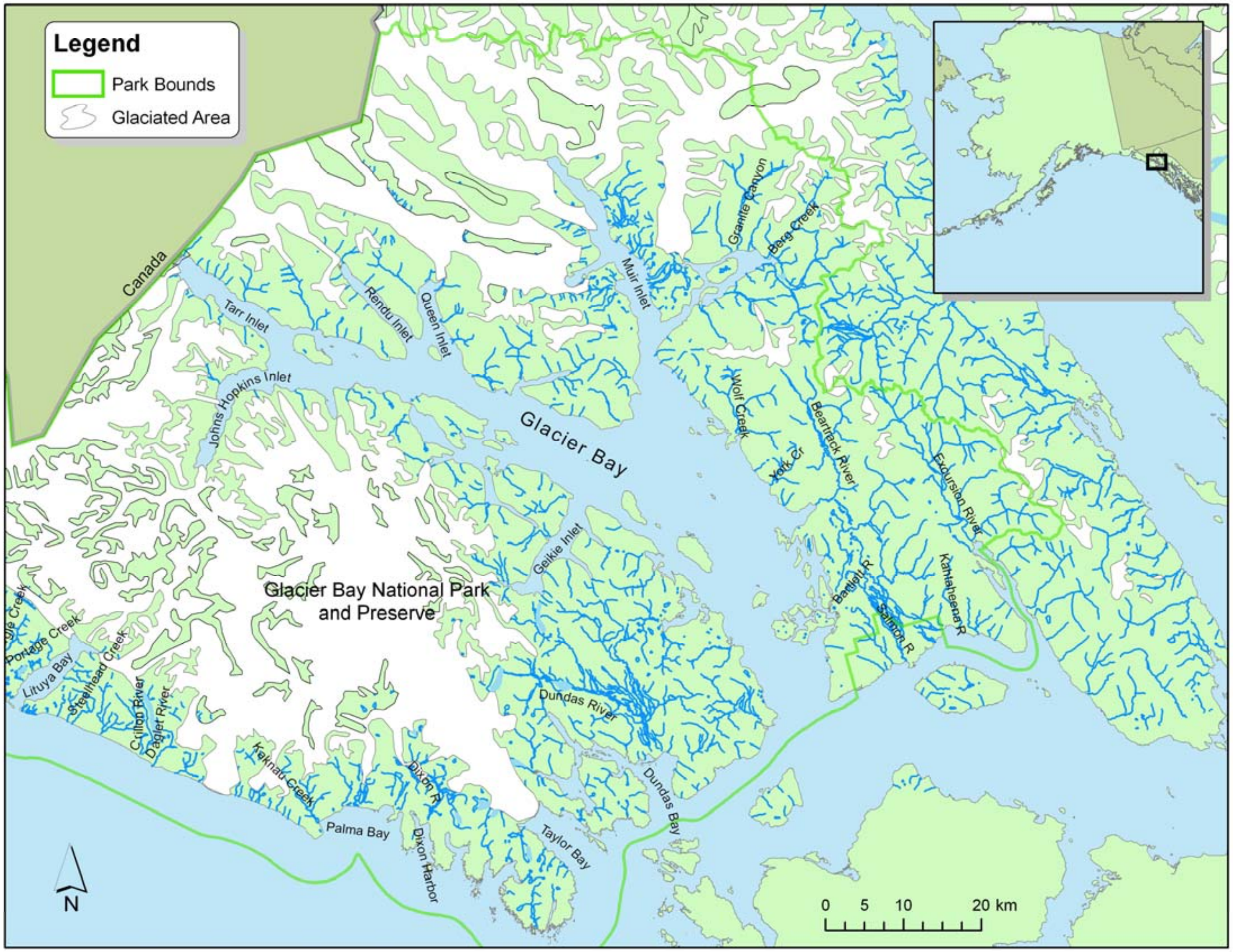

Figure 11. Location of major rivers and streams in the eastern portion of GLBA.

A2c2. Lakes and Ponds

Freshwater lakes and ponds are typical features of recently deglaciated landscapes and, as a result, are abundant in GLBA. The largest lakes in the park, from north to south, are Alsek Lake, the unnamed lakes at the termini of the Grand Plateau and the Fairweather Glaciers, Crillon Lake, and two lakes draining into Palma Bay (west of the Brady Glacier). Small lakes are particularly abundant in the area between the Dundas River and the southwestern shore of Glacier Bay and in the region between Gustavus and the Beartrack River.

Numerous lakes in GLBA have been investigated in an effort to understand their chemical and physical evolution following deglaciation (Engstrom and Fritz 1988, Fritz and Engstrom 1993, Engstrom et al. 2000, Fritz et al. 2004). Engstrom et al. (2000) demonstrated that lake and pond communities are closely linked to the adjacent terrestrial systems. They found that young lakes (<100 years old) are characterized by high pH, high dissolved solids, and low dissolved organic carbon (DOC), because overland flow across bare soils and high inputs from groundwater are the dominant sources of water to the lakes. As terrestrial vegetation and mature soils develop, precipitation is increasingly routed through acidic, organic-rich soils. Consequently, the pH decreases and the DOC concentrations increase in the lakes, rendering them more capable of supporting diverse aquatic food chains. Decreases in pH and dissolved solids and increases in acidity and DOC continue even after 1,000 to 3,000 years, because soil hardpans are formed under the organic soil horizons, thereby maintaining the routing of water through the soil zones. Over time, these chemical progressions reduce the lake's biological productivity, even though carbon and nutrients continue to accumulate in the adjacent terrestrial surroundings (Engstrom et al. 2000).

Two notable freshwater systems in GLBA are glacial ice ephemeral ponds and glacier-dammed lakes. Ephemeral ponds exist on the outer coast area near Cape Fairweather, where the Fairweather Glacier previously resided before retreating to its present location (Bill Eichenlaub, NPS-GLBA, personal communication, 2005). Here, forest growth overlies glacial ice, and where the underlying ice and debris melted, the forest collapsed, producing large ponds (Figure 12). As the stagnant portion of the Fairweather Glacier continues to melt away, these ponds will disappear altogether. Glacier-dammed lakes are formed when a lake or river is blocked by a surging glacier. More information on floods from glacier-dammed lakes is provided in section C5c. Glacial Outburst Floods.

Figure 12. Glacial ice ephemeral pond on remnant of the Fairweather Glacier. The pond formed in an area where ice and debris underlying the forest collapsed. Photo courtesy of Bill Eichenlaub, NPS-GLBA.

A2c3. Snow, Ice, and Glaciers

Glacial ice is the dominant landform in GLBA. Currently, approximately 27 percent of GLBA, over 356,000 ha (880,000 acres), is covered by glacial ice (Figure 2). Most of the glaciers have been retreating since the end of the Little Ice Age ~250 years ago, which opened the inlets and bays, including Glacier Bay, that characterize GLBA. Glacier ice in portions of GLBA has retreated more than 100 km (62 miles) since Vancouver visited Glacier Bay in 1794. Many of the glaciers in the park are still retreating, however there are a small number that are advancing. In order to better understand the rates and timing of glacial retreat in GLBA, several recent studies have compared 21st century images of glaciers with corresponding historical photographs (e.g. Mickelson and Ham, 1993; Molnia et al, 2004). For a discussion of the impacts of climate change on GLBA glaciers, see section C6. *Climate Change*. Today, GLBA contains over 200 glaciers, twelve of which are tidewater glaciers that calve iceburgs into the Muir, Tarr, and Johns Hopkins inlets (Figures 13-14). There are at least 10 glaciers in GLBA that have lengths greater than 15 km (9 miles) (Molnia, 1982). The longest glacier in GLBA is the Grand Pacific Glacier which begins in the western portion of GLBA, passes through British Columbia and terminates at the head of Tarr Inlet just north of the GLBA boundary (Figure 14). GLBA 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 and has a dramatic influence on the annual sediment yield and hydrograph of glacial rivers and streams (Lawson, 1993).

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, 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 GLBA that have ongoing programs to measure mass balance. The closest glaciers to GLBA that have long-term records of mass balance are the Lemon and Mendenhall Glaciers near Juneau (Motkya et al 2002), and the Wolverine Glacier on the Kenai Peninsula and the Gulkana Glacier in the Alaska Range, both of which are US Geological Survey Benchmark Glaciers (http://ak.water.usgs.gov/glaciology/).

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 GLBA 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.

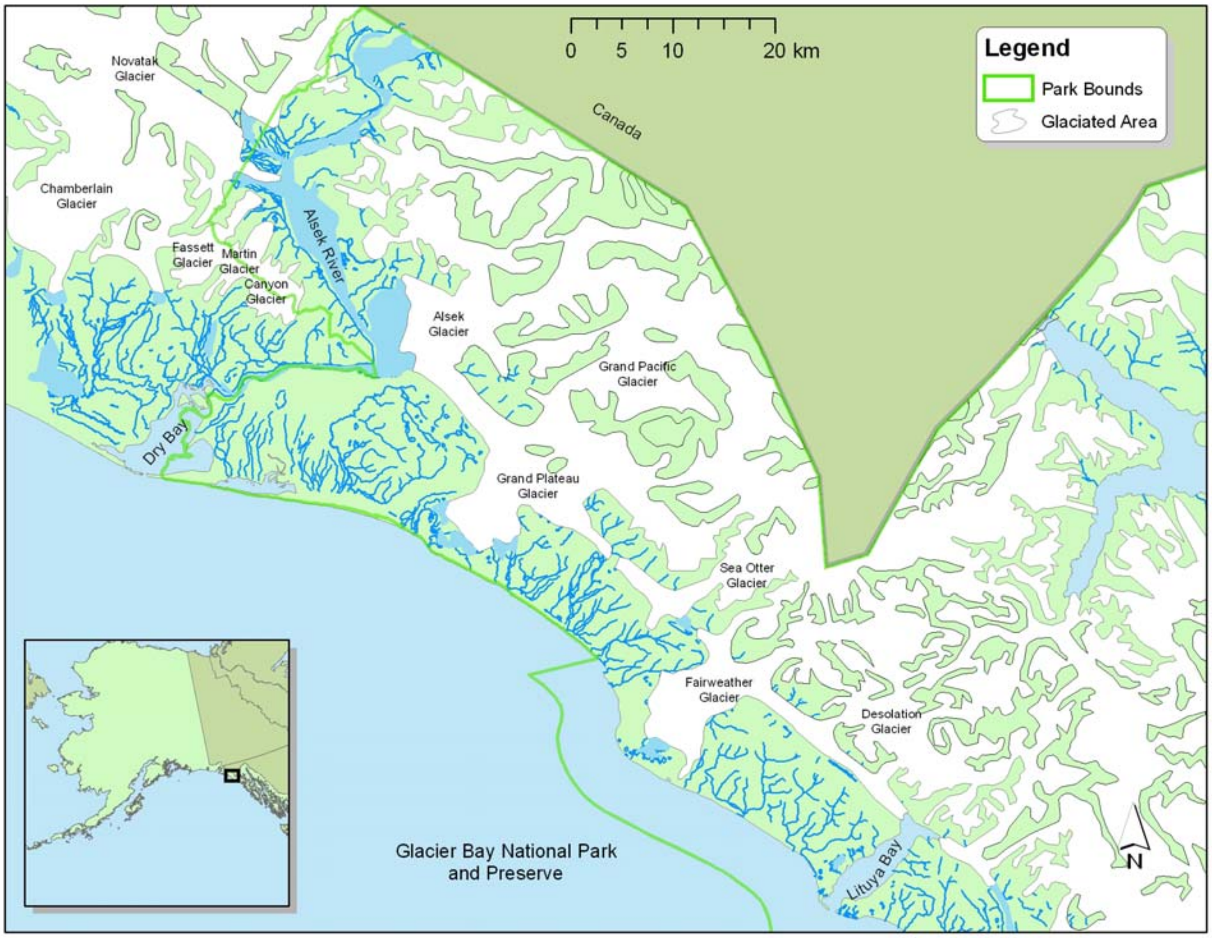

Figure 13. Location of major glaciers in the western portion of GLBA.

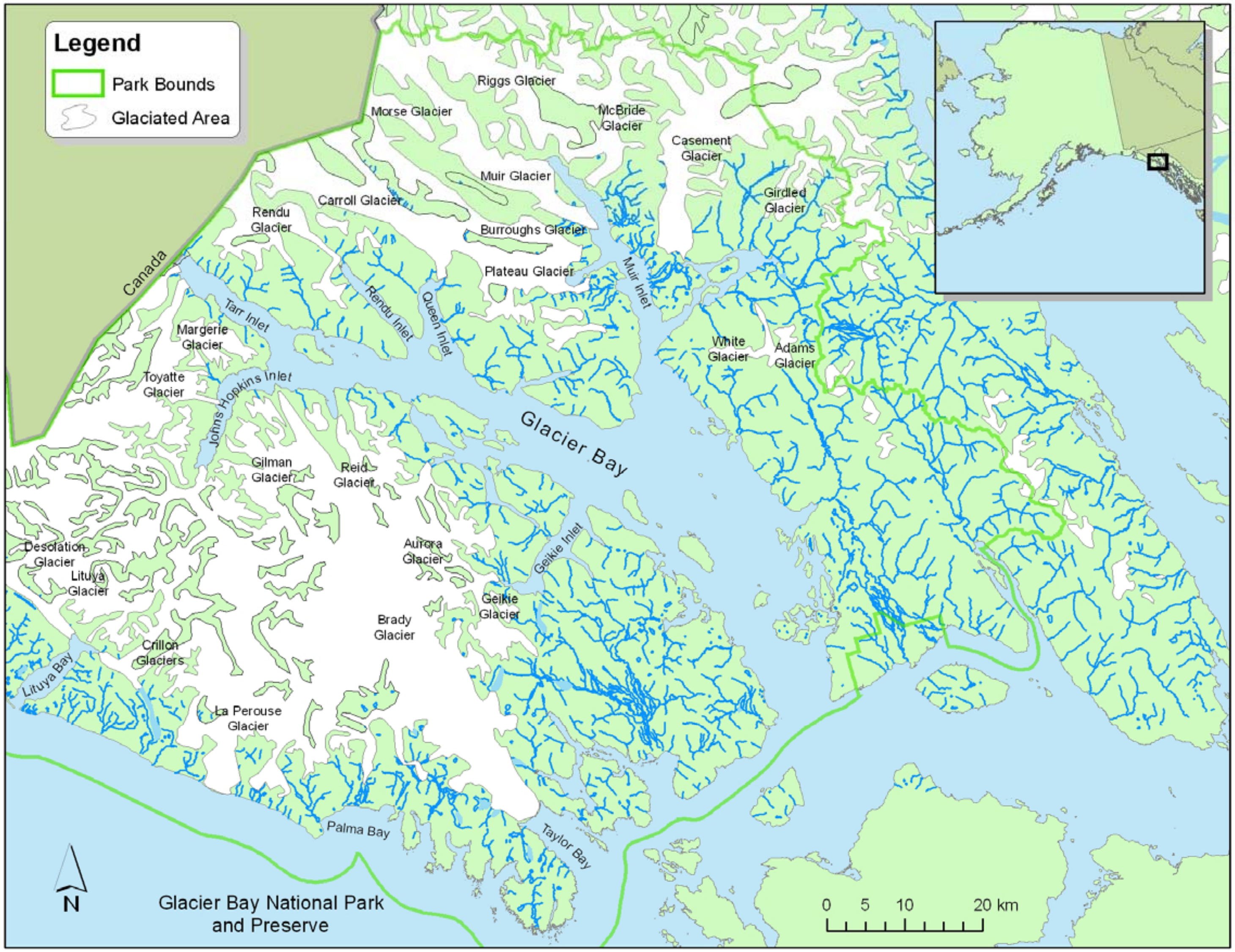

Figure 14. Location of major glaciers in the eastern portion of GLBA.

A2c4. Groundwater

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

A2c5. Wetlands

The majority of wetlands in Glacier Bay are coastal intertidal wetlands and palustrine and riverine wetlands located along valley bottoms. The US Fish and Wildlife Service National Wetlands Inventory mapping program has mapped wetlands in the western and southeastern portions of GLBA (Figure 15). Updated wetlands maps are also available through the USFWS (http://wetlandsfws.er.usgs.gov/). In total, 278 km^2 (107 mi^2) of wetlands have been been mapped in upland areas of GLBA, this includes 85 km^2 (33 mi^2) of riverine wetlands, 131 km^2 (51 mi^2) of palustrine wetlands, and 62 km^2 (24 mi^2) of lacustrine wetlands. In addition, 338 km^2 (131 mi^2) of estuarine wetlands have been mapped.

Wetland areas are important because they serve as an interface between terrestrial habitats and aquatic environments such as streams, lakes and near-shore marine zones. It is possible that the area of intertidal and riverine wetlands at the outlet of major rivers in GLBA will increase as new land becomes exposed as a result of glacial recession and rapid land surface uplift (see C5a. *Land Surface Uplift*). The ADEC recently developed a guidebook and methodology for functional assessment of streamside wetlands in southeastern and southcentral 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.

A2d. Oceanography

A2d1. Bathymetry and tides

GLBA encompasses marine areas in the outer coast, Cross Sound, Icy Strait, Glacier Bay, and smaller bays including Dundas Bay, Lituya Bay, Torch Bay and Dry Bay (Figure 2). Glacier Bay is connected to the eastern Gulf of Alaska (GOA) through Icy Strait, which enters Cross Sound through two narrow passages. Cross Sound opens to the GOA with a 13 km (8 mi)-wide opening with depths of 225 to 350 m (738 to 1150 ft). This passage directly

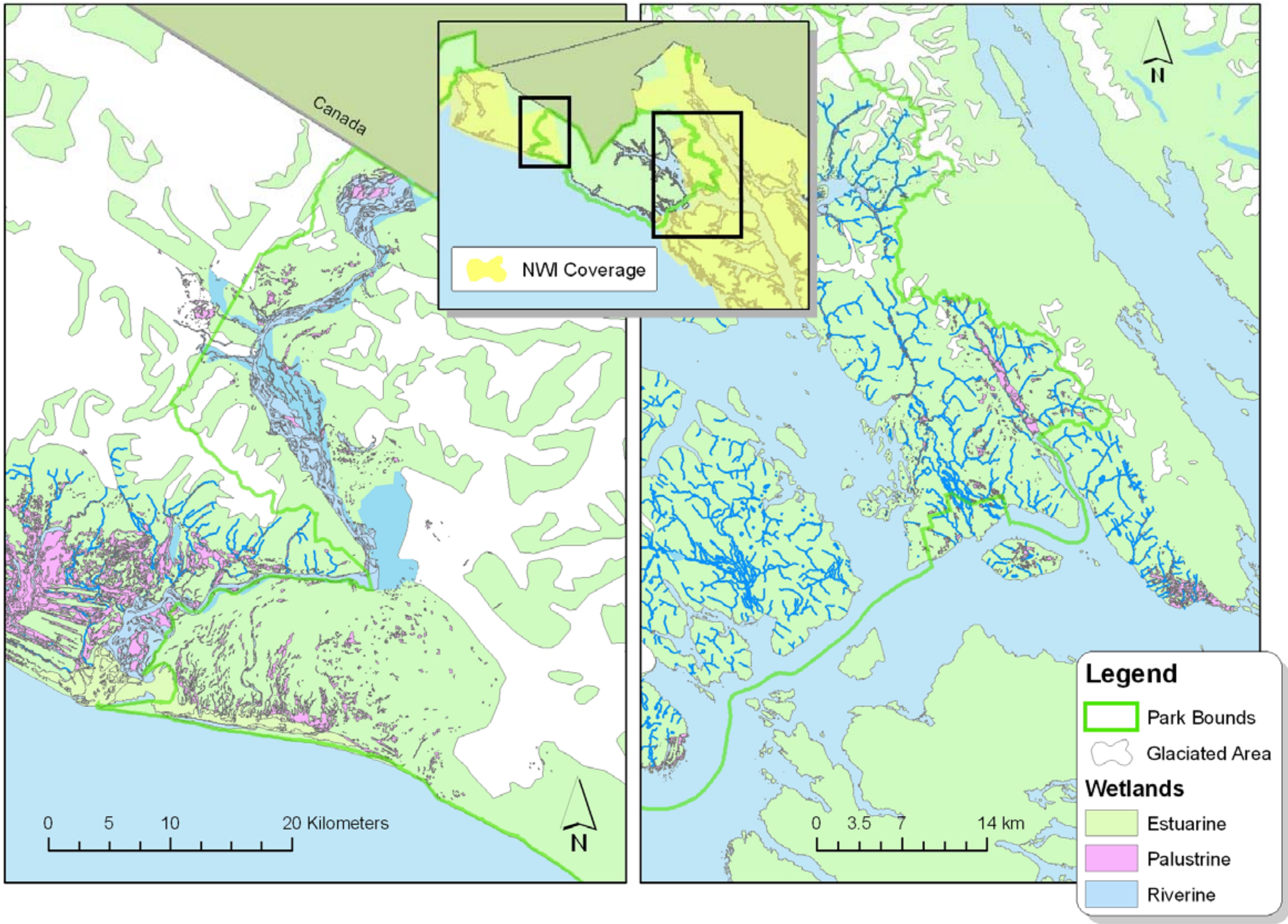

Figure 15. Wetland areas in and around GLBA as delineated by the USFWS National Wetland Inventory (NWI). Only the western and southeastern portions of the park have been mapped through the NWI (see inset).

connects to a canyon that slopes downward and outward through the ~35 km (~22 mi) wide coastal shelf and out to the shelf break. The Alaska Current, which is characterized by relatively low salinities and predominant northerly flow, borders the outer coast.

Multiple sills, embayments, tidewater glaciers, islands and other topographic features characterize Glacier Bay's complex bathymetry (Figure 3). At its mouth, Glacier Bay has a shallow (~25 m [~80 ft]) sill that may limit water exchange between the bay and the GOA. The East Arm sill is at ~60 m (~200 ft) depth, while that at the West Arm is at 240 m (~800 ft). Deep basins with depths up to 458 m (1500 ft) exist between sills. In addition to multiple sills and basins, there are numerous locations where Glacier Bay alternately narrows and widens. These contractions produce constrictions of water flow, resulting in strong currents, turbulence, and a well-mixed water column. This phenomenon is particularly evident at Sitakaday Narrows where average maximum velocities are 2.7 ms^{-1}, and can reach 4.5 ms^{-1} during extreme spring tides. Glacier Bay has mixed semi-diurnal tides and a large tidal range (averaging 3.7 m [12 ft] near the mouth to greater than 4.2 m [14 ft] at the heads).

A2d2. Circulation

Since 1992, the National Park Service (NPS) and US Geological Survey (USGS) have monitored physical conditions, including temperature, salinity, turbidity, photosynthetically active radiation (PAR), and in situ fluorometric measurements at 24 stations distributed throughout the Bay (Figure 16, Hooge and Hooge 2002, Etherington et al. 2004). Glacier Bay shows characteristics of both a stratified deep ocean basin estuary and a tidally mixed estuary. Vertical isopycnals and cold sea surfaces characterize mixing at the entrance sill during ebb and flood tide, but during near-slack currents, water in the vicinity of the sill has been observed to stratify. Just inside the Bay, internal waves may be generated at Sitakaday Narrows as water rushes through this shallow, narrow channel (Hooge and Hooge 2002). The mid-Bay area that is deep and wide has a strong stratification for much of the year. In spring, summer, and fall, increased freshwater runoff from rain and glacier melting result in a brackish surface water layer in the Bay.

Traditional fjord oceanography predicts that once stratification in surface waters reaches sill depth, it will result in "capping off" denser waters at the bottom of inner basins, effectively minimizing deep water exchange. According to this paradigm, renewal of Glacier Bay's subsurface waters via Cross Sound would be highest during the winter when the water is not stratified. However, Hooge and Hooge (2002) argue that deep water renewal is likely to occur during spring flood tides year round, because they observed great tidal input from Cross Sound into Glacier Bay. Deep water from the GOA can reach Glacier Bay via a submarine canyon into Cross Sound and then be advected into Glacier Bay. The East Arm sill appeared to restrict some movements of water in a similar manner, but renewal occurred throughout the year except for short periods. Circulation is strongly affected by cold freshwater influx from tidewater glaciers at the head of the bays. The upper arms of Glacier Bay are cold year round and characterized by a surface lens of less saline water from glacial melting. Upwelling of water from the base of tidewater glaciers may occur, as zones of apparently upwelled water frequently were seen adjacent to the active tidewater glacier faces (Hooge and Hooge, 2002). A proposed mechanism for this upwelling is subsurface melting of tidewater glaciers, which injects low salinity water at depth (Greisman, 1979). This low salinity water rises to the surface, because it is less dense than the water above. Support for this mechanism in the upper reaches of Glacier Bay comes from observations of low-salinity spikes near the bottom of the water column (Hooge and Hooge 2002). Submarine channel underflows may occur where outwash streams interact with large sedimentary deltas during low tide (Phillips and Smith 1988). These channels have been observed in Queen Inlet, and may be present in Riggs Embayment and Wachusett Inlet when sediment rich meltwater becomes denser than saline fjord water and flows underneath (Carlson et al. 1988, Phllips and Smith 1988).

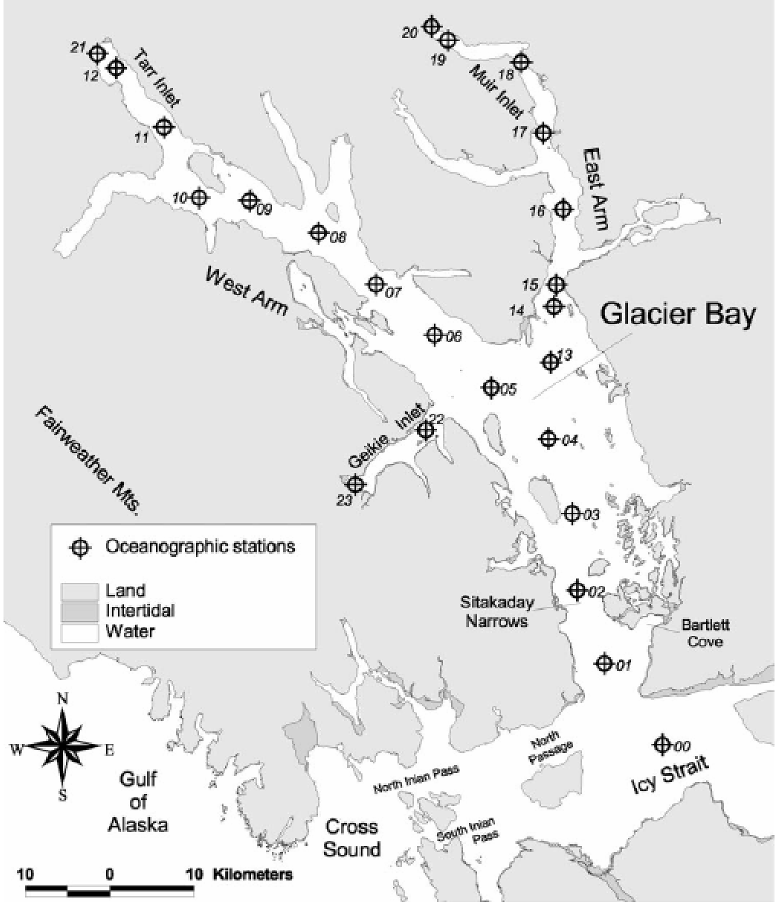

Figure 16. USGS Oceanographic monitoring stations.

A2d3. Patterns of salinity, temperature, density

Hooge and Hooge (2002) measured salinities from 3.8 to 31.9. The least saline waters were found in narrow surface lenses near tidewater glaciers, and the most saline were found at depth near the mouth of the Bay. Measured water temperatures were 1.9 to 12.2 ºC (35 to 54 ºF), with the coldest temperatures at the heads of the two arms and the warmest observed near the mouth. The density anomaly (sigma-t) of the water varied from 2.8 to 25.2 kg/m^3, with the least dense water at the surface near tidewater glaciers, and the densest water at the bottom of the Bay’s deepest basins or at the mouth. Density fluctuations are primarily driven by salinity.

Salinities of the deep basin experienced the least change throughout the year. In contrast, surface waters were much fresher during summer and fall when narrow surface lenses (up to 3m [10 ft] deep) near the glacier are nearly fresh. In winter, surface waters are of similar salinity to deeper waters, generally not below 30. Temperature also varies with season. Depending on the year and location, surface waters warm to greater than 10 ºC (50 ºF) in the summer, then cool again in fall and winter to 3 to 4 ºC (37 to 39 ºF). During late fall/early winter there is a mid-water temperature maximum resulting from downward penetration of the previous summer's warmth, overlain by winter surface cooling. Thus, considerable vertical, horizontal and temporal variations in temperature and salinity are evident.

Density anomalies in January and February are generally higher than 24.5 kg/m^3 in deep basins and higher than 24 kg/m^3 near the surface with little density difference between surface and deep waters at this time. In early spring however, stratification begins and persists through the summer with surface water sigma-t often considerably less than 22 kg/m^3 and deep basin water greater than 24.25 kg/m^3. Density differences between surface and deep waters were also greatest during spring, summer and fall due to freshwater input, however intermediate and deeper waters were fresher in late fall and early winter. Due to interannual variations in surface salinity (and temperature) fluctuations, the onset of stratification varies among years, starting as early as February and as late as April.

A2d4. Patterns of sediment and light penetration

Light penetration is reduced by sedimentation resulting from glacial runoff and by increases in phytoplankton biomass. The factors driving reductions in light penetration are important to understand because the amount of light available impacts phytoplankton production. Turbidity data collected with an OBS (Optical Back Scatter) sensor have been used to evaluate light penetration and to estimate relative sediment loading in Glacier Bay (Hooge and Hooge 2002). Sediment load varied by location and month. The highest OBS values (highest turbidity) were detected immediately adjacent to tidewater glaciers in the upper reaches of both East and West Arms. Multiple tidewater glaciers in the East Arm produced higher turbidity levels along its length than seen in the West Arm. Seasonally the peak of sediment discharge occurred in August and September. October through May exhibited the least sediment discharge with an intermediate level observed during June and July. Similar patterns of sediment loading were seen from Landsat TM images with surface suspended sediments highest in the 2 tributary arms with another peak in the lower Bay extending from Sitakaday narrows into Icy Strait and Cross Sound (Figure 3, Hooge and Hooge 2002).

Photosynthetically Active Radiation (PAR) generally penetrated to greater depths further from tidewater glaciers, though high current areas also sometimes exhibited rapid light attenuation. In summer the 1% light level would be as shallow as 1 m (3.3ft) immediately adjacent to tidewater glaciers, but usually was between 8-15 m (26-50 ft) in the central Bay. In winter, PAR penetrated to slightly greater depths with the 1% light level usually between 15-20 m (50-66 ft) (Hooge and Hooge 2002).

A2d5. Nutrients, phytoplankton and zooplankton

Phytoplankton is routinely monitored by the USGS/NPS oceanographic monitoring program using an *in situ* fluorometer, which provides an estimate of chlorophyll a and serves as a proxy for phytoplankton biomass; however readings may be unreliable in areas of high glacial sediment load. Fluorometer readings increase in March, remain at relatively high levels into the fall (Hooge and Hooge 2002, Etherington et al. 2004), and are highest in the central Bay and lower East and West Arms, although distributions are temporally and spatially patchy (Hooge and Hooge 2002, Etherington et al. 2004). Discrete water sampling from 2004 shows a similar pattern in chlorophyll a abundance (Figure 17, Eisner 2005). Stability due to stratification of the water column, light availability due to reduced sediment concentrations, and nutrient availability likely contribute to high fluorometer readings and high chlorophyll a levels (Etherington et al. 2004). Historic nutrient data are quite sporadic with only one sampling program with a limited spatial coverage conducted in 1967 (Chang 1971). Data from July 1967 indicate that a nutracline was present at ~ 10 –20 m (~30-60 ft) depth at stations in lower and upper Glacier Bay (Hale and Wright 1979). If limitation does occur, then nitrogen is likely to be the limiting nutrient with depletion in surface waters possibly occurring during periods of highest phytoplankton abundance in May or June (Hale and Wright 1979). Hooge and Hooge (2002) postulate that the sustained high phytoplankton biomass observed from spring through fall relies on high and continued nutrient availability, however data to support this theory are needed. Discrete water samples for chlorophyll a, nutrients (ammonium, nitrite + nitrate, orthophosphate and silicate) and phytoplankton taxonomy along with vertical profiles of CTD, fluorometry, turbidity and PAR were collected at 23 stations (3 depths) throughout Glacier Bay in a preliminary study in July and and August 2002 (L. Eisner, NOAA Auke Bay Lab., personal communication, 2005). This preliminary data shows high spatial variability in nutrient distributions. Nutrient samples were collected in 2004 at 87 stations; however these data are still being processed (L. Eisner, NOAA Auke Bay Lab., personal communication, 2005). Future sampling and analyses are needed to determine the inter-relationship between nutrients and phytoplankton biomass. Analyses are also needed to calibrate the *in situ* fluorometric measurements with discrete chlorophyll a samples, so that phytoplankton biomass (i.e. chlorophyll a) can be adequately estimated from vertical fluorescence profiles.

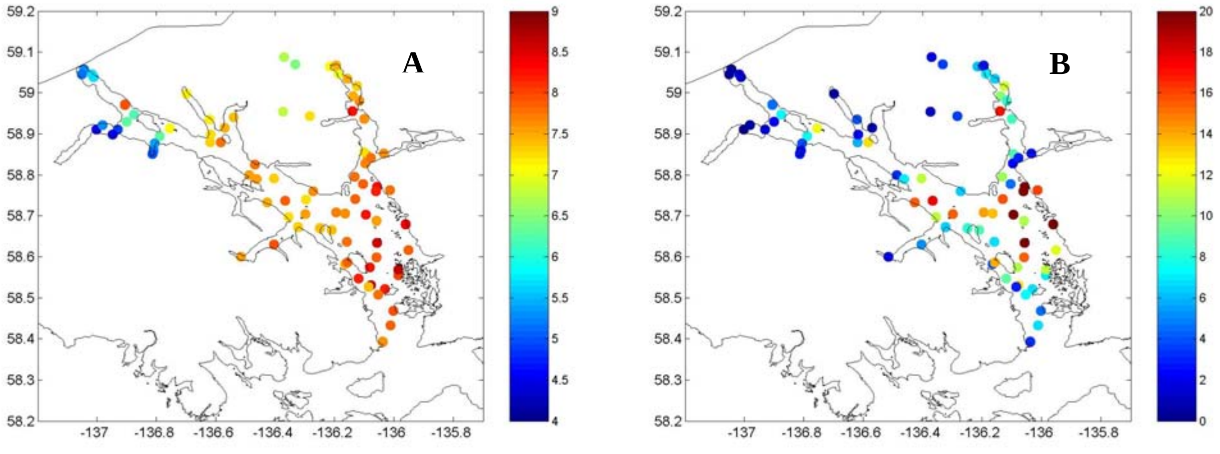

Figure 17. A. Temperature (ºC) and B. chlorophyll a (µg per L) in late June and July 2004 X axis is latitude (ºN) and Y axis is longitude (ºW) from Eisner (2005).

Zooplankton surveys indicate rich productivity in a variety of locations within Glacier Bay, particularly in upper inlets with and without tidewater glaciers and near river and stream outlets (Robards et al. 2003). Copepods, euphausiids, chaetognaths and various meroplankton (larval invertebrates) dominated zooplankton samples, while juvenile pollock, capelin and slender eelblenny dominated ichthyoplankton samples (Robards et al. 2003). Small schooling fishes and zooplankton prey aggregated in a few discrete areas with 8% of the survey area containing patch densities suitable for marine birds and mammals, and in fact, piscivorous and surface-feeding marine birds were often associated with high-density patches of prey (Robards et al. 2003). Epibenthic and planktonic invertebrates were found to occur in remarkably high densities in areas proximal to McBride and Riggs Glaciers, a pattern that is likely established by tidal currents and meltwater-driven upwelling and therefore may occur in other ice-proximal areas (Simenstad and Powell 1988).

A3. Biological Resources

A3a. Marine

A3a1.Marine Mammals

Humpback Whales (Megaptera novaeangliae)

Humpback whales are endangered; however they are a common species in northern Southeast Alaska where they feed during the spring, summer and fall. The NPS, in cooperation with whale researchers, has monitored humpback whale populations and investigated vessel interactions, reproductive parameters and feeding behavior in GLBA since 1985 (e.g., Krieger and Wing 1986, Baker and Herman 1989, Baker et al. 1992, Erbe 2003, Doherty and Gabriele 2004). Humpback whales are distributed throughout Glacier Bay, but are most common in the central and lower Bay (Figure 18, Doherty and Gabriele 2004). The number of whales documented in recent years in Glacier Bay has increased (Figure19, Doherty and Gabriele 2004) and the Central North Pacific population is estimated to be increasing at a rate of 7% per year (Mobley et al. 2001).

Killer Whales (Orcinus orca)

Three ecotypes of killer whales have been documented in Southeast Alaska, including Glacier Bay: residents, transients and offshores. Residents eat fish (Ford et al. 1998, Saulitis 2000) and form stable social groups. Transients eat marine mammals and birds (Ford et al. 1998, Saulitis 2000) and form smaller and less stable social groups. Offshores are seen infrequently and their diet is unknown. Deecke et al. (2001) have studied vocalizations in both residents and transients in Glacier Bay. Glacier Bay is a particularly good place to study transients because of the abundance of killer whales that come regularly in May and June to feed on harbor seals which have hauled out on ice for pupping (Matkin 1990, Matkin and Dahlheim 1995). Matkin et al. (2004) have studied killer whale interactions with other marine mammals and photo-identified killer whales in Glacier Bay since the early 1990s.

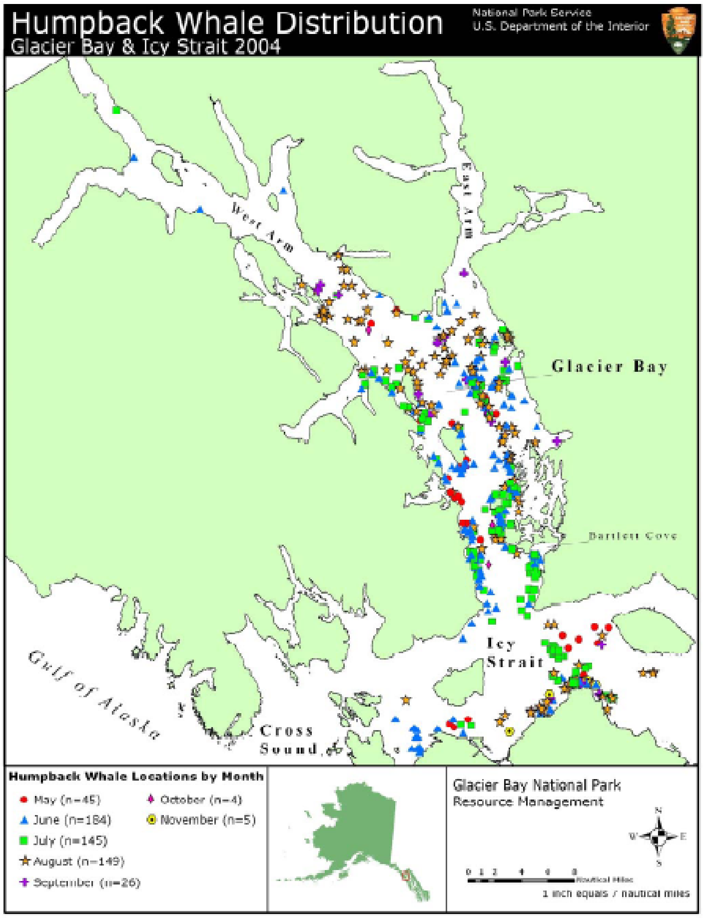

Figure 18. Humpback whale distribution and abundance in Glacier Bay in 2004 (Doherty and Gabriele 2004)

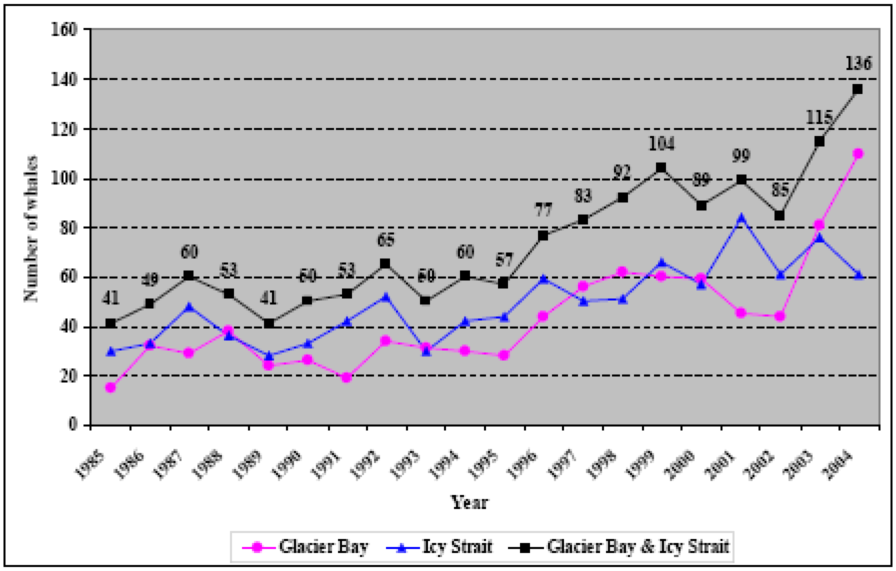

Figure 19. Number of individual whales in Glacier Bay and Icy Strait, 1985-2004 (Doherty and Gabriele 2004).

Harbor Seals (Phoca vitulina)

Harbor seals maintain a breeding colony in Johns Hopkins Inlet at the tip of the west arm of Glacier Bay (Mathews 1995, Mathews and Kelly 1996). In addition, about 20 tidally influenced terrestrial sites in Glacier Bay are used as resting areas during the breeding and molting seasons (Mathews and Pendleton 2006). August counts of adult seals at the Johns Hopkins colony demonstrated declines, up to 10% per year on average from 1992-2002, although the number of pups at this colony was constant from 1994-1999 (Figure 20, Mathews and Pendleton 2006). Numbers of seals on terrestrial haulouts showed a more severe decline of 14.5% per year from 1992-2001 (Figure 20, Mathews and Pendleton 2006). Pelagic surveys have also found declines of harbor seals (Robards et al. 2003). Hypothesized causes of declines include interspecific competition (Mathews and Pendleton 2006) and predation by sleeper sharks (Taggart et al. 2005) and killer whales (Matkin and Dalheim 1995), contaminant load, disease, and altered prey base, among others. Blundell and Gende (2004) are studying reproduction, survival, and behavior of harbor seals in order to better understand the ecology and decline in the Glacier Bay population.

Steller Sea Lions (Eumetopias jubatus)

Steller sea lions (*Eumetopias jubatus*) are federally-listed as endangered west of Cape Suckling due to declining populations throughout the western Gulf of Alaska and Bering Sea regions (Sease and Loughlin 1997, Gelatt et al. 2004). Sea lions from both stocks have been documented in GLBA. The eastern stock in Southeast Alaska is currently stable (Calkins et al. 1999) and listed as threatened (Gelatt et al. 2004). Sea lions haul out on South Marble Island, Graves Rocks in Dry Bay and along the coast just south of Lituya Bay (all within GLBA), and the NPS imposes a restriction on boaters to remain 100 yds (91 m) offshore of any hauled out sea lion. Graves Rocks is also a small rookery, where pupping occurs. Alaska Department of Fish and Game (ADFG) brands pups at rookeries, and then surveys sea lion haulouts and rookeries regularly to study movements and survival of individuals and population productivity. In recent years, ADFG biologists have collected scat samples (including within GLBA) to compare diets between western Alaska and eastern Alaska stocks (Gelatt et al. 2004)

Sea Otters (Enhydra lutris)

Sea otters have undergone a dramatic increase within Glacier Bay in the last decade. Sea otters began recolonizing Glacier Bay in 1993, and populations soared from five otters in 1995 to over 1200 in 2002 (Figure 21, Bodkin et al. 2002) with an abundance of pups, indicating successful immigration and reproduction within the Bay. The majority of sightings in Glacier Bay proper are in the lower and mid bay. Sea otters in Glacier Bay forage on a variety of species, mostly invertebrates and predominantly clams, mussels, urchins and crabs (Bodkin et al. 2002). This sea otter colonization will have large effects on community structure of nearshore marine communities because many otter prey items are themselves key species structuring communities and habitats.

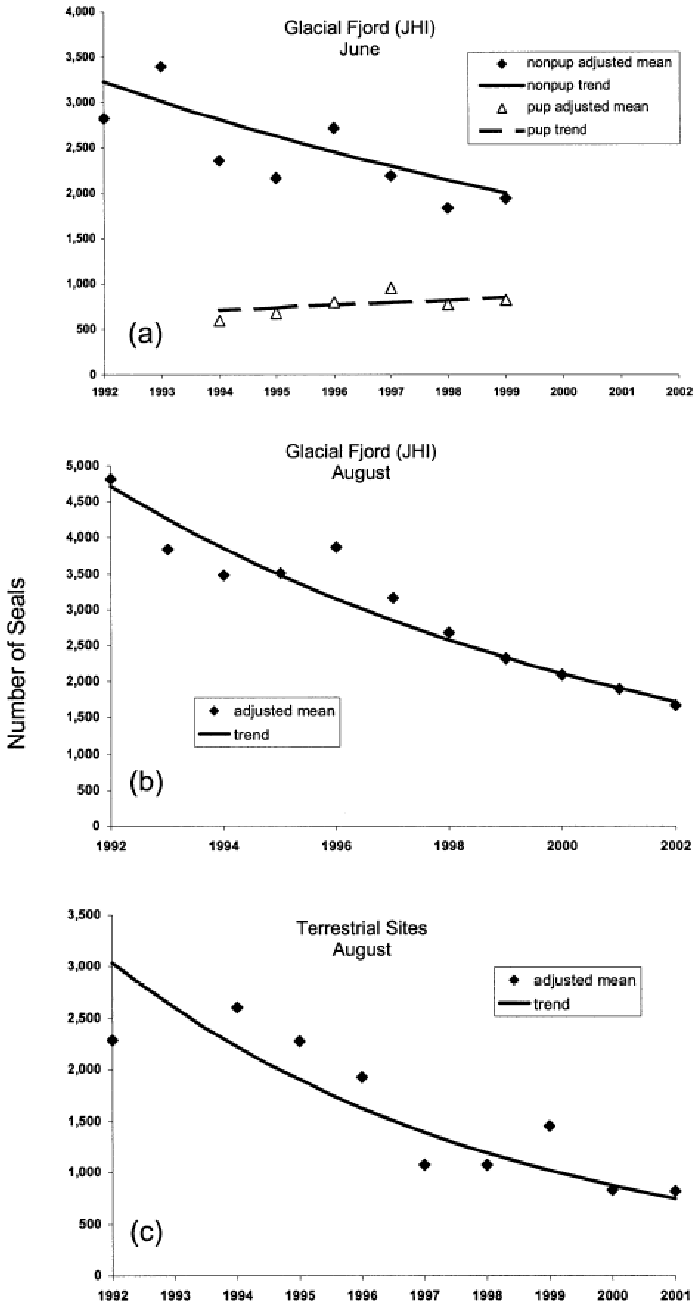

Figure 20. Harbor seal population decline in GLBA.
Population trajectories (lines) and adjusted mean counts (symbols) for harbor seals in Johns Hopkins Inlet, a tidewater glacial fjord (a) for non-pups (diamonds) and pups (triangles) during June 1994–1999.. From Mathews and Pendleton 2006.

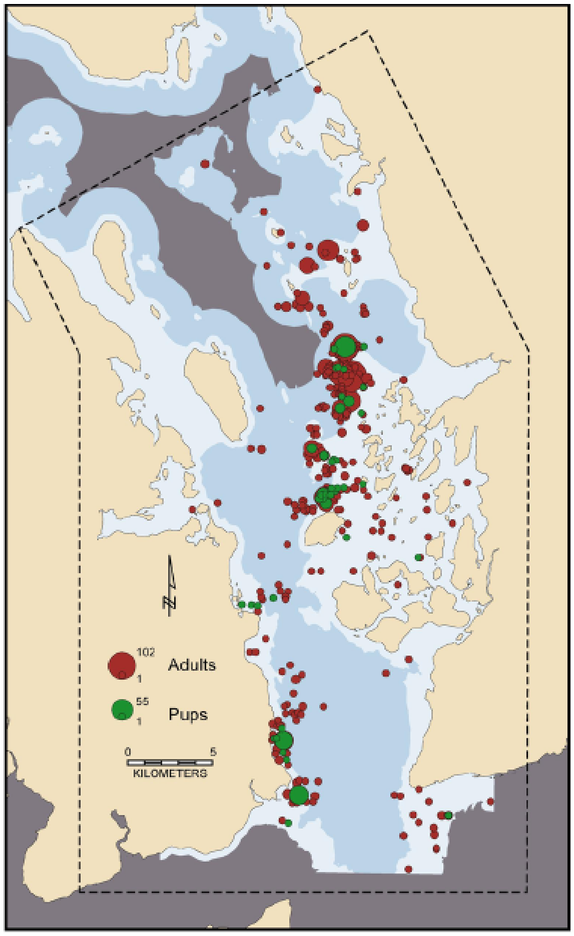

Figure 21. Distribution and abundance of sea otters in lower Glacier Bay based on aerial surveys in May 2002 (Bodkin et al. 2002). Spot size is proportional to group size. Note that in 1995 only 5 otters were observed in the Bay and over 1200 were counted in 2002.

Other Marine Mammals

In addition to the species described above, harbor porpoises (*Phocoena phocoena*) are regularly observed in or adjacent to GLBA (Gabriele and Lewis 2000, Robards et al. 2003). Minke whales (*Balaenoptera acutorostrata*) are less frequent, with only 29 individuals sighted from 1994-1999 (Gabriele and Lewis 2000). Dall's porpoises (*Phocoenoides dalli*) are infrequent and were only observed three times from 1994-1999 (Gabriele and Lewis 2000). There was one sighting of a gray whale in Glacier Bay proper from 1994-1999 (Gabriele and Lewis 2000).

A3a2. Fishes

Fish diversity in GLBA is very high. An inventory of marine and estuarine fishes was completed for both Glacier Bay proper and GLBA outer coast waters using mid-water trawls, bottom trawls, herring trawls, and beach seining (Litzow et al. 2002, Arimitsu et al. 2003). Armitsu et al. (2003) captured 100 species in GLBA and combined their data with historical records to generate a fish species list with 160 species (Appendix 1). Glacier Bay is an important nursery area for fishes and may be a spawning location for several key forage species, including capelin, sand lance, walleye pollock and herring (Robards et al. 2003). Robards et al. (2003) document spatial and temporal variation in fish abundances in pelagic and nearshore areas of Glacier Bay, most notably they found high fish densities in close proximity to tidewater glaciers and streams. The distribution and abundance of halibut were studied by USGS researchers, who found year to year site fidelity and no relationship of halibut abundance to depth nor proximity to tidewater glaciers (Mondragon et al. 2004a). NPS has collected information on sport harvest catches of halibut and salmon within GLBA, however to date, resources have not been sufficient to analyze the data (Chad Soiseth, NPS-GLBA, personal communication, 2005). Although adult salmon spend most of their lives in marine waters, they are predominantly studied in freshwater. See *A3d. Freshwater biological resources* for more information on salmon.

A3a3. Marine-associated birds

Glacier Bay provides important habitat for many marine-associated birds, with species composition shifting from predominantly seabirds in the summer to predominantly waterfowl in the winter (Robards et al. 2003). Summer residents include black-legged kittiwake, common mergansers, and murrelets that use the Bay as reproductive habitat (Robards et al. 2003). Winter residents include Barrow's goldeneye, mallard, and northwestern crow (Robards et al. 2003). All bird species observed during Robards et al. (2003) surveys are included in Appendix 2. In 2004, shore surveys were conducted to locate, identify, and map coastal marine bird nesting sites in order to determine impacts of visitors on nesting behavior and success (M. Arimitsu, USGS, personal communication, 2005; Arimitsu et al 2004). Some species of marine birds have been declining in Glacier Bay, including Kittlitz's and marbled murrelets (Robards et al. 2003), which have been declining throughout Alaska (van Vliet 1993, van Vliet and McAllister 1994, Piatt and Naslund 1995). There is particular concern about Kittlitz's murrelets due to declines throughout their range and because so little is known about their behavior and life history. Glacier Bay may include critical habitat for this species (Romano et al. 2004).

A3a4. Invertebrates

Tanner (*Chionoecetes bairdi*), Dungeness (*Cancer magister*), and king crabs (*Paralithodes* spp.) are abundant and were or are commercially fished in GLBA (see *A1b. History and Human Utilization*). Abundance and distribution of Dungeness crabs was surveyed in 1999 by USGS, and adult Dungeness crabs were most abundant in lower Bay within 40 km (25 mi) of the mouth (Taggart et al. 2003). The mean number of Dungeness crabs per pot was 32 times higher in the lower Bay than in the upper Bay; however a few large adult males were found in the upper arms, indicating that adult crabs could tolerate environmental conditions there and that their restricted distribution was likely a result of lack of larval supply or intolerance of early juvenile stages to environmental conditions (Taggart et al. 2003). Recent research on these species has focused on distribution and abundance and effectiveness of Glacier Bay as a marine reserve for these species (Andrews et al. 2004, Eckert et al. 2004, Fisher 2004, Mondragon et al. 2004b, Nielsen et al. 2004, Park et al. 2004, Taggart et al. 2004). Male Dungeness crabs increased in relative abundance and size after fishery closure in Glacier Bay proper (Taggart et al. 2004). Larvae emigrate out of the Bay during development and return when they are ready to settle, which indicates that protecting the adults may not protect the next generation (Fisher 2006, Eckert and Herter 2006).

Intertidal clam density, biomass, and species composition was surveyed at 59 sites in Glacier Bay in order to determine if sea otter presence affected intertidal clam populations (Bodkin et al. 2001). Clam density and biomass were higher in lower Bay sites than in either the west or east arms, presumably because of differences in sediment sizes (Figure 22, Bodkin et al. 2001). No direct effects of otter foraging were detected.

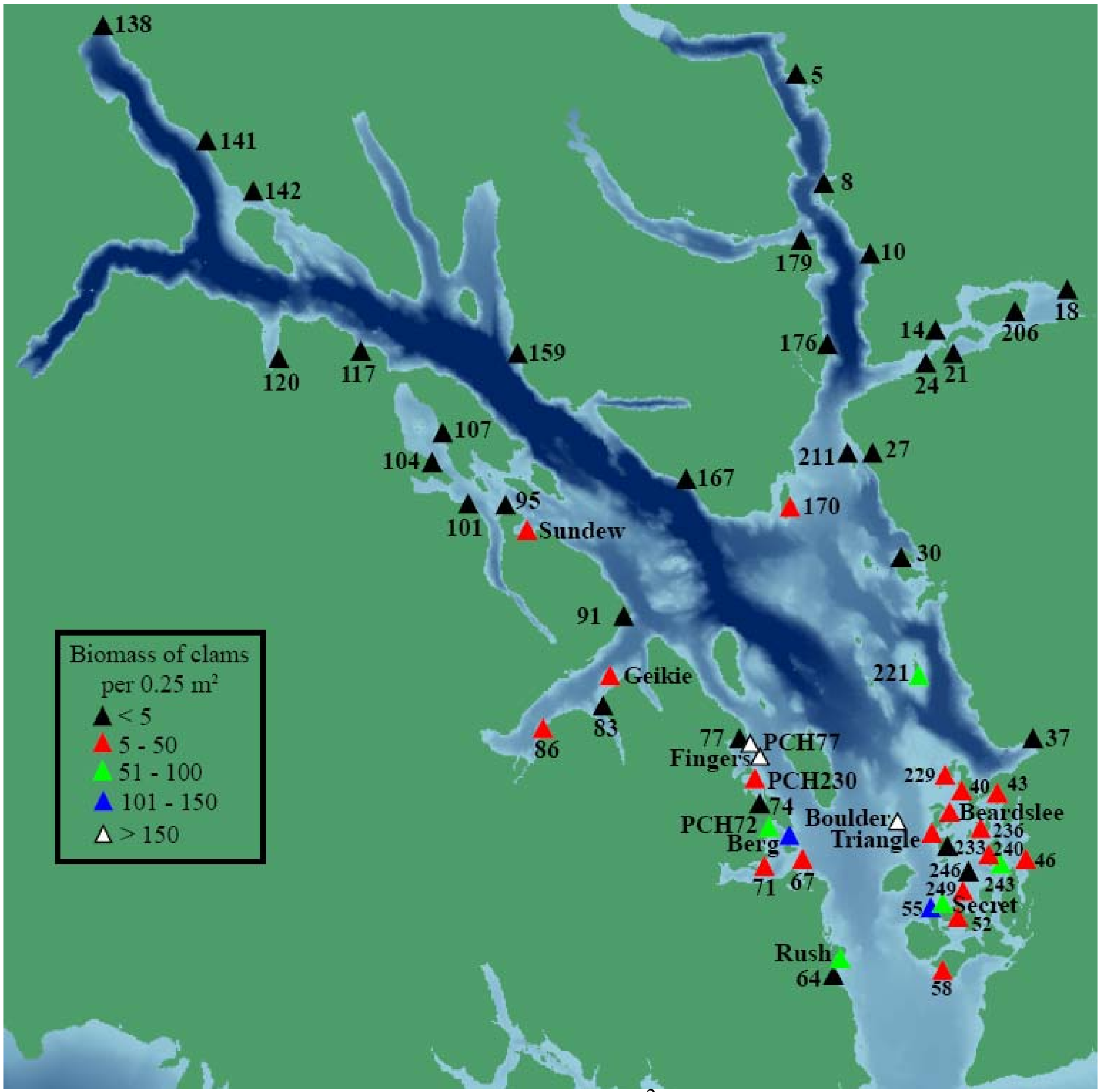

Figure 22. Biomass (g dry wt) of clams per 0.25 m^2 in GLBA
From Bodkin et al. (2001).

A3b. Intertidal

A detailed description of the rocky intertidal community found at Dixon Harbor and Torch Bay along the outer coast is found in Streveler and Worley (1975). The intertidal community in Bartlett Cove is described by Duggins and Quinn (1979). Community development in the marine rocky intertidal following glacial recession is described in Sharman (1988). Marine intertidal species richness increases with substrate age and distance from tidewater glacier termini (Sharman 1988). Reciprocal transplant experiments demonstrate that these differences are likely the result of strong gradients in the physical environment, predominantly in water clarity, temperature, and salinity (Sharman 1988).

An intertidal monitoring program was established by USGS and NPS in 1997 in recognition of the potential for natural and human-induced changes to intertidal communities. Effort was concentrated in Glacier Bay proper, which has a coastline of 1,109 km (689 mi) (Irvine 1998). Aerial surveys were conducted of 241 segments, each 200 m long, arrayed systematically along the coast from a random point. Substrate type and the extent of certain common biota (barnacles, mussels, *Fucus*- a brown alga) were estimated categorically from aerial photos. Cobble-boulder was determined to be the most abundant substrate within the Bay. Based on these results, 25 segments of bedrock and/or cobble/boulder substrates were randomly selected for coarse-grained study, while a subset of 6 of these sites were sampled more intensively (Figure 23). The 25 sites were sampled four times over a five year time-span (1997-1999, 2001), and the 6 sites were sampled solely in 1997. The protocol included sampling vertical transects to assess percent cover of dominant species (algae and invertebrates). Coarse-grained sites were sampled using 6 vertical transects, with percent cover sampled at 1 point per m, while the fine-grained sites were sampled using 10 vertical transects, with percent cover sampled at 5 points per m. Survey methods were also developed for mobile species, such as the predatory snail *Nucella lima*. Power analyses conducted on percent cover data for predominant species indicated that sampling more sites in a less intense manner was more effective in detecting change than sampling fewer sites more intensively (Irvine 1998, 2001). This monitoring data will serve as an important baseline to document potential future changes in intertidal areas of Glacier Bay proper. In addition to the monitoring design work, Irvine has conducted several process-oriented studies that should help elucidate the dynamics responsible for changes in intertidal communities, such as studying secondary succession following ice scour at one of the long-term monitoring sites (G. Irvine, USGS-Alaska Science Center, personal communication, 2005).

ShoreZone is a project sponsored by multiple agencies and organizations that conducted aerial surveys of the outer coast of GLBA in 2005 and surveyed other areas of Southeast Alaska in 2004-2005. This project aerially surveyed intertidal and shallow subtidal areas to identify shoreline morphology, substrate, wave exposure, and biota of intertidal and nearshore habitats. This coastal habitat mapping effort produced an online database with interactive GIS layers, digital maps, aerial images and video (http://mapping.fakr.noaa.gov/Website/ShoreZone/). At the time of publication of this report, ShoreZone data layers, video, and photos were not yet available for the GLBA outer coast, but should become available in 2006.

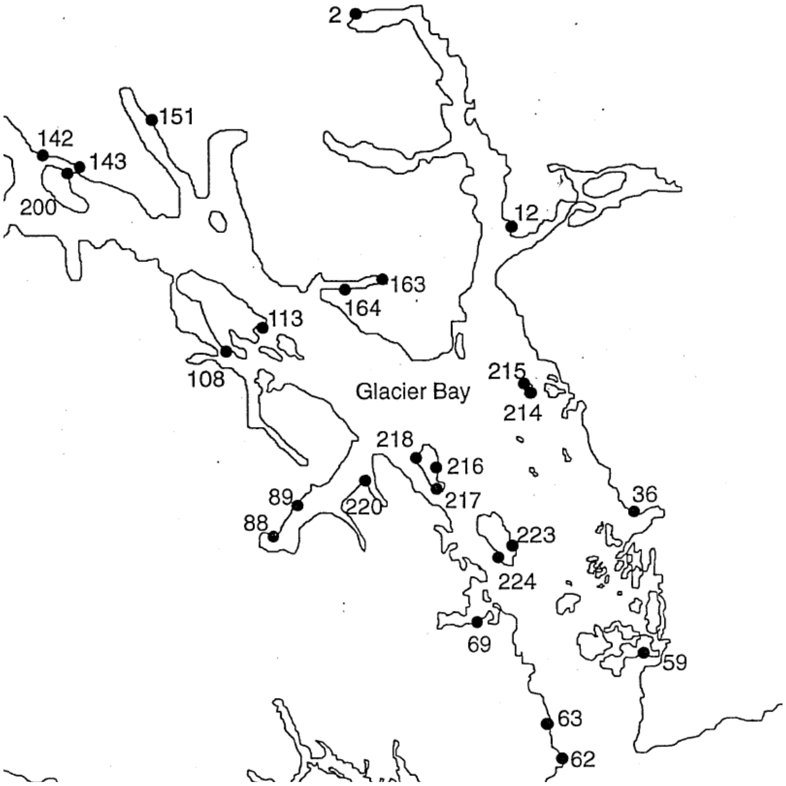

Figure 23. Locations of sites in intertidal monitoring program.
Sites 59, 63, 69, 36, 89 and 217 were selected for fine-grained sampling, and all were selected for coarse-grained sampling (Irvine 1998).

The National Park Service implemented a predecessor to ShoreZone, called the Coastal Resources Inventory and Mapping Program, which collected baseline data on over 1545 km (960 mi) of intertidal coast in GLBA (Sharman et al. 2003). The area inventoried and mapped includes the continuous shoreline from Taylor Bay to the Park boundary in Excursion Inlet, including all of Glacier Bay proper and Dundas Bay, plus the shoreline of Lituya Bay, Dixon Harbor, Torch Bay, Graves Harbor, and Dicks Arm, including all islands within the Park in these areas. This protocol and its resulting GIS layers are used to collect, analyze, and display biological and physical shoreline data. The program uses georeferenced aerial photos along with ground-based observations and photos to categorize and describe surface substrate, record presence or absence of key intertidal flora and fauna, describe vertical zonation patterns in vegetation, identify major stream characteristics, and indicate presence/absence of a variety of special-interest resource attributes such as archeological sites, offshore reefs, kelp beds, clam habitat, urchin recruitment areas, tidepools, seabird colonies, and pinniped haulouts. All of this information is available in a database which can be queried to view graphical summaries of transect data, over 21,000 ground photos, and locator maps. The database is available on DVD. Intertidal resources were mapped (Figure 24), as well as other resources that may be viewed from the intertidal such as streams and offshore kelp (Figure 25). More information about this program can be found at http://www.nps.gov/glba/InDepth/learn/preserve/projects/coastal/

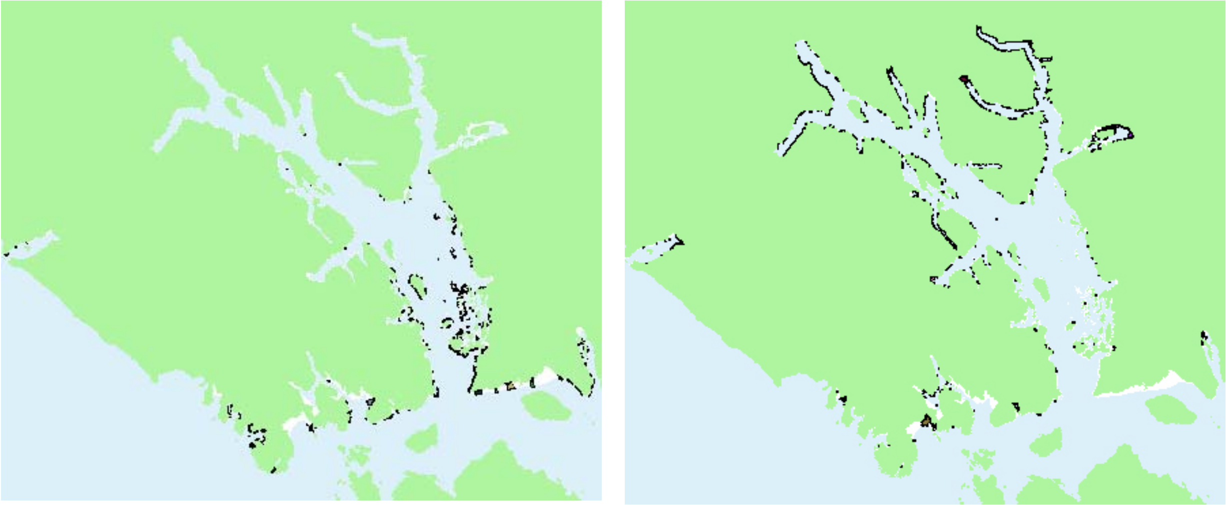

Figure 24. Sample distribution maps from the Coastal Resources Inventory and Mapping Program
Left panel: Intertidal areas with relatively high observed species richness; Right panel: Intertidal areas with relatively low observed species richness. From Sharman et al. (2003)

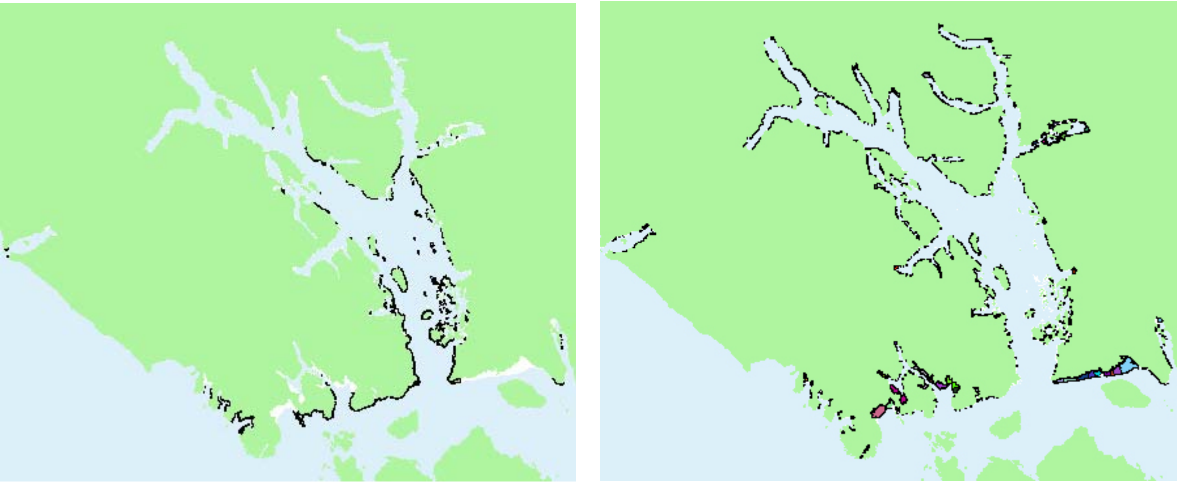

Figure 25 Offshore kelp distribution (left) and locations where streams are present (right) From Sharman et al. (2003)

A3c. Upland

Glacier Bay is well known as a natural laboratory, and starting with John Muir and William S. Cooper, classic studies of ecological succession began in the late 1800s and early 1900s. Vegetation changes along the gradient of glacier recession are well-documented and are classic textbook examples of ecological succession (Figure 26, Cooper 1931, Crocker and Major 1955, Decker 1966, Lawrence et al. 1967, Reiners et al. 1971, Chapin et al. 1994). Four major successional stages occur in Glacier Bay. The first, pioneer community consists of crusts of blue-green algae, liverworts, and lichens, which increase in vascular plant cover as they age, including horsetail (*Equisetum variegatum*), forbs, *Dryas drummonii*, willows (*Salix* spp.), and cottonwood (*Populus trichocarpa*) seedlings. The pioneer community exists for the first 20-30 years and shifts to a community dominated by *Dryas* mats. Alder (*Alnus* *sinuata*) replaces *Dryas* after approximately 50 years and forms dense thickets. Spruce (*Picea sitchensis*) replaces alder within 100 years and develops into mature forest along with western hemlock (*Tsuga heterophylla*) and mountain hemlock (*Tsuga mertensiana*). Eventually, spruce-hemlock forest is replaced by a *Sphagnum*-dominated muskeg; however that stage is rare in Glacier Bay proper because of the steep terrain and recent glaciation.

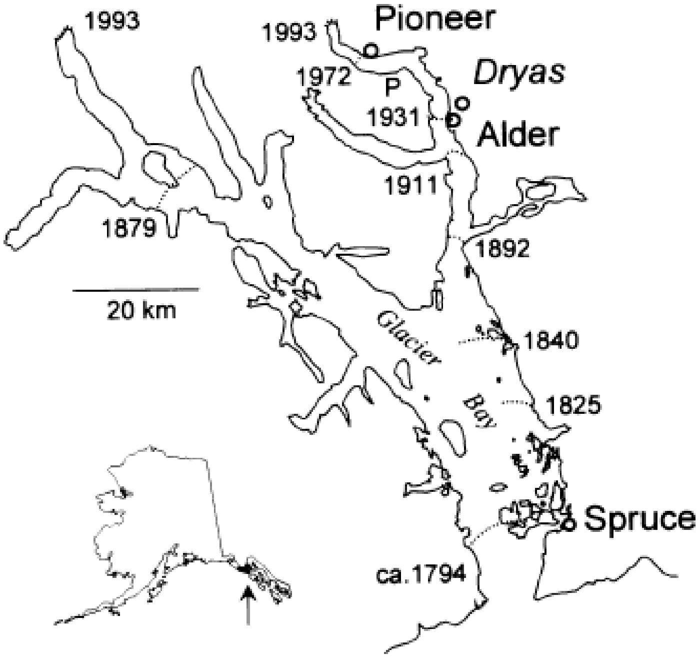

Figure 26. Location and chronosequence of glacial retreat along the east arm of Glacier Bay with successional communities indicated (Chapin et al. 1994).

A3d. Freshwater

The biological development of young streams in GLBA formed in response to glacial retreat has been studied extensively. Previous research on glacial stream ecosystems includes: macroinvertebrate succession (Milner 1987, Milner 1988, Milner 1993, Milner 1994, Robertson and Milner1999, Milner et al. 2000, Flory 2000, Robertson and Milner 2001), succession effects on streamwater chemistry (Stottlemyer 1988) and stream geomorphology (Sidle and Milner 1989), salmonid colonization (Milner and Bailey 1989), and soil, microbial, and vegetative succession patterns following deglaciation in watersheds (Cooper 1931, Crocker and Major 1955, Crocker and Dickson 1957, Lawrence et al. 1967, Hitchcock and Cronquist 1973, Binkley 1981, Stottlemyer and Rutkowski 1987, Chapin 1994, Fastie 1995, Hobbie 1998, Bardgett and Walker 2004). The youngest and most rapidly developing streams are those closest to glaciers. These stream systems are constantly changing and are characterized by high rates of sediment transport, variable flows, high turbidity, and poor-quality salmonid habitat (Soiseth and Milner 1993). GLBA has also been the site of several investigations of lake evolution; with specific focus on limno-terrestrial connections in the control of lake development (Engstrom and Fritz 1988, Fritz and Engstrom 1993), on chemical and biological trends during lake evolution (Engstrom et al. 2000, Fritz et al. 2004), and on aquatic community colonization (Olson et al 1993).

Milner et al. (2000) conducted a study of 16 streams in the Park that ranged in age from 36 to 1377 years since deglaciation. These streams were described as having <5% gradients in the lower reaches, no barriers to salmonid migration, and watershed sizes that range from 10 to 100 km^2 (4 to 40 mi^2). Milner et al. (2000) demonstrated that the successional development of plant and animal communities in streams is closely connected with the growth and maturation of adjacent terrestrial plant communities. Biological development in streams advances after stream sediment load is decreased, stream temperatures rise, and flow rates become less erratic—processes that accelerate when there are upstream lakes that can temper flow rates and sediment inputs (Milner 1997). Stream invertebrates colonize streams after dissolved organic carbon inputs by colonizing stream bank vegetation reach adequate levels. As plant succession continues, woody debris may accumulate in streams, providing shelter for fish and promoting colonization by anadromous salmonids (Milner et al. 2000).
Most freshwater fishes in GLBA are anadromous, and thus freshwater ecosystems are important for these species. A majority of the streams in GLBA contain spawning and rearing salmon, even those streams directly under glacial influence. Still, more salmon travel through GLBA's marine waters than spawn in its streams. The streams in GLBA that provide important salmonid habitat are those that have the right quality and quantity of water because salmon distribution is closely related to stream water velocity and turbidity (Murphy et al. 1989).

The Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes (Johnson and Weiss 2006) 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 Alaska. According to this catalog, the Alsek River contains all 5 species of Pacific salmon, Dolly Varden, and steelhead trout. Other major rivers with anadromous fish in the western portion of GLBA include the Dixon River, which is listed as having coho salmon; and the Dundas River, with sockeye, coho, pink, and chum salmon, and Dolly Varden. Also in the western portion of GLBA, South Trick Lake near the Brady Glacier is documented as hosting chum salmon. On the east side of Glacier Bay, the Beartrack River has pink and chum salmon, and Dolly Varden; the Bartlett River contains sockeye, coho, pink, and chum salmon, Dolly Varden, and steelhead trout; and the Excursion River hosts coho and chum salmon and Dolly Varden (Johnson and Weiss, 2006). Information on species presence in numerous other streams in GLBA 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). The National Park Service also maintains a relational database containing physical characteristics (i.e., location, stream length, watershed size, gradient, stream order, etc.) for the more than 300 streams within the park plus known fish species observations for each stream where these data exist. However, comprehensive fish species presence and distribution among park streams are not well known because many systems have not been intensively sampled (Chad Soiseth, NPS- GLBA, personal communication, 2006). Moreover, stream-specific estimates of run timing and relative abundance are lacking.

The maintenance of healthy salmon stocks and appropriate fish passage throughout coastal streams and rivers in southeast Alaska is important not only for fisheries resources but also because spawning salmonids have significant impacts on biological resources in both terrestrial and freshwater ecosystems (Gende et al 2002). When salmon return to their natal streams to spawn, they transport marine nutrients and energy from the ocean to freshwater systems. On the spawning reaches, the carcasses, eggs, and metabolic waste products contain nutrients that are made accessible to components of the freshwater and terrestrial biota via a variety of mechanisms and pathways (Willson et al. 1998, Cederholm et al. 1999, Johnston et al. 2004). These nutrients can be important in the overall health of coastal watersheds (Bryant and Everest 1998) and may influence productivity (Wipfli et al. 1998, Chaloner and Wipfli 2002). In particular, the seasonal pulse of salmon carcasses can dramatically elevate streamwater nutrients levels (Mitchell and Lamberti 2005) and thereby affect 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. 2004). 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 2001). Finally, salmon can also influence streambed morphology and associated invertebrate communities during spawning activities (Moore and Schindler 2005). These findings highlight the ecological importance of salmon in coastal ecosystems and suggest that fisheries management decisions related to salmon have the potential to affect biological resources within GLBA.

Two species of amphibians occur or were observed in GLBA. The western toad (*Bufo boreas),* has been documented in a variety of habitats and elevations from sea level to 1000 m (3280 ft) within GLBA. They have been observed in austere, recently glaciated environments and in the intertidal zone, both of which are unexpected (Anderson 2004). Western toads are common in the Bartlett Cove area and few surveys have been conducted in other areas, with the exception of museum speciments collected from the Dixon River on the outer coast in 1974 (Anderson 2004). Anderson (2004) documented breeding areas in 2002 and 2003 and inventoried 17 adults in 2001, 8 in 2002, and 13 in 2003. Populations may be declining; however there are not currently sufficient data to support this supposition. The dynamic nature of the landscape in GLBA due to post-glacial uplift may reduce wetland spawning habitat for amphibians (Anderson 2004). Amphibians from old-growth glacial refugia in GLBA may prove to be genetically unique (Anderson 2004). There is a single unconfirmed observation of a northwestern salamander (*Ambystoma gracile*) in a stream in Graves Harbor on the outer coast in 2000 (Anderson 2004). Moreover, two adult wood frogs were observed along the Tatshenshini River 15-20 km upstream of the Preserve boundary in 1994 data (Chad Soiseth, NPS- GLBA, personal communication, 2006). Anderson (2004) concludes that the Columbia spotted frog (*Rana pretiosa*), wood frog (*Rana silvatica*), and the rough-skinned newt (*Taricha granulosa*) are probably present although they have not been observed inside GLBA boundaries.

B. Water Resources Assessment

B1. Water Quality

Water quality within GLBA has been studied in few locations and with little temporal consistency. Based on these limited data sources, water quality in GLBA is generally considered to be of high quality, with some comparatively small and localized areas of impairment, both natural and anthropogenic.

The most comprehensive source of information on surface water quality in GLBA is a 1995 Baseline Water Quality Data Inventory and Analysis Technical Report (NPS 1995). This report is based on an exhaustive compilation of all water quality records for water resources within the park plus a buffer zone of 4.8 km (3 mi) upstream and 1.6 km (1 mi) downstream of park boundaries, through the early 1990s. Data searches were conducted using five US EPA national databases: Storage and Retrieval (STORET) database management system; River Reach File (RF3); Industrial Facilities Discharge (IFD); Drinking Water Supplies (DRINKS); and Flow Gages (GAGES). The results of the NPS (1995) data retrieval included the identification of one industrial discharger (Excursion Inlet Packing Co., which is outside the GLBA boundary) and no drinking water intakes. Five water quality stations within GLBA were identified as being in operation sometime between 1963 and 1993:
1) Alder Creek near Glacier Bay Lodge (51 observations, between 1963-1968);
2) Wolf Creek near Gustavus (23 observations, all in October 1967);
3) Tributary to Wolf Creek near Gustavus (23 observations, all in October 1967);
4) Sandy Cove Creek near Gustavus (22 observations, all in September, 1967);
5) Alsek River near Yakutat (311 observations, all between 1991 and 1993).
Data at these stations and 2 outside the GLBA boundaries were collected by the US Forest Service and US Geological Survey, and a total of 468 observations for 96 separate parameters were measured.

Comparisons to EPA and Water Resources Division (WRD) water quality criteria found turbidity in the Alsek River exceeded the WRD screening limit of 50 FTU for the protection of aquatic life two of the seven times it was measured between 1991 and 1993 (NPS 1995). (Please see section *B1a3* below for more information regarding Alsek River water quality.) No other water quality violations were reported in NPS (1995). However, the study concluded that potential future sources of contamination to GLBA surface waters include glacial meltwater sediments, park development (parking lots, roads, and utilities), mining claims, and boating.

The paucity of water quality data as of 1993 is striking, even for "Level I" parameters, which are those considered to be of highest priority and include pH, dissolved oxygen, alkalinity, temperature, flow, conductivity, turbidity, rapid bioassessment baselines, nitrate-nitrogen, phosphate-phosphorus, sulfates, and toxic elements (NPS 1995). Only 7-45 observations for each these parameters were made between 1963 and 1993, according to NPS (1995). However, the NPS (1995) study did not include several studies that provide some water quality data within GLBA prior to 1993. These studies include: Letarte and Stottlemyer (1984), Sidle and Milner (1989), Stottlemyer (1988), and Stottlemyer (1989). Since the publication of the NPS (1995) study, several other water quality investigations have been conducted on specific streams (see section B1a) and lakes (see section B1c.) within GLBA. Letarte and Stottlemyer (1984) present the baseline stream water chemistry of 4 GLBA streams (Berg Bay South, Ice Valley, Nunatak Creek, and Wolf Creek) and more limited (single-event) sampling on several others (Dundas River, Old Dundas River, Alsek River, East Alsek River, Dog Salmon River, Vivid Lake, Reid Stream, and Ptarmigan Creek)

(Letarte and Stottlemyer 1984). Results of this showed that all streams were well-buffered and that the most recently deglaciated sites have the highest Ca, Mg, and HCO_3^- (alkalinity) concentrations. The authors made some comparisons of the water quality in GLBA to streams in the lower 48. Nitrate concentrations were very low (>9 times lower) compared with sites in New England and the Great Lakes Region, and in general, cation concentrations were comparatively high and anion concentrations comparatively low. While the authors provide figures that show the range of chemical variation at their sample sites (e.g.: cations ranged from 600-2600 μeq/l; anions from 450-2400 μeq/l, and alkalinity 400-2600 μeq/l), stream-specific and parameter-specific data tables are not provided. As a result, a very limited amount of chemical information is available through the study.

Sidle and Milner (1989) focused primarily on the development of stream geomorphic characteristics (e.g. stream width and depth, floodplain and streambank stability, gravel bar dynamics, and pool development) in five streams (Wolf Point Creek, Nunatak Creek, Ice Valley, Berg Bay South, and Berg Bay North) along a deglaciation chronosequence within GLBA. As part of this study, they measured total suspended solids (TSS) and turbidity in the streams and described their seasonal variations. In all streams except the most glaciated one (Wolf Point Creek) TSS levels during baseflow conditions (streamflow <2 m^3/sec) were similar in magnitude (1-8 mg/L). When flow exceeded 2 m^3/sec, TSS levels increased to 18-35 mg/L in these streams, but only in the springtime. By contrast, in Wolf Point Creek TSS levels were higher during summer and autumn baseflows (103-111 mg/L), compared with winter and spring (3.4-31 mg/L). This is attributed to the increased glacial melting and associated silt supply during the summer and autumn. Log TSS versus log discharge were positively and significantly ($p<0.05$) correlated ($r^2=0.54-0.89$) at 4 of the 5 streams. Log TSS and log turbidity were also well correlated ($r^2=0.77$). Data values are presented in graphical instead of table formats, and so exact values cannot be extracted from the paper. However, 8 turbidity measurements in the 5 streams appear to have measured between ca. 700-1200 NTU, which is far higher than the maximum of 440 NTU detected in the Alsek River by the USGS before 1993 and above the state water quality limit of 50 NTU (Appendix 3). Nonetheless, it must be considered that these water quality violations are products of natural processes relating to glacial melt. Based on the conclusions of Sidle and Milner (1989), as glaciers continue to recede in GLBA, the sediment supplies to streams can be expected to decrease in magnitude over time and their flux through the streams to shift toward occurring dominantly during spring thaws instead of during summer and autumn.

Stottlemyer (1988) and Stottlemyer (1989) evaluated soil chemistry in 5-6 post-glacial variable-aged watersheds in GLBA and traced the evolution of floodplain soil chemistry with vegetative establishment and related it to stream chemistry. In early successional stages of soil and vegetative development in the watersheds, both sulfate and nitrate concentrations were high in streamwaters relative to precipitation (Stottlemyer 1989). Nitrogen fixation by Sitka alder (*Alnus sinuata*), which dominates the early- successional terrestrial vegetation, appeared to exceed biotic uptake, resulting in excess nitrogen releasing through soils and reaching streamwaters (Stottlemyer 1989). Streamwater sulfate concentrations also exceeded concentrations in precipitation, suggesting mineralization of sulfur within the ecosystem. Stottlemyer (1989) concluded that early successional ecosystems in GLBA may be particularly sensitive to anthropogenically-enhanced atmospheric inputs of nitrate and sulfate, due to the low adsorption capacity shown in soils and floodplains in the recently deglaciated stream valleys of GLBA.

Water quality in the Lituaya Bay region was investigated by Bishop (1980) who measured streamflow and collected water quality samples from a variety of waterbodies including: Justice, Echo, Steelhead, and Topsy Creeks; Fish Lake; and the Crillon and Dagelet rivers. Measurements were made and samples were collected 1-3 times from each site in 1976 and 1977. Overall, the samples indicated distinct temperature signatures of glacial and non-glacial streams, above-neutral pH values in all the streams (pH between 7.0 and 8.5), and normal concentrations of dissolved ions.

Few studies have focused on groundwater hydrology and chemistry in GLBA, but a few have included these topics as parts of larger studies. For example, in a study of the Lituya Bay region, Bishop (1980) made indirect observations of groundwater characteristics by noting gaining and losing reaches of various streams. Generally, streams were effluent (gaining groundwater) in upland areas, but once they entered zones of high-permeability beach deposits, surface flow was greatly diminished. Specific emphasis in the report is placed on surfacewater-groundwater flow dynamics in Justice Creek and Echo Creek. Water chemistry data are included from a single groundwater pit near Echo Creek. Concentrations were generally similar to those in nearby surface water, although pH was lower (at 6.2) and iron-manganese metals were higher; yet overall, no water quality impairment was noted in this single sample. In another study, Simpkins and Mickelson (1988) investigated the hydrogeology and groundwater geochemistry at the margin of the Burroughs Glacier in the northeastern area of GLBA. Their purpose was to study the evolution of groundwater geochemistry in a recently deglaciated (40 years prior) region; water chemistry results are discussed in section *B1b. Groundwater*. In addition to the geochemical analysis, Simpkins and Mickelson (1988) also estimated hydraulic conductivity of the till using both grain size analysis and one slug test, and they calculated that values for the till units ranged from 10^{-5} to 10^{-7} ms^{-1}.

A study on the hydrology and meteorology of the Dry Bay area is ongoing (Soiseth et al. 2005). This investigation aims to decipher the varying roles of precipitation and the Alsek River stage on controlling the physical and chemical dynamics of the East Alsek River. Included in the study are water table elevations and groundwater chemistry monitoring, based on four piezometers spaced at approximately regular intervals along the length of the East Alsek. At this writing, the report is in draft phase and the study will continue in the summer of 2006.

More information on the evolution of water chemistry in streams and lakes following deglaciation and the linkages between aquatic and terrestrial systems is provided in section *A3d. Biological Resources- Freshwater* and *A2c2. Water Resources: Lakes and Ponds.* More recent studies on water quality within GLBA are specific to individual streams. An overview of unimpaired water quality conditions in specific water bodies within GLBA is provided in *B1a. Surface Water*. A description of water quality impairments is given in *B2. Water Quality Impairments.*

B1a. Surface Water

B1a1. Kahtaheena River

Currently, the water quality of the Kahtaheena River (also known as Falls Creek) near Gustavus is considered to be very good, and the Alaska Department of Environmental Conservation (ADEC) does not list this river on the 303(d) list of water quality limited waterbodies. Background water quality information collected in 1999-2000 indicated the river is of high water quality and typical of a relatively undisturbed, coldwater stream in southeast Alaska. The report's conclusions are based on three sampling events (low, middle, and high flow) at two locations on the Kahtaheena River (Streveler 2000). The streamwater was circumneutral (pH 7.9 to 8.2), and the alkalinity was within a normal range of between 51-75 mg/L; these pH and alkalinity measurements indicated a strong influence of bedrock geology on the water quality, and little influence by muskegs in the lower watersheds. Heavy metals/metalloids (arsenic, cadmium, chromium, copper, lead, manganese, mercury, silver, and zinc) and fecal coliform were all below the detectable limits. There are two USGS gage sites on the Kahtaheena River, as discussed in section *A2b. Hydrology.*

B1a2. Alder Creek

At the GLBA headquarters in Bartlett Cove, maintenance staff collect water quality data from Alder Creek because it is the drinking water source for the area (Arch Thompson, NPS-GLBA, personal communication, 2005). Daily samples for turbidity and annual samples for total and volatile organic compounds, arsenic, and nitrates are collected. No water quality violations have been reported to date (Arch Thompson, NPS-GLBA, personal communication, 2005).

B1a3. Alsek River and Dry Bay

The Alsek River is a part of a large Alsek-Tatshenshini river system that originates in Canada, flows into Alaska at the northern boundary of GLBA, and then terminates at Dry Bay. The Alsek River has a drainage area of 20,000 km^2 (7720 mi^2) and is characterized by high volumes of both glacial meltwater and sediment transport (Deschu et al. 1995. The lower river includes Alsek Lake and is a major migratory route and riparian habitat for wildlife. Because of this river system's unique qualities, it is a popular destination for river runners who take out at Dry Bay.

In 1992, the NPS, US Geological Survey, Water Survey of Canada, and the International Joint Commission (US State Department) established a continuous hydrological recording gage station on the Alsek River to collect data on flow characteristics and baseline water quality (Deschu et al. 1993). Between 1991 and 1996, water quality parameters, suspended sediment, and bed sediment samples were collected 1-5 times per year as a part of the National Water Quality Assessment Program (Deschu et al. 1993, USGS 2006). Water quality parameters measured included temperature, pH, specific conductance, alkalinity, hardness, cations/anions, dissolved oxygen, nitrogen, phosphorus, suspended sediment, turbidity, and dissolved metals. Water quality samples were also collected on single occasions in 1999 (9/1/99) and 2000 (9/20/2000) (USGS 2006). Both filtered and unfiltered samples were collected, and the single 2000 sample was analyzed for total recoverable (unfiltered and acid-digested) chemical concentrations as well. Selected water quality data are provided in Table 1; and bed sediment and suspended sediment data in Table 2.

Flow data show that meltwater from glaciers drives the Alsek River discharge, with the peak flow occurring in July (Deschu et al. 1993). These summertime glacial meltwaters caused the river to become very turbid and loaded with suspended particulates; while in the winter months it had low flow and ran clear (Deschu et al. 1993). All concentrations for dissolved metals fell below current (2006) EPA water quality criteria for acute and chronic exposure to aquatic life. Water temperatures were cold, never exceeded 6.7 ºC (44.1 ºF) on sampling events, and were far below the state water quality limit of 13 ºC (55.4 ºF) for nadramous spawning areas and egg and fry incubation, and 15ºC (59 ºF) for migration routes and rearing areas (Appendix 3, ADEC 2006b). Dissolved oxygen (mean=12.2 mg/L) and pH (mean=8.2) levels also easily fell within state water quality criteria. Nutrient and alkalinity values in the Alsek River were relatively low year round. Total phosphorus was highest in the summer, and nitrogen concentrations did not exhibit a seasonal variation based on these limited data.

Turbidity is the one parameter that exceeded water quality criteria, and 2 exceedences (180 and 400 NTU) were noted in NPS (2005) as the only known water quality violations between 1963 and 1993 (based on very limited data). Eight subsequent turbidity measurements taken between 1994 and 2000 did not exceed 440 NTUs. Alaska law states that when natural turbidity is greater than 50 NTU, it may not exceed more than 10% of the natural level, and never by more than 25 NTU (ADEC 2006b). However, turbidity levels in the Alsek varied within 4 orders of magnitude in the USGS samples: from 0.4 NTU in February, 1996 to 440 NTU in November, 1995. The substantial erosion produced by the glacial activity within the Alsek River watershed is undoubtedly the source of the high turbidity, and turbidity only increases with higher flows (Figure 27). The high amount of suspended material in streamwater in this case is a natural event and cannot be mitigated. However, increasing temperatures due to global warming and rapid melting of glaciers may exacerbate turbidity levels in the Alsek above those that would be expected in a cooler or stable climate in which rates of glacial melt and downstream discharge were lower. While the water quality data from the USGS are useful, they are insufficient to accurately quantify chemical flux and to characterize seasonal and daily trends in water and sediment quality.

An ongoing study by Soiseth et al. (2005) provides the most recent water quality information for several water bodies (Alsek River, East Alsek River and estuary, Dog Salmon Creek, several springs) in the Dry Bay area at the northwest boundary of GLBA. Preliminary sampling results from the summer of 2005 indicate streamwater temperatures of 7 to 16ºC (44.6 to 60.8 ºF), pHs of 7.7 to 8.5, dissolved oxygen concentrations of 8.6-13.4 mg/L, conductivity values of 0.2-0.9 mS/cm, salinity values of 0.12-0.24 ppt, and oxidation-reduction potentials of 0-233 mV. Temperatures in the estuaries were as high as 20.2 ºC (68.4 ºF), and a tidally-influenced site near Dog Salmon Creek had higher salinity and conductivity values. Total nitrate and nitrate-N and total P were usually at or near detection limits (<0.051 mg/L) at most sites, with the exception of the site upstream of Dog Salmon Creek that measured 0.227 mg/L on June 6 and 2.83 mg/L on July 8 (still below water quality standards). A single sample above two concessionaire lodges on the East Alsek River showed a high DOC concentration (17 mg/L) and normal alkalinity (153 mg/L $CaCO_3$). Fecal coliform and E.coli bacteria analyses indicated some high values near Dog Salmon Creek although the source is not yet known (see section B2d). Additional sampling and final reports from the study are planned (Soiseth et al. 2005).

Table 1. Water quality on the Alsek River
for 8 of the 20 dates on which samples were collected between 1991 and 2000. (USGS 2006).
Below detection: Be (<0.5), Co (<3), Pb (<1), Tl (<0.9), Ag (<1), V(<6), Sn (<1), Se (<1), U (<1) µg/L.

		Sample date							
Parameter	*units*	12/91	9/92	4/93	6/94	8/94	4/96*	9/99	9/00
Temp	°C	0	6	4		4	3.15	4	3
Q	cfs	5400	51600	9800	75700	79600	4140	37900	45800
Turb.	NTU	8.5	180	20	160	250	9.9		
Cond.	µS/cm	250	140	246	148	150	241	141	167
D.O.	mg/L			10.6		12.9	12.9		
TSS	mg/L		514	315				103	312
pH	units	7.8	8.4	8.2	8.4	8.6	8.1	8.2	8.5
ANC	mg/L $CaCO_3$	80	48	83	54		70		56
NH_3	mg/L N	0.02	0.02	< .010	0.02	0.02	< .01		0.004
NO_2^-	mg/L N	< .010	< .010	< .010	< .010	< .010	< .010		0.001
$NO_3^- + NO_2^-$	mg/L N	0.2	0.07	0.32	0.093	< .050	0.15		0.072
P	mg/L	< .01	< .01	< .01	< .01	< .01	0.02		0.004
Ortho-P	mg/L P	< .01	< .01	< .01	< .01	< .01	0.01		0.001
PO_4^{3-}	mg/L P	0.03	< .01						
Cl	mg/L	< .10	0.2	0.9	0.4		1.9	0.35	
SO_4^{2-}	mg/L	36	18	36	17	16	37	18.4	
F	mg/L	0.2	< .1	0.1	< .1	< .1	< .1	< .1	
Ca	mg/L	36	20	34	23	21	34	20.3	
Mg	mg/L	5.9	2.8	6	3.4	2.4	5.8	2.88	
Na	mg/L	2.2	1.1	2.4	1.5	1.1	2.1	1.1	
K	mg/L		1.5	2	1.4	1.3	2		
Si	mg/L	4.3	2.5	4.4	3.4	2	4	2.29	
Ba	µg/L	28	11	27	16	12	25	12.1	15
Cd	µg/L		1	< 1	< 1	< 1	< 1	< 8	< 1.00
Cr	µg/L		2	< 1	1.1	2.4	< 1.0	< 1.0	Est .8
Cu	µg/L		1	< 1.0	< 1.0	< 1.0	< 1.0	< 10	< 1.0
Fe	µg/L	20	56	11	130	49	< 3	< 10	
Mn	µg/L	< 1.0	3	1	5	8	1	E 1.4	3.3
Mo	µg/L	< 10	< 10	< 10	< 10	< 10	< 10	< 34	1.6
Ni	µg/L	1	< 1.0	1	< 1.0	< 1.0	< 1.0	< 40	< 1.00
Sr	µg/L	180	100	180	110	97	170	103	116
Zn	µg/L		< 3	5	4	23	< 3	< 20	< 1.0
Al	µg/L	10	90	30	20	90	30		61
Li	µg/L		< 4	< 4	< 4	< 4	< 4	< 4	1.2
Hg	µg/L		< .1	< .1	0.1	0.6	< .1		

Table 2. Chemical concentration of bed sediments (<2 mm) and suspended sediment samples collected from the Alsek River between 1992 and 2000 (USGS 2006). Below detection: Ag (<0.5 µg/g) and Se (<1) µg/L.

		Bed sediments				Suspended sediments	
	Units	9/2/1992	4/28/1993	6/21/1994	11/9/1994	4/28/1993	6/21/1994
Al	%	6.6	7.3	7.2	7.4	6.2	5.9
Sb	µg/g	0.2	0.4	0.5	0.5	0.6	0.8
As	µg/g	5	2.4	3.4	2.1	6.8	6.1
Ba	µg/g				570		
Be	µg/g				1		
Cd	µg/g	0.1	0.2	0.2	< .2	< 1.0	0.4
Cr	µg/g	63	60	66	50	89	83
Co	µg/g	16	16	14	11	25	20
Cu	µg/g	30	26	27	22	48	44
Pb	µg/g	8	7	16	4	14	10
Zn	µg/g	62	51	56	55	100	180
Ni	µg/g	30	20	26		42	42
Hg	µg/g	< .10	< .10	0.03		< 1.0	0.07
Ti	%	0.4	0.42	0.43	0.38	0.46	0.43
Fe	%	3.6	3.7	3.5	3	4.9	4.2
Mn	µg/g	700	660	630	570	870	730
Li	µg/g				13		

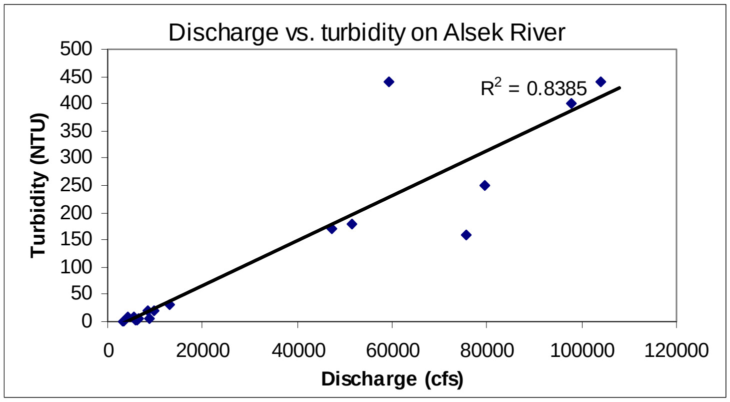

Figure 27. Turbidity increases with discharge on the Alsek River based on USGS data collected between 1991 and 2000. Source USGS (2006).

B1a4. Dixon Harbor

A three year biological and environmental survey, including water quality, along the outer coast of GLBA was completed in the Dixon Harbor area (Figure 28) to collect baseline data in the event that development for minerals was initiated (Streveler et al. 1974, Streveler and Worley 1975, Streveler and Worley 1977). Water samples were taken from various lakes, rivers, streams, and tributaries in the Dixon Harbor area. Lake waters in the area were found to consistently have the lowest pH, hardness and iron values, as well as low specific conductance. The Glacial Palma River had somewhat acidic water with low hardness and relatively high iron concentrations in July (Strevelor and Worley 1977). Consistently elevated metal concentrations, including copper, zinc and nickel, were found in the lower

Dixon River. These higher concentrations are unexplained and the authors speculate that they may have been derived from the Deception lobe or the Dixon lobe of the Brady Glacier (Streveler and Worley 1977). However, considering the date of this study, it is probable that elevated metals concentrations were due to contamination of the samples during collection and analysis. In the past 15 years, several studies have effectively invalidated much of trace metal work done for much of the last century due to the discovery of major contamination problems associated with standard sampling protocols (Windom et al. 1991, Benoit 1994, Horowitz et al. 1994, Taylor and Shiller 1995). These studies have demonstrated that by following meticulous “clean” (or “ultra-clean”) sampling, processing, and analytical techniques, trace metal contamination of water samples can be drastically reduced. As a result, the data on elevated trace metals in the Dixon Harbor area should be treated with skepticism, and new analyses using clean methods are warranted in order to accurately assess water quality.

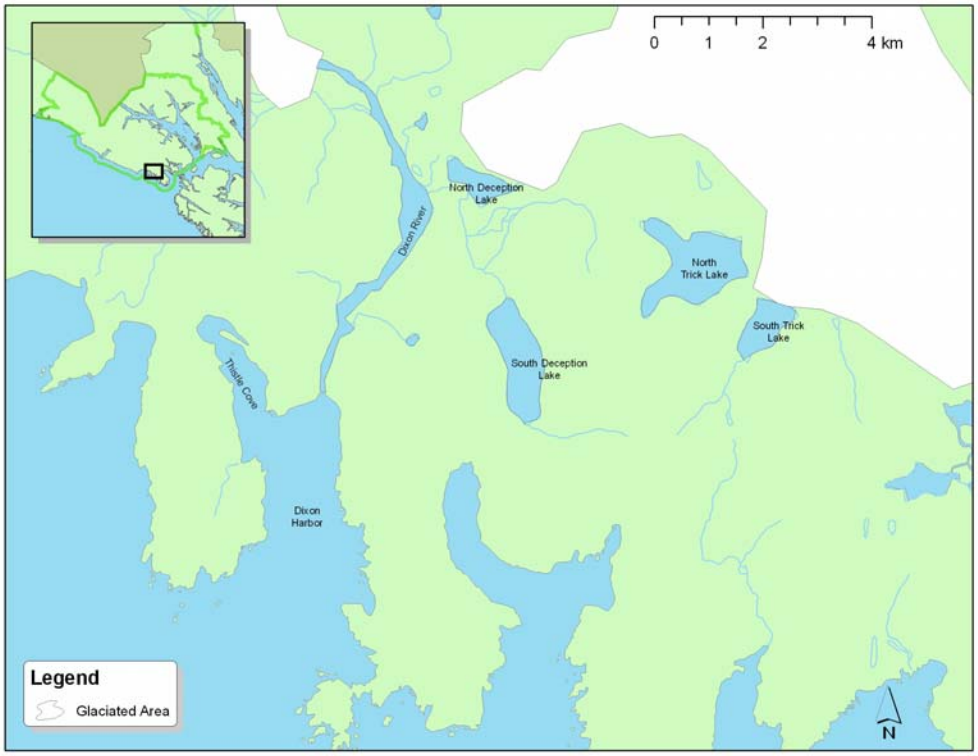

Figure 28. Dixon Harbor.

B1b. Groundwater

In 2004, a groundwater monitoring investigation was performed at the Bartlett Cove Residential Quarters in order to assess the extent of hydrocarbon contamination from fuel tank leakages; contaminant results are discussed in *B2b. Water Quality Impairments, Bartlett Cove* below (Hart Crowser, Inc. 2004). Although the study focused on hydrocarbon contamination, general information on groundwater elevation, gradient, and flow direction, and groundwater chemistry was obtained. The water table in the area was between 25 and 29 feet below ground surface, and the gradient was calculated as 0.008. Chemical measurements in June 2004 indicated that the pH of the groundwater was near neutral (7.1-7.3); the ground water was well oxygenated, with dissolved oxygen concentrations between 6.1 and 7.7 mg/L; conductivity was 46-50 mS/cm; and turbidity was 44-134 NTU.

In a study of the Burroughs Glacier area, (Simpkins and Mickelson 1988) reported high groundwater pH values (average 8.3), a calcium to bicarbonate ratio of 1:2; and cation concentrations higher in groundwater than in precipitation, suggesting silicate weathering. Generally, spatial trends in groundwater show an evolution from calcium-sulfate water near the ice margin to calcium-bicarbonate water near Wachusett Inlet. Their study included one rainwater sample, 5 samples of glacial ice, 16 meltwater samples, and 7 groundwater samples. Mean concentrations of analytes are listed in Table 3.

Table 3. Analytical concentration of samples in the Burroughs Glacier area.
From (Simpkins and Mickelson 1988).

		Temp	Cond	Cations (mmoles/L)				Anions (mmoles/L)				
Sample	pH	(°C)	(mS/m)	Ca	Mg	Na	K	HCO_3	SO_4	Cl	PO_4	H_4SiO_4
Rainwater (*n*=1)	6.05	9.6	12	0.01	-	0.04	0.02	-	0.02	0.07	-	-
Glacial ice (*n*=5)	7.45	10.9	17	0.06	0.02	0.04	0.02	0.14	0.03	0.03	0.01	0.2
Meltwater (*n*=16)	8.65	6.9	47	0.2	0.02	0.04		0.36	0.06	0.03	0.01	0.08
Groundwater (*n*=7)	8.34	11.3	297	1.2	0.07	0.18	0.03	1.72	0.57	0.03	-	0.12

Soiseth et al (2005) provide groundwater temperature information for a single site in the Dry Bay area in the summer of 2005; temperatures in a piezometer in the upper East Alsek River drainage measured 4.8-5.4 ºC (40.6 to 41.7 ºF) between June and September, 2005. This Dry Bay area hydrology study is expected to continue in 2006.

B1c. Lakes

Studies of lake chemistry have largely been conducted in the context of studying lake chemistry evolution over time (see section *A2c. Water Resources: Lakes and Ponds*). Valuable baseline water quality data have emerged from these studies. Fritz et al. (2004) provide a summary of recent water quality data collected from GLBA lakes (Table 4). No impairments are noted.

B1d. Precipitation

The chemistry of precipitation is not currently being monitored in GLBA; however, a new National Atmospheric Deposition Program (NADP) site was established in southeastern Alaska north of Juneau in 2004. The NADP is a nationwide network containing more than 200 precipitation chemistry monitoring sites in the continental United States, Alaska, Puerto Rico, and the Virgin Islands. There are 4 NADP sites in Alaska, two of which are administered by the National Park Service (Denali and Gates of the Arctic). The NADP site near Juneau (NADP #AK02) is the closest station to GLBA and is likely representative of precipitation received there. Preliminary data from the Juneau NADP 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 (E. Hood, unpublished data). Data on precipitation chemistry in Alaska are available through the NADP website located at: http://nadp.sws.uiuc.edu/sites/ntnmap.asp?

B2. Water Quality Impairments

There are no 303d impaired water bodies in GLBA. Current and potential sources of impairments to water quality in GLBA include mining claims and historic mining pollution; development of human facilities, marine vessels and associated fuel spills, sewage, and other waste pollution; construction of a hydroelectric facility; and degradation of streams by all-terrain vehicle (ATV) use.

B2a. Ptarmigan Creek

Ptarmigan Creek drains into the west arm of Glacier Bay between Reid Inlet and Lamplugh Glacier. The LeRoy gold mine, which was active from 1938 to 1945 and run by the Mount Parker Mining Company, was located 1.1 km (0.7 mi) south of the mouth of Ptarmigan Creek (Sidle 1982). In a study on baseline water chemistry for watersheds in GLBA, Ptarmigan Creek and other streams were sampled for inorganic constituents and heavy metals (Letarte and Stottlemyer 1984). The study aimed to assess the influence of the old LeRoy mine site tailings on water quality in Ptarmigan Creek. During a site visit in 1984, water samples were collected in surface runoff from above and below mine tailings, in Ptarmigan Creek, and below runoff inputs from the tailings area. According to EPA water quality criteria (EPA 1977), concentrations of lead (Pb) in the tributary above the mine tailings and on both stations on Ptarmigan Creek exceeded EPA limits for domestic water supplies. Concentrations of cadmium (Cd) in samples taken from the tributary above and below the mine tailings and in Ptarmigan Creek exceeded EPA criteria for domestic water supplies and for freshwater salmonids, cladocerans and other aquatic life (Letarte and Stottlemyer 1984). We found no recent information on water quality since the Letarte and Stottlemyer (1984) study. As mentioned above, the lack of 'ultraclean' techniques in studies before 1990 result in the need for new analyses using the clean methods in order to accurately assess water quality.

B2b. Bartlett Cove

Bartlett Cove is the major site of human interaction in GLBA and the only location in the park that is human-occupied year-round. Barlett Cove, located approximately 16 km (10 mi) northwest of Gustavus, is the site of the GLBA headquarters (Figure 3). It is a small estuary with freshwater input from the Bartlett River, and seawater input from the Beardslee Islands, Sitakaday Narrows, and the mouth of Glacier Bay (Figure 29). Water quality in Bartlett Cove is a function of geology, climate, streamflow, and human interaction. Permanent facilities in the area include a lodge, guest cabins, campground, administrative facilities, boat docks including a fuel dock, boat anchorage, employee housing, and maintenance facilities, including fuel storage and delivery, wastewater treatment, and waste transfer facility. Wastewater from the NPS water treatment facility is discharged into Bartlett Cove approximately 30-40 m out from the low tide line. Post-treated discharge is tested periodically (discussed below in *B3a. Point Source Pollution*).

Table 4. Summary table of characteristics and chemistry of 33 lakes in GLBA. Excerpted from Fritz et al. (2004).

No.	Site	Age (years)	pH	Colour (Pt-Co)	DOC (mg L^{-1})	Cond. (µS cm^{-1})	Ca (mg L^{-1})	Mg (mg L^{-1})	Na (mg L^{-1})	K (mg L^{-1})	Alk (µeq L^{-1})	Cl (mg L^{-1})	SO_4 (mg L^{-1})	d-Si (mg L^{-1})	total-N (ppb)	total-P (ppb)	Chl. *a* (ppb)
1	Casement 1	10	8.18	0	1.02	157	28.16	1.81	1.27	1.64	1.17	0.49	20.13	1.30	55	5.5	0.04
2	Plateau 2	10	7.93	0	1.29	57	9.70	0.52	0.46	0.45	0.51	0.33	1.09	0.58	114	9.3	1.18
3	Casement 2	20	8.35	1	1.83	199	34.69	3.03	2.64	1.55	1.77	0.44	12.37	2.76	161	3.1	0.23
4	Plateau-1	20	8.14	0	1.01	199	36.49	1.51	1.91	0.72	1.46	0.49	22.56	1.89	199	8.6	0.24
5	Burroughs	25	8.11	0	1.33	204	37.07	1.37	1.88	0.53	1.19	0.44	36.00	2.21	111	4.9	0.23
6	Wachusett	30	8.23	0	0.91	161	22.77	2.40	4.54	1.06	1.08	0.71	19.78	0.96	168	5.2	0.18
7	Seal River	30	8.11	0	2.02	262	49.01	2.60	0.84	1.54	2.44	0.42	9.77	1.98	264	3.2	0.32
8	Forest Creek	35	8.24	2	1.73	255	52.56	4.14	2.93	1.60	2.73	0.52	14.98	2.97	146	4.1	0.25
9	Wolf Creek	45	7.89	8	2.21	61	10.68	0.43	0.48	0.67	0.53	0.71	1.67	0.30	209	9.2	0.38
10	Nunatak	50	8.17	2	1.57	199	36.16	2.13	1.48	1.01	1.55	0.70	16.75	2.43	336	5.2	0.28
11	Klotz Hills	80	8.05	6	3.62	243	44.09	2.26	3.47	1.30	2.41	1.68	5.87	2.28	271	6.0	0.39
12	Charpentier	100	8.04	8	2.47	136	24.17	1.94	1.56	0.40	1.34	0.88	1.37	1.16	213	5.7	0.47
13	Blue Mouse	110	7.47	36	5.42	75	12.40	1.08	1.30	0.87	0.63	1.21	1.63	0.64	338	8.1	0.41
14	Spokane Cove	120	8.06	4	2.10	251	40.84	6.48	1.59	0.98	2.26	0.91	13.83	1.70	284	3.7	0.21
15	Hutchins Bay	160	8.29	5	2.78	134	20.70	3.14	1.17	1.38	1.19	1.37	5.14	1.03	216	4.9	0.53
16	Bartlett River	180	8.15	4	3.24	87	15.10	1.35	1.01	0.84	0.82	1.52	1.96	0.18	260	9.5	0.34
17	Lester 1	180	6.27	38	5.12	21	1.31	0.36	1.67	0.50	0.03	3.25	0.64	0.03	295	9.9	0.30
18	Lester 2	180	7.70	25	4.88	75	11.74	1.08	1.70	0.88	0.61	2.77	1.14	0.14	266	10.5	1.05
19	Lester 3	180	7.91	8	3.24	238	41.81	3.02	1.85	2.66	2.25	2.61	2.58	1.90	222	7.5	0.63
20	Ripple Cove	190	7.97	2	1.69	145	25.12	0.96	1.80	0.37	1.03	2.87	12.46	1.46	235	3.8	0.67
21	Bartlett	220	6.19	2	2.11	8	0.56	0.13	0.67	0.13	0.01	1.45	0.34	0.02	122	7.9	0.28
22	Paps	350	6.55	80	7.97	52	1.96	1.30	5.59	0.53	0.07	9.81	2.52	0.23	147	5.1	0.12
23	Harbor Point	350	5.62	93	8.69	63	0.92	1.47	7.75	0.43	– 0.02	14.39	2.17	0.08	270	9.0	0.45
24	Red Loon	350	7.14	15	2.65	55	3.92	1.70	3.58	0.66	0.26	4.94	2.55	1.35	220	2.6	–
25	Coal Creek	350	7.83	13	2.08	213	29.86	4.84	6.12	0.95	1.69	3.76	14.84	2.54	138	5.9	0.49
26	Huscroft	400	7.27	28	3.72	66	7.14	1.39	3.38	0.98	0.61	5.29	3.73	1.80	215	5.5	0.35
27	Crillon	400	7.19	25	5.08	70	9.71	1.02	2.44	0.55	0.53	3.64	1.77	1.37	167	3.8	0.07
28	Dagelet	1100	6.18	33	2.87	21	0.47	0.68	2.04	0.13	0.02	3.57	0.58	0.05	167	3.9	0.08
29	Brady	1200	6.34	33	2.32	15	0.85	0.30	1.25	0.25	0.03	1.51	0.85	0.11	154	5.3	0.11
30	LaPerouse	2700	6.96	55	4.52	55	5.53	1.17	4.11	0.15	0.40	3.24	1.08	1.73	138	10.2	0.30
31	Pleasant 1	12 000	6.18	81	10.66	27	1.85	0.74	2.85	0.22	0.06	4.02	0.75	0.18	263	4.1	0.70
32	Pleasant Muskeg	13 000	4.74	143	13.71	19	0.76	0.28	1.30	0.09	– 0.03	1.78	0.25	0.12	396	7.7	1.23
33	Pleasant 3	13 000	5.40	170	12.14	18	1.62	0.33	1.56	0.12	0.01	1.78	0.30	0.13	273	6.3	1.21

In 2004, a pollution study was conducted in Bartlett Cove as a part of a large EPA project by Jim Gendron of the ADEC. The sampling station in Bartlett Cove was located just off the dock and sampled for dissolved oxygen, suspended solids, chlorophyll, temperature, salinity, depth, and nutrients (nitrate, nitrite, phosphorus, and ammonia). Benthic sediment samples were also collected for the analysis of heavy metals, organic pollutants, and hydrocarbons. The results from this research will be published as part of a larger EPA study focusing on pollutants in Southeast Alaskan coastal waters and are expected by summer 2006 (Jim Gendron, ADEC, personal communication, 2005)

Groundwater in the Bartlett Cove area was contaminated by an underground heating fuel storage tank in 1989. Since 1989, all NPS underground storage tanks have been removed, the area is currently monitored, and the current tanks are above ground (Mark Foster, NPS-GLBA, personal communication, 2005). In the spring of 1989, a leaking 1,000 gallon heating oil underground storage tank (UST) and associated fuel supply lines were removed from Bartlett Cove Residential Quarters. Soil at the site was found to be in excess of the ADEC Method Two Soil Cleanup Level, with diesel-range organics (DRO) concentrations as high as 10,000 mg/kg below the former fill pipe location (Hart Crowser Inc. 2004). Contaminated soil was removed from the site in the fall of 2000, and three groundwater monitoring wells were installed and sampled in November of 2000. DRO concentrations in two of the wells, MW-1 and MW-3 exceeded the ADEC Groundwater Cleanup Level of 1.5 mg/L (Appendix 3), with 3.14 mg/L detected in MW-1 and 34.4 mg/L in MW-3 (Hart Crowser Inc. 2004). In July 2001 and June 2004, these groundwater monitoring wells were sampled again, and DRO concentrations were detected above the ADEC Groundwater Cleanup Level only in MW-3, with 30mg/L (Hart Crowser Inc. 2004). Hart Crowser, Inc. (2004) reports that because these compounds are not found in the other 2 wells it is unlikely that they are impacting nearby surface waters above the total aromatic hydrocarbon and total aqueous hydrocarbon water quality standards set forth in the Alaska Water Quality Standards 18 AAC 70.

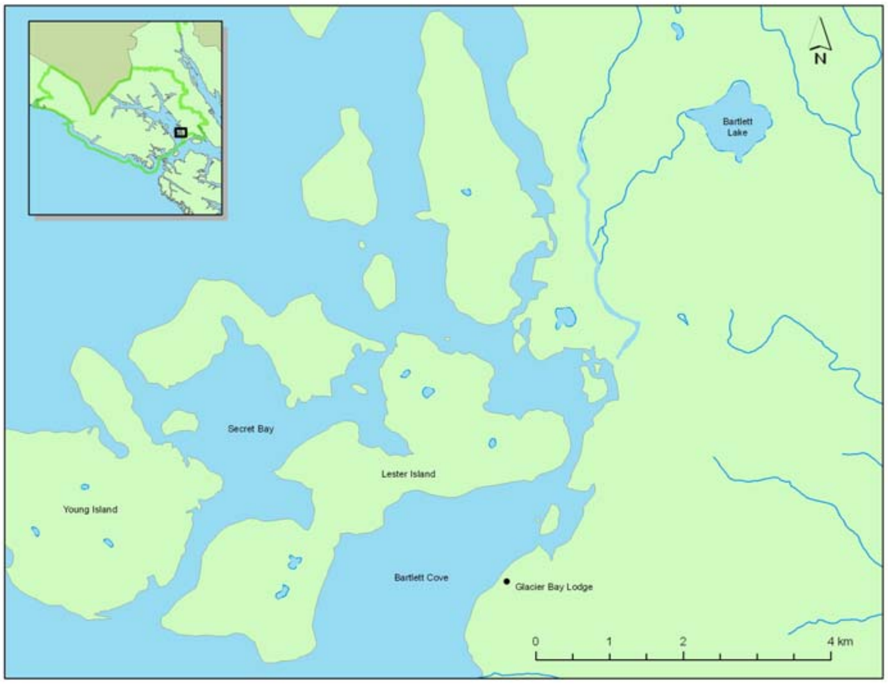

Figure 29. Park headquarters, housing and visitor facilities are based in Bartlett Cove.

B2c. Kahtaheena River (Falls Creek)

In March 2006, the State of Alaska and the NPS traded GLBA land to allow for the construction of a hydroelectric facility that will serve the town of Gustavus, which currently relies on expensive diesel power generation (ADNR 2006, Bluemink 2006). NPS traded 418 ha (1,034 acres) along the Kahtaheena River (also known as Falls Creek) in exchange for 421 ha (1,040 acres) of land along the Chilkoot Trail in Klondike Gold Rush National Historic Park (KLGO). In order to offset the loss of federal wilderness in the NPS system, the NPS also gained federal wilderness protection of an unnamed small island in Blue Mouse Cove and of Cenotaph Island in Lituya Bay (ADNR 2006). Discrepancies in land values cost the NPS $66,000, which was paid to the State of Alaska. Within days of the trade agreement, construction of the $5 million, 800- kilowatt project began.

The project's 2004 Final Environmental Impact Statement (EIS), entitled "Falls Creek Hydroelectric Project (FERC No. 11659) and Land Exchange," was produced jointly by the Federal Energy Regulatory Commission (FERC) and the NPS (Gustavus Electric Company 2004). The project area occupies 3.2 km (2 mi) of the lower Kahtaheena River and includes an unnamed creek west of the Kahtaheena River, Homesteader Creek, Rink Creek, and five waterfalls on the Kahtaheena River (Gustavus Electric Company 2004). This river system drains an area of approximately 26 km^2 (10.7 mi^2) characterized by steep gradients and numerous waterfalls. The EIS identified several effects of the hydroelectric project on water quantity and quality as well as effects on the local fisheries, habitats, and wildlife including the following (Gustavus Electric Company 2004).

- The natural flow regime of the Kahtaheena River would be altered and could potentially adversely affect water quality or other aquatic resources

- Erosion, sedimentation, and embeddedness of stream gravel in the Kahtaheena River and other project area streams could increase.
- Water temperature and timing and patterns of icing could be affected.
- The accidental release of fuels, lubricants, and other hazardous materials into the water could be increased.
- Construction and operation of the Falls Creek Hydroelectric project could destabilize the steep slopes of the lower portion of the Kahtaheena River and cause erosion of deep organic soils in the upper watershed.
- The project also could alter existing drainage patterns throughout the area, disturb nearby wetlands, or even cause loss of wetland habitat.
- Quality and quantity of fish habitat in the Kahtaheena River and other project area streams may be reduced during and after construction. Spawning habitat could degrade due to sediment loading, bedload transportation, and aggradation/degradation patterns. Inadequate instream flows may reduce fish passage, particularly for resident Dolly Varden char.

The Kahtaheena River downstream from the Lower Falls supports pink salmon, chum salmon, coho salmon, Dolly Varden char, cutthroat trout, and coast range sculpin (Table 5, Gustavus Electric Company 2004). Above the lower falls, the only species present is Dolly Varden, whose distribution reaches to the second large waterfall (Table 5, Gustavus Electric Company 2004). Tilmant and Soiseth (2004) state that the hydroelectric project would significantly reduce water quantity in the wintertime, which may negatively impact the resident Dolly Varden char population.

Table 5. Presence of fish in the vicinity of the Falls Creek Hydroelectric Project (Flory 2001, Gustavus Electric Company 2004).

Species	Downsteam from Lower Falls	Above Lower Falls	Homesteader Creek	Rink Creek	Soughs	Unamed Creek
Dolly Varden char (*Salvelinus malma*)	P	P	P	L	L	I
Cutthroat trout (*Salmo clarki*)	P	A	P	P	I	I
Pink salmon (*Pncorynchus gorbuscha)*	P	A	P	P	I	L
Chum salmon (*O. keta*)	P	A	P	P	L	L
Coho salmon (*O. kisutch*)	P	A	P	P	P	P
Coast range sculpin (*Cottus aleuticus*)	P	A	P	P	P	P

P = presence confirmed, A = absent, L = annual use likely, I = intermittent use likely

B2d. Alsek River and Dry Bay

All-terrain vehicles (ATVs) supporting commercial and subsistence fishing in the Dry Bay fish camp areas on the lower Alsek and East Alsek Rivers could potentially impact water quality in this region. The lower East Alsek River, from Alsek Lake to the Dry Bay estuary, is unique in that it is used seasonally for commercial and subsistence fishing in a designated "Temporary Fish Camp Zone" (NPS 2006b). Permanent fish camps and lodges, gill net sites, and airstrips on both rivers are accessed by ATV's throughout the summer. The lower section of the main Alsek River forms the boundary between the GLBA and the Tongass National Forest. This area was originally made into a Preserve by Congress in order to allow continuance of commercial fishing and subsistence activities (NPS 2005b). Under ANILCA, commercial fishing, subsistence hunting and fishing, trapping, and hunting, along with recreational fishing continue in this area. Fishing and hunting in this area have historically been important for the community of Yakutat, a predominantly Native village, as well as to non-Native commercial fishermen who live in the area during the summer months (Catton 1995, Ramos 2004). The GLBA Compendium (NPS 2006b) states in 13.21(c) that the use of ATVs is allowed by permit on designated trails (Figure 30). Specifically, ATV use was originally allowed only in support of commercial fishing activities. However, area residents including commercial fishers, lodge owners and their clients regularly participate in recreational ATV use over a wide range of trails. NPS staff has noted that users fail to limit their traffic to existing trails, and new ATV tracks cross numerous streams and other sensitive habitats (Bill Eichenlaub, NPS-GLBA, personal communication, 2005). When impacted areas are sandy, gravelly, and/or unvegetated, the impact may be ephemeral; however, impacts in grasslands, forests, and wetlands are likely persistent. The NPS initiated a NEPA process in spring of 2006 to evaluate existing trails and ATV use. An environmental assessment will identify and evaluate different alternatives for continued ATV trail use and designation as well as trail closures.

NPS staff have recently noted an increased growth of aquatic plants in the East Alsek River which is changing water flow and sedimentation patterns (Chad Soiseth and Bill Eichenlaub, NPS-GLBA, personal communication, 2005). These aquatic plants are native, and all have not yet been identified. Species that have been identified include *Hippuris vulgaris*, *Ranunculus aquatilis*, *Potamogeton spp.*, and mosses that likely include *Cratoneuron filicinum and Drepanocladus aduncus* (Dr. Wilf Schofield, Curator of Bryophytes, University of British Columbia personal communication, 2006). These plants grow quickly and dense clusters, which trap organic material and decrease water flow. The increased abundance of these plants in the East Alsek River is hypothesized to result from the lack of periodic flooding of the East Alsek by the Alsek River, which is believed to be due to uplift, subsequent river downcutting, and elevation of the flood plain (Chad Soiseth, NPS-GLBA, personal communication, 2005). This area is known to have the highest uplift rates in the world, so lower portions of the land that were more wet are consequently becoming more dry over time. The NPS is analyzing and documenting these vegetative changes (Bill Eichenlaub, NPS-GLBA, personal communication, 2005).

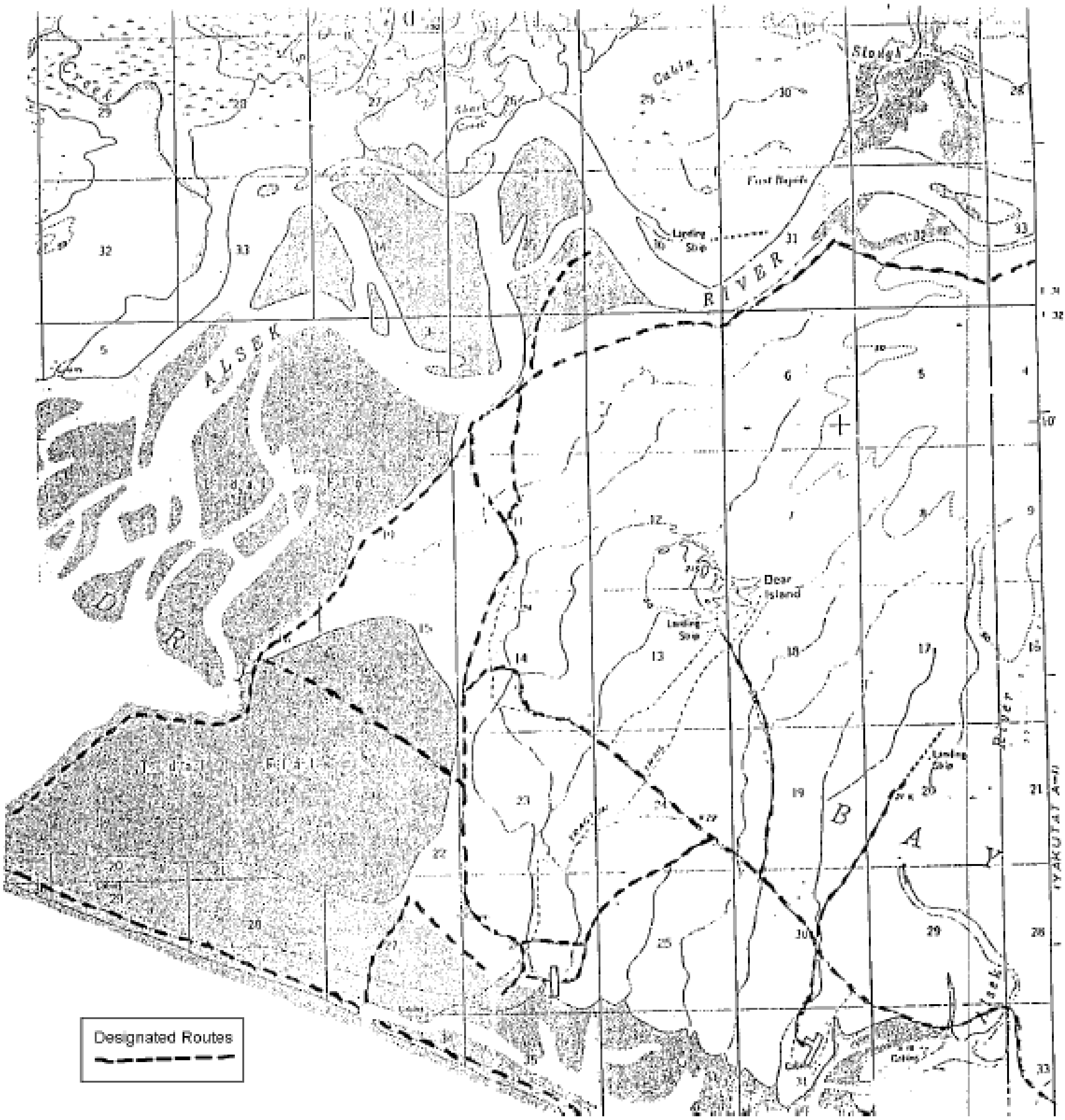

Figure 30. Designated ATV trails near the mouth of the Alsek River in the Dry Bay preserve. The use of ATVs for commercial fishing purposes is allowed inside the boundary of the designated Temporary Fish Camp Zone identified on the map. Source NPS (2006b).

Finally, water quality may be impaired by coliform bacteria in the vicinity of Dog Salmon Creek in the Dry Bay area. High total coliform and *E. coli* bacterial concentrations were found in August in the lower estuary, but were below detection, <1 MPN/100 ml in June (Soiseth et al. 2005). The highest total coliform counts were 1,200 and 1,420 Most Probably Number (MPN)/100 ml, and highest *E. coli* bacteria counts were 22.6-248 MPN/100 ml, and were taken from sites just upstream of the confluence of Dog Salmon Creek and the estuary and at the mouth of Dog Salmon Creek (Soiseth et al. 2005). State water quality standards limit fecal coliform concentrations to <20 Fecal Colonies (FC)/100 ml for water supplies and <200 FC/100 ml for aquaculture uses (ADEC 2006b). The source of the bacteria was not determined, but further work is planned in the area for the summer of 2006 that may provide more information on this local fecal contamination.

B3. Pollutants

B3a. Point Source

B3a1. Petroleum

Petroleum poses a range of environmental risks when released into the environment, 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. Petroleum can enter GLBA waters through the following mechanisms:

- Leaks, spills, or discharge of bilge or ballast water.
- Discharge from a two-stroke engine.
- Leaks or spills at the Bartlett Cove petroleum transfer and storage facility.
- Spills by the NPS fueling barge in Blue Mouse Cove.
- Accidental release through a vessel grounding or collision.
- Natural oil and gas seeps in the Gulf of Alaska.

The impact of a release of petroleum from any of the above mechanisms 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. Baker (2000) estimates discharges in GLBA are most likely to occur while dispensing fuel to marine vessels. Such a spill averages 1 pint of gasoline or diesel fuel. Larger spills, on the order of hundreds or thousands of gallons, may occur from failure of piping, hoses, or coupling during fuel transfer or rupture of the 3,000 gallon fuel oil tanks (Baker 2000). Three of these tanks are used for fuel storage by the Glacier Bay Lodge, and one is used for fuel storage at the Utility Service Building. Another study by Eley (2000) identifies the most probable fuel spills in GLBA, the impact of discharge on Park resources, and determines what response equipment and performance standards are needed for an effective level of response. Currently, Geographic Response Strategies (GRS) are available for certain areas of GLBA (Figure 31). These spill response plans were tailored by ADEC and other agencies to protect a specific sensitive area from oil impacts following a spill. Seven GRS locations in GLBA, including Pt. Carolus, Bartlett Cove, Berg Bay, Hugh Miller Inlet, N Beardslee Island, S Marble Island, and Sandy Cove, were selected based on environmental sensitivity criteria in the Southeast Alaska Subarea Plan (Figure 31).

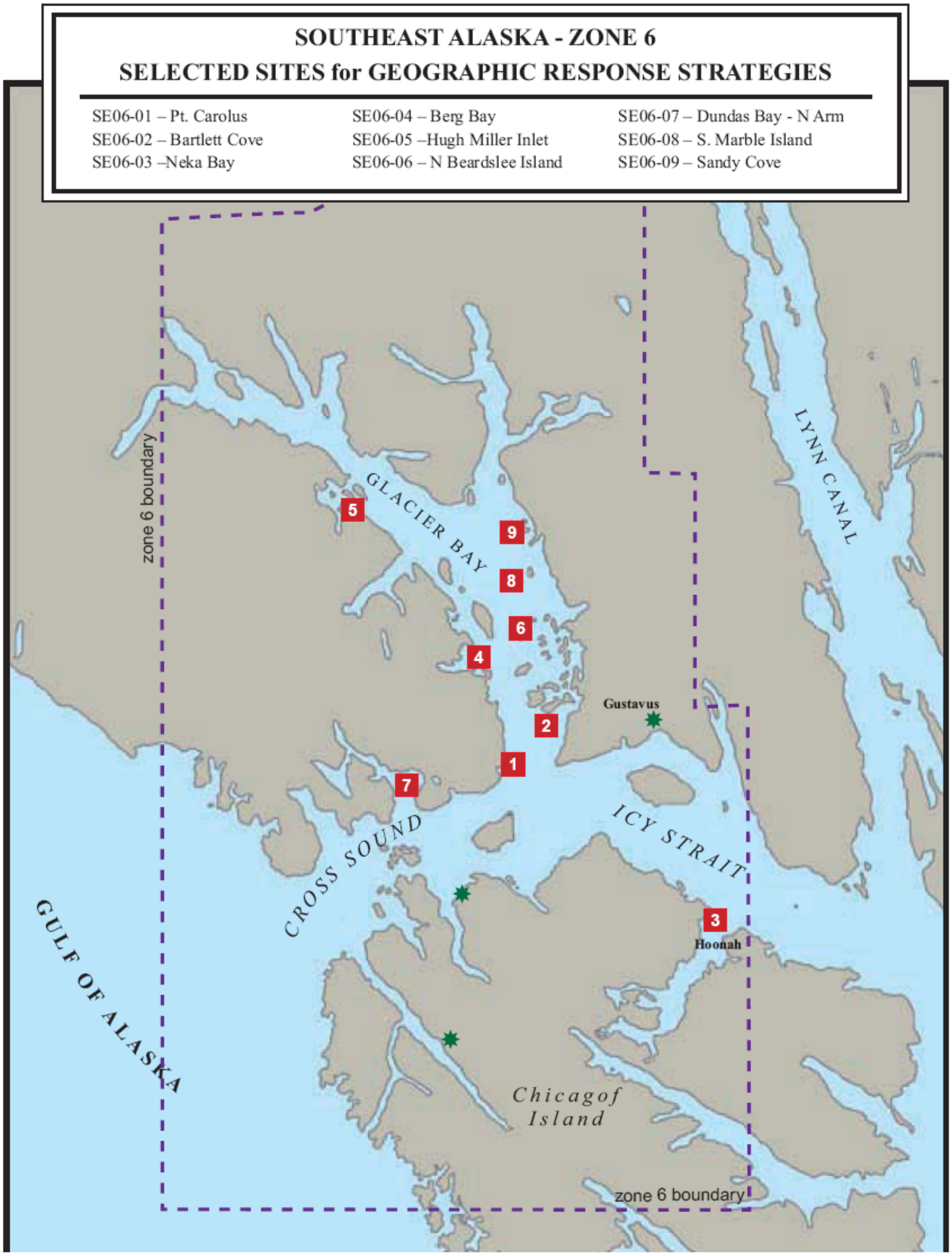

Figure 31. Geographic Response Strategies for zone 6 of Southeast Alaska. Source: ADEC 2006a

A 1980 survey of the Lituya Bay region addressed the susceptibility of Lituya Bay and the GLBA coast in general to oil spills (Molnia 1980). The author of the survey characterized the beaches of GLBA as being at high risk of damage from an oil spill because of 1) the large amount of storm-deposited debris accumulated along the upper limits of beaches, and 2) extensive vegetated meadows behind the most active beach segments that could act as oil deposition and retention sites. ShoreZone aerial surveys rank shoreline in their GIS database in terms of oil residency (see *A3b. Intertidal resources*).

B3a2. Fish cannery waste

Fish processing waste is produced or was produced in the past at Dry Bay and Excursion Inlet. Sitka Sound Seafoods at Dry Bay is no longer operational, while the packing plant at Excursion Inlet is one of the largest, American-owned fish canneries in the US. This seafood processing plant is the largest employer and wage provider for the Borough of Haines. It was owned by Ward's Cove Packing Company until 2003, when it was purchased by Ocean Beauty Seafoods. Today, this active fish cannery employs about 500 people in the summer months. According to data self-reported by the processor to the EPA as part of its obligations under the company's NPDES permit (General Permit #AK-G52-0059), 4.5 to 6.1 million kg of waste was discharged annually between 2001-2004 (Tara Martich, US EPA Alaska Operations Office, personal communication, 2006). The outfall is in 10-11 m (33-36 ft) of water (on a benthic slope that quickly reaches 30 m (100ft) depth within 20-40 m (65-130 ft) from the outfall) and approximately 0.5 km (0.3 mi) from the NPS mid-channel boundary. Fish waste accumulations of up to nearly 560 m^2 and up to about 3.5 m (11.5 ft) depth have been documented by annual dive surveys (Tara Martich, US EPA Alaska Operations Office, personal communication, 2006). Impacts of this waste have not yet been studied in Excursion Inlet.

B3a3. Human waste

Currently there is no evidence that GLBA coastal waters are polluted by bacteria, specifically fecal coliform. The Beach Environmental Assessment and Coastal Health (BEACH) Act, signed into law October 2000, states that coastal water monitoring should be taking place in areas used recreationally, especially those areas that are close to a pollution source (EPA 2005). Through surveys and community visits, the Alaska BEACH Grant Program has ranked public use beaches by their potential risk of being exposed to marine water polluted by fecal contamination by a variety of sources. Potential sources of fecal bacteria could be sewage, storm water runoff, boating waste, malfunctioning septic systems, animal waste, and other sources. At this time, beaches in Glacier Bay have been ranked low risk by the Alaska BEACH Grant Program (Barbara Smith, ADEC, personal communication, 2005). Possible pollution by marine vessels, including cruise ships, tour boats, charter boats, and private vessels is addressed in section *C1b. Marine Vessel Impacts on Water Quality*.

Bartlett Cove sewage treatment

Water, wastewater, and electric utility service are provided to the various buildings and facilities at the Bartlett Cove headquarters complex. The Bartlett Cove waste treatment plant, operated by the NPS, provides secondary waste treatment that is discharged into the deep waters of Bartlett Cove approximately 30-40 m (33-43 yds) out from low tide. This post-treatment water is routinely measured for various parameters including fecal coliform bacteria and chlorine, of which there have not been any detectable amounts (Arch Thompson, NPS-GLBA, personal communication, 2005). The NPS also tests 7 times a year for dissolved oxygen, suspended solids, pH, temperature, chlorine, and fecal coliform near and at the discharge pipe. Lower dissolved oxygen and higher temperatures have been measured close to the pipe. Additionally, suspended solids, which have been found to be composed of dead bacteria from the waste treatment system, are discharged. Overall, the waste treatment facility appears to have minimal impact on water quality in Bartlett Cove.

Gustavus sewage treatment

Gustavus lacks municipal sewage waste treatment, and private sewage waste treatment systems range from outhouses, composting toilets, cesspools, and septic tanks with leach fields. The high elevation of the water table in Gustavus renders it susceptible to contamination from surface and near-surface sources. Because much of Gustavus is located on a flat expanse of glacial outwash sediments that are characterized by poorly-drained, sandy soils, the groundwater is very shallow, and during wet months, can even be at or near the surface (Carson Dorn, Inc. 2002). In 2002, the town of Gustavus had 121 regularly active septic tanks or cesspools (Carson Dorn, Inc. 2002). ADEC requires there to be septic systems in Gustavus and recommends these systems be pumped every five years. However, Gustavus has no facility to pump septic systems, and meanwhile many of the septic systems are approaching their design life. In a report by Carson Dorn, Inc. (2002), various options are recommended for how to deal with properly handling the community's septic systems and disposing of the raw sewage. These include procuring a septic tank pumper truck for the town, disposing of sewage at the Bartlett Cove treatment facility, building a sludge dewatering system to process sewage and shipping the dewatered sewage to Juneau to be disposed of, or landfilling the dewatered sewage. Currently, much of the residential refuse disposal occurs outside of supervised landfills, to widely varying standards. In fact, anecdotes exist of individuals burying outhouse waste below the top layer of soil and vegetation (Chad Soiseth, NPS-GLBA, personal communication, 2005). A few homeowners pump out their septic tanks themselves into a lined pit on their property (Carson Dorn, Inc. 2002). It is difficult to say how these practices affect the water quality of the local watersheds; however, there is the possibility of the local groundwater becoming contaminated.

Watersheds that may be impacted include Salmon River, Good River, Rink Creek, Homesteader Creek, and Dude Creek. The Salmon River originates in GLBA lands, collects most of its water from the slopes of Excursion Ridge, and flows into Gustavus. Most of the residential houses in Gustavus are located within the drainage basin of the Salmon River. The Salmon River has a gravel river bed and healthy populations of pink salmon, chum salmon, coho salmon, steelhead, cutthroat trout and Dolly Varden char (Bishop and Streveler 1987). The Good River and Rink Creek run through the community of Gustavus and have small numbers of spawning salmonids (Bishop and Streveler 1987). Good River is smaller than Rink Creek with the entirety of its watershed occurring within Gustavus. Rink Creek is approximately 15 km long, with the lower fifth of the stream in Gustavus, and its outflow in the intertidal inside GLBA (Bishop and Streveler 1987). Much lower densities of private homes are located along both Good River and Rink Creek in comparison with Salmon River. Homesteader Creek originates in GLBA lands and a small portion of the creek flows through Gustavus before it flows back into the Park.

Backcountry sewage treatment

Backcountry use and associated disposal of human waste in GLBA has not generated any known water quality problems, except in the Alsek River (NPS 1989a). Disposal of human waste on the Alsek River is prohibited within one-half mile of the river (NPS 2006b). GLBA encourages rafters to haul out all waste and deposit it at the waste dump station at the take-out area. In 2004 the NPS built a new human waste dump station at the Alsek River rafter take-out area and installed a septic system at the ranger station because of the failure of the previous dump station and ranger station outhouse to meet ADEC standards. With the exception of the East Alsek River Public Use Cabin, which has an outhouse that meets state standards, all of the NPS facilities at the Alsek River now have a septic system. Waste from the septic tanks is run thru a "bagger" system that filters out the solids from the septic tank and allows them to freeze, thaw, and dry over the winter. By spring the waste is rendered non- pathogenic and this is transported to Gustavus where it is incinerated annually. To date, the NPS does not foresee any long-term problems with this system except making the aboveground parts of the dump station bear proof (Jim Capra, NPS-GLBA, personal communication, 2005). Because human waste disposal by backcountry users in Glacier Bay proper is not monitored, it is not possible to assess the extent to which it is impacting water resources. However, backcountry use in the park is diffuse and most human waste is deposited in the intertidal zone where it is rapidly diluted.

B3b. Nonpoint Source Pollutants

B3b1. Atmospherically-derived contaminants

While GLBA is generally considered to be a pristine environment, there is growing evidence that Alaska and other arctic and sub-arctic regions are being contaminated by chemicals that travel far from their original sources (Fitzgerald et al. 1998, Heiman et al. 2000, AMAP 2002, AMAP 2004). Some of these chemicals reach Alaska from distant sources in temperate and tropical regions, enter the food chain, and biomagnify up trophic levels; thereby posing serious threats to the health of marine, freshwater, and terrestrial organisms (EPA 2002).

Mercury and a group of chemicals known as Persistent Organic Pollutants (POPs) are the 2 major subjects of concern for Alaska in terms of global contaminants. Mercury (Hg), 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). While there are some localized sources for these chemicals, the vast majority of them are carried to Alaska via long-range atmospheric pathways (Strand and Hov 1996, Schroeder and Munthe 1998, Wania et al. 1999), and their concentrations in northern latitudes have been rising (AMAP 2002, AMAP 2004).

Highly volatile POPs may travel directly to Alaska by long-range atmospheric transport, and less volatile POPs reach the region due to the “grasshopper effect”, in which they are deposited and revolatilized in a successive northbound pattern (Wania and Mckay 1996). Once deposited in the northern latitudes, they are slow to decompose due to the cold climate. Like some of the more volatile types of POPs, Hg accesses Alaska in a gaseous form.

Gaseous Hg is highly volatile and sparingly soluble, and consequently, it can travel far distances and over long time periods (~1 yr) before being deposited (Petersen et al. 1995, Schroeder and Munthe 1998). Anthropogenic mercury deposition to Alaska appears to be similar in magnitude to that in temperate latitudes (Fitzgerald et al. 2005). Elevated levels of methylmercury in fish have led to consumption advisories throughout most of the USA and much of Canada (EPA 2004, Pilgrim et al. 2000, Environment Canada 2004).

Several studies within Southeast Alaska indicate the region as a whole is being impacted by these contaminants. One study examined the record of Hg in lakebed sediments specifically in GLBA (Engstrom and Swain 1997), and one group of studies evaluated the POPs and Hg concentrations in seabird eggs from various locations in Alaska (Christopher et al. 2002, Vander Pol et al. 2004, Davis et al. 2004, Day et al. 2004). The study of dated sediment cores collected at three lakes in GLBA concluded that modern Hg accumulation rates in sediments are approximately double pre-industrial accumulation rates (Engstrom and Swain 1997) (Figure 32). Additionally, Hg deposition in GLBA did not show the recent declines (since the1960s) observed at sites in the continental US where regional mercury emissions have been reduced. These results suggest that southeast Alaska is being affected by mercury emissions from remote sources (e.g. in Asia), that are steadily increasing their output (Pacyna and Pacyna 2002a).

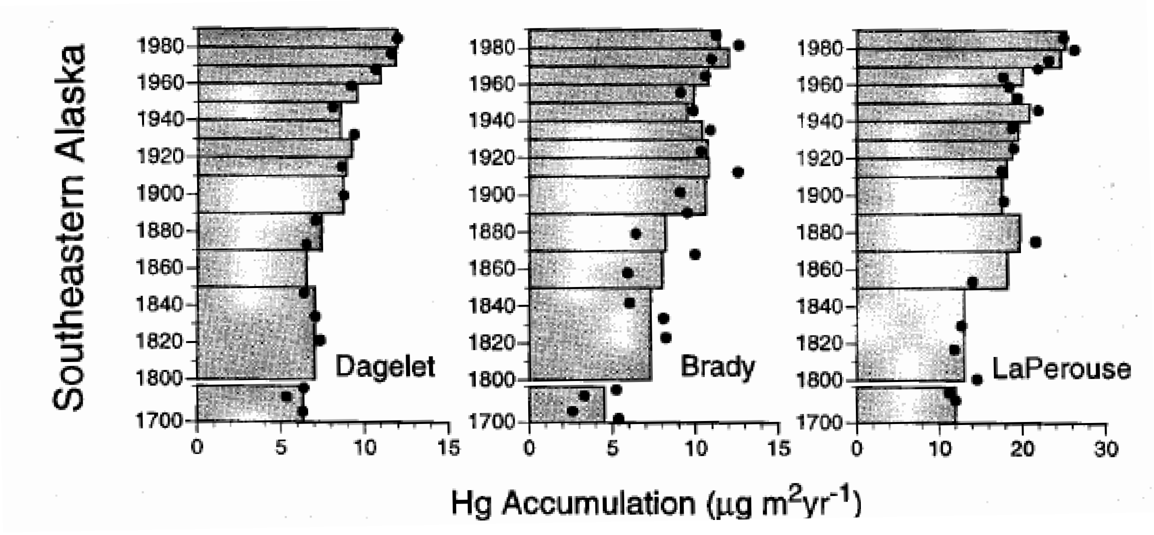

Figure 32. Hg accumulation rates for individual lake sediment strata averaged at decadal intervals in ^{210}Pb-dated cores from lakes in GLBA. Source: Engstrom and Swain (1997).

Results of the seabird egg project showed that concentrations of POPs in common murre eggs from two islands in the Gulf of Alaska were significantly higher than in eggs from three colonies in the Bering Sea. Eggs from St. Lazaria (in Sitka Sound) had higher concentrations of PCBs than eggs from any other Alaskan colonies (Figure 33). Samples from Gulf of Alaska colonies also showed that the contribution of 4,4'-DDE (dichlorodiphenyldichloroethylene) to the total concentration of POPs was twice as high as it was at the three Bering Sea colonies (Vander Pol et al. 2004). Geographic differences in the POPs concentrations are not understood, but they are thought to be products of global wind and ocean current patterns that result from variable deposition characteristics within Alaska. Studies of mercury concentrations in the seabird eggs indicated that mercury pollution may also be more of a concern in southeast Alaska compared to other regions of Alaska (Christopher et al. 2002, Davis et al. 2004, Day et al. 2004, 2006). Murre eggs collected from islands in the Gulf of Alaska had mercury concentrations that were several-fold higher than eggs from islands in the Bering Sea, and the highest concentrations of mercury were again from St Lazaria Island in the Sitka Sound (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 high rates of wet deposition, the relatively warm temperatures, and presence of estuaries—all factors that stimulate mercury methylation processes—as well as strong freshwater discharge and high erosion rates. Wetlands and other organic-rich, saturated areas are particularly efficient methylmercury generators because their biogeochemical conditions are highly supportive of bacterial methylation (by sulfate-reducing bacteria) of Hg, the main process that converts inorganic Hg (mainly Hg^{2+}) to toxic MeHg. More information on the seabird egg contaminant studies can be found at http://www.absc.usgs.gov/research/ammtap/stamp.htm

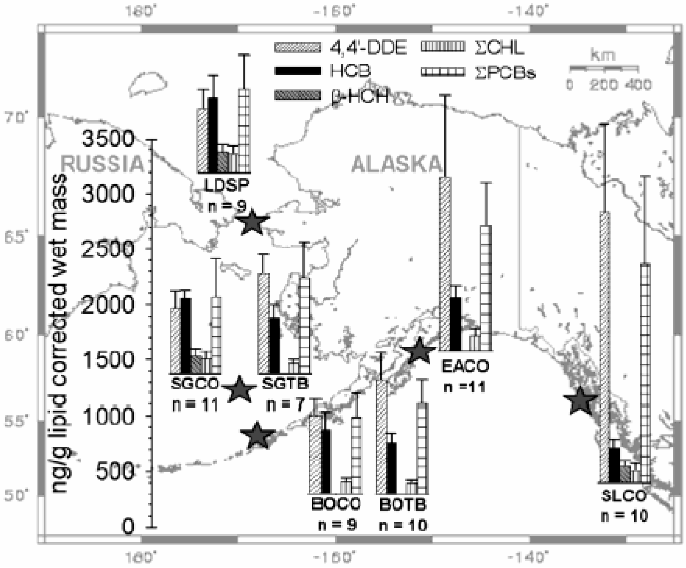

Figure 33. Mean values (±1 standard error bar) of primary POPs in murre *(Uria spp.)* eggs collected by STAMP in 1999 and 2000. (BO= Bogoslof Island, EA= East Amatuli Island, LD=Little Diomede Island, SG= St. George Island, and SL= St. Lazaria Island; CO= common murres, TB= thick-billed murres, and SP= murre species. From Vander Pol et al. (2004).

Deposition of POPs and Hg in southeast Alaska is predicted to continue. Although 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 GLBA, numerous other forms of POPs are still being manufactured and released into the environment in large quantities with unknown consequences (Giles 2004). Whereas mercury emissions in the USA have decreased in recent decades, global emission rates 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 2002b). As a result, Southeast Alaska is likely to be impacted by rising mercury contributions for decades to come. In sum, although field studies has proved that assessing the effects of environmental contaminant exposure to organisms or ecosystem processes is difficult (Keller et al. 2000), the limited studies to date strongly suggest that the threats posed by mercury and POPs to otherwise pristine ecosystems such as those in GLBA are significant and deserve further evaluation and monitoring.

B3b1. Marine-derived biological sources of pollutants

Mercury and POPs may be contributed to stream systems via biological vectors. As salmon develop their biomass (95% in the marine environment), they incorporate marine contaminants such as Hg and POPs and transport them into watersheds where they spawn (Ewald et al. 1998, Krümmel et al. 2003, Senkowsky 2004, Zhang et al. 2001). For example, Krümmel, et al. (2003) report strong correlations between the density of salmon runs with PCB concentrations in lake sediments in southwestern Alaska. The researchers found that the input of PCBs by spawning salmon resulted 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 showed that salmon may be major transporters (accounting for 21 kg of methylmercury transported into eight Bristol Bay watersheds over the past 20 years) of marine-derived Hg into freshwater environments (Zhang et al. 2001). 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.

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 the Gulf of Alaska, with GLBA as no exception. Many streams in GLBA support salmon runs and salmon are likely to continue colonizing newly exposed streams in GLBA as deglaciation processes result in increased stream habitat that is suitable for salmon spawning. The potentially deleterious side-effect of salmon colonization of new streams is that levels of Hg and POPs may rise accordingly, and the increased loading of pollutants to the watersheds via salmon import are likely to have effects up the food chain (Christensen et al. 2005).

C. Other Areas of Concern

C1. Marine Vessel Impacts on Water Quality

GLBA contains 2430 km^2 (940 mi^2) of marine waters. Maritime shipping, commercial fishing, cruise ships, and pleasure craft frequent local waterways in Southeast Alaska, which are the highways of the area. Limited vessel numbers and operating requirements have been in place within Glacier Bay proper since 1979 because of concerns that marine vessels might negatively impact endangered humpback whales. The NPS is proposing to establish new limits and operating requirements for watercraft in GLBA, and a final environmental impact statement (FEIS) gives a detailed analysis of vessel traffic and related impacts on GLBA (NPS 2003). Because of the extensive treatment of potential water quality impacts in this FEIS, we only briefly discuss this issue here.

Marine vessels have the potential to degrade water quality in GLBA by the accidental release of petroleum (discussed above in *B3a1. Petroleum*), the release of wastewater or other discharges, or by resuspension of sediments (NPS 2003). Wastewater generated by marine vessels that may serve as a source of marine pollution in or near GLBA waters includes graywater (laundry, shower, and galley sink wastes), blackwater (treated sewage), hazardous waste, solid waste and marine debris (NPS 2003). Nearly all large cruise ships are now outfitted with Advanced Wastewater Treatment equipment which treats both grey and blackwater and allows them to continuously discharge treated water. However, advanced wastewater treatment equipment likely does not treat for micro-contaminants such as personal care products (soaps, lotions), pharmaceuticals, and drugs (e.g., caffeine). These microcontaminants are not monitored, in part because there are no national standards by which to compare them to (Elizabeth Kim, EPA, personal communication). Therefore, no data exist on the occurrence of microcontaminants in cruiseship discharge, although they have been found in treated effluent and thus have the potential to survive cruiseship waste treatment procedures(Kolpin et al. 2002, Pedersen et al. 2005). It is illegal to dump raw sewage within 5 km (3 mi) of shore, and therefore no discharge should occur near shore in GLBA. Private vessels may not be able to treat their wastewater before it is discharged; however NPS (2003) reports that because of the small volumes and large dilution factor, that the effects of this wastewater would not be significant. ADEC (2002) 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. 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. Another way in which 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 in GLBA are most likely temporary and limited to the immediate area of vessel traffic.

C2. 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. One thing that is certain is that HABs 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).

Harmful algal blooms have been documented for centuries. Early records from explorers and hunters describe outbreaks of illness after men ate local shellfish that are most likely the result of ingesting toxic dinoflagellates in shellfish tissues. The first recorded deaths due to PSP occurred during exploration of Puget Sound and the Strait of Georgia in 1791-1792 when several members of Capt. George Vancouver's crew died after eating shellfish from a cove near modern day Vancouver, BC. The earliest recorded event in Alaska was in 1799 when a party of Aleut hunters under the command of a Russian fur trading company ingested mussels. Within minutes, half the party experienced nausea and dry mouth, and two hours later, 100 hunters had died. Alaska has figured prominently in the discovery of HABs and associated toxins, as the family of toxins responsible for PSP were named saxitoxins because they were extracted from the butter clam *Saxidomus giganteus* from Peril Strait, just northeast of Sitka.

The largest problem caused by HABs in Alaska is paralytic shellfish poisoning (PSP) from shellfish that have bioaccumulated the dinoflagellate *Alexandrium* sp. (Figure 34). 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 (Figure 35, Gessner 1996).

Figure 34. *Alexandrium* sp., the dinoflagellate responsible for PSP

Figure 35. 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 GLBA. 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 GLBA. 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.

C3. Invasive or Nuisance Species

The National Invasive Species Council, which was created by Presidential Executive Order 13112, defines invasive species as species that are "nonnative (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health." 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. This plan can be found on the ADFG Invasive Species Website at http://www.adfg.state.ak.us/special/invasive/invasive.php.

Nonindigenous aquatic invasive species that have been introduced or are moving into Alaskan waters include multiple species of fish, plants, and invertebrates (Appendix 4). 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). Farmed Atlantic salmon in Washington State and British Columbia are acidentally 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 can survive 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). ADFG has documented over 700 recoveries of Atlantic salmon throughout Alaskan waters which represent an estimated 3,000 immigrants per year. Atlantic salmon have been caught in many locations throughout Southeast Alaska including Lynn Canal, Icy Strait, Ketchikan, Petersburg, and Yakutat (ADFG 2002b). Atlantic salmon pose a real threat to GLBA and have been documented in the park,. In fact, an adult fish was caught by a recreational angler in the Dry Bay Preserve's Doame River in 2000. The most likely 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. NPS has not conducted surveys of aquatic or marine invasive species in GLBA (Lewis Sharman, NPS-GLBA, personal communication, 2006).

C4. Future Development

The number of people who visit and reside in the Glacier Bay region is growing each year. This increase in human presence means there will need to be a corresponding increase in support infrastructure. With increasing visitation to GLBA, Bartlett Cove will likely need improvements in visitor accommodations, utilities, Park housing and concessions, and Park administrative and science facilities. Growth in Gustavus and Excursion Inlet may spur an increase in development and roads in these areas. Numerous streams pass through areas in Gustavus where water quality may be impaired from human development. In particular, the lower-most reaches of Rink Creek, Homesteader and Falls Creek lie within the park boundary. Water quality should be monitored to determine potential impairments. Already, hundreds of miles of logging roads have been built through nearly every watershed on northeast Chichagof Island and south of Excursion Inlet during the last two decades. Another future development issue includes the possibility of the Brady Mine operations proceeding (discussed below in section *C4b.*). In addition, it is possible, but not likely, that logging and development may occur in any of the private land holdings in GLBA. Any such future development is likely to become an important resource management issue for GLBA.

C4a. Brady Mining Claim

The Brady Glacier, which is approximately 16 km (10 mi) long and 5 to 6 km (3 to 4 mi) wide, is located in a remote area in the southwestern part of GLBA. Derksen (1976) gives a detailed account of the glacial history of the Brady Glacier and the geology of the region. In the 1950s, Newmont Mining Company discovered the Brady Glacier ore body. This nickel-copper deposit is located largely under the ice (Hickok et al. 1981, Catton 1995). In the 1970s, the Newmont Mining Company studied the feasibility of mining under the Brady Glacier.

Today, the University of Alaska owns the mining claims that exist for the Brady Glacier. If operations were to proceed, significant development in the surrounding area would have to take place. Tunnels, trams and roads would need to be built to transport ore; a coastal port at Palma Bay, Torch Bay or Dixon Harbor would have to be constructed; and accommodations would need to be built for onsite workers. One of the NPS's major concerns about these possible future operations center around possible water quality degradation as a result of tailings storage and ore transportation. So far, the NPS has not received a plan of operations from the University of Alaska to develop the ore body associated with the Brady Glacier and is unaware of specific plans for future mining exploration or production at the Brady Glacier (Catton 1995).

C5. Physical impacts

Hazards associated with natural hydrological processes are found throughout GLBA. Potential hazards include: outburst floods, landslides, land surface uplift (isostatic rebound), snow avalanches, advancing glacial systems, and seismic activity. Of these hazards, landslides, seismic activity, and isostatic rebound present relatively well documented threats to coastal water resources.

C5a. Land Surface Uplift

Active tectonics in southeastern Alaska, as well as the increased thinning of glaciers, are contributing to the extremely high rates of land surface uplift in the region. Icefields in coastal southeastern Alaska have experienced rapid retreat and thinning in the last 100-200 years, and the rate at which ice is being lost appears to be increasing (Arendt et al 2002). In GLBA, the collapse of the Glacier Bay Icefield has resulted in a loss of 3030 km^3 (2.8×10^{12} kg) of ice (or 8 mm of global sea level rise) since the end of the Little Ice Age (LIA) in the late 18th century (Larsen et al 2005). The entire north Gulf of Alaska coast also contains active fault systems associated with the juncture of the Pacific and North American tectonic plates. Thus, active tectonic deformation of the southeastern Alaska region is also a possible source of uplift. Seismic activity near GLBA is high, with the Fairweather Fault running through the park, and five earthquakes with a magnitude of 7.0 or higher were recorded in Yakutat to the northwest of the park in the last century (City of Yakutat 2005). However, the effects of tectonic activity on land surface uplift are thought to be relatively minor compared to isostatic rebound from the loss of glacial ice (Larsen et al. 2004). Moreover, the unloading of the earth's surface associated with ice loss has resulted in isostatic rebound of the earth's crust over a large area of southeastern Alaska (Hicks and Shofnos 1965, Clark 1977, Sauber et al. 2000, Larsen et al. 2004).

Current rates of land surface uplift in southeastern Alaska are among the highest ever recorded. GPS measurements have recorded rebound rates of up to to 28 mm (1.1 in) per year in Glacier Bay and 34 mm (1.34 in) per year centered over the Yakutat Icefield to the northwest (Larsen et al 2004). Rates of uplift in GLBA are generally highest in the center of the park and decrease by more than 50% (to approximately 12 mm (0.5 in) per year) moving toard the coast (Figure 36). This uplift is altering the landscape of GLBA. Surveys of raised shorelines in GLBA have recorded relative sea level changes of as much as 5.7 m (18.7 ft) within the park since the end of the LIA (Figure 37). This relative change in the height of sea level has been shown to cause dramatic changes in fisheries and wildlife habitat in nearby 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 GLBA 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. One example in GLBA is discussed above. Vegetation in the East Alsek River is changing stream flow and sedimentation, likely as a result of changes in flooding regime, which has changed as a result of uplift (see *B2d. Water Quality Impairments – Alsek River and Dry Bay*). Recent research in the Mendenhall Valley near Juneau has shown that water table levels have been decreasing at approximately 3.7 cm/yr (1.5 in/yr) during the last two decades, likely as a result of land surface uplift (Walter et al. 2004). This decrease in the water table appears to be affecting the hydrology of streams within the valley. For example, during the last decade, Duck Creek, a small salmon stream, has experienced a steady decrease in low flows of approximately 0.003 m^3/s/yr (Walter et al 2004). As a result, the lower reaches of Duck Creek often now run dry in the spring and summer. The GLBA region is currently experiencing greater uplift rates than Juneau, thus it is possible that coastal streams fed by groundwater may experience similar reduced flows and become impassable for fish, limiting the range of certain anadramous stocks. The US Geological Survey office in Juneau is currently preparing a report on recent changes in the hydrology of Duck Creek resulting from land surface uplift (Edward Neal, USGS Juneau Office, personal communication, 2005).

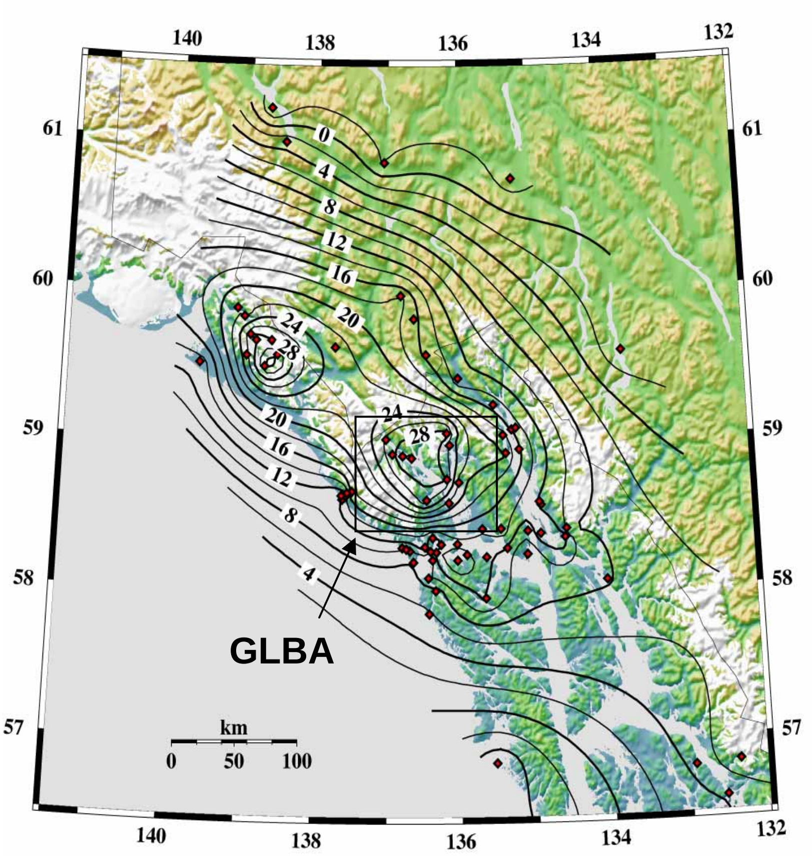

Figure 36. Land surface uplift rates in southeast Alaska from GPS measurements. Modified from Chris Larsen, University of Alaska Fairbanks Geophysical Institute (http://www.giseis.alaska.edu/Input/chris/gpsuplift.jpg).

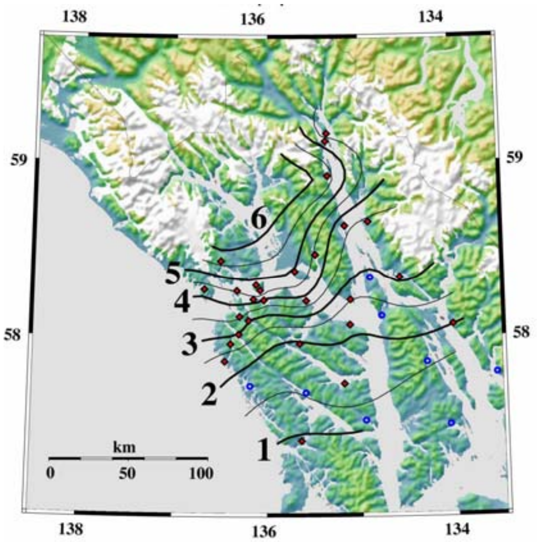

Figure 37. Relative sea level change (m) in southeastern Alaska near GLBA. Contour interval is 0.5 m. Modified from Chris Larsen, University of Alaska Fairbanks Geophysical Institute (http://www.giseis.alaska.edu/Input/chris/shorelinecontour2.jpg).

C5b. Landslide-induced Wave Hazards in Tidal Inlet

A large potential rock avalanche has been identified above the northern shore of Tidal Inlet in GLBA (Figure 38). A slope failure at this location would generate landslide-induced waves that could present a risk for park visitors. Previous field surveys indicate that a landslide of between 5 and 10 million m^3 moved in Tidal Inlet between AD 1892 and 1919 (Wieczorek et al 2003). Evidence suggests that glacial debutressing after the end of the Little Ice Age caused slope weakening and the slide may have been triggered earthquakes in Yakutat Bay at the end of the 19th century. While there is not evidence of current slope movement at the site (Figure 39), the concern remains that an earthquake along the nearby Fairweather fault system could trigger a massive rock slump and debris avalanche into Tidal Inlet. Preliminary analyses show that waves induced by such a landslide could generate large waves (tens of meters in amplitude) with a runup on the opposite shore of Tidal Inlet esceeding 100 m (Geist et al. 2003). Outside of Tidal Inlet large waves would persist in shallow regions, particularly near the mouth of the inlet. Landslide-generated waves have the potential to impact a large portion of the West Arm of GLBA, however wave amplitude would decrease in the deeper waters in the central portion of the West Arm (Geist et al. 2003).

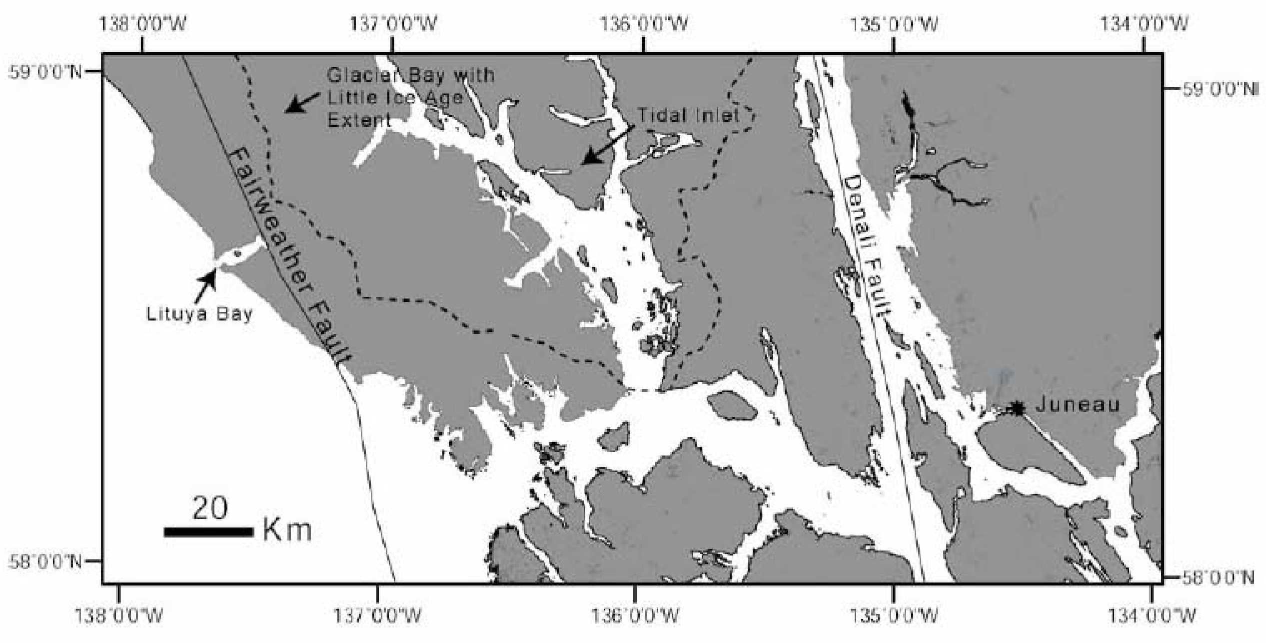

Figure 38. Location of Tidal Inlet in GLBA.
Source Geist et al. (2003).

Figure 39. Detached landslide mass perched above the northern shore of Tidal Inlet. The peak in the center of the photo is approximately 1130 m high. Picture from Wieczorek et al 2003.

C5c. Glacial Outburst Floods

Southeast Alaska has one of the highest concentrations of glacier-dammed lakes anywhere in the world (Grover 1997). These lakes can form when glacial ice along the main stem of a glacier blocks streamflow from a tributary valley. As glacier-dammed lakes expand over time, lake water may leak through tunnels or drainage systems within the ice. However, if the lake becomes large enough, it may force the ice dam to become buoyant, which results in a rapid emptying of the lake and a catastrophic outburst flooding or "jökulhlaup" (Björnsson 1998). The large volume of water associated with these flood events can eliminate vegetation and trees, deposit vast amounts of sediment lower in the watershed, and cause the river channel to be relocated. Within GLBA, the post-flood succession of vegetation has been studied in watersheds affected by jökulhlaups events (Derksen 1976).

At the present time, no infrastructure in GLBA is threatened by glacial outburst floods. However, glacier-dammed lakes occur in several places in GLBA. Post and Mayo (1971) recorded the presence of 10 glacier-dammed lakes around the margins of the Brady Glacier, including Abyss Lake, located approximately 8 km (5 mi) up the Brady Glacier from Dundas Bay (Figure 40). Abyss Lake is dammed on its southwest end by the Brady Glacier and drains out on the other side of the mountains to the Dundess River. Abyss Lake has been estimated to contain130,742,000 m^3 of water and peak flows associated with outburst floods from the lake have been estimated at greater than 1000 m^3/sec (35,000 ft^3/sec; Grover 1997). Outburst flood events occurred in the Abyss Lake system six times between 1994 and 2005 with a return period of between 1 and 4 years (Chad Soiseth, NPS-GLBA, personal communication, 2006). Another glacier-dammed lake is an unnamed one on the west side of the Brady Glacier that drains out the Dixon River (Bill Eichenlaub, NPS-GLBA, personal communication, 2005). This feature explains why the Dixon River, which normally does not have that much water, is disproportionately wide. Very large glacier-dammed lakes existed in the recent past but are now empty. An example of probably the largest ice-dammed lake in North America was the Neoglacial Lake Alsek, which was dammed by the Lowell Glacier and was once almost 200 m (650 ft) deep and 100 km (62 mi) long (Clague and Rampton 1982).

Figure 40. Abyss Lake in August 2002. This image clearly shows the “bathub ring” indicator of previous higher lake levels. Photo provided by Bill Eichenlaub, NPS-GLBA.

C6. 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, Mitchell 1989, Serreze et al. 2000) and future changes in temperature are projected to be proportionally higher in high-latitude systems (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 et al. 1997; Serreze et al. 2000). The reasons for the observed temperature increases at high latitudes are not fully understood, but are thought to involve cyospheric effects such as the snow/ice albedo feedback effect (e.g. Sturm et al. 2005), coupled with changes in the atmospheric circulation, and possibly ocean currents.

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). Glaciers in both maritime and continental regions of Alaska are thinning and retreating at rapid rates (Arendt et al 2002). At the end of the Little Ice Age, glaciers extended to the mouth of Glacier Bay and GLBA was largely covered by the Glacier Bay Icefield (Figure 41). Since the end of the little ice age, glacier ice in parts of GLBA has thinned by more than 1500 m (Figure 42) and today less than 30% of the park area is under glacier ice. Currently, many of the glaciers in GLBA are thinning, some at rates of greater than 3 m (10 ft) per year (Figure 43). Losses of ice have been most dramatic at lower elevations along the coast, probably due to a warmer climate. Meteorological data from nearby stations at Juneau, Sitka and Yakutat show increasing air temperatures over the last half century. In Juneau, mean annual air temperature has increased by more than 1.5 ˚C (2.7 ˚F) since 1943 when the meteorological record began (Motyka et al. 2003). Water temperatures in GLBA have also increased since the mid-1960s. Measurements by Hooge and Hooge (2002) suggest that both winter and summer water temperatures have increased by 2 ˚C (3.6 ˚F) or more. In addition, salinities of intermediate and deep waters in the bay have freshened by 0.25-0.75 during this time period and currently show less seasonable variability consistent with greater glacial melting in the winter (Hooge and Hooge 2002).

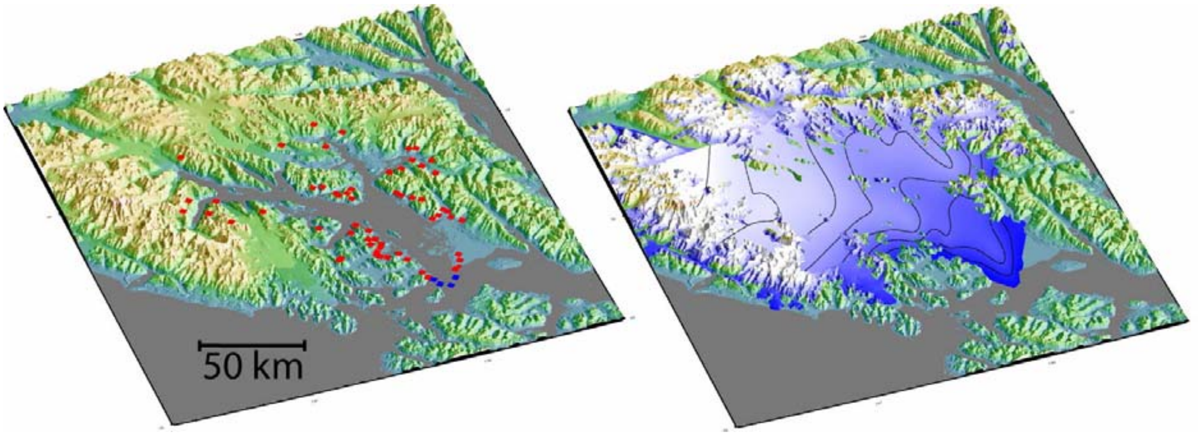

Figure 41. Glacier Bay ice field reconstruction.
(Left) Field locations where data were gathered to reconstruct the extent of the Glacier Bay Ice Field. (Right) Reconstruction of the peak areal extent for the Glacier Bay Ice Field around 1750. Figure modified from Chris Larsen, University of Alaska Fairbanks Geophysical Institute, http://www.giseis.alaska.edu/Input/chris/2panel_3d.jpg

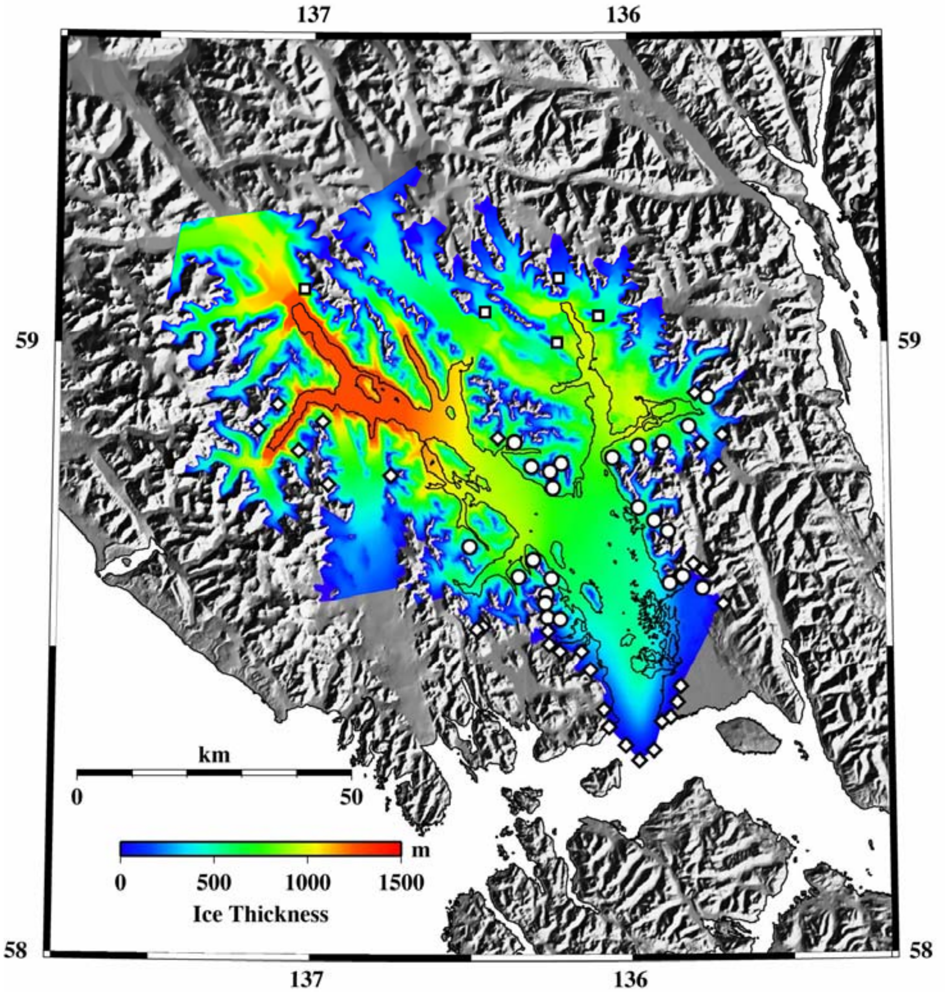

Figure 42. Changes in glacier ice thickness in GLBA since 1750.
Figure modified from Chris Larsen, University of Alaska Fairbanks Geophysical Institute, http://www.giseis.alaska.edu/Input/chris/gb_lia_icethick.jpg

Despite ongoing glacial retreat, some projections suggest that increasing winter temperatures in high-latitude areas may lead to greater snow accumulation (Mayo and Trabant 1984, Mayo and March 1990). Increases in snowfall could in turn slow glacial retreat or even cause glacial advance. Indeed some GLBA glaciers, particularly on the west side of the park, have shown periods of advance during the latter half of the 20th century including the Carroll, Johns Hopkins, Lamplugh, Reid, Margerie, Brady, and Grand Pacific glaciers (Hall et al. 1995). It is also important to note that the effects of climate change on GLBA glacier may be very different for tidewater glaciers compared to glaciers that have a land-grounded terminus. Glaciers that terminate at tidewater typically follow their own cycles of advance and retreat that are often independent of short-term changes in regional climate. For example Hunter and Powell (1993) found that terminus dynamics at the Grand Pacific and Muir Glaciers are controlled by morainal bank sediment dynamics and concluded that tidewater termini in GLBA are insensitive to climate forcing. However, regional climate warming does appear to be affecting non-tidewater glaciers in GLBA, the majority of which are receding. This glacial recession is most pronounced on the Bay's east and southwest sides where glacial thinning rates at lower elevations are on the order of 4 m (13 ft) per year (Figure 43).

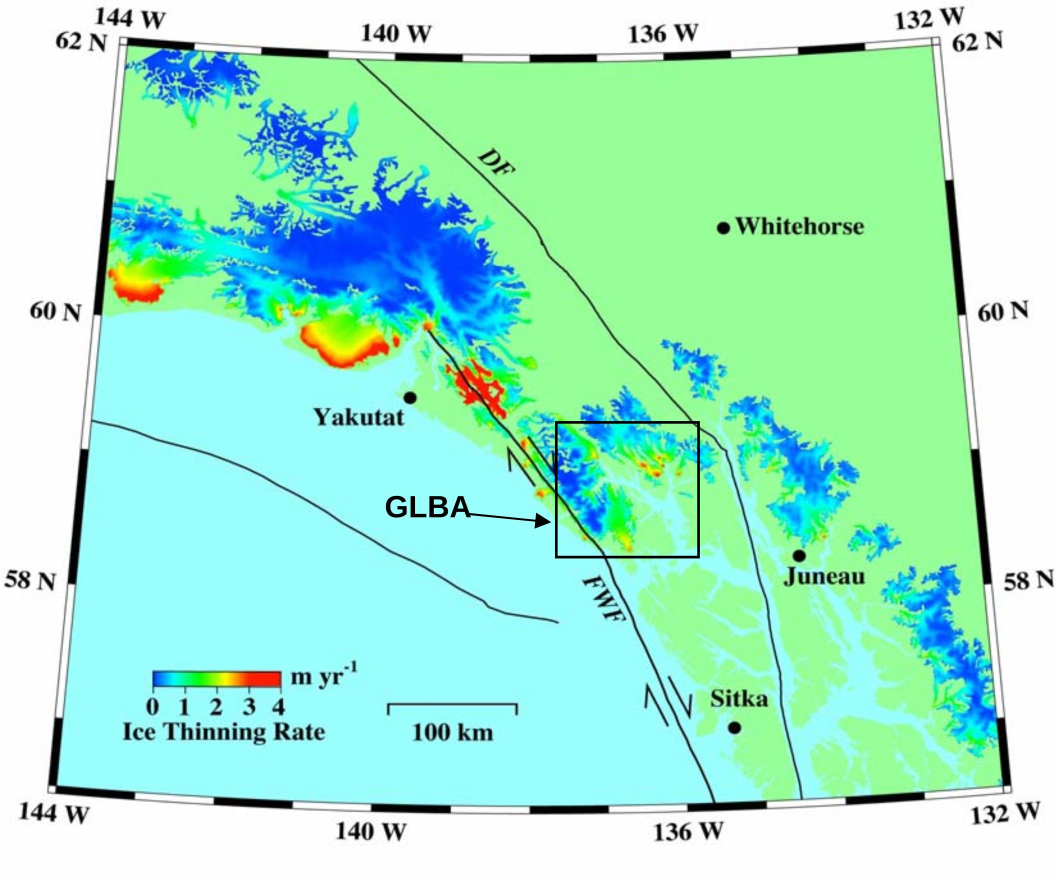

Figure 43. Current rates of glacier ice thinning in southeastern Alaska as measured by laser altimetry. FWF depicts the location of the Fairweather Fault.
Modified from Roman Motkya, University of Alaska Fairbanks, Geophysical Institute.

Glacial recession continues to shape the landscape of coastal GLBA. Another important hydrologic effect of increased glacier melt is an increase in 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, glaciers in GLBA may produce less runoff as glacier mass decreases significantly (Benson et al. 1986).

Climate warming may impact the hydrology of terrestrial systems in GLBA by causing areas of permafrost to thaw and dry out. This shift in the soil moisture regime would impact terrestrial ecosystems because the water-logged soils that make up permafrost contribute to the high diversity of plant life in many areas (Bruemmer 1987). Oswood et al. (1992) also suggests that the warming of northern soils may increase the carbon dioxide flux to the atmosphere which could exacerbate global warming. Thus, the loss of permafrost could increase carbon dioxide emissions from park ecosystems. Previous research has shown that melting permafrost can shift tundra ecosystems from net sinks to net sources of carbon dioxide by facilitating the decomposition of soil carbon stocks locked up in permafrost (Chapin 1984, Billings 1987, Roots 1989).

Increasing air temperatures also have the potential to impact waterbodies such as high-altitude muskeg ponds and glacier-dammed lakes. The effects of climate change on the chemistry of lakes and streams are unknown. Research on linkages between terrestrial and aquatic systems suggests that elevated temperatures and carbon dioxide levels will affect the distribution and productivity of plants which will in turn affect the amount and quality of leaf litter entering streams and rivers (Meyer and Pulliam 1992). Sweeney et al. (1992) also predict increases in woody debris entering streams. Because soil microbial activity is linked to soil temperature and moisture, climate shifts will affect microbial processing of organic material in terrestrial systems. Overall, changes in inputs from terrestrial systems to lakes and streams will lead to shifts in litter decomposition rates (Webster and Benfield 1986), as well as changes in the productivity of heterotrophic and invertebrate populations (Anderson and Sedell 1979, Oswood et al. 1992). Stream water quality could also be altered by changes in the frequency of disturbances such as forest fires, wind storms, and coastal floods (Meyer and Pulliam 1992). Ultimately, changes to the quality and quantity of runoff from terrestrial ecosystems will affect nearshore marine systems in GLBA because the productivity of these systems is partially controlled by the input of nutrients from coastal watersheds.

D. Recommendations

D1. Condition overview

Table 6. Potential for impairment of GLBA water resources.

Indicator	Freshwater	Marine Outer Coast	Marine Bays & Estuaries
Water Quality			
Eutrophication	OK	OK	OK
Contaminants	PP	PP	PP
Hypoxia	OK	OK	OK
Turbidity	OK	OK	OK
Pathogens	OK	OK	OK
Water Quantity	OK	NA	NA
Habitat Disruption			
Physical benthic impacts	OK	OK	OK
Coastal development	PP	OK	OK
Altered flow	OK	OK	OK
Erosion/Sedimentation	OK	OK	OK
Altered salinity	OK	OK	OK
Recreation/Tourism usage	OK	OK	OK
Other Indicators			
Harmful algal blooms	NA	PP	PP
Aquatic invasive species	PP	PP	PP
Impacts from fish/shellfish harvesting	OK	PP	OK
Climate change	PP	PP	PP

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

GLBA contains dynamic freshwater and marine ecosystems. These systems are relatively pristine with few protential problems of concern; however, in many cases, little data is available (Table 6). Our rationale for assignments is well described in the body of the report and briefly described below.

Freshwater – Water quality in freshwater areas is high; however few studies of stream, lake or groundwater water quality have been conducted. Atmospheric deposition poses a threat to freshwater water quality. Habitat disruption is generally very limited. Human development may impair water quality in streams that pass through this area before entering the park. No sampling has been done to evaluate the presence of aquatic invasive species. Freshwater fishing only occurs within limited areas by a small number of users, and is therefore not considered a threat. Climate change effects are unknown but could be significant at high latitudes. As glaciers recede, land surfaces will uplift and change hydrological patterns.

Marine Outer Coast and Bays & Estuaries– Water quality in marine and intertidal areas is high; however few studies of marine water quality have been conducted. Atmospheric deposition poses a threat to marine water quality. Habitat disruption is generally very limited. NPS restricts recreation and tourism usage, and these impacts are likely minimal. No sampling has been done to evaluate the presence of harmful algal blooms or aquatic invasive species. Given the prevalence of harmful algal blooms, clam or mussel harvest should be discouraged. Fish and shellfish harvest effects may decrease within Glacier Bay proper as fishing is phased out and effects on the outer coast are a potential problem that warrants further study. Water quality effects of the fish processing plant in Excursion Inlet are unknown. Climate change effects are unknown but could be significant at high latitudes. As glaciers recede, land surfaces will uplift, changing sea level height and affecting intertidal communities.

D2. Recommendations

During the course of writing this report, we identified data gaps and areas in which further investigation or monitoring is warranted. These recommendations are enumerated below (Table 7) and elaborated in the following section.

Table 7. List of recommendations.

Data access/management

1. Online archives of NPS publications and reports
2. Integration of information into centralized and web-accessible GIS

Water quality

1. Assess threat from atmospheric contaminants
2. Establish baseline freshwater water quality and watershed condition
3. Establish baseline marine water quality
4. Evaluate marine vessel impacts on water quality
5. Monitor and/or evaluate areas with previous or potential water quality concerns

Biological resources and habitats

1. Wetlands inventory
2. Intertidal monitoring program & Coastal database
3. Identification of marine food web
4. Continue stream successional studies
5. Study impacts of sea otter colonization
6. Invasive species survey

Hydrology/Oceanography

1. Climate/weather stations
2. Continue oceanographic monitoring
3. Quantify freshwater inputs from stream and glaciers
4. Oceanographic circulation model
5. Primary productivity and harmful algal bloom survey

D2a. Data access/management

Online archives of NPS publications and reports

Obtaining information for this report was arduous and difficult; however information could be more readily obtained if NPS were to generate publicly-accessible online archives of NPS publications and reports. Such an archive should be searchable. Historical documents should be entered to the extent possible.

Integration of information into centralized and web-accessible GIS

Data from surveys, monitoring activities, impairments, and inventories should be integrated into a centralized and web-accessible GIS.

D2b. Water quality

Assess threat from atmospheric contaminants

GLBA should partner with other parks in the SEAN network to assess the threat from global-scale pollutants such as mercury and POPs to network parks. 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. These pollutants should be monitored in both water and biological resources.

Establish baseline freshwater water quality and watershed condition

Baseline freshwater water quality should be inventoried at a set of GLBA lakes and streams and monitored at a subset of these. Physical and chemical parameters would include: turbidity (streams), Secchi depth (lakes), temperature, conductivity, total dissolved solids (TDS), dissolved oxygen (DO), pH, organic and inorganic nitrogen and phosporus, sulfate, dissolved organic carbon (DOC), and DOC quality. In addition, regular inventories of macroinvertebrate communities following established bioassessment protocols should be conducted in streams where water quality is being monitored. Many of the watersheds in GLBA are highly dynamic, and differentiating natural changes in water quality and anthropogenically-driven changes is a challenge. 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, and the extent of riparian vegetation. All of this information should be stored in a database as a way to facilitate data access.

Establish baseline marine water quality

Baseline marine water quality should be inventoried. Likely locations include USGS/NPS Oceanographic monitoring stations and other areas of concern such as Excursion Inlet. Sampling should include collections of water and sediments for nutrients, total suspended solids, hydrocarbons, fecal coliform and other contaminants of concern. Contaminants could be inventoried over a large spatial scale by using protocols developed by the NOAA Mussel Watch program. Mussels are collected from the intertidal and then analyzed for over 70 polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorinated pesticides, butyltins, and toxic trace elements, such as copper, cadmium and lead. Sediments at the test sites are also regularly analyzed for chemical contaminants, and shellfish from selected locations are analyzed for radionuclides. In addition, Mussel Watch monitors the health of mussel populations, including condition index, size frequency, stage of reproductive development, and prevalence and intensity of diseases, parasites and pathologies. GLBA could join the Mussel Watch network and sample several sites annually. This activity would provide opportunity for long-term time series as well as the opportunity to compare data to hundreds of others in the national program.

Evaluate marine vessel impacts on water quality

The baseline marine water quality inventory (above) should include sites that can be ranked in terms of vessel use to address whether water quality differs in areas which are regularly used by vessels (e.g. Bartlett Cove) in comparison to areas which are less frequently visited. Sampling design must take natural geographic variation in marine water quality into consideration.

Monitor and/or evaluate areas with previous or potential water quality concerns

A study of the heavy metals pollution issue in Ptarmigan Creek is recommended to determine whether mine tailings continue to impact the stream, as more than 20 years have passed since the last water quality evaluation of the area and no remedial actions have been conducted. Groundwater contamination from a fuel spill in Bartlett Cove deserves further monitoring to track possible local contamination leaching to nearby surface water. In addition, we recommend that NPS continue to monitor the treated sewage wastewater that is discharged into Bartlett Cove. Impacts of fish processing waste in Excursion Inlet need to be studied. The effects of ATV use on water quality in the Dry Bay area should be studied and we recommend that ATV users be better educated about the impacts of their activity and the importance of using designated trails. Finally, we recommend that a monitoring program be designed that would allow for the detection of any changes in water quality in park waters that may result from the construction of the Falls Creek Hydroelectric Project.

D2c. Biological resources and habitats

Wetlands inventory

The National Wetlands Inventory has only mapped a portion of GLBA. The remainder needs to be mapped.

Intertidal monitoring program & Coastal database

The intertidal monitoring program should be continued at some regular interval, and NPS should require reports and analyses for work conducted. If a new protocol is implemented, then the previous one and the new one should be conducted simultaneously to determine data comparability. The Coastal Resources Inventory and Monitoring Database should be made publicly accessible online. This will give anyone with access to the internet the ability to "walk the coast" of Glacier Bay National Park, focusing on the information of greatest interest to them. The risk of exposure to oil spills and other parameters found in ShoreZone should be fully implemented to facilitate data transferability between the two. The NPS should obtain GIS layers from ShoreZone to integrate into centralized GIS (see above) and should participate in ground-truthing for ShoreZone.

Identification of marine food web

Recent declines in marine mammals and other species may be better understood in light of predator and prey interactions. A thorough understanding of the marine food web is necessary to predict marine system responses to changes in patterns of biotic and abiotic factors, although we recognize that such an understanding may be difficult. NPS could encourage process-based studies that investigate food web linkages as a step in this process.

Continue stream successional studies

Stream succession in GLBA is a unique opportunity to study the creation of a stream and colonization by biological organisms, including salmon. Glacier Bay is one of the few places where these studies can be conducted, and these studies provide useful information about long-term changes in park hydrologic resources as well as insight that can be applied to other locations where freshwater and marine ecosystems are being altered by deglaciation (e.g. Patagonia). NPS should facilitate and encourage continuation of ongoing studies on successional processes in GLBA watersheds.

Study impacts of sea otter colonization

Sea otter colonization in GLBA is a unique opportunity to study the impact of a top-level predator on the nearshore marine ecosystem. Decreases in otter food items (e.g. crabs, urchins, clams) will likely have large effects on community structure. NPS should study this process in order to better understand changes that will occur as otters colonize Glacier Bay.

Invasive species survey

Aquatic and marine environments should be surveyed for invasive species that are most likely to occur. 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.

D2d. Hydrology/Oceanography

Monitor climate

Climate change is one of the major threats to water resources in Alaskan parks. The hydrology of coastal parks such as GLBA is particularly sensitive to climate change because the mean air temperature at sea level in southeastern Alaska during winter 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 GLBA should be monitored, at various elevations, including ocean-based stations. 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. GLBA should install an automated climate station in Bartlett Cove and should support climate stations in other locations to provide baseline climate information and aid GLBA resource managers in detecting future changes in climate and in determining impacts on biological resources. To the extent possible, existing climate stations should be continued and supported by NPS.

Continue oceanographic monitoring
The USGS/NPS oceanographic monitoring program should be continued. To the extent possible, sampling should occur at regular intervals. In addition, the progam should include installation of automated sensors for autonomous and continuous collection of data. NPS should join with the Alaska Ocean Observing System (AOOS) and provide oceanographic monitoring data to AOOS and national databases to facilitate data sharing and archiving.

Quantify freshwater outputs from streams and glaciers into the marine environment
Freshwater input into GLBA is significant and affects coastal circulation in Southeast Alaska and in the Gulf of Alaska. Quantification of freshwater input or proxies should be developed. At least one glacial and non-glacial stream within Glacier Bay should be gaged to record seasonal and temporal changes in hydrology.

Develop a model of circulation in Glacier Bay
Circulation in the marine waters of GLBA affects pollutant transport, population recovery/regeneration, connectivity with outside areas, hotspots for biological productivity and sensitive areas, and effects of marine vessels. A detailed circulation model should be developed.

Primary productivity and harmful algal bloom survey
The timing and intensity of phytoplankton blooms need further study in order to temporally and spatially document productivity that influences many higher trophic levels in GLBA and to detect the presence of toxic algal species, which may be harmful to humans or other marine wildlife. Water sampling for phytoplankton should be added to existing oceanographic monitoring and could be supplemented with more frequent shipboard or *in situ* water sampling. Such sampling could be conducted by ships of opportunity, such as ferries or cruise ships that are fitted with autonomous sampling devices. Satellite observations of ocean color may provide synoptic, large scale indications of primary productivity, although high cloud cover and high latitude result in limited availability of good images.

References Cited

ADEC. 2001. Interim Cruise Ship Sampling Data Summary. Alaska Department of Environmental Conservation.

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.

ADEC. 2003. Alaska's Final 2002/2003 Integrated Water Quality Monitoring and Assessment Report. Alaska Department of Environmental Conservation.

ADEC. 2006a. Geographic Response Strategies for Southeast Alaska. http://www.dec.state.ak.us/spar/perp/grs/se/home.htm. Last accessed: March 20, 2006.

ADEC. 2006b. 18 AAC 70 Water Quality Standards as amended through March 23, 2006. Available at http://www.dec.state.ak.us/water/wqsar/wqs/pdfs/18_AAC_70_revised_March2306.pdf. Last accessed March, 2006.

ADFG. 2002a. Alaska Aquatic Nuisance Species Management Plan. Alaska Department of Fish and Game, Juneau, AK.

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

ADNR. 2006. State-federal Falls Creek land trade opens door for Gustavus hydro electric project. Alaska DNR in the News, 3 April 2006. Internet news release at http://www.dnr.state.ak.us/standard/dsp_media_release.cfm?id=612&title=State-Federal%20Falls%20Creek%20Land%20Trade.

AMAP. 2002. AMAP Assessment Report: Arctic Pollution Issues: Persistent Organic Pollutants, Heavy Metals, Radioactivity, Human Health, Changing Pathways. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

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 Inventory & Monitoring Program.

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

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

Anderson, N. H., and J. R. Sedell. 1979. Detritus procession by macroinvertebrates in stream ecosystems. Annnual Review of Entomology 24:351-377.

Andrews, A. G., S. J. Taggart, J. Mondragon, and J. Nielsen. 2004. Testing the effectiveness of a high latitude marine reserve network: A multi-species movement study in Glacier Bay National Park. *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

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

Arimitsu, M. L., Michael A. Litzow, John F. Piatt, Martin D. Robards, Alisa A. Abookire, Gary S. Drew. 2003. Inventory of Marine and Estuarine Fishes in Southeast and Central Alaska National Parks. USGS.

Arimitsu, M., M. Romano, and J. Piatt. 2004. Ground-nesting Marine Bird Distribution and Potential for Human Impacts in Glacier Bay National Park. *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Armstrong, R. H., R. L. Carstensen, and M. F. Willson. 2004. Hotspots: Bird Survey of Mendenhall Wetlands, April 2002 to May 2003. Juneau Audubon Society and Taku Conservation Society, Juneau, AK.

Baker, C. S. and L. M. Herman (1989). Behavioral responses of summering humpback whales to vessel traffic: experimental and opportunistic observations, US National Park Service, Anchorage, Alaska, 50 pp.

Baker, C. S., Straley, J. M., and Perry, A. 1992. Population characteristics of individually identified humpback whales in southeastern Alaska - Summer and Fall 1986: Fishery Bulletin, v. 90, no. 3, p. 429-437.

Baker, M. 2000. Facility Response Plan - Bartlett Cove Fuel Transfer and Storage Facility, Alaska. Prepared for the U.S. Department of Interior, National Park Service, by Michael Baker Jr., Inc.

Bardgett, R. D., and L. R. Walker. 2004. Impact of coloniser plant species on the development of decomposer microbial communities following deglaciation. Soil Biology & Biochemistry 36:555-559.

Benoit, G. 1994. Clean technique measurement of Pb, Ag, and Cd in freshwater: a redeifintion of metal pollution. Environmental Science and Technology 28:1987-1991.

Benson, C. S., G. Wendler, and R. March. 1978. On the Climate and Air Pollution Potential in Glacier Bay National Monument, Alaska. Geophysical Institute of the University of Alaska, Fairbanks, Fairbanks, AK.

Benson, C., W. Harrison, J. Gosnik, S. Bowling, L. Mayo, and D. Trabant. 1986. Workshop on Alaskan Hydrology: Problems related to glacierized basins. Geophysical Institute Report UAG-R (306), University of Alaska Fairbanks, Fairbanks, AK.

Betts, M. F., Kookesh, M., Shroeder, R. F., Thornton, T. F., and Victor, A. M. 1998. Subsistence resource use patterns in Southeast Alaska: Gustavus. Alaska Department of Fish and Game, Division of Subsistence, Juneau, AK.

Bilby, R. E., B. R. Fransen, and P. A. Bisson. 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 53:164-173.

Billings, W. D. 1987. Carbon balance of Alaskan tundra and taiga ecosystems: Past, present and future. Quaternary Science Reviews 6:165-177.

Binkley, D. 1981. Nodule biomass and acetylene reduction rates of red alder and Sitka asler on Vancouver Island, British Columbia. Canadian Journal of Forest Research 11:218-286.

Bishop, D. M., 1980, Soils, Hydrology, *in* Streveler, G. P., Worley, I. A., and Molnia, B., eds., Lituya Bay Environmental Survey Volume I: Text: Juneau, Alaska, National Park Service, p. 348.

Bishop, D. M., and G. P. Streveler. 1987. Gustavus ditching and drainage study. Environaid.

Björnsson, H. 1998. Hydrological characteristics of the drainage system beneath a surging glacier. Nature 395:771 - 774.

Bluemink, E. 2006. Glacier Bay hydro plans move forward. *Juneau Empire* 5 April 2006.

Blundell, G., S. M. Gende, and E. Mathews. 2004. Investigating Harbor Seal Decline in Glacier Bay National Park. *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Bodkin, J. L, K. A. Kloecker, G. G. Esslinger, D. H. Monson, and J. D. DeGroot. 2001. Sea otter studies in Glacier Bay National Park and Preserve: Aerial surveys, foraging observations, and intertidal clam sampling. 2000 Annual Report. U.S. Geological Survey, Biological Resources Division, Anchorage, AK.

Bodkin, J. L., K. A. Kloecker, G. G. Esslinger, D. H. Monson, H. A. Coletti, and J. Doherty. 2002. Sea Otter Studies in Glacier Bay National Park and Preserve. Annual Report 2002. US Geological Survey, Anchorage, AK and Glacier Bay National Park and Preserve, Gustavus, AK.

Bosworth, R. G. 1988. Consistency and change in subsistence use of Glacier Bay, Alaska. Pages 101-107 *in* J. A. M. Milner and J. D. Wood, editors. Proceedings of the Second Glacier Bay Science Symposium. National Park Service, Anchorage, Alaska.

Bruemmer, F. 1987. Life upon the permafrost. Natural History 96:30-39.

Bryant, M. D., and F. H. Everest. 1998. Management and condition of watersheds in Southeast Alaska: The persistence of anadromous salmon. Northwest Science 72:249.

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

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 15:462-477.

Carlson, P. R., R. D. Powell, D. M. Rearic, and P. Quinterno. 1988. Channel-forming processes active in Queen Inlet, Glacier Bay, Alaska. Pages 41-46 *in* J. A. M. Milner and J. D. Wood, editor. Proceedings of the Second Glacier Bay Science Symposium. National Park Service, Anchorage, Alaska.

Carson Dorn Inc. 2002. Technical report for Gustavus septage disposal options: final report. Gustavus and Village Safe Water. Juneau, AK.

Catton, T. 1995. Land Reborn: A History of Administration and Visitor Use in Glacier Bay National Park and Preserve. National Park Service, Glacier Bay National Park and Preserve, AK.

Cederholm, C. J., M. D. Kunze, T. Murota, and A. Sibatani. 1999. Pacific salmon carcasses: Essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24:6-15.

Chaloner, D. T., and M. S. Wipfli. 2002. Influence of Decomposing Pacific Salmon Carcasses and Macroinvertebrate Growth and Standing Stock in Southeastern Alaska Streams. Journal of the North American Benthological Society 21:430-442.

Chang, J. C. 1971. An ecological study of butter-clam (*Saxidomus giganteus*) toxicity in Southeast Alaska. MS Thesis. University of Alaska, Fairbanks, AK.

Chapin, F. S. 1984. The impact of increased air temperature on tundra plant communities. Pages 143-146 *in* J. H. McBeath, G. P. Juday, G. Weller, and M. Murray, editors. The Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska. School of Agriculture and Land Resources Management, University of Alaska Miscellaneous Publication 83-1.

Chapin, F. S., L. R. Walker, C. L. Fastie, and L. C. Sharman. 1994. Mechanisms of primary succession following deglaciation at Glacier Bay, Alaska. Ecological Monographs 64:149-175.

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 39 (18): 6952-6960.

Christopher, S. J., S. S. Vander Pol, R. S. Pugh, D. Day, and P. R. Becker. 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 17:780-785.

City of Yakutat. 2005. Greater Yakutat Chamber of Commerce webpage. Last accessed: June 02, 2005.

Clague, J. J., and V. N. Rampton. 1982. Neoglacial Lake Alsek. Canadian Journal of Earth Science 19:94-117.

Clark, J. A. 1977. An inverse problem in glacial geology: The reconstruction of glacier thinning in Glacier Bay, Alaska between A.D. 1910 and 1960 from relative sea level data. Journal of Glaciology 18:481-403.

Conner, C., and D. O'Haire. 1988. Roadside geology of Alaska. Roadside Geology Series. Mountain Press Publishing Company, Missoula.

Cooper, W. S. 1931. A third expedition to Glacier Bay, Alaska. Ecology 12:61-95.

Crocker, R. L., and B. A. Dickson. 1957. Soil development on the recessional moraines of the Herbert and Mendenhall Glaciers, south-eastern Alaska. Journal of Ecology 45:169-185.

Crocker, R. L., and J. Major. 1955. Soil development in relation to vegetation and surface age at Glacier Bay, Alaska. Ecology 43:427-448.

Davis, W. C., S. S. Vander Pol, M. M. Schantz, S. E. Long, R. D. Day, and S. J. Christopher. 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 19:1546-1551.

Day, R. D., S. J. Christopher, S. S. Vander Pol, R. S. Pugh, and P. R. Becker. 2004. Seabird eggs as indicators of mercury contamination in the Alaskan marine environment. Proceedings of the International Conference on Environmental Science and Technology.

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. Murre eggs (*Uria aalge* and *Uria iomvia*) as indicators of mercury contamination in the Alaskan marine environment. Environmental Science and Technology 40(3): 659-665.

Decker, H. F. 1966. Soil Development and Ecological Successsion in a Deglaciated Area or Muir Inlet, Southeast Alaska. Institute of Polar Studies Report No. 20. Ohio State University, Columbus, Ohio.

Deecke, V., C. O. Matkin, H. Yurk, and J. K. B. Ford. 2001. NPS Investigator Annual Report: Acoustic monitoring of killer whales in Glacier Bay National Park. National Park Service.

Derksen, S. J. 1976. Glacial geology of the Brady Glacier region, Alaska. Report No. 60. Institute of Polar Studies, Columbus, OH.

Deschu, N., D. Thompson, H. Seitz, and K. Thompson. 1993. International Gaging Station Established on the Alsek River. Pages 184-189 *in* D. R. Engstrom, editor. Third Glacier Bay Science Symposium. National Park Service, Glacier Bay National Park and Preserve, Alaska.

Doherty, J. L., and C. M. Gabriele. 2004. Results of humpback whale population monitoring in Glacier Bay and adjacent waters: 2004. Glacier Bay National Park and Preserve, Gustavus, AK.

Duggins, D., and J. Quinn. 1979. The intertidal life of Bartlett Cove. Glacier Bay National Monument, Gustavus, AK.

Dyurgerov, M. B., and Meier, M. F., 2000. Twentieth century climate change: Evidence from small glaciers. Proceedings of the National Academy of Science 97: 1406-1411.

Eckert, G., J. Douglas, J. Taggart, and J. Fisher. 2004. Temporal and spatial patterns in Dungeness crab larval abundance within Glacier Bay. *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Eckert, G.L. and H. L. Herter. 2006. How Big is Big Enough? America's Largest Temperate Marine Reserve May Not Be Self Sustaining for Some Species: Recruitment of Dungeness Crabs in Glacier Bay. Ocean Sciences 2006. Honolulu, HI.

Eisner, L. 2005. Biomass and relative particle size of phytoplankton in Glacier Bay, Alaska. Alaska Marine Science Symposium, Anchorage, AK, January 2005.

Eley, W. D. 2000. Needs Assessment for a Major Fuel Oil Spill, Glacier Bay National Park and Preserve. Cape Decision International Services, Juneau, Alaska.

Engstrom, D. R., and E. B. Swain. 1997. Recent declines in atmospheric mercury deposition in the upper midwest. Environmental Science and Technology 31:960-967.

Engstrom, D. R., and S. C. Fritz. 1988. Early lake ontogeny following neoglacial ice recession at Glacier Bay, Alaska. Pages 127-132 *in* A. M. M. a. J. D. W. Jr., editor. Proceedings of the second Glacier Bay Science Symosium. Glacier Bay National Park and Preserve, Gustavus, AK.

Engstrom, D. R., S. C. Fritz, J. E. Almendinger, and S. Juggins. 2000. Chemical and biological trends during lake evolution in recently deglaciated terrain. Nature 408:161-166.

Environment Canada. 2004. Mercury and the environment: Fish consumption. http://www.ec.gc.ca/MERCURY/EN/fc.cfm#BC. Last accessed: July 11, 2005

EPA. 1972. Water Quality Criteria 1972: a report of the Committee on Water Quality Criteria. Environmental Stud. Board Nat. Academy of Sciences, National Academy of Engineering, Washington DC.

EPA. 1977. Quality Criteria for Water. Environmental Protectoin Agency. U.S. Government Printing Office 258-389/6057, Washington D.C.

EPA. 2002. Persistent Organic Pollutants: A Global Issue, A Global Response. http://www.epa.gov/oiamount/toxics/pop.htm#pops. Last accessed: July 15, 2005

EPA. 2005. Alaska BEACH Grant Program Webpage. http://www.state.ak.us/dec/water/wqsar/wqs/beachprogram.htm. Last accessed: February 7, 2005

Erbe, C., 2003, Assessment of Bioacoustic Impact of Ships on Humpback Whales in Glacier Bay, Alaska: National Park Service.

Etherington, L. L., P. N. Hooge, and E. R. Hooge. 2004. Factors affecting seasonal and regional patterns of surface water oceanographic properties within a fjord estuarine system: Glacier Bay, AK. National Park Service, Gustavus, Alaska.

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 51: 40-47.

Fastie, C. L. 1995. Causes and ecosystem consequences of multiple pathways ofprimary succession at Glacier Bay, Alaska. Ecology 76:1899-1916.

Finnegan, D.C., D.E. Lawson, and S.E. Copczynski. 2004. Assessing contemporary and holocen glacial and glacial-marine environments. *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Fisher, J. 2004. Distribution, abundance, and timing of brachyuran larvae in a high-latitude fjord. *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Fisher, J. in press 2006. Seasonal timing and duration of brachyuran larvae in a high-latitude fjord. Marine Ecology Progress Series.

Fitzgerald, W. F., D. R. Engstrom, C. H. Lamborg, C. M. Tseng, P. H. Balcom, and C. R. Hammerschmidt. 2005. Modern and historic atmospheric mercury fluxes in northern Alaska: Global source and arctic depletion. Environmental Science and Technology 39:557-568.

Fitzgerald, W. F., D. R. Engstrom, R. P. Mason, and E. A. Nater. 1998. The case for atmospheric mercury contamination in remote areas. Environmental Science and Technology 32:1-7.

Flory, E. A. 2001. Resident Dolly Varden, anadromous fish species and benthic invertebrates of the Falls Creek area, 2000. Prepared by Aquatic Science Inc., Juneau, AK. Prepared for Gustavus Electric Company, Gustavus AK.

Flory, E. A., and A. M. Milner. 2000. Macroinvertebrate community succession in Wolf Point Creek, Glacier Bay National Park, Alaska. Freshwater Biology 44:465-480.

Ford, J. K. B., G. M. Ellis, L. G. Barrett-Lennard, A. B. Morton, R. S. Palm, and K. C. Balcomb. 1998. Dietary specialization in two sympatric populations of Killer Whales (Orcinus orca) in coastal British Columbia and adjacent waters. Canadian Journal of Zoology 77:2000.

Fountain, A.G., R.W. Jacobel, R. Schlichting, and P. Jansson. 2005. Fractures as the main pathways of water flow in temperate glaciers. Nature 433: 618-621. doi: 10.1038/nature03296

Fritz, S. C., and D. R. Engstrom. 1993. Patterns of early lake ontogeny in Glacier Bay as inferred from diatom assemblages. *in* D. R. Engstrom, editor. Proceedings of the third Glacier Bay science symposium. National Park Service, Gustavus, AK.

Fritz, S. C., D. R. Engstrom, and S. Juggins. 2004. Patterns of early lake evolution in boreal landscapes: a comparison of stratigraphic inferences with a modern chronosequence in Glacier Bay, Alaska. The Holocene 14:828-840.

Gabriele, C. M., and T. M. Lewis. 2000. Summary of Opportunistic Marine Mammal Sightings in Glacier Bay and Icy Strait 1994-1999. Glacier Bay National Park and Preserve. National Park Service, Gustavus, AK.

Geist, E.L., M. Jakob, G.F. Weiczorek, and P. Dartnell. 2003. Preliminary hydrodynamic analysis of landslikde-generated waves in Tidal Inlet, Glacier Bay National Park, Alaska. USGS Open-File Report 03-411.

Gelatt, T., A. Trites, K. Pitcher, K. Hastings, and L. Jemison. 2004. Steller sea lion population trends, diet, and brand-resighting observations in Glacier Bay. *in* Glacier Bay Science Symposium., Juneau, AK.

Gende, S. M., R. T. Edwards, M. F. Willson, and M. S. Wipfli. 2002. Pacific salmon in aquatic and terretrial ecosystems. BioScience 52:917 - 926.

Gende, S.M., T.P. Quinn, M.F. Willson, R. Heintz, and T. Scott. 2004. Magnitude and fate of salmon-derived nutrients and energy in a coastal stream ecosystem. Journal of Freshwater Ecology 19:149-160.

Gessner, B. D. 1996. Epidemiology of paralytic shellfish poisoning outbreaks in Alaska. Alaska's Marine Resources 8:16-17.

Gessner, B. D., and M. Schloss. 1996. A population-based study of paralytic shell fish poisoning in Alaska. Alaska Medicine 38:54-58.

Giles, J. 2004. Treaty calls time on long term pollutants. Nature 247:768.

Goh, B. P. L., and L. M. Chou. 1997. Heavy metals in marine sediments of Singapore. Environmental Monitoring and Assesment:67-80.

Greisman, P. 1979. On upwelling driven by the melt of ice shelves and tidewater glaciers. Deep Sea Research 26A:1051-1065.

Grover, S. 1997. An Investigation of the 1997 Abyss Lake Jökulhlaup in Glacier Bay National Park. National Park Service, Gustavus, AK.

Gustavus Electric Company. 2004. Final environmental impact statement: Falls Creek Hyroelectric Project and Land Exchange. FERC Project No. 11659-002. Glacier Bay National Park and Preserve, National Park Service, Washington, D.C.

Hale, L. Z., and R. G. Wright. 1979. The Glacier Bay marine ecosystem: a conceptual ecological model. National Park Service, Anchorage, AK.

Hall, D. K. 1988. Assessment of climate change using satellite technology. Reviews of Geophysics 26:26-39.

Hall, D.K., C.S. Benson and W.O. Field. 1995. Changes of glaciers in Glacier Bay, Alaska, using ground and satellite measurements. Physical Geography 16(1):27-41.

Hart Crowser Inc. 2004. Groundwater monitoring report, Glacier Bay National Park and Preserve, Bartlett Cove, Alaska. National Park Service, Gustavus, AK.

Hawkins, C. M., and R. M. Slatt. 1972. Iron in surface and subsurface waters, Grizzly Bar, S.E. Alaska. Institute of Water Resources, University of Alaska Pub. IWR - 29, Fairbanks, AK.

Heiman, M., M. Brown, J. Middaugh, J. Berner, P. Cochran, M. Davis, S.Marcy, C. Hild, P. Johnson, J. Hohn, P. Miller, B. Wang, B. Wright, and M. Bradley. 2000. Contaminants in Alaska: Is America's Arctic at Risk? A white paper published by the Department of the Interior and the State of Alaska. Avaliable at http://www.conservationinstitute.org/contaminantsinalaska.htm.

Helfield, J. M., and R. J. Naiman. 2001. Effects of salmon-derived nitrogen on riparian forest growth and implications for stream productivity. Ecology 82:2403-2409.

Hickok, D. M., G. Weller, T. N. Davis, V. Alexander, and R. Elsner. 1981. United States Arctic Science Policy. Alaska Division, American Association for the Advancement of Science.

Hicks, S. D., and W. Shofnos. 1965. The determination of land emergence from sea-level observations in southeast Alaska. Journal of Geophysical Research 70:3315-3320.

Hitchcock, C. L., and A. Cronquist. 1973. Flora of the Pacific Northwest. University of Washington Press, Seattle, WA.

Hobbie, E. A., S. A. Macko, and H. H. Shugart. 1998. Patterns in N dynamics and N isotopes during primary succession in Glacier Bay, Alaska. Chemical Geology 152:3-11.

Hooge, P. N., and E. R. Hooge. 2002. Fjord Oceanographic Processes in Glacier Bay, Alaska. National Park Service, Gustavus, AK.

Horowitz, A. J., C. R. Dems, K. K. Fitzgerald, T. L. Miller, and R. D.A. 1994. US Geological Survey protocol for the collection and processing of surface-water samples for the subsequent determination of inorganic constituents in filtered water. US Geological Survey Open-File Report 94-539.

Hunn, E.S., D.R. Johnson, T.S. Thornton, P.N. Russell. 2004. The Huna Tlingit people's use of gull eggs and the establishment of Glacier Bay National Park. Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Hunter, L.E. and R.D. Powell. 1993. Climatic controls on glacier mass balance in Glacier Bay National Park and Preserve, Alaska. Pages 46-54 *in* D.R. Engstrom, editor. Proceedings of the Third Glacier Bay Science Symposium. National Park Service, Glacier Bay, Alaska.

Hutchinson, T. C. 1973. Comparative studies of the toxicity of heavy metals to phytoplankton and their synergistic interactions. Water Pol. Rep. 8:68-90.

IPCC. 2001. IPCC Third Assessment Report-Climate Change 2001: The Scientific Basis. http://www.ipcc.ch/pub/online.htm. Last accessed: Last accessed: July 1, 2005

Ireland, M. P. 1973. Result of fluvial zonc pollution on the zinc content of littoral and sub-littoral organisms in Cardigan Bay water. Environmental Pollutants 4:27-35.

Irvine, G.V. 1998. Development of coastal monitoring protocols and process based studies to address landscape-scale variation in coastal communities of Glacier Bay NP&P, Katmai NP&P, and Wrangell-St. Elias NP&P. Phase II: Development and testing of monitoring protocols for selected intertidal habitats and assemblages. Annual Report, BRD-NRPP Project. Submitted to Glacier Bay National Park and Preserve.

Irvine, G.V. 2001. Coastal monitoring protocols and process-based studies to address landscape-scale variation in coastal communities of Glacier Bay National Park and Preserve. Phase II: Development and testing of monitoring protocols for selected intertidal habitats and assemblages. Draft Final Annual Report, NRPP project, submitted to Glacier Bay National Park and Preserve.

Johnson, J. and E. Weiss. 2006.Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes—Southeastern Region. Effective March 1, 2006. Alaska Department of Fish and Game Special Publication 06-04. 470 pp. Available at http://www.sf.adfg.state.ak.us/SARR/FishDistrib/PDFs/_SEA2006_CATALOG_COMPLETE.pdf

Johnston, N. T., E. A. MacIsaac, P. J. Tschaplinski, and K. J. Hall. 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 61:384-403.

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

Keller, J. M., J. N. Meyer, M. Mattie, T. Augspurger, M. Rau, J. Dong, and E. D. Levin. 2000. Assessment of immunotoxicology in wild populations: Review and recommendations. Reviews in Toxicology 3:167-212.

Kipple, B. 2002. Southeast Alaska Cruise Ship Underwater Acoustic Noise. Naval Surface Warfare Center. Technical Report NSWCCDE-71-TR-2002/574. Prepared for Glaicer Bay National Park and Preserve.

Kipple, B., and C. Gabriele. 2003. Glacier Bay Watercraft Noise. Naval Surface Warfare Center. Technical Report NSWCCDE-71-TR-2003/522. Prepared for Glaicer Bay National Park and Preserve.

Kipple, B., and C. Gabriele. 2004. Glacier Bay Watercraft Noise- Noise Characterization for Tour, Charter, Private, and Government Vessels. Naval Surface Warfare Center. Technical Report NSWCCDE-71-TR-2004/545. Prepared for Glaicer Bay National Park and Preserve.

Kolpin, D. W., E. T. Furlong, M. T. Meyer, E. M. Thurman, S. D. Zaugg, L. B. Barber, and H. T. Buxton. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: A national reconnaissance. Environmental Science & Technology 36:1202-1211.

Krieger, K. J. and F. L. Wing (1986). Hydroacoustic monitoring of prey to determine humpback whale movements. National Oceanic and Atmospheric Administration and the National Marine Fisheries Service**.** 61 pp.

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 425: 255-256.

Larsen, C. F. 2003. Rapid uplift of southern Alaska caused by recent ice loss. University of Alaska Fairbanks, Fairbanks, Alaska.

Larsen, C. F., R. J. Motyka, J. T. Freymueller, K. A. Echelmeyer, and E. R. Ivins. 2004. Rapid uplift of southern Alaska caused by recent ice loss. Geophysical Journal International 158:1118-1133.

Larsen, C., R.J. Motkya, J.T. Freymuller, K.A. Echelmeyer, and E.R. Ivins. 2005. Rapid viscoelastic uplift in southeast Alaska caused by post-Little Ice Age glacial retreat. Earth Planet. Sci. Letters 237: 548-560.

Lawrence, D. B., R. D. Schonike, Q. Quispel, and G. Bond. 1967. The role of *Dryas drummondii* in vegetation development following ice recession at Glacier Bay, Alaska, with special reference to its nitrogen fixation by root nodules. Journal of Ecology 55:793-813.

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

Letarte, J., and R. Stottlemyer. 1984. Baseline Stream Water Chemistry for Watersheds of Glacier Bay National Park, Alaska, 1984 Progress Report. GLARSU Report #11, Department of Biological Sciences, Michigan Technological University, Houghton, MI, Submitted to Glacier Bay National Park.

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

Litzow, M. A., J. F. Piatt, and M. Arimitsu. 2002. Inventory of marine and estuarine fishes in Southeast Alaska National Parks during summer, 2001. Alaska Science Center, Biological Science Office, US Geological Survey, Anchorage, AK.

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

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

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

Mathews, E. A. 1995. Long-term trends in abundance of harbor seals (Phoca vitulina richardsi) and development of monitoring methods in Glacier Bay National Park, Alaska. Pages 254-264 *in* D. R. Engstrom, editor. Proceedings of the Third Glacier Bay Science Symposium, 1993. Dept. of the Interior, Anchorage, AK.

Mathews, E. A., and B. P. Kelly. 1996. Extreme temporal variation in harbor seal (*Phoca vitulina ricardsi)* numbers in Glacier Bay, a glacial fjord in southeast Alaska. Marine Mammal Science 12:483-489.

Mathews, E. A., and Pendleton, G. W., 2006. Declines in harbor seals *(Phoca vitulina)* numbers in Glacier Bay National Park, Alaska, 1992-2002. Marine Mammal Science 22: 167-189.

Matkin, D. R. 1990. Killer whales in Glacier Bay and Icy Strait, Alaska. Pages 96-100 *in* A. M. Milner and J. D. W. Jr., editors. Second Glacier Bay Science Symposium, 1988. National Park Service., Glacier Bay National Park & Preserve, AK.

Matkin, D. R., and M. E. Dahlheim. 1995. Feeding behaviors of killer whales in northern Southeastern Alaska. Pages 246-254 *in* D. R. Engstrom, editor. Third Glacier Bay Science Symposium, 1993. U.S. National Park Service, Glacier Bay National Park & Preserve, AK.

Matkin, D., J. Straley, and C. Gabriele. 2004. Killer Whale Feeding Ecology and Non-predatory Interactions with Other Marine Mammals. *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Mayo, L. R., and R. S. March. 1990. Air temperature and precipitation at Wolverine Glacier, Alaska; Glacier growth in a warmer, wetter climate. Ann. Glaciol. 14:191-194.

Mayo, L., and D. C. Trabant. 1984. Observed and predicted effects of climate change on Wolverine Glacier, southern Alaska. Pages 114-123 *in* J. H. McBeath, G. P. Juday, G. Weller, and M. Murray, editors. The Potential Effects of Carbon Dioxide-Induced Climate Change in Alaska. School of Agriculture and Land Resources Management, University of Alaska Miscellaneous Publications 83-1.

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

Mickelson, D.M. and N.R. Ham. 1993. Thirty years of glacier process studies at Burroughs Glacier, Wachusett Inlet, Glacier Bay, Alaska. Pages 55-65 *in* D.R. Engstrom, editor. Proceedings of the Third Glacier Bay Science Symposium. National Park Service, Glacier Bay, Alaska.

Mills, D. D., and A. S. Firman. 1986. Fish and Wildlife Use in Yakutat Alaska: Contemporary Paterns and Changes. Alaska Department of Fish and Game, Division of Subsistence, Douglas, AK.

Milner, A. M. 1987. Colonization and Ecological Development of New Streams in Glacier-Bay National-Park, Alaska. Freshwater Biology 18:53-70.

Milner, A. M. 1988. Community Development in a Glacial Stream. Pages 116-119 *in* J. A. M. Milner and J. D. Wood, editor. Proceedings of the Second Glacier Bay Science Symposium. National Park Service, Anchorage, AK.

Milner, A. M. 1993. Community Development in Wolf Point Creek, Glacier Bay National Park, Alaska. Pages 164-173 *in* D. R. Engstrom, editor. Third Glacier Bay Science Symposium. National Park Service, Gustavus, AK.

Milner, A. M. 1994. Colonization and Succession of Invertebrate Communities in a New Stream in Glacier-Bay-National-Park, Alaska. Freshwater Biology 32:387-400.

Milner, A. M. 1997. Glacial recession and freshwater ecosystems in coastal Alaska. Pages 303-330 *in* A. M. Milner and M. W. Oswood, editors. Freshwaters of Alaska: ecological synthesis. Springer-Verlag, New York.

Milner, A. M., E. E. Knudsen, C. Soiseth, A. L. Robertson, D. Schell, I. T. Phillips, and K. Magnusson. 2000. Colonization and development of stream communities across a 200-year gradient in Glacier Bay National Park, Alaska, USA. Canadian Journal of Fisheries and Aquatic Sciences 57:2319-2335.

Milner, A. N., and R. G. Bailey. 1989. Salmonid colonization of new streams in Glacier Bay National Park, Alaska. Aquaculture and Fisheries Management 20:179-192.

Mitchell, J. F. B. 1989. The "greenhouse" effect and climate change. Rev. Geo. phys. 27:115-139.

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

Mobley, J. M., S. Spitz, R. Grotefendt, P. Forestell, A. Frankel and G. Bauer. 2001. Abundance of humpback whales in Hawaiian waters: Results of 1993-2000 aerial surveys. Report to the Hawaiian Islands Humpback Whale National Marine Sanctuary. 16 pp.

Molnia, B. 1980. Environmental Dynamics: Beach characteristics and physical aspects of oilspill susceptibility, *in* Streveler, G. P., Worley, I. A., and Molnia, B. F., eds., Lituya Bay Environmental Survey Volume I: Text: Juneau, Alaska, National Park Service, p. 348.

Molnia, B. 1982. Alaska’s Glaciers. Alaska Geographic 9(1): 144 pp.

Molnia, B.F., R.D. Karpilo, and H.S. Pranger. 2004. Post-Little-Ice-Age landscape and glacier change in Glacier Bay National Park: Documenting more than a century of variability with repeat photography. American Geophysical Union, Fall Meeting, abstract C42A-03.

Mondragon, J., L. Etherington, S. J. Taggart, and P. N. Hooge. 2004a. The Distribution and Relative Abundance of Pacific Halibut in a Recently Deglaciated Fjord: The Role of Glacial Inputs and Ecosystem Age. *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Mondragon, J., S. J. Taggart, A. G. Andrews, and J. K. Nielsen. 2004b. Spatial distribution and relative abundance of Tanner and red king crab inside and outside of marine reserves in Glacier Bay, Alaska. *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Moore, J.W., D.E. Schindler, and M.D. Scheuerell. 2004. Disturbance of freshwater habitats by anadramous salmon in Alaska. Oecologia 139(2): 298-308. DOI: 10.1007/s00442-004-1509-3

Motyka, R. J., L. Hunter, K. A. Echelmeyer, and C. Connor. 2003. Submarine melting at the terminus of a temperate tidewater glacier, LeConte Glacier, Alaska. Annals of Glaciology 36:57-65.

Murphy, M. L., J. Heifetz, J. F. Thedinga, S. W. Johnson, and K. Koski. 1989. Habitat utilization by juvenile pacific salmon (Onchorynchus) in the glacial Taku River, Southeast Alaska. Canadian Journal of Fisheries Aquatic Science 46:1677-1685.

Nielsen, J., S. J. Taggart, T. C. Shirley, J. Mondragon, and A. G. Andrews. 2004. Glacial fjords in Glacier Bay National Park: Nursery areas for Tanner crabs? *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

NOAA. 2005. National Weather Service Webpage. http://weather.gov/. Last accessed: August 2, 2005

NPS, 1995, Baseline Water Quality Data Analysis and Inventory, Glacier Bay National Park and Preserve: National Park Service, Technical Report NPS/NRWRD/NRTR-95/56. 193 pp

NPS. 1989a. Alsek River Visitor Use Management Plan. Pages 19 *in*. National Park Service.

NPS. 1989b. Wilderness Visitor Use Management Plan. Glacier Bay National Park and Preserve. Available at http://www.nps.gov/applications/parks/glba/ppdocuments/ACF63C2.pdf Last accessed March 30, 2006.

NPS. 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.

NPS. 2005a. Freshwater Ecosystems Monitoring Scoping Workshop Notebook. Southeast Alaska Inventory and Monitoring Network, National Park Service, Glacier Bay National Park and Preserve, AK.

NPS. 2005b. Glacier Bay National Park and Preserve (webpage). http://www.nps.gov/glba/. Last accessed: March 30, 2006.

NPS. 2005c. Glacier Bay National Park and Preserve Regulations. http://a257.g.akamaitech.net/7/257/2422/08aug20031600/edocket.access.gpo.gov/cfr_2003/julqtr/pdf/36cfr13.65.pdf. Last accessed: August 15, 1005

NPS. 2005d. Backcountry Wilderness Planning. Glacier Bay National Park and Preserve. http://www.nps.gov/glba/InDepth/learn/preserve/issues/backcountry/index.htm Last accessed August 15, 2005.

NPS. 2006a. 2007 Cruise Ship Proposal from the Glacier Bay National Park and Preserve Superintendent . Available at http://parkplanning.nps.gov/showFile.cfm?projectId=14389&docType=public&MIMEType=application%252Fpdf&filename=Draft%20GLBA%20Cruise%20ship%20day%20use%20quota%202006%20%26%202007%2Epdf&clientFilename=Draft%20GLBA%20Cruise%20ship%20day%20use%20quota%202006%20%26%202007%2Epdf Last accessed March 30, 2006.

NPS. 2006b. Glacier Bay National Park and Preserve Compendium. http://www.nps.gov/glba/InDepth/visit/Compendium2006.pdf Last accessed April 17, 2006.

Olson, O. G., Daniel R. Engstrom, Sherilyn C. Fritz. 1993. Long-term changes in zooplankton community structure inferred from a chronosequence of lakes in Glacier Bay National Park, Alaska. Pages 154-163 *in* D. R. Engstrom, editor. The Third Glacier Bay Science Symposium. National Park Service, Gustavus, AK.

Oswood, M. W., A. M. Milner, and J. G. I. Irons. 1992. Climate change and Alaskan rivers and streams. Pages 192-210 *in* P. Firth and S. G. Fisher, editors. Global Climate Change and Freshwater Ecosystems. Springer-Verlag, New York, NY.

Overpeck, J. et al. 1997. Arctic environmental change of the last four centuries. Science 278 (5341): 1251-1256. DOI: 10.1126/science.278.5341.1251

Pacyna, E. G., and J. M. Pacyna. 2002. Global emission of mercury from anthropogenic sources in 1995. Water, Air, and Soil Pollution 137:149-165.

Park, W., T. Shirley, and S. J. Taggart. 2004. Relationship between abundance of Dungeness crab adults and larvae: Regional population increase or larval export from an MPA? *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Pedersen, J. A., M. Soliman, and I. H. Suffet. 2005. Human pharmaceuticals, hormones, and personal care product ingredients in runoff from agricultural fields irrigated with treated wastewater. Journal of Agricultural and Food Chemistry 53:1625-1632.

Petersen, G., A. Iverfeldt, and J. Munthe. 1995. Atmospheric mercury species over Central & Northern Europe, 1987 and 1988. Atmospheric Environment 29:47-67.

Phillips, A. C., and N. D. Smith. 1988. Suspended sediment dynamics of glacial deltas: Implications for maintenance of submarine channels. Pages 47-49 *in* J. A. M. Milner and J. D. Wood, editors. Proceedings of the Second Glacier Bay Science Symposium. National Park Service, Anchorage, Alaska.

Piatt, J. F., and N. L. Naslund. 1995. Abundance, distribution and population status of Marbled Murrelets in Alaska. Pages 285-294 *in* C. J. Ralph, G. Hunt, M. Raphael, and J. F. Piatt, editors. Ecology and Conservation of the Marbled Murrelet. General Technical Report PSW-GTR-152. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture., Albany, CA.

Pilgrim, W., L. Poissant, and L. Trip. 2000. The northeast states and eastern Canadian provinces mercury study: a framework for action: summary of the Canadian chapter. The Science of the Total Environment 261:177-184.

Post, A., and L. R. Mayo. 1971. Glacier dammed lakes and outburst floods in Alaska. *in* US Geological Survey Hydrological Investigations Atlas HA-455. US Geological Survey, Washington DC.

Powell, J., D. D'Amore, R. Thompson, T. Brock, P. Huberth, B. Bigelow, and M. T. Walter. 2003. Functional HGM wetland assessment guidebook. State of Alaska Department of Environmental Conservation, Juneau, AK.

Ramos, J. 2004. Tlingit traditional knowledge and clan management of sockeye salmon in Dry Bay, Alaska. Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Reiners, W. A., I. A. Worley, and D. B. Lawrence. 1971. Plant diversity in a chronosequence at Glacier Bay, Alaska. Ecology 52:55-69.

Robards, M., G. Drew, J. Piatt, J. M. Anson, A. Abookire, J. Bodkin, P. Hooge, and S. Speckman. 2003. Ecology of selected marine communities in Glacier Bay: zooplankton, forage fish, seabirds and marine mammals. Final report to the National Park Service, USGS ASC, Anchorage, AK.

Robertson, A. L., and A. M. Milner. 1999. Meiobenthic arthropod communities in new streams in Glacier Bay National Park, Alaska. Hydrobiologia 397:197-209.

Robertson, A. L., and A. M. Milner. 2001. Coarse Particulate Organic Matter: A habitat or food resource for the meiofaunal community of a recently formed stream? Archiv Fur Hydrobiologie 152:529-541.

Romano, M., and J. F. Piatt. 2004. Temporal and Spatial Variability in Distribution of Kittlitz's Murrelets in Glacier Bay. Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Roots, E. F. 1989. Climate Change: High latitude regions. Climate Change 15:223-253.

Royer, T. C. 1982. Coastal freshwater discharge in the Northeast Pacific. Journal of Geophysical Research 87:2017 - 2021.

Ruiz, G. M., J. T. Carlton, E. D. Grosholz, and A. H. Hines. 1997. Global invasions of marine and estuarine habitats by non-indigenous species: Mechanisms, extent, and consequences. American Zoologist 37:621-632.

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 49(4):891-899.

Sauber, J., G.Plafker, B. F. Molnia, and M. A. Bryant. 2000. Crustal deformation associated with glacial fluctuations in eastern Chugach Mountains, Alaska. J. Geophys. Res. 105:8055-8077.

Saulitis, E. 2000. Foraging strategies of sympatric killer whale populations in Prince William Sound, Alaska. Marine Mammal Science 16:94-109.

Scammell, M. S., G. E. Batley, and C. I. Brockbank. 1991. A field study of the impact on oysters of tributyltin introduction and removal in a pristine lake. Archives of Environmental Contamination and Toxicology:276-281.

Schindler, D. 1999. From acid rain to toxic snow. Ambio 28:352-355.

Schroeder, R. F. 1993. Historic and contemporary Tlingit use of Glacier Bay. *in* Proceedings of the Third Glacier Bay Science Symposium. National Park Service, Gustavus, AK.

Schroeder, W. H., and J. Munthe. 1998. Atmospheric mercury - An overview. Atmospheric Environment 32:809-822.

Sease, J. L., and R. L. Loughlin. 1997. Status and population trends of Steller sea lions. Pages 22-30 *in* G. Stone, J. Goebel, and S. Webster, editors. 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.

Senkowsky, S. 2004. Fear of fish: The contaminant controversy. BioScience 54(11): 986-988.

Serreze, M. C., J. E. Walsh, F.S. Chapin III, T. Osterkamp, M. Dyergerov, V. Romanovsky, W. C. Oechel, J. Morison, T. Zhang, and R. G. Barry. 2000. Observational evidence of recent change in the northern high latitude environment. Climate Change 46:159-207.

Sharman, L. 1988. Marine intertidal community developed following glacial recession in Glacier Bay, Alaska. Pages 108-115 *in* J. A. M. Milner and J. D. Wood, editor. Proceedings of the Second Glacier Bay Science Symposium. National Park Service, Anchorage, AK.

Sharman, L., B. Eichenlaub, D. Van Leeuwen, S. Croll, J.S. Grover, G. Lenhart and P. Hooge. 2003. NPS Alaska Coastal Resources Inventory and Mapping Field Protocol - The Polygon Method - Developed at Glacier Bay National Park and Preserve 1997-1998. Glacier Bay National Park and Preserve. Databased provided on DVD by L. Sharman, October 2004.

Sidle, R. C. 1982. Report on Site Conditions in Vicinity of Leroy No. 1 Mine, Ptarmigan Creek Watershed, Glacier Bay National Park. Report to USDI, National Park Service, Glacier Bay National Park and Preserve., Juneau, AK.

Sidle, R. C., and A. M. Milner. 1989. Stream Development in Glacier Bay National-Park, Alaska, USA. Arctic and Alpine Research 21:350-363.

Simenstad, C. A. and R. D. Powell. 1988. Benthic, epibenthic and planktonic invertebrates in ice-proximal glacimarine environs: Life in the turbidity Llane. Pages 120-139 *in* J. A. M. Milner and J. D. Wood, editors. Proceedings of the Second Glacier Bay Science Symposium. National Park Service, Anchorage, Alaska.

Simpkins, W. W., and Mickelson, D. M., 1988, Groundwater flow systems and geochemistry near the margin of the Burroughs Glacier, *in* A. M. Milner and J. D. Wood, J., eds., Proceedings of the Second Glacier Bay Science Symposium: Anchorage, Alaska, U.S. National Park Service, p. 26-33

Slemr, F., and E. Langer. 1992. Increase in Global Atmospheric Concentrations of Mercury Inferred From Measurements Over the Atlantic Ocean. Nature 355:434-437.

Soiseth, C. 1995. Summary of Stream Surveys in Glacier Bay National Park and Preserve: 1952-1994. National Park Service, Glacier Bay National Park and Preserve, Gustavus, AK.

Soiseth, C. R., and A. M. Milner. 1993. Predicting salonid occurrence from physical caracteristiscs of streams in Glacier Bay National Park and Preserve. Pages 174-183 *in* D. R. Engstrom, editor. Third Glacier Bay Science Symposium. National Park Service, Gustavus, AK.

Soiseth, C., C. Murdoch, and D. Faber. 2005. DRAFT: Results of weather and water monitoring in the Dry Bay Preserve, Glacier Bay National Park 2005. National Park Service report:30 pp.

Stephenson, D. A., Fleming, A. H., and Mickelson, D. M. 1988. Glacial deposits, *in* Back, W., Rosenshein, J. S., and Seaber, P. R., eds., Hydrogeology: Decade of North American Geology Project F. Series.: Boulder, CO. Geological Society of America, Inc. p. 301-314.

Stokes, P. M., T. C. Hutchinson, and K. Krauter. 1973. Heavy metal tolerance in algae isolated from polluted lakes near Sudbury, Ontario smelters. Water Pol. Rep.

Stottlemyer, R. 1988. Effect of ecosystem succession on soil and streamwater chemistry in Glacier Bay. Pages 140-146 *in* J. A. M. Milner and J. D. Wood, editors. Proceedings of the Second Glacier Bay Science Symposium 1988. National Park Service, Anchorage, AK.

Stottlemyer, R. 1989. Nitrification, soil acidification and streamwater chemistry following deglaciation, Glacier Bay National Park and Preserve. Environmental Monitoring and Assessment 12:1573-2959.

Stottlemyer, R., and D. Rutkowski. 1987. Baseline stream water chemistry for watersheds of Glacier Bay National Park and Preserve, Alaska, GLARSU Tech. Rept. #22. Naitonal Park Service, Alaska Regional Office, Anchorage, AK.

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

Streveler, G. P., and I. A. Worley. 1975. Dixon Harbor Biological Survey, Final Report on the Summer Phase of 1974 Research. National Park Service, Juneau, AK.

Streveler, G. P., and I. A. Worley. 1977. Dixon Harbor Biological Survey, Final Report on the Summer Phase of 1975 Research. National Park Service, Juneau, AK.

Streveler, G. P., I. A. Worley, C. J. Terry, and R. J. Gordon. 1974. Dixon Harbor Biological Survey, Final Report on the Summer Phase of 1973 Research. National Park Service, Juneau, AK.

Streveler, K. C. 2000. Falls Creek Water Chemistry. Prepared for Gustavus Electric Company, Icy Strait Environmental Service, Gustavus, Alaska.

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

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

Taggart, S. J., Andrews, A. G., Mondragon, J., and Mathews, E. A. 2005. Co-occurrence of Pacific sleeper sharks *Somniosus pacificus* and harbor seals *Phoca vitulina* in Glacier Bay. Alaska Fishery Research Bulletin 11: 113-117.

Taggart, S. J., O'Clair, C. E., Shirley, T. C., and Mondragon, J. 2004. Estimating Dungeness crab (*Cancer magister*) abundance: crab pots and dive transects compared: Fishery Bulletin 102: 488-497.

Taggart, S. J., P. N. Hooge, J. Mondragon, E. R. Hooge, and A. G. Andrews. 2003. Living on the edge: distribution of Dungeness crab Cancer magister in a recently deglaciated fjord. Marine Ecology-Progress Series **246**:241-252.

Taggart, S. J., T. C. Shirley, C. E. O'Clair, and J. Mondragon. 2004. Increase in the relative abundance of large male Dungeness crabs following closure of commercial fishing in Glacier Bay, Alaska. *in* Glacier Bay Science Symposium. National Park Service, Juneau, AK.

Taylor, H. E., and A. M. Shiller. 1995. Mississippi River methods comparison study: Implications for water quality monitoring of dissolved trace elements. Environmental Science and Technology 29:1313-1317.

Taylor, M. S., and A. Perry. 1988. Commerical Fishing Patterns in Glacier Bay National Park, Alaska. Pages 78-100 *in* J. A. M. Milner and J. D. Wood, editor. Proceedings of the Second Glacier Bay Science Symposium. National Park Service, Anchorage, AK.

Tilmant, J., and C. Soiseth. 2004. White Paper: Park Resources Loss Associated with the Implemetation of the Falls Creek Project (FERC No. 11657). National Park Service.

USGS. 2006. Website for “USGS 15129000 ALSEK R NR YAKUTAT AK.” http://waterdata.usgs.gov/ak/nwis/nwisman/?site_no=15129000&agency_cd=USGS. Last accessed March, 2006.

van Vleit, G. B. 1993. Status concerns for the ‘global’ population of Kittlitz’s Murrelet: is the ‘glacier murrelet’ receding? Pacific Seabird Group Bulletin 20:15-16.

van Vleit, G. B., and M. McAllister. 1994. Kittlitz’s Murrelet: the species most impacted by direct mortality from the Exxon Valdez oil spill? Pacific Seabirds 21:5-6.

van Vliet, G. 1993. Flyways and the marbled murrelet. US Fish and Wildlife Service, Anchorage, AK.

Vander Pol, S. S., Becker, P. R., Kucklick, J. R., Pugh, R. S., Roseneau, D. G., and Simac, K. S. 2004. Persistent organic pollutants in Alaskan murre (*Uria* spp.) eggs: Geographical, species, and temporal comparisons. Environmental Science and Technology 38: 1305-1312.

Walter, M. T., E. Neal, and C. Byers. 2004. Duck Creek is dying: Evidence that uplift may by one of the killers. *in* Geological Society of America Annual Meeting, Seattle, WA.

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

Wania, F., D. Mackay, Y.-F. Li, T. F. Bidleman, and A. Strand. 1999. Global chemical fate of α-hexachlorocyclohexane. 1. Evaluation of a global distribution model. Environmental Toxicology and Chemistry 18:1390-1399.

Warnick, S. L., and H. L. Bell. 1969. The acute toxicity of some heavy metals to different species of aquaticd insects. Journal of Water Pol. Con. Fed. 41.

Webster, J. R., and E. F. Benfield. 1986. Vscular plant breakdown in freshwater ecosystems. Annu. Rev. Ecol. Syst. 17:567-594.

Wieczorek, G.F., M. Jakob, R. J. Motyka, S. L. Zirnheld, and P. Craw. 2003. Preliminary assessment of landslide-induced wave hazards: Tidal Inlet, Glacier Bay National Park, Alaska. U. S. Geological Survey Open-File Report 03-100.

Williams, P. 1989. Adapting water resources management to global climate change. Climate Change 15.

Willson, M. F., S. M. Gende, and B. H. Marston. 1998. Fishes and the forest: expanding perspectives on fish-wildlife interactions. BioScience 48:445-462.

Windom, H. L., J. T. Byrd, R. G. Smith, and F. Huan. 1991. Inadequacy of NASQAN data for assessing metal trends in the nation's rivers. Environ. Sci. Technol. 25:1137-1142.

Wipfli, M. S., J. Hudson, and J. Caouette. 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 55:1503-1511.

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 42(10):993-997.

Appendices

Appendix 1. Species list of fishes for GLBA

Source Armitsu et al. (2003).

Family	Scientific	Name	Common Name
Myxinidae	*Epatatretus*	*stoutii*	Pacific hagfish
Chimaeridae	*Hydrolagus*	*colliei*	spotted ratfish
Scyliorhinidae	*Apisturus*	*brunneus*	brown cat shark
Lamnidae	*Lamna*	*ditropis*	salmon shark
Lamnidae	*Carcharodon*	*carcharias*	white shark
Dalatidae	*Somniosus*	*pacificus*	Pacific sleeper shark
Squalidae	*Squalus*	*acanthias*	spiney dogfish
Rajidae	*Bathyraja*	*interupta*	sandpaper skate
Rajidae	*Bathyraja*	*trachurs*	black skate
Rajidae	*Raja*	*binoculata*	big skate
Rajidae	*Raja*	*rhina*	longnose skate
Clupeidae	*Clupea*	*pallasii*	Pacific herring
Esocidae	*Esox*	*lucius*	northern pike
Bathylagidae	*Leuroglossus*	*schmidti*	northern smoothtongue
Osmeridae	*Hypomesus*	*pretiosus*	surf smelt
Osmeridae	*Mallotus*	*villosus*	capelin
Osmeridae	*Spirinchus*	*starksi*	night smelt
Osmeridae	*Spirinchus*	*thaleichthys*	longfin smelt
Osmeridae	*Thaleichthys*	*pacificus*	eulachon
Coregoninae	*Thymallus*	*arcticus*	Arctic grayling
Salmonidae	*Oncorhynchus*	*gorbuscha*	pink salmon
Salmonidae	*Oncorhynchus*	*keta*	chum salmon
Salmonidae	*Oncorhynchus*	*kisutch*	coho salmon
Salmonidae	*Oncorhynchus*	*nerka*	sockeye salmon
Salmonidae	*Onchrhynchus*	*clarkii*	cutthroat trout
Salmonidae	*Oncorhynchus*	*mykiss*	rainbow trout
Salmonidae	*Salmo*	*salar*	Atlantic salmon
Salmonidae	*Salvelinus*	*malma*	Dolly Varden char
Scopelarchidae	*Benthalbella*	*dentata*	northern pearleye
Myctophidae	*Diaphus*	*theta*	California headlampfish
Myctophidae	*Stenobrachius*	*leucopsarus*	northern lampfish
Lamprididae	*Lampris*	*guttatus*	spotted opah
Merlucciidae	*Merluccius*	*productus*	Pacific hake
Gadidae	*Gadus*	*macrocephalus*	Pacific cod
Gadidae	*Microgadus*	*proximus*	Pacific tomcod
Gadidae	*Theragra*	*chalcogramma*	walleye pollock
Scomberesocidae	*Cololabis*	*saira*	Pacific saury
Aulorhynchidae	*Aulorhynchus*	*flavidus*	tubesnout
Gasterosteidae	*Gasterosteus*	*aculeatus*	threespine stickleback
Scorpaenidae	*Sebastolobus*	*alascanus*	shortspine thornyhead
Scorpaenidae	*Sebastes*	*aleutianus*	rougheye rockfish
Scorpaenidae	*Sebastes*	*alutus*	Pacific ocean perch
Scorpaenidae	*Sebastes*	*babcocki*	redbanded rockfish
Scorpaenidae	*Sebastes*	*borealis*	shortraker rockfish
Scorpaenidae	*Sebastes*	*brevispinus*	silvergrey rockfish
Scorpaenidae	*Sebastes*	*ciliatus*	dusky rockfish
Scorpaenidae	*Sebastes*	*crameri*	darkblotched rockfish
Scorpaenidae	*Sebastes*	*flavidus*	yellowtail rockfish
Scorpaenidae	*Sebastes*	*jordani*	shortbelly rockfish
Scorpaenidae	*Sebastes*	*melanops*	black rockfish
Scorpaenidae	*Sebastes*	*maliger*	quillback rockfish
Scorpaenidae	*Sebastes*	*nebulosus*	China rockfish
Scorpaenidae	*Sebastes*	*nigrocinctus*	tiger rockfish
Scorpaenidae	*Sebastes*	*saxicola*	stripetail rockfish
Scorpaenidae	*Sebastes*	*reedi*	yellowmouth rockfish
Scorpaenidae	*Sebastes*	*ruberrimus*	yelloweye rockfish
Scorpaenidae	*Sebastes*	*variegatus*	harlequin rockfish

Anoplopomatidae	*Anoplopoma*	*fimbria*	sable fish
Hexagrammidae	*Hexagrammos*	*decagrammos*	kelp greenling
Hexagrammidae	*Hexagrammos*	*lagocephalus*	rock greenling
Hexagrammidae	*Hexagrammos*	*octogrammus*	masked greenling
Hexagrammidae	*Hexagrammos*	*stelleri*	whitespotted greenling
Hexagrammidae	*Ophiodon*	*elongatus*	lingcod
Hexagrammidae	*Pleurogrammus*	*monopterygius*	Atka mackerel
Rhamphocottidae	*Rhamphocottus*	*richardsonii*	grunt sculpin
Cottidae	*Artedius*	*fenestralis*	padded sculpin
Cottidae	*Clinocottus*	*acuticeps*	sharpnose sculpin
Cottidae	*Clinocottus*	*embryum*	calico sculpin
Cottidae	*Clinocottus*	*globiceps*	mosshead sculpin
Cottidae	*Cottus*	*aleuticus*	coastrange sculpin
Cottidae	*Enophrys*	*bison*	buffalo sculpin
Cottidae	*Enophrys*	*cf. diceraus*	(antlered) sculpin
Cottidae	*Gymnocanthus*	*galeatus*	armorhead sculpin
Cottidae	*Gymnocanthus*	*pistilliger*	threaded sculpin
Cottidae	*Hemilepidotus*	*hemilepidotus*	red irish lord
Cottidae	*Hemilepidotus*	*jordani*	yellow Irish lord
Cottidae	*Hemilepidotus*	*spinosus*	brown Irish Lord
Cottidae	*Icelinus*	*borealis*	northern sculpin
Cottidae	*Icelus*	*spatula*	spatulate sculpin
Cottidae	*Icelus*	*spiniger*	thorny sculpin
Cottidae	*Leptocottus*	*armatus*	Pacific staghorn sculpin
Cottidae	*Myoxocephalus*	*polyacanthocephalus*	great sculpin
Cottidae	*Myoxocephalus*	*stelleri*	frog sculpin
Cottidae	*Oligocottus*	*maculosus*	tidepool sculpin
Cottidae	*Radulinus*	*asprellus*	slim sculpin
Cottidae	*Triglops*	*macellus*	roughspine sculpin
Cottidae	*Triglops*	*pingelii*	ribbed sculpin
Hemitripteridae	*Blepsias*	*bilobus*	crested sculpin
Hemitripteridae	*Blepsias*	*cirrhosus*	silverspot sculpin
Hemitripteridae	*Hemitripterus*	*bolini*	bigmouth sculpin
Hemitripteridae	*Nautichthys*	*oculofasciatus*	sailfin sculpin
Hemitripteridae	*Nautichthys*	*pribilovius*	eyeshade sculpin
Hemitripteridae	*Nautichthys*	*robustus*	shortmast sculpin
Psychrolutidae	*Dasycottus*	*setiger*	spineyhead sculpin
Psychrolutidae	*Malacocottus*	*zonurus*	darkfin sculpin
Psychrolutidae	*Psychrolutes*	*paradoxus*	tadpole sculpin
Psychrolutidae	*Psychrolutes*	*sigalutes*	soft sculpin
Agonidae	*Anoplagonus*	*inermis*	smooth aligator fish
Agonidae	*Bathyagonus*	*alascanus*	gray starsnout
Agonidae	*Bathyagonus*	*cf. pentacanthus*	(bigeye) poacher
Agonidae	*Bathyagonus*	*infraspinatus*	spineycheek starsnout
Agonidae	*Bathyagonus*	*nigripinnis*	blackfin poacher
Agonidae	*Hypsagonus*	*quadricornis*	fourhorn poacher
Agonidae	*Leptagonus*	*frenatus*	sawback poacher
Agonidae	*Pallasina*	*barbata*	tubenose poacher
Agonidae	*Podothecus*	*accipenserinus*	sturgeon poacher
Cyclopteridae	*Aptocyclus*	*ventricosus*	smooth lumpsucker
Cyclopteridae	*Eumicrotremus*	*orbis*	Pacific spiney lumpsucker
Liparidae	*Careproctus*	*gilberti*	small disk snailfish
Liparidae	*Careproctus*	*rastrinus*	salmon snailfish
Liparidae	*Careproctus*	*scottae*	peachskin snailfish
Liparidae	*Liparis*	*callyodon*	spotted snailfish
Liparidae	*Liparis*	*cyclopus*	ribbon snailfish
Liparidae	*Liparis*	*dennyi*	marbled snailfish
Liparidae	*Liparis*	*fucensis*	slipskin snailfish
Liparidae	*Liparis*	*gibbus*	variegated snailfish
Liparidae	*Liparis*	*pulchellus*	showy snailfish
Liparidae	*Paraliparis*	*deani*	prickly snailfish
Liparidae	*Nectoliparis*	*pelagicus*	tadpole snailfish

Bramidae	*Brama*	*japonica*	Pacific pomfret
Bathymasteridae	*Bathymaster*	*leurolepis*	smallmouth ronquil
Bathymasteridae	*Bathymaster*	*signatus*	searcher
Bathymasteridae	*Ronquilus*	*jordani*	northern ronquil
Zoarcidae	*Bothrocara*	*pusillum*	Alaska eelpout
Zoarcidae	*Lycodes*	*pacificus*	black belly eelpout
Zoarcidae	*Lycodes*	*palearis*	shortfin eelpout
Zoarcidae	*Lycodapus*	*mandibularis*	pallid eelpout
Zoarcidae	*Lycodapus*	*psarostomatus*	specklemouth eelpout
Stichaeidae	*Anisarchus*	*medius*	stout eelblenny
Stichaeidae	*Anoplarchus*	*purpurescens*	high cockscomb
Stichaeidae	*Chirolophis*	*decoratus*	decorated warbonnet
Stichaeidae	*Leptoclinus*	*maculatus*	daubed shanny
Stichaeidae	*Lumpenella*	*longirostris*	longsnout prickleback
Stichaeidae	*Lumpenus*	*sagitta*	snake prickleback
Stichaeidae	*Poroclinus*	*rothrocki*	whitebarred prickleback
Stichaeidae	*Stichaeus*	*puntatus*	Arctic shanny
Stichaeidae	*Xiphister*	*atropurpureus*	black prickleback
Stichaeidae	*Xiphister*	*mucosus*	rock prickleback
Cryptacanthodidae	*Cryptacanthodes*	*giganteus*	giant wrymouth
Pholidae	*Apodichthys*	*flavidus*	penpoint gunnel
Pholidae	*Pholis*	*laeta*	crescent gunnel
Anarhichadidae	*Anarrhichthys*	*ocellatus*	wolf eel
Ptilichthyidae	*Ptilichthys*	*goodei*	quillfish
Zaproridae	*Zaprora*	*silenus*	prowfish
Trichodontidae	*Trichodon*	*trichodon*	Pacific sandfish
Gobiesocidae	*Rimicola*	*muscarum*	kelp clingfish
Ammodytidae	*Ammodytes*	*hexapterus*	Pacific sandlance
Paralichthyidae	*Citharichthys*	*sordidus*	Pacific sanddab
Pleuronectidae	*Atheresthes*	*stomias*	arrowtooth flounder
Pleuronectidae	*Hippoglossoides*	*elassodon*	flathead sole
Pleuronectidae	*Hippoglossus*	*stenolepis*	Pacific halibut
Pleuronectidae	*Isopsetta*	*isolepis*	butter sole
Pleuronectidae	*Lepidopsetta*	*bilineata*	southern rock sole
Pleuronectidae	*Lepidopsetta*	*polyxystra*	northern rock sole
Pleuronectidae	*Limanda*	*aspera*	yellowfin sole
Pleuronectidae	*Lyopsetta*	*exilis*	slender sole
Pleuronectidae	*Microstomus*	*pacificus*	dover sole
Pleuronectidae	*Parophrys*	*vetulus*	English sole
Pleuronectidae	*Psettichthys*	*melanosticus*	sand sole
Pleuronectidae	*Platichthys*	*stellatus*	starry flounder

Appendix 2. List of birds observed in GLBA during Robards et al. (2003) surveys.

Common Name	Latin Name
Aleutian Tern	*Sterna aleutica*
American Robin	*Turdus migratorius*
American Wigeon	*Anas americana*
Ancient Murrelet	*Synthliboramphus antiquus*
Arctic Tern	*Sterna paradisaea*
Bald Eagle	*Haliaeetus leucocephalus*
Barrow's Goldeneye	*Bucephala islandica*
Barn Swallow	*Hirundo rustica*
Black-billed Magpie	*Pica pica*
Belted Kingfisher	*Ceryle alcyon*
Black Bear	*Ursus americanus*
Black-Legged Kittiwake	*Rissa tridactyla*
Black Oystercatcher	*Haematopus bachmani*
Black Scoter	*Melanitta nigra*
Black Turnstone	*Arenaria melanocephala*
Bonaparte's Gull	*Larus philadelphia*
Brant	*Branta bernicla*
Brachyramphus Murrelet	*Brachyramphus spp.*
Bufflehead	*Bucephala albeola*
Canada Goose	*Branta candensis*
Canada Jay (Gray Jay)	*Perisoreus canadensis*
Caspian Tern	*Sterna caspia*
Cliff Swallow	*Hirundo pyrrhonota*
Common Goldeneye	*Bucephala clangula*
Common Loon	*Gavia immer*
Common Merganser	*Mergus merganser*
Common Murre	*Uria aalge*
Common Raven	*Corvus corax*
Double-crested Cormorant	*Phalacrocorax auritus*
Fork-tailed Storm Petrel	*Oceanodroma furcata*
Gadwall	*Anas strepera*
Great Blue Heron	*Ardea herodias*
Golden Eagle	*Aquila chrysaetos*
Greater Scaup	*Aythya marila*
Glaucous-winged Gull	*Larus glaucescens*
Green-winged Teal	*Anas crecca*
Harlequin Duck	*Histrionicus histrionicus*
Herring Gull	*Larus argentatus*
Horned Grebe	*Podiceps auritus*
Kittlitz's Murrelet	*Brachyramphus brevirostris*
Marbled Murrelet	*Brachyramphus marmoratus*
Mew Gull	*Laurs canus*
Mallard	*Anas platyrhynchos*
Northwestern Crow	*Corus caurinus*
Northern Pintail	*Anas acuta*
Northern Shoveler	*Anas clypeata*
Long-tailed Duck	*Clangula hyemalis*
Parasitic Jaeger	*Stercorarius parasiticus*
Pacific Loon	*Gavia pacifica*
Pelagic Cormorant	*Phalacrocorax pelagicus*
Pigeon Guillemot	*Cepphus columba*
Red-breasted Merganser	*Mergus serrator*
Red-faced Cormorant	*Phalacrocorax urile*
Red-necked Grebe	*Podiceps grisegena*
Red-necked Phalarope	*Phalaropus lobatus*
Red-throated Loon	*Gavia stellata*
Scaup	*Aythya spp.*
Spotted Sandpiper	*Actitis macularia*
Stellar's Jay	*Cyanocitta stelleri*

Surfbird	*Aphriza virgata*
Surf Scoter	*Melanitta perspicillata*
Tufted Puffin	*Fratercula cirrhata*
Unidentified Alcid	*Alcidae spp.*
Unidentified Albatross	*Phoebastria spp.*
Unidentified Cormorant	*Phalacrocorax spp.*
Unidentified Duck	*Anas spp.*
Unidentified Eagle	*Haliaeetus spp.*
Unidentified Goldeneye	*Bucephala spp.*
Unidentified Grebe	*Podiceps spp.*
Unidentified Gull	*Larus spp.*
Unidentified Jaeger	*Stercorarius spp.*
Unidentified Large Larid	*Larid spp.*
Unidentified Loon	*Gavia spp.*
Unidentified Merganser	*Mergus spp.*
Unidentified Phalarope	*Phalaropus spp.*
Unidentified Raptor	*Accipitridae spp.*
Unidentified Shorebird	*shorebird spp.*
Unidentified Scoter	*Melanitta spp.*
Unidentified Swan	*Cygnus spp.*
Unidentified Storm Petrel	*Oceanodroma spp.*
Unidentified Swallow	*Hirundinidae spp.*
Unidentified Tern	*Sterna spp.*
Unidentified Teal	*Teal spp.*
Western Grebe	*Aechmophorus occidentalis*
Western Screech Owl	*Otus kennicottii*
White-winged Scoter	*Melanitta fusca*
Yellow-billed Loon	*Gavia adamsii*

Appendix 3. Selected water quality standards for the State of Alaska (ADEC 2003). Standards for all parameters except fecal coliform bacteria refer to the criteria for the “Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife”. Fecal Coliform bacteria refers to the “Water Recreation – contact recreation” criterion.

Parameter	Criteria
Fresh Water Standards	
Fecal Coliform Bacteria (FC)	In a 30-day period, the geometric mean of samples may not exceed 100FC/100 ml, and not more than one sample, or more than 10% of the samples if there are more than 10 samples, may exceed 200FC/100 ml.
Dissolved Gas	Dissolved Oxygen (D.O.) must be greater than 7 mg/L in waters used by anadramous or resident fish. In no case may D.O. be less than 5 mg/L to a depth of 20 in the interstitial waters of gravel used by anadramous or resident fish for spawning. For waters not used by anadramous or resident fish, D.O. must be greater than or equal to 5 mg/L. In no case may D.O. be greater than 17 mg/L or exceed 110% of saturation.
Dissolved Inorganic Substances	Total dissolved solids (TDS) may not exceed 1,000 mg/L. A concentration of TDS may not be present in water if that concentration causes or could reasonably be expected to cause an adverse effect to aquatic life.
Petroleum, Hydrocarbons, Oils and Grease	Total aqueous hydrocarbons (TAqH) in the water column may not exceed 15µg/L. total aromatic hydrocarbons (TAH) in water may not exceed 10 µg/L. There may be no concentrations of petroleum hydrocarbons, animal fats, or vegetable oils in shoreline or bottom sediments that cause deleterious effects to aquatic life. Surface waters and adjoining shorelines must be virtually free from floating oil, film, sheen, or discoloration.
pH	May not be less than 6.5 or greater than 8.5. May not vary more than 0.5 pH units outside of the naturally occurring range.
Sediment	The percent accumulation of fine sediment (0.1-4.0 mm) in the spawning grounds of anadramous or resident fish may not be increased more than 5% by weight above natural conditions. In no case may the fine sediment range in those gravel beds exceed a maximum of 30% by weight (as shown from grain size accumulation graph). In all other surface waters, no sediment loads (suspended or deposited) that can cause adverse effects on aquatic animal or plant life, their reproduction or habitat may be present.
Temperature	May not exceed 20˚C at any time. The following maximum temperatures may not be exceeded, where applicable: Migration routes 15˚C

	Spawning areas 13˚C Rearing areas 15˚C Egg and fry incubation 13˚C For all other waters, the weekly average temperature may not exceed site-specific requirements needed to preserve normal species diversity or to prevent the appearance of nuisance organisms.
Turbidity	May not exceed 25 nephelometric turbidity units (NTU) above natural conditions. For all lake waters, may not exceed 5 NTU above natural conditions.
Marine Water Standards	
Fecal Coliform Bacteria (FC)	Same as fresh water standard.
Dissolved Gas	Surface dissolved oxygen concentration in coastal water may not be less than 6.0 mg/L for a depth of one meter except when natural conditions cause this value to be depressed. D.O. may not be reduced below 4 mg/L at any point beneath the surface. D.O. concentrations in estuaries and tidal tributaries may not be less than 5.0 mg/L except where natural conditions cause this value to be depressed. In no case may D.O. levels exceed 17 mg/L. the concentration of total dissolved gas may not exceed 100% of saturation.
Dissolved Inorganic Substances	Maximum allowable variation above natural salinity (parts per thousand): Natural Salinity — Human-Induced Salinity 0.0 to 3.5 — 1 Greater than 3.5 to 13.5 — 2 Greater than 13.5 to 35.0 — 4
Petroleum, Hydrocarbons, Oils and Grease	Same as fresh water standard.
pH	May not be less than 6.5 or greater than 8.5. May not vary more than 0.2 pH units outside of the naturally occurring range.
Sediment	No measurable increase in concentration of settable solids above natural conditions, as measured by the volumetric Imhoff cone method.
Temperature	May not cause the weekly average temperature to increase more than 1C. the maximum rate of change may not exceed 0.5C per hour. Normal daily temperature cycles may not be altered in amplitude or frequency.
Turbidity	May not reduce the depth of the compensation point for photosynthetic activity by more than 10%. May not reduce the

	maximum secchi disk depth by more than 10%.

The Alaska Water Quality Standards specify the degree of degradation that may not be exceeded in a waterbody as a result of human actions (ADEC 2003). The Alaska Water Quality Standards designate specific uses for which water quality must be protected, and specifies the pollutant limits, or criteria, necessary to protect these uses.

There are seven designated uses for fresh waters, and seven designated uses for marine waters specified in the Alaska Water Quality Standards (ADEC 2003). The seven freshwater uses are: drinking water; agriculture; aquaculture; industrial; contact recreation; non-contact recreation; and growth and propagation of fish, shellfish, other aquatic life, and wildlife. The seven marine water uses are: aquaculture; seafood processing; industrial; contact recreation; non-contact recreation; growth and propagation of fish, shellfish, other aquatic life, and wildlife; and harvesting for consumption of raw mollusks or other raw aquatic life. For each of these uses, the Alaska Water Quality Standards specify criteria for a variety of parameters or pollutants, which are both numeric and descriptive (ADEC 2003). According to the federal Clean Water Act Section 305(b) and Section 303(d), waterbodies are compared to the criteria for these parameters to determine if persistent water quality violations occur, and if so into which status category waterbodies are listed.

Appendix 4. 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.

NPS D-142, July 2006