National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Aniakchak National Monument and Preserve

Natural Resource Condition Assessment

Natural Resource Report NPS/ANIA/NRR—2016/1129

ON THE COVER

The Gates into Aniakchak Caldera. Origin of the Aniakchak River as it winds down through The Gates. Photograph by: Troy Hamon, NPS.

Aniakchak National Monument and Preserve

Natural Resource Condition Assessment

Natural Resource Report NPS/ANIA/NRR—2016/1129

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program aims to provide documentation about the current conditions of important park natural resources through a spatially explicit, multi-disciplinary synthesis of existing scientific data and knowledge. Findings from the NRCA will help Aniakchak National Monument and Preserve (ANIA) managers to develop near-term management priorities, engage in watershed or landscape scale partnership and education efforts, conduct park planning, and report program performance (e.g., Department of the Interior's Strategic Plan "land health" goals, Government Performance and Results Act).

The objectives of this assessment are to evaluate and report on current conditions of key park resources, to evaluate critical data and knowledge gaps, and to highlight selected existing stressors and emerging threats to resources or processes. For the purpose of this NRCA, staff from the National Park Service (NPS) and Saint Mary's University of Minnesota – GeoSpatial Services (SMUMN GSS) identified key resources, referred to as "components" in the project. The selected components include natural resources and processes that are currently of the greatest concern to park management at ANIA. The final project framework contains 11 resource components, each featuring discussions of measures, stressors, and reference conditions.

This study involved reviewing existing literature and, where appropriate, analyzing data for each natural resource component in the framework to provide summaries of current condition and trends in selected resources. When possible, existing data for the established measures of each component were analyzed and compared to designated reference conditions. The discussions for each component, found in Chapter 4 of this report, represent a comprehensive summary of current available data and information for these resources, including unpublished park information and perspectives of park resource managers, and present a current condition designation when appropriate. Each component assessment was reviewed by ANIA park resource managers and NPS Southwest Alaska Network (SWAN) staff.

Overall, the conditions of the resources in this park are good. However, threats and stressors of high concern may cause resource impact in the near future. Several park-wide threats and stressors influence the condition of priority resources in ANIA. Those of primary concern include climate change and oil spills. Understanding these threats, and how they relate to the condition of these resources, can help the NPS prioritize management objectives and better focus conservation strategies to maintain the health and integrity of park ecosystems.

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Acronyms and Abbreviations

AAR- Accumulation Area Ratio

ADF&G- Alaska Department of Fish and Game

ADNR- Alaska Department of Natural Resources

ANIA- Aniakchak National Park and Preserve

ANILCA- Alaska National Interest Lands Conservation Act

ANM- Aniakchak National Monument

ANP- Aniakchak National Preserve

BLM- Bureau of Land Management

DO- Dissolved Oxygen

DU- Ducks Unlimited

ELA- Equilibrium Line Altitude

EPA- Environmental Protection Agency

EROS- Earth Resources Observation and Science Center

GMU- Game Management Units

I&M - Inventory and Monitoring

KATM- Katmai National Preserve and Park

NAPCH - Northern Alaska Peninsula Caribou Herd

NCEDC - Northern California Earthquake Data Center

NPS- National Park Service

NRCA- Natural Resource Condition Assessment

SMUMN GSS - Saint Mary’s University of Minnesota Geospatial Services

SWAN- Southwest Alaska Inventory and Monitoring Network

USFWS- U.S. Fish and Wildlife Service

USGS- U.S. Geological Survey

Chapter 1: NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue- and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- are multi-disciplinary in scope;[1]
- employ hierarchical indicator frameworks;[2]
- identify or develop reference conditions/values for comparison against current conditions;[3]
- emphasize spatial evaluation of conditions and GIS (map) products;[4]
- summarize key findings by park areas; and[5]
- follow national NRCA guidelines and standards for study design and reporting products.

NRCAs Strive to Provide…

Credible condition reporting for a subset of important park natural resources and indicators

Useful condition summaries by broader resource categories or topics, and by park areas

[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products. Complied

Important NRCA Success Factors

Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline

Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)

Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings

NRCAs can yield new insights about current park resource conditions but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations
(near-term operational planning and management)

Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values
(longer-term strategic planning)

Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public
("resource condition status" reporting)

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a

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[6]An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

Over the next several years, the NPS plans to fund a NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information on the NRCA program, visit http://nature.nps.gov/water/nrca/index.cfm.

Chapter 2 Introduction and Resource Setting

2.1 Introduction

2.1.1 Enabling Legislation

The Aniakchak Caldera formed approximately 3,500 years ago after a large volcanic eruption. The eruption caused the 2,134-m (7,000-ft) mountain to collapse nearly 914 m (3,000 ft), creating a 610-m (2,000-ft) deep caldera (NPS 1986). The Aniakchak Caldera is one of the largest calderas found on the Alaska Peninsula.

In December of 1978, Aniakchak Caldera and River (Photo 1) as well as the surrounding area of the Aniakchak National Park and Preserve (ANIA) became a unit of the National Park System. In order to ensure the protection of the surrounding area's natural and cultural resources, ANIA was later designated a National Monument and Preserve on 2 December 1980 by section 201(1) of the Alaska National Interest Lands Conservation Act (ANILCA) (NPS 1986).

Photo 1. Aniakchak River delta (NPS photo by Troy Hamon).

ANILCA defines the purpose of designating ANIA to a National Monument and Preserve in section 201(1):

> Maintain the Anikchak Caldera and its associated features and landscape, including the Anikchak River and other lakes and streams, in their natural state; to study, interpret, and assure continuation of the natural process of biological succession; to protect habitat for, and populations of fish and wildlife, including, but not limited to, brown/grizzly bears, moose, caribou, sea lions seals, and other marine mammals, geese, swans, and other waterfowl and in a manner consistent with the foregoing, to interpret geological and biological processes for

visitors. Subsistence uses by local residents shall be permitted in the monument where such uses are traditional (NPS 1986, p. 30).

The Aniakchak River became a National Wild River on 2 December 1980 by ANILCA section 601(27). This includes 51 km (32 mi) of river starting in Surprise Lake and ending in Aniakchak Bay, as well as 50 km (31 mi) of major tributaries (NPS 1986). This section was meant to preserve and protect the river and its corridor by maintaining its free-flowing condition, for future generations to enjoy and appreciate (NPS 2008).

2.1.2 Geographic Setting

Aniakchak National Monument and Preserve is located in Southwest Alaska on the Alaska Peninsula (Plate 1). More specifically, ANIA is found at the southern edge of the Lake and Peninsula Borough which has a population of 1,631 people (U.S. Census 2010). The national monument and preserve's headquarters are located in King Salmon, which is located in Bristol Bay Borough with a population of 997 (U.S. Census 2010). ANIA encompasses 242,812 ha (600,000 ac) of land.

Photo 2. Aerial photo of Aniakchak Caldera (NPS photo).

Volcanism is an important geologic process within the monument. Aniakchak Caldera (Photo 2) is approximately 10 km (6 mi) wide and 78 km^2 (30 mi^2) in area (Plate 1, NPS 1986). A dominant feature of the caldera is its largest vent, Vent Mountain. Vent Mountain reaches 671 m (2,200 ft) and was observed steaming during the last eruption in 1931 (APG 1973). Vegetation became sparse after the eruption, but with the volcano remaining inactive, the vegetation has had time to advance over the ash flows. The densest vegetation in the caldera is found near Surprise Lake (APG 1973). Wildlife were also absent for many years after the last eruption but eventually returned to the caldera (APG 1973).

A diversity of soil types are found in the monument and preserve. At the high elevations of the peaks and ridges of the caldera, there is an absence of soil. The foothills of the caldera wall, the river drainages, and the coastal plains have the most developed and deep soil. Near the northwest region of the caldera, where the ash cover is deepest and most recent, there are shallow soils. The Meshik River valley contains rather deep soil that is poorly drained; fibrous peat is formed here due to the various layers of ash in combination with sedge and moss growth (NPS 1986).

ANIA has two distinct climates. The eastern side of ANIA has a maritime climate, which is characterized by high levels of annual precipitation and strong winds. The western portion of the monument and preserve, near Bristol Bay, has more of a continental climate, which means there is a larger annual temperature range and lower levels of precipitation (NPS 1986). Port Heiden, just west of the monument, has average high temperatures reaching 14°C (57°F), with the warmer months being June through September. The coldest month in Port Heiden is February, with an average low temperature of -6.5°C (20°F); the cooler months include December through March (Table 1; WRCC 2011).

Table 1. Monthly temperature and precipitation normals (1981-2010) for ANIA (Station 507700, Port Heiden, Alaska) (Western Regional Climate Center 2011).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Temperature (°C)													
Max	0.2	-0.8	1.7	2.7	7.9	11.6	13.8	14.2	11.6	6.4	1.9	1.4	6.1
Min	-4.7	-6.5	-3.8	-2.9	1.6	5.4	8.7	9.1	6.7	1.1	-2.8	-3.1	0.8
Average Precipitation (cm)													
Total	2.9	1.4	2.7	1.6	1.9	2.9	4.7	4.4	5.1	4.1	3.9	4.3	40.1

2.1.3 Visitation Statistics

Annual visitation to the park is low; the visitation count was 10, 14, and 62 people in 2008, 2009, and 2010, respectively (NPS 2010a). This is due to the remoteness of the monument. The main means of transportation to ANIA are floatplanes or amphibious vehicles. Most visitors fly from King Salmon to Surprise Lake (located in Aniakchak Caldera) (NPS 1986).

There are several reasons for visiting ANIA, which include fishing, hunting, trapping, hiking, camping, and rafting. Subsistence fishing, hunting, and trapping by local residents are permitted in the monument and preserve. Sport fishing is also allowed in both the preserve and monument. However, sport hunting and trapping are only allowed in the preserve (NPS 1986). Moose (*Alces alces*) and brown bear (*Ursus arctos*) are two of the primary species of game in the park (NPS 2010c).

Hiking, backpacking, and camping occur in ANIA. In order to preserve the ecological condition of the monument and preserve, hiking trails and campgrounds were not developed. Most visitors find the hiking conditions to be excellent on the caldera floor (NPS 2010c). Many visitors can access the caldera floor through “The Gates” of the caldera (break in the caldera wall) which also allows the Aniakchak River to flow from the caldera to the sea (APG 1973, p. 11). Some hikers may find themselves using game and other animal trails; information regarding wildlife encounters can be found at ANIA headquarters in King Salmon (NPS 1986). When camping, visitors are required to leave little to no evidence of their presence after leaving the camp site.

Another activity that brings visitors to ANIA is rafting. The high gradient of the Aniakchak River makes rafting challenging. The first 24 km (15 mi) of the river drops greater than 305 m (1,000 ft); the last 19 km (12 mi) of the river are a slightly smoother trip through the open tundra (NPS 2010b). Rafting this river from the beginning to end requires expert/advanced rafting skills, and visitors are recommended to bring extra equipment in case there is damage due to the river’s composition (large boulders, sharp bends) and rapidly changing conditions, which can be severe or life-threatening (NPS 2010c).

2.2 Natural Resources

2.2.1 Ecological Units and Watersheds

ANIA is a part of Environmental Protection Agency's (EPA) Pacific Northwest Region 10. This region provides support for Alaska, Idaho, Oregon, Washington, and 271 Native Tribes (EPA 2011). The monument and preserve is found in the Alaska Peninsula Mountains Ecoregion.

The Alaska Peninsula Mountains ecoregion includes a portion of the Kodiak Islands and runs down the eastern side of the Aleutian Islands. This region's climate is considered marine with high annual rates of precipitation (Griffith 2010). The vegetation composition found throughout this region includes dwarf shrubs, willow, birch and alder. The Aleutian mountains give this region a large elevation range (sea level to 2,600 m) and have sporadically placed volcanoes (Griffith 2010). The volcanic activity has affected the soil because many soils in the region have "formed in deposits of volcanic ash and cinder" (Griffith 2010, p. 19).

ANIA belongs to the Aniakchak River watershed. The watershed begins in the Aniakchak Caldera (Surprise Lake) and runs east into Aniakchak Bay. This watershed is approximately 43 km^2 (16 mi^2) including the entire Aniakchak Caldera, Aniakchak River, and the river's tributaries (Nagorski et al. 2007). This watershed does not contain any dams; it is a naturally free- flowing river watershed (NPS 1986). The caldera was said to have been a large snow-fed reservoir for the watershed, but over the years a leak in the caldera wall caused most of the caldera to drain, forming the National Wild Aniakchak River (NPS 1986).

2.2.2 Resource Descriptions

ANIA encompasses many unique biomes. The Alaska Planning Group (1973) has classified four vegetative types in ANIA: alpine tundra, wet tundra, moist tundra, and shrub. The alpine tundra is located on the eastern slopes of the mountain. On the western slopes of the caldera and in the Cinder River Valley, moist tundra is present. The wet tundra occupies much of the coastal plains near Bristol Bay. The shrub vegetative type inhabits most of the river valleys (e.g., Meshik, Cinder, and Aniakchak) (APG 1973). According to Lenz et al. (2002), there are roughly 472 plant species in the national monument and preserve. Regrowth of vegetation in the caldera has been occurring since the last eruption in 1931.

ANIA provides habitat for 28 species of mammals, including three semi-aquatic species and three marine species (NPS 2013). Common species include brown bear, moose, and caribou (*Rangifer tarandus*; Photo 3). The moderate climate in the unit permits brown bears to be active longer throughout the year; ANIA bears have held off hibernation until December in some years. Brown bears are often found in areas of ANIA where the salmon availability is highest, which includes the caldera when salmon reach Surprise Lake (NPS 2003). Bears also prey on moose and caribou at different times over the course of

Photo 3. A caribou in Aniakchak Caldera (NPS photo).

the year. The moose in ANIA exceeded their carrying capacity around 1960 in the Aleutian Range, which caused a population decline. Brown bear predation also keeps moose density down. Moose have been observed in the northern region of the preserve by the Cinder River, where there is higher quality wintering habitat (NPS 2003). Some species that are present, but observed less frequently, include wolves (*Canis lupus*), lynx (*Lynx canadensis*), wolverines (*Gulo gulo*), and porcupines (*Erethizon dorsatum*) (NPS 2003).

There are 134 documented bird species in ANIA; there are approximately 54 landbird species, 33 inland waterfowl species, and 47 seabird species (NPS 2013). Some of the more common species include harlequin ducks (*Histrionicus histrionicus*), mergansers (*Mergus* spp.), bald eagles (*Haliaeetus leucocephalus*), rough-legged hawks (*Buteo lagopus*), American pipit (*Anthus rubescens*), black oystercatchers (*Haematopus bachmani*), Kittlitz's murrelets (*Brachyramphus brevirostris*), and horned puffins (*Fratercula corniculata*; Photo 4) (Stroud and Fuller 1983, Manski et al. 1987, Meyer 1987, Sowl 1988, Starr and Starr 1988, Savage 1993, as cited by NPS 2003). Bald eagles can be found from the coast to the caldera in ANIA; they are commonly found and have been observed building nests along the rivers and lakes (NPS 1986).

Photo 4. Horned puffins (USFWS photo).

ANIA supports a number of fish from freshwater to marine species According to NPS (2013), there are 18 species of fish in ANIA waters. Some species found in the freshwater streams include Dolly Varden (*Salvelinus malma*), arctic char (*S. alpinus*), and rainbow trout (*Oncorhynchus mykiss*) (NPS 1986). The anadromous fish include several species of salmon (e.g., coho, chum, king, sockeye, and pink) (*Oncorhynchus* spp.), which are harvested to benefit both commercial and subsistence fishermen. Marine fish that are found on the coast of ANIA include halibut (*Hippoglossus* spp.), cod (*Gadus* spp.), herring (*Clupea* spp.), and flounder (*Platichthys* spp.), which are also very important to commercial and subsistence fishermen (NPS 1986).

2.2.3. Resource Issues Overview

ANIA is largely protected from human impacts by its remoteness; it is the most remote NPS unit in the nation with the lowest amount of annual visitors (Nagorski et al. 2007). However, several issues or events have altered or threaten multiple resources within the monument and preserve. Aniakchak was devastated by the Exxon Valdez oil spill in 1989; approximately two-thirds of the eastern coastline was contaminated with oil (Nagorski et al. 2007). The run-aground tanker spilled roughly 11 million gallons of oil. ANIA is located 756 km (470 mi) from the wreck and it only took 56 days for oil to reach this unit (Nagorski et al. 2007). Marine wildlife, including mammals, fish, and seabirds, were most adversely affected by the spill. A restoration plan was created in 1994 by the Exxon Valdez Oil Spill Committee to restore the resources lost or damaged in the area. The plan contains actions to rehabilitate the environment by replanting intertidal plant species to prespill conditions, and limiting human use in the park and surrounding areas until populations stabilize (EVOS Council 1994).

Climate change has begun to alter ANIA resources, but the extent of future impact is uncertain. The average temperatures have risen 2.2°C (4°F) since the 1950s and are predicted to continue to increase by 2.8-10°C (5–18°F) by 2100 (Nagorski et al. 2007). A warming climate will most seriously impact water resources, especially at high altitudes (Hall 1988, Serreze et al. 2000), by affecting snow cover, glaciers, and sea/lake ice cover (Nagorski et al. 2007). Warmer winters will cause the snowpack to decrease while increasing rain events (Nagorski et al. 2007). This will result in a drier spring environment. Drier conditions may then cause an increase in the fire regime (SNAP et al. 2009).

There is a slight risk of exotic fish species entering ANIA. Anadromous fish that escape fish farms or aquaculture may make their way up ANIA rivers (Nagorski et al. 2007). One example of an exotic fish species that is already present in Alaskan waters is the northern pike (*Esox lucius*); it may alter native fish species composition because it is a competitive fish species (ADF&G 2002). The Alaska Department of Fish and Game (ADF&G) created a management plan to reduce invasive species spread into Alaskan waters. The Alaska Aquatic Nuisance Species Management Plan was finished in 2002; it is used to prevent the invasion of those species that are considered the highest threat (ADF&G 2002).

Exotic plant species do not seem to be a major problem, as long as the monument controls off-road vehicles and annual visitor counts remain low. Fewer visitors traveling in and out of the park will most likely mean a low risk of exotic invasions. According to a survey by Lipkin (2005), no introduced plant species were observed in the monument and preserve.

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance

ANIA's Master Plan (APG 1973) outlined the monument's purpose, before the development of the general management plan in 1986, by setting out objectives to protect the monument and preserve. These general management objectives are as follows:

- Recognize the management requirements for the Natural Area Category of the National Park System and the National Wild and Scenic Rivers System and apply them accordingly to Aniakchak Caldera and the Aniakchak National Wild River.
- Manage Aniakchak as a unit of the Alaska State Office of the NPS with direct supervision by an area superintendent.
- Offer ANIA visitors yearly services that are seasonally appropriate.
- Work cooperatively with others (e.g., private enterprises) to develop an appropriate mode of transportation for visitors that is both efficient and energy efficient to benefit the monument and preserve as well as the region (APG 1973).

The ANIA General Management Plan (NPS 1986) has several management objectives for natural resources, cultural resources, visitor use and interpretation and commercial operation purposes. These objectives are as follows:

Natural resources:

- Ensure the continuation of the monument's ecological processes and systems by maintaining the natural resources.
- Encourage the natural growth of vegetation and wildlife in the monument and emphasize the importance of the caldera and its features as resources that need protection.
- Develop a program to permit sport hunting in the preserve and subsistence hunting and fishing throughout the unit to balance the wildlife populations and ensure the health of their habitat.
- Cooperate with organizations such as Alaska Department of Fish and Game and Public Safety, as well as the local government, native corporations and private interests to create a suitable monitoring system for the area natural resources.
- Work with private interests to ensure that high environmental standards are met when considering future exploration and potential development inside or near the monument and preserve.

Cultural resources:

- Recognize and follow the legislative and executive requirements and policies of the National Park Service when assessing the unit's resources (historical, archeological, and cultural).
- Collect cultural resources information (oral and written) relevant to the unit and use that information to create fun and educational materials and programs for visitors.
- Encourage and assist local people, groups, and native corporations to perpetuate the cultural heritage of the region.

Visitor use and interpretations:

- Develop a baseline inventory of recreational resources to provide visitors the necessary services and means of accessing the monument to minimize unauthorized travel and negative impacts in the monument and preserve.
- Encourage and provide information and technical assistance to private enterprise to provide appropriate visitor services, preferably with bases of operation outside the boundaries of the monument and preserve.
- Create informative programs to educate potential visitors and the public of the monument and preserve's key resources, environmental factors, weather, and visitor activities that may influence their decision to visit the unit.

Commercial operations:

- Identify appropriate levels and types of commercial services feasible for providing visitor services and issue permits and commercial use licenses as appropriate to meet the needs of visitors and to perpetuate resources (NPS 1986).

2.3.2 Status of Supporting Science

The Southwest Alaska Network Inventory and Monitoring Network (SWAN) identifies key resources network-wide and for each of its parks that can be used to determine the overall health of the parks. These key resources are called Vital Signs. In 2006, the SWAN completed and released a Vital Signs monitoring plan (Bennett et al. 2006). Table 2 shows the network Vital Signs selected for monitoring in ANIA.

Table 2. SWAN Vital Signs selected for monitoring in ANIA (adapted from Bennett et al. 2006). Those in bold are Vital Signs that the SWAN is working independently or jointly with a network park, federal, state, or private partner to develop and implement monitoring protocols using funding from the Vital Signs or water quality monitoring programs while those in italics Vital Signs that are monitored independently of SWAN by a Network park, another NPS program, or another federal, state, or private agency.

Category	ANIA Vital Signs
Air and Climate	*Visibility and particulate matter*
Geology and Soils	*Volcanic and earthquake activity*
Water	Surface hydrology, freshwater chemistry
Biological Integrity	*Invasive/exotic species*, resident lake fish, *salmon*, bald eagle, brown bear, wolf, wolverine, moose, *caribou*, vegetation composition and structure, sensitive vegetation communities
Human Use	*Resource harvest for subsistence and sport, visitor use*
Landscapes (Ecosystem Pattern and Processes)	Land cover/land use, landscape processes

The coastal areas of ANIA have been inventoried and digitally mapped through a project funded by NOAA. This process produced a series of Environmental Sensitivity Index (ESI) maps that summarized sensitive natural and human-use resources for prevention planning and accident response. While produced primarily for oil and chemical spill planning and response these maps can provide a base for other natural resource planning as well.

Sensitive shoreline habitat, sensitive biological resources and human-use resources are all indicated on these maps. Shoreline type (substrate, grain size, origin, elevation), exposure to wave energy, biological productivity and sensitivity and ease of cleanup (in response to a spill) are all factors that determine the sensitivity of a shoreline. Biological resources identified on the maps include six major categories; terrestrial mammals, marine mammals, birds, fish, invertebrates, and benthic marine habitats and are the resources most likely to be impacted by an oil spill. Finally, human-use resources such as airports, wildlife refuges, critical habitat, and national park lands are also identified in these data.

The ESI series of maps (and associated attribute data) along with other sources such as the NSM data are available to ANIA for planning and response purposes.

2.4 Landcover and Landscape Processes

Exisiting landcover datasets do not lend themselves to assessment due to their variability in defining landcover classes from one data set year to the next. However, some general observations between data set years can be made, as well as statements regarding the importance of how natural processes shape the ANIA landscape.

2.4.1. ANIA Landcover

Landcover datasets for ANIA were created in both 1983 and 2008. The 1983 dataset was created in fulfillment of the Bristol Bay landcover mapping project initiated by the Alaska Department of Natural Resources (ADNR) and U.S. Geological Survey (USGS) using satellite imagery (Plate 2). This landcover mapping ground condition survey was completed and published by the USGS Earth Resources Observation and Science Center (EROS). Data are raster format with a 50-meter cell size. A total of 15 landcover types are included (Table 3). The most prevalent landcover type identified was barren, covering 59,511 hectares or 24% of the total park area.

The 2008 landcover dataset of ANIA was completed in an effort to continue mapping the Alaskan Peninsula by the U.S. Fish and Wildlife Service (USFWS), the Bureau of Land Management (BLM)-Alaska, and Ducks Unlimited (DU). Data are raster format with a 30-meter cell size. The data set presented in this publication is a compilation of four Landsat TM satellite scenes: Path 71 Row 20 (acquired 13 August 2002) Path 72 Row 19 and 20 (acquired 13 August 2002) and Path 72 Rows 19 and 20 (acquired 28 August 1999, 15 September 2000 and 17 June 2002 (Plate 3). A total of 36 landcover classes were included (Table 4). The most prevalent landcover type identified was upland dwarf shrubs, covering 53,365 hectares or 21% of the total park area.

Table 3. 1983 landcover classes and coverage areas in ANIA (USGS/EROS 1989).

Landcover Class	Hectares	% Landcover
Barren	59,511	24
Snow/Cloud/Light Barren	45,714	19
Closed Shrub Graminoid	39,713	16
No Data	35,664	15
Open Low Shrub Gramin./Mesic Bog/Gramin. Lichen Shrub TundraShrub Tundra	27,187	11
Open Low Shrub Eric./Conifer Woodland/Mes.Bog/Eric.Shrub Tundra	14,832	6
Miscellaneous Deciduous (Open Alder, Cottonwood, Birch, Willow)	12,671	5
Wet Bog/Wet Meadow'	5,245	2
Marsh/Very Wet Bog	2,066	1
Deep Clear Water	403	0

Table 3 (continued). 1983 landcover classes and coverage areas in ANIA (USGS/EROS 1989).

Landcover Class	Hectares	% Landcover
Shallow/Sedimented Water	367	0
Shallow/Sedimented Water - Offshore	337	0
Deep Clear Water - Offshore	293	0
Mountain Shadow	217	0
Lichen Shrub Tundra	12	0
Total Area	244,232	100

Table 4. 2008 landcover classes and coverage areas in ANIA (DU 2009).

Landcover Class	Hectares	% Landcover
Dwarf Shrub - Upland	53,365	21
Rock/Gravel	34,105	14
Tall Shrub - Alder	31,343	12
Low Shrub - Willow	17,604	7
Tall Shrub - Willow	17,520	7
Dwarf Shrub - Other	15,233	6
Tall Shrub - Other	9,498	3
Dwarf Shrub - Lichen	8,381	3
Snow	8,187	3
Tall Shrub - Alder/Willow	8,002	3
Sparse Vegetation	7,476	3
Low Shrub - Other	5,755	2
Dwarf Shrub - Lush	5,712	2
Mesic/Dry Forb	4,746	1
Mesic/Dry Grass Meadow	2,739	1
Cloud	2,593	1
Low Shrub - Alder	2,375	1
Dwarf Shrub - Wet	1,699	0
Low Shrub - Alder/Willow	1,535	0
Non-Vegetated Soil	1,394	0
Clear Water	987	0
Mesic/Dry Sedge Meadow	850	0
Wet Graminoid	770	0
Turbid/Shallow Water	606	0
Emergent	604	0
Wet Sedge	513	0
Ocean Water	260	0

Table 4 (continued). 2008 landcover classes and coverage areas in ANIA (DU 2009).

Landcover Class	Hectares	% Landcover
Bryoid Moss/Dwarf Shrub - Lichen	150	0
Other Crypto-Biotic Soil	144	0
Mesic/Dry Graminoid	38	0
Floating Algea	14	0
Closed Poplar	6	0
Moss	4	0
Cloud Shadow	1	0
Wet Forb	0	0
Total Area	244,223	100

2.4.2. Dominant Landscape Processes

Volcanic Activity

Hasselbach (1995) reports that vegetation communities in ANIA in general and specifically within the caldera have been affected by significant volcanic disturbances such as the 1931 eruption. Volcanic eruptions alter the previous landscape and vegetation by burying large areas with lava flows and ash fallout, providing the opportunity for successional processes.

Succession Patterns

Landscape-changing events such as earthquakes, wild fires, and volcanic eruptions can create large areas of barren ground. These barren areas are common locations for vegetation succession to take place. The plant life that first establishes an area, along with the successors, is largely dependent on the previous flora of the area and the current conditions of the succession site (e.g., substrate type, steepness of slope, or abundance of nitrogen-fixing taxa) (Hasselbach 1995). Re-establishment of plant life is generally accelerated in sites affected by fires compared to those made barren from a volcanic eruption where the acidity level, ash coverings, and rocky terrain slow succession rates (Hasselbach 1995). Hasselbach (1995) describes the vegetative succession patterns in the caldera area of ANIA to be slow since the damage from the1931 eruption.

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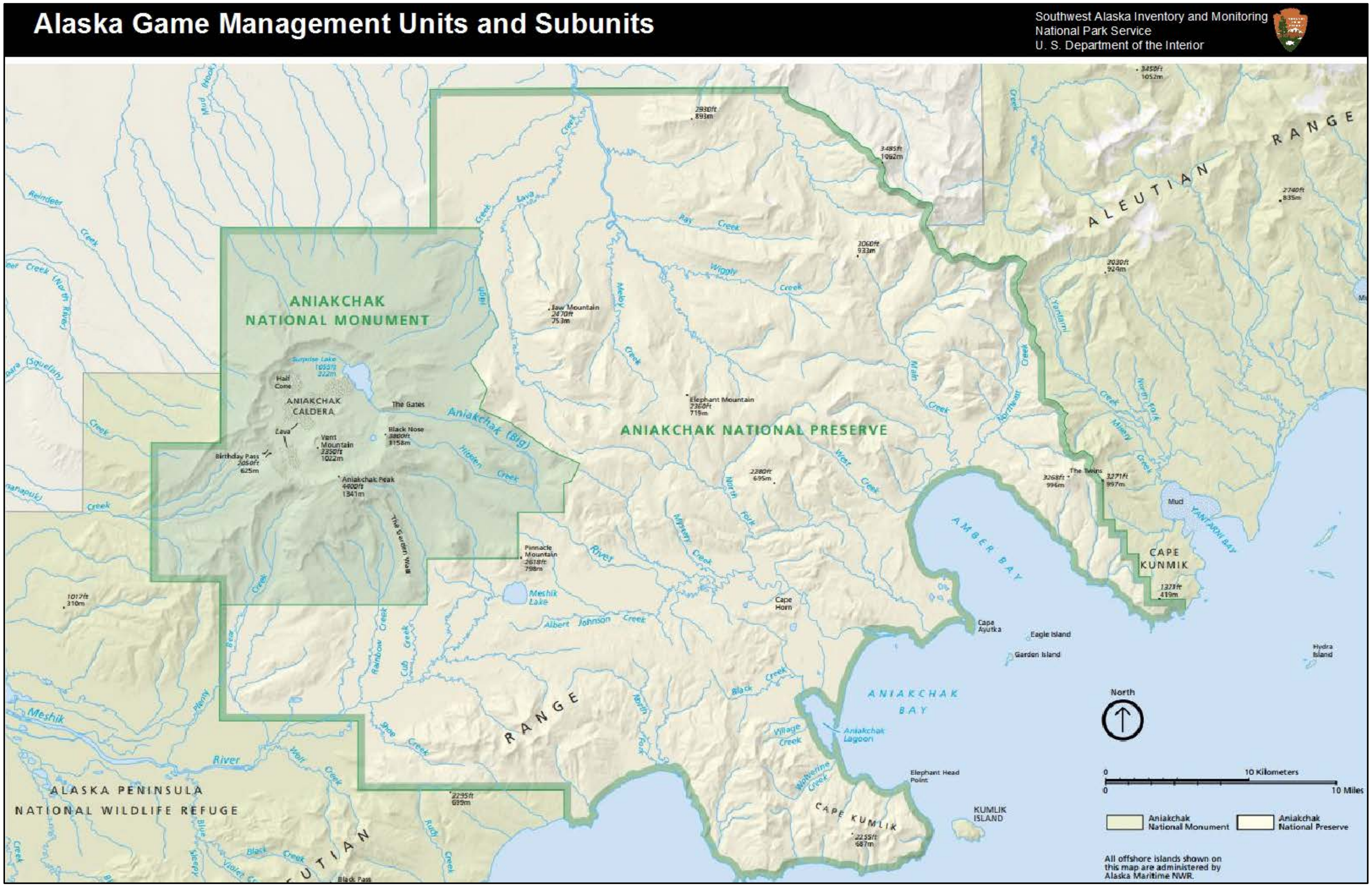

Plate 1. Aniakchak Park Map (NPS).

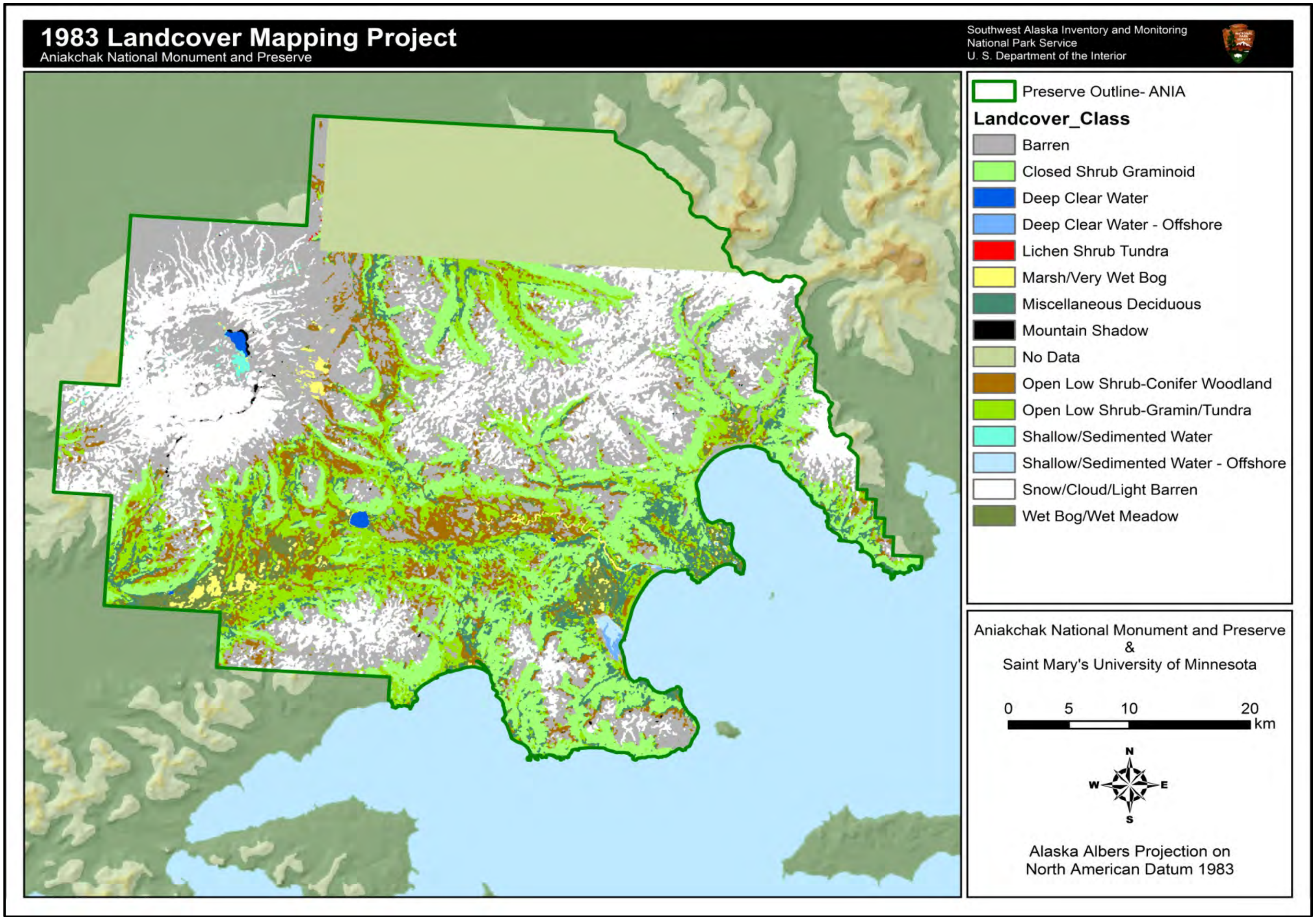

Plate 2. Landcover classes and coverage area for ANIA in 1983. Landcover classes combined from original data for display purposes (USGS/EROS 1989).

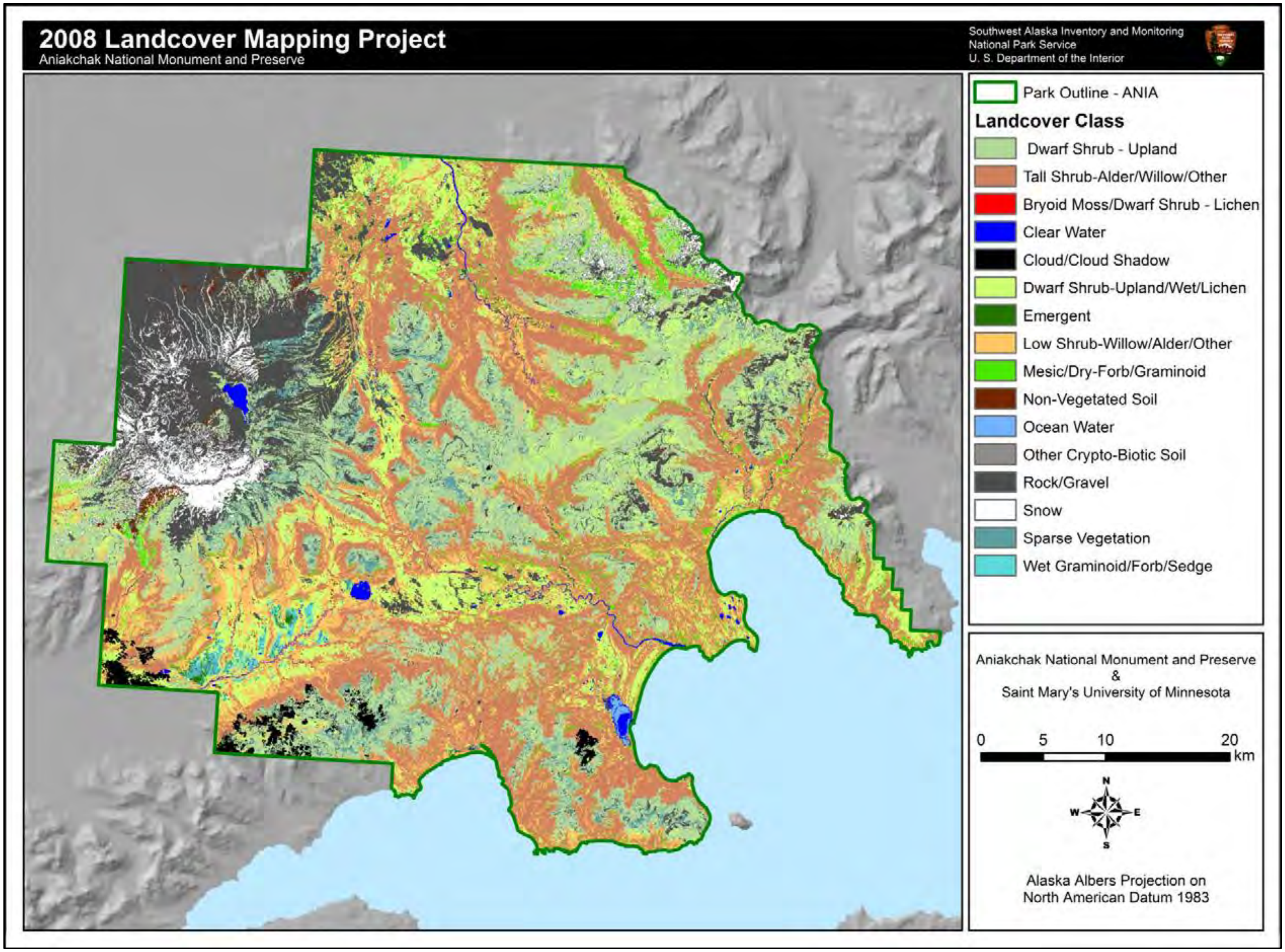

Plate 3. Landcover classes and coverage area for ANIA in 2008. Landcover classes combined from original data for display purposes (DU 2009).

Chapter 3. Study Scoping and Design

This NRCA is a collaborative project between the NPS and Saint Mary's University of Minnesota Geospatial Services (SMUMN GSS). Project stakeholders include the ANIA resource management team and SWAN staff. Before embarking on the project, it was necessary to identify the specific roles of the NPS and SMUMN GSS. Preliminary scoping meetings were held, and a task agreement and a scope of work document were created cooperatively between the NPS and SMUMN GSS.

3.1 Preliminary scoping

A preliminary scoping meeting was held during November 2011. At this meeting, SMUMN GSS and NPS staff confirmed that the purpose of the ANIA NRCA was to evaluate and report on current conditions, critical data and knowledge gaps, and selected existing and emerging resource condition influences of concern to park managers. Certain constraints were placed on this NRCA, including the following:

- Condition assessments are conducted using existing data and information.
- Identification of data needs and gaps is driven by the project framework categories.
- The analysis of natural resource conditions includes a strong geospatial component.
- Resource focus and priorities are primarily driven by the park resource management.

This condition assessment provides a "snapshot-in-time" evaluation of the condition of a select set of park natural resources that were identified and agreed upon by the project team. Project findings will aid ANIA resource managers in the following objectives:

- Develop near-term management priorities (how to allocate limited staff and funding resources);
- Engage in watershed or landscape scale partnership and education efforts;
- Consider new park planning goals and take steps to further these;
- Report program performance (e.g., Department of Interior Strategic Plan "land health" goals, Government Performance and Results Act [GPRA]).

Specific project expectations and outcomes included the following:

- For key natural resource components, consolidate available data, reports, and spatial information from appropriate sources including: park resource staff, the NPS Integrated Resource Management Application (IRMA) website, Inventory and Monitoring Vital Signs, and available third-party sources. The NRCA report will provide a resource assessment and summary of pertinent data evaluated through this project.
- When appropriate, define a reference condition so that statements of current condition may be developed. The statements will describe the current state of a particular resource with respect to an agreed upon reference point.
- Clearly identify "management critical" data (i.e., those data relevant to the key resources). This will drive the data mining and gap definition process.

- Where applicable, develop GIS products that provide spatial representation of resource data, ecological processes, resource stressors, trends, or other valuable information that can be better interpreted visually.
- Utilize “gray literature” and reports from third party research to the extent practicable.

3.2 Study Design

3.2.1 Indicator Framework, Focal Study Resources and Indicators

Selection of Resources and Measures

As defined by SMUMN GSS in the NRCA process, a “framework” is developed for a park or preserve. This framework is a way of organizing, in a hierarchical fashion, bio-geophysical resource topics considered important in park management efforts. The primary features in the framework are key resource components, measures, stressors, and reference conditions.

“Components” in this process are defined as natural resources (e.g., birds), ecological processes or patterns (e.g., natural fire regime), or specific natural features or values (e.g., geological formations) that are considered important to current park management. Each key resource component has one or more “measures” that best define the current condition of a component being assessed in the NRCA. Measures are defined as those values or characterizations that evaluate and quantify the state of ecological health or integrity of a component. In addition to measures, current condition of components may be influenced by certain “stressors,” which are also considered during assessment. A “stressor” is defined as any agent that imposes adverse changes upon a component. These typically refer to anthropogenic factors that adversely affect natural ecosystems, but may also include natural processes or disturbances such as floods, fires, or predation (adapted from GLEI 2010).

During the NRCA scoping process, key resource components were identified by NPS staff and are represented as “components” in the NRCA framework. While this list of components is not a comprehensive list of all the resources in the park, it includes resources and processes that are unique to the park in some way, or are of greatest concern or highest management priority in ANIA. Several measures for each component, as well as known or potential stressors, were also identified in collaboration with NPS resource staff.

Selection of Reference Conditions

A “reference condition” is a benchmark to which current values of a given component’s measures can be compared to determine the condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal/objective (e.g., a bison herd of at least 200 individuals) (adapted from Stoddard et al. 2006).

Reference conditions in this project were identified during the scoping process using input from NPS resource staff. In some cases, reference conditions represent a historical reference before human activity and disturbance was a major driver of ecological populations and processes, such as "pre-fire suppression.” In other cases, peer-reviewed literature and ecological thresholds helped to define appropriate reference conditions.

Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science's "State of Our Nation's Ecosystems 2008" (Heinz Center 2008). This initial framework was presented to park resource staff to stimulate meaningful dialogue about key resources that should be assessed. Significant collaboration between SMUMN GSS analysts and NPS staff was needed to focus the scope of the NRCA project and finalize the framework of key resources to be assessed.

The NRCA framework was finalized in May 2012 following acceptance from NPS resource staff. It contains a total of 13 components (Table 5) and was used to drive analysis in this NRCA. Two components (near shore sensitivity index, landcover/landscape processes) were subsequently removed from the framework and the concerns around these components were incorporated into Chapter 2 of this document. This framework outlines the components (resources), most appropriate measures, known or perceived stressors and threats to the resources, and the reference conditions for each component for comparison to current conditions.

Table 5. ANIA natural resource condition assessment framework.

ANIA National Park – *Scoping Meeting*

Natural Resource Condition Assessment Framework

Component	*Experts*	*Data Sources*	*Measures or Specific Analysis*	*Stressors*	*Reference Condition*
Biotic Composition					
Ecological Communities					
Landcover/Landscape Processes (Chapter 2 discussion)	Parker Martin, Amy Miller	Two landcover datasets available in ThemeManager: Landcover - ANIA Group (1981 - ADNR); Landcover ANIA 2008 - early 2000s DU)	Discussion of the dominant landscape processes - successional patterns, fire, insect outbreak effects, permafrost change. References to invasives section for that information.	climate change (precipitation, temp, etc.)	Team agreed that this component does not lend itself to a condition graphic/scoring.
Mammals					
Moose	Sherri Anderson	Moose data being compiled by the park over the winter. ADF&G moose management report provides limited survey information.	Metrics defined in ADF&G moose summary documents: population density, bull:cow ratio	Brown bear predation on neonatal moose. Overbrowsing resulting in poor calf survival.	ADF&G defined management goals
Bear	Sherri Anderson	Bear data being compiled by the park over the winter. ADF&G bear management report indicates little data are available for GMU 9E	Population Density	Identify during component development.	Need to define // all we will have is harvest records - this is not compiled
Caribou	Troy Hamon, Dominic Watts	ADF&G Caribou Reports (complete herd and composition estimates for many years)	North Alaska Peninsula Herd size, Herd compostion	Identify during component development.	Troy and Dominic will work to define reference condition.
Birds					
Passerines	Sherri Anderson, Susan Savage (USFWS)	A few dated literature sources provided by park staff, nothing recent.	Species abundance, Species richness and diversity	not clear what may actually be causing stress on birds overall, most are likely not from in-park issues	Team agreed that this component does not lend itself to a condition graphic/scoring.
Fish					
Salmon	Troy Hamon	Salmon escapement data provided by Troy.	Escapement, Percent Harvest, Run Timing	harvest (which is already a measure).	Talk with Troy about escapement data - aerial state surveys - a lot of data but not related to condition assessment.
Native Fish (non-anadromous)	Troy Hamon	Data are limited to three documents: Meshik corridor survey, freshwater fish inventory of the caldera, FW fish inventory from I&M (use to establish baseline)	**Specific Analysis:** Compile existing data and information from the defined literature sources and provide to the park for future use and updating. Develop a concise summary of the information for Chapter 4 and provide a statement of condition according to conversations with Troy.	Identify during component development.	Team agreed that this component does not lend itself to a condition graphic/scoring. Once data are compiled, we might be able to infer condition from trends.

Table 5 (continued). ANIA natural resource condition assessment framework.

	Component	*Experts*	*Data Sources*	*Measures or Specific Analysis*	*Stressors*	*Reference Condition*
Environmental Quality						
	Human Activity	Kyler Smith, Michael Shephard	most visitor use is reported by consessionares, as it is primarily guided hunting	**Specific Analysis:** Use available datasets to provide an overview of visitor use (distribution and primary activity) in the park with close attention to use during hunting seasons, as this is when most conflicts occur. Identify the areas most prone to user conflict based on findings (spatial and non-spatial). Explain the level of subsistence use in the park based on community survey data and park staff knowledge.	Identify during component development.	Due to the lack of visitation, human use is minimal. Need to determine how to frame this in respect to condition (if at all).
	Water Quality	Claudette Moore	Claudette will provide data during mid-November.	**Specific Analysis:** Examine the available data and information and georeference that data when possible to enable future GIS data display and storage. If enough data exist for individual lakes or rivers, present these data and describe condition accordingly. Provide a brief synopsis of the SWAN temp profile data that are being collected currently.	diesel fuel spills, other sources?	Team agreed that this component does not lend itself to a condition graphic/scoring
Physical Characteristics						
	Seismic Activity	USGS and AVO - John Paskievitch	Alaska Volcano Observatory Data	**Specific Analysis:** Provide a summary of the recorded seismic history of the park, both background levels of activity and major events.	consult Paskievitch	Team agreed that this component does not lend itself to a condition graphic/scoring
	Climate	Chuck Lindsey	PRISM Data	Summarize PRISM and other available data.	human activity	Team agreed that this component does not lend itself to a condition graphic/scoring
	Glacier Extent	Bruce Giffen, Chuck Lindsey	Identify with component experts	Extent, terminus retreat, volumetric estimates (mass balance)	Identify during component development.	Rely on Bruce for developing this component - minimal data.

3.2.2 General Approach and Methods

This study involved gathering and reviewing existing literature and data relevant to each of the key resource components included in the framework. No new data were collected for this study; however, where appropriate, existing data were further analyzed to provide summaries of resource condition or to create new spatial representations. After all data and literature relevant to the measures of each component were reviewed and considered, a qualitative statement of overall current condition was created and compared to the reference condition when possible.

Data Mining

The data mining process (acquiring as much relevant data about key resources as possible) began at the initial scoping meeting, at which time ANIA staff provided data and literature in multiple forms, including: NPS reports and monitoring plans, reports from various state and federal agencies, published and unpublished research documents, databases, tabular data, and charts. GIS data were provided by NPS staff. Additional data and literature were also acquired through online bibliographic literature searches and inquiries on various state and federal government websites. Data and literature acquired throughout the data mining process were inventoried and analyzed for thoroughness, relevancy, and quality regarding the resource components identified at the scoping meeting.

Data Development and Analysis

Data development and analysis was highly specific to each component in the framework and depended largely on the amount of information and data available for the component and recommendations from NPS reviewers and sources of expertise including NPS staff from ANIA and the SWAN. Specific approaches to data development and analysis can be found within the respective component assessment sections located in Chapter 4 of this report.

Preparation and Review of Component Draft Assessments

The preparation of draft assessments for each component was a highly cooperative process among SMUMN GSS analysts and park staff. Though SMUMN GSS analysts rely heavily on peer-reviewed literature and existing data in conducting the assessment, the expertise of NPS resource staff also plays a significant and invaluable role in providing insights into the appropriate direction for analysis and assessment of each component. This step is especially important when data or literature are limited for a resource component.

The process of developing draft documents for each component began with a detailed phone or conference call with an individual or multiple individuals considered local experts on the resource components under examination. These conversations were a way for analysts to verify the most relevant data and literature sources that should be used and also to formulate ideas about current condition with respect to the NPS staff opinions. Upon completion, draft assessments were forwarded to component experts for initial review and comments.

Development and Review of Final Component Assessments

Following review of the component draft assessments, analysts used the review feedback from resource experts to compile the final component assessments. As a result of this process, and based on the recommendations and insights provided by park resource staff and other experts, the final component assessments represent, the most relevant and current data available for each component and the sentiments of park resource staff and resource experts.

Format of Component Assessment Documents

All resource component assessments are presented in a standard format. The format and structure of these assessments is described below.

Description

This section describes the relevance of the resource component to the park and the context within which it occurs in the park setting. For example, a component may represent a unique feature of the park, it may be a key process or resource in park ecology, or it may be a resource that is of high management priority in the park. Also emphasized are interrelationships that occur among a given component and other resource components included in the broader assessment.

Measures

Resource component measures were defined in the scoping process and refined through dialogue with resource experts. Those measures deemed most appropriate for assessing the current condition of a component are listed in this section, typically as bulleted items.

Reference Conditions/Values

This section explains the reference condition determined for each resource component as it is defined in the framework. Explanation is provided as to why specific reference conditions are appropriate or logical to use. Also included in this section is a discussion of any available data and literature that explain and elaborate on the designated reference conditions. If these conditions or values originated with the NPS experts or SMUMN GSS analysts, an explanation of how they were developed is provided.

Data and Methods

This section includes a discussion of the data sets used to evaluate the component and if or how these data sets were adjusted or processed as a lead-up to analysis. If adjustment or processing of data involved an extensive or highly technical process, these descriptions are included in an appendix for the reader or a GIS metadata file. Also discussed is how the data were evaluated and analyzed to determine current condition (and trend when appropriate).

Current Condition and Trend

This section presents and discusses in-depth key findings regarding the current condition of the resource component and trends (when available). The information is presented primarily with text but is often accompanied by detailed maps or plates that display different analyses, as well as graphs, charts, and/or tables that summarize relevant data or show interesting relationships. All relevant data and information for a component is presented and interpreted in this section.

Threats and Stressor Factors

This section provides a summary of the threats and stressors that may impact the resource and influence to varying degrees the current condition of a resource component. Relevant stressors were described in the scoping process and are outlined in the NRCA framework. However, these are elaborated on in this section to create a summary of threats and stressor based on a combination of available data and literature, and discussions with resource experts and NPS natural resources staff.

Data Needs/Gaps

This section outlines critical data needs or gaps for the resource component. Specifically, what is discussed is how these data needs/gaps, if addressed, would provide further insight in determining the current condition or trend of a given component in future assessments. In some cases, the data needs/gaps are significant enough to make it inappropriate or impossible to determine condition of the resource component. In these cases, stating the data needs/gaps is useful to natural resources staff who wishes to prioritize monitoring or data gathering efforts.

Overall Condition

This section provides a qualitative summary statement of the current condition that was determined for the resource component using the WCS method. Condition is determined after thoughtful review of available literature, data, and any insights from NPS staff and experts, which are presented in the Current Condition and Trend section. The Overall Condition section summarizes the key findings and highlights the key elements used in determining and justifying the level of concern, if any, that analysts attribute to the condition of the resource component. Also included in this section are the graphics used to represent the component condition.

Sources of Expertise

This is a listing of the individuals (including their title and affiliation with offices or programs) who had a primary role in providing expertise, insight, and interpretation to determine current condition (and trend when appropriate) for each resource component.

Literature Cited

This is a list of formal citations for literature or datasets used in the analysis and assessment of condition for the resource component. Note, citations used in appendices and plates referenced in each section (component) of Chapter 4 are listed in that section's "Literature Cited" section.

3.3 Literature Cited

Great Lakes Environmental Indicators Project (GLEI). 2010. Glossary, Stressor. http://glei.nrri.umn.edu/default/glossary.htm (accessed 16 March 2015).

The H. John Heinz III Center for Science, Economics, and the Environment. 2008. The state of the nation's ecosystems 2008: Measuring the land, waters, and living resources of the United States. Island Press, Washington, D.C.

Stoddard. J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. J. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16(4):1267-127

Chapter 4 Natural Resource Conditions

This chapter presents the background, analysis, and condition summaries for the 11 key resource components in the project framework. The following sections discuss the key resources and their measures, stressors, and reference conditions. The summary for each component is arranged around the following sections:

1. Description
2. Measures
3. Reference Condition
4. Data and Methods
5. Current Condition and Trend (including threats and stressor factors, data needs/gaps, and overall condition)
6. Sources of Expertise
7. Literature Cited

The order of components is as follows:

4.1 Moose

4.2 Bear

4.3 Caribou

4.4 Passerines

4.5 Salmon

4.6 Native Fish

4.7 Seismic Activity

4.8 Climate

4.9 Human Activity

4.10 Glacial Extent

4.11 Water Quality

4.1 Moose

4.1.1 Description

Photo 5. Cow moose grazing with two calves (USFWS photo by K. O'Reilly Doyle).

Moose (*Alces alces*) (Photo 5) are ubiquitous in the ANIA biotic community, present throughout the inland, river and lake riparian zones, and coastal areas of the park (NPS 2003). Moose are normally associated with northern forests and subarctic climates typical of southwestern Alaska. They are solitary mammals that rarely gather in groups except during the mating season. Females weigh in excess of 363 kg (800 lbs), while males can weigh up to 725 kg (1,600 lbs) and exceed 1.83 m (6 ft) in height (Rausch et al. 2008). Antlers develop on males within the first year of life and generally grow larger each subsequent summer until the animal health decreases with the onset of old age. Antlers typically develop in three to five months beginning in the spring, and are shed after the mating season. The average moose life span is 16 years, although 25-year-old individuals have been reported (Rausch et al. 2008).

Moose are herbivorous, feeding primarily on willow (*Salix* spp.), aspen (*Populus* spp.), aquatic vegetation, and a variety of grasses (Rausch et al. 2008). Moose are most often associated with open low or mixed shrub vegetation classifications near riparian zones. Sexual maturity and breeding occur at about 28 months. Calves are born in the spring, with females typically producing one or two calves per year. During the mating season, sparring between bulls occurs in order to secure mates; injuries are common but rarely serious. Adult moose are generally calm and subdued, although aggressive behavior is frequently displayed by cows with calves when they become startled, angered, or when offspring are threatened, as well as by bulls during the breeding period (Rausch et al. 2008).

Natural predators in ANIA include wolves and brown bears. Predation on yearlings or adults weakened by disease or injury is most common (Butler 2010). Moose populations are protected from sport hunting within the 55,432-ha (137,000-ac) Aniakchak National Monument (ANM). However, subsistence hunting is legal within ANM but is considered to be quite rare. Limited sport hunting is permitted in the Aniakchak National Preserve (ANP), which comprises 188,179 ha (465,000 ac). Concession contracts are issued for sport hunting services within ANIA to manage wildlife populations and protect subsistence uses (NPS 2003). Game Management Units (GMUs) were established to give residents and visitors fair and equal hunting rights throughout the state of Alaska. The Alaska Department of Fish and Game (ADF&G) tracks parameters such as population density, population composition, habitat, and harvest for selected species in each GMU. ADF&G establishes individualized management objectives for moose in each GMU and in many cases for each subunit. ANIA is located within GMU 9, which covers the entire southwestern Alaskan Peninsula. GMU 9 has multiple subunits; ANIA is in GMU 9E (Plate 4).

4.1.2 Measures

- Population size
- Population composition (bull:cow ratio)

4.1.3 Reference Conditions/Values

According to the NPS's enabling legislation, ANIA, like all other NPS managed lands, is to manage animal species in a manner consistent with maintaining a natural and healthy population. NPS policies that support the naturally occurring and healthy population are found in sections 4.4.1 and 4.4.3 of the NPS Management Policies (2006) which state that;

> *The NPS will maintain as parts of the natural ecosystem of parks all plants and animals native to park ecosystems…*
>
> *…preserving and restoring the natural abundances, diversities, dynamics, distributions, habitats, and behaviors of native plant and animal populations and the communities and ecosystems in which they occur…*
>
> *…minimizing human impacts on native plants, animals, populations, communities, and ecosystems, and the processes that sustain them.*
>
> *…the Service* (NPS) *does not engage in activities to reduce the numbers of native species for the purposes of increasing the numbers of harvested species (i.e., predator control), nor does the Service permit others to do so on lands managed by the National Park Service*

Management of the moose population in ANIA is intended to be implemented through the cooperative efforts of the NPS and the ADF&G . However, when the species in question is a harvested or game species, it should be noted that the NPS management policies may not be congruent with local or state wildlife management policies due to differing management objectives.

Currently, quantitative moose population metrics have not been established by the NPS that would define a set of moose population reference conditions (i.e., ranges of natural variability that embody natural and healthy populations). In lieu of NPS established moose population reference conditions, the following section reports population metrics according to ADF&G defined management goals. While the ADF&G defined management goals are discussed below, it is important to recognize that the NPS goals may differ and that management objectives of the ADF&G do not necessarily represent the management objectives of the NPS.

Two reference conditions were outlined in the ADF&G moose management report for GMU 9 (Butler 2006). The reference condition used in this assessment is the ADF&G-determined population goal for each GMU. The first reference condition, population size, is the maintenance of existing moose densities in areas where the current population density is considered moderate (0.5-1.5 moose/mi^2 or 0.19-0.58 moose/km^2), assuming non-limiting habitat conditions (Butler 2010). The second reference condition, population composition (bull: cow ratio), is the maintenance of sex ratios of at least 25 bulls:100 cows in areas where the current population is density is considered moderate (0.5-1.5 moose/mi^2 or 0.19-0.58 moose/km^2) (Butler 2010). GMU 9E, which includes ANIA, had a

1983 survey result of 1,148 moose within a 1,314 mi^2 (3,403 km^2) study area and would be a moderate density moose population (Butler 2010).

4.1.4 Data and Methods

ADF&G management reports (Butler 2006, 2008, 2010) provide information on defined management goals. ADF&G conducts annual sex and age composition surveys from November through early December, assuming adequate snow cover, for all GMU 9 subunits (Butler 2010). Harvest rates and other sources of mortality are also reported (Butler 2010). ADF&G reports establish moose population and composition objectives, as well as monitor temporal trends in population size and composition.

ADF&G surveys of moose within ANIA recorded population, density, and composition information from trend areas surveyed by airplane transects along the trend area boundaries (Plate 5). ADF&G trend areas for ANIA are outlined as the Meshik and Cinder River Valleys, and the head of Amber Bay. Trend areas around the Cinder River in northern ANIA and coastal habitat of southeast ANIA are classified as moderate- to high-quality moose wintering habitat. A new trend area in the southwest preserve has been surveyed once and is defined as another ANIA wintering habitat area. Observations and counts were documented and geographic locations recorded using GPS units (NPS 2003).

4.1.5 Current Condition and Trend

<u>Population Size</u>

In the absence of quantitative moose population metrics from the NPS the following section reports population metrics according to ADF&G defined management goals. While the ADF&G defined management goals are discussed below, it is important to recognize that the NPS goals may differ and that management objectives of the ADF&G do not necessarily represent the management objectives of the NPS.

Butler (2006) noted that moose were present but scarce on the Alaskan Peninsula prior to 1900 and spread throughout the southwest in the 1950s and 1960s. Cahalane (1956) noted that Alaska moose were numerous in the area throughout the early 1950s with populations peaking in the late 1960s (Butler 2010). Implementation of liberal hunting regulations resulted in slowed moose population growth and recovery of willow stands that were depleted from over browsing. The population then declined, most notably in unit 9E even after 1973 when hunting restrictions were enforced. Despite improved range conditions, moose densities in the early 1980s were 60% below peak levels observed in the 1960s (Butler 2010). Unit 9E was considered in 1999 to be “important for providing high levels of human consumptive use” by the Alaska Board of Game (Butler 2010, p. 116). Currently, moose population densities in Unit 9E are generally considered moderate (0.8-0.9 moose/mi^2 or 0.31-0.35 moose/km^2) (Butler 2010).

The 2005 ADF&G fall sex and age composition survey of ANIA moose indicated slight declines for Unit 9E. However, Butler (2008, 2010) reported that, overall, Unit 9 moose populations (a much larger area) were relatively stable over the past 30 years. In 1983, ADF&G conducted a survey resulting in a rough estimate of 2,500 moose in unit 9E, according to data extrapolated from a 2114 km^2 (1,314 mi^2) survey of the center portion of Unit 9E. That survey identified 1,148 moose (90% CI ± 16%) (Butler 2010). Unit 9 moose surveys are frequently limited by poor weather conditions and inadequate snowfall.

Population Composition (bull:cow ratio)

In the absence of quantitative moose population metrics from the NPS the following section reports population metrics according to ADF&G defined management goals. While the ADF&G defined management goals are discussed below, it is important to recognize that the NPS goals may differ and that management objectives of the ADF&G do not necessarily represent the management objectives of the NPS. It is noted that in 2008, Young and Bortell reported that in lightly hunted and remote areas of Alaska 60-80 bulls: 100 cows were observed.

Historically, bull:cow ratios varied across unit 9 (Butler 2010). A recent survey of unit 9E was not sufficient to define population composition at the subunit scale. However, bull:cow ratios are generally above the 25:100 ratio set as a management goal by ADF&G in unit 9E. Past ADF&G surveys from 1999, 2002, 2003, and 2005 confirm a bull:cow ratio well above the standard of 25:100 for most years (Table 6). The 2005 survey represents the only year that bull:cow ratios were not well above ADF&G parameters. Since 2000, unit 9 has shown stable bull:cow ratios, and a ratio in 2010 well above the established 25:100 parameter (Butler 2010). Considering historic variation and small sample size, the population of unit 9E appears stable and the bull:cow ratio is not being affected by harvest (Butler 2010).

Table 6. Moose population composition in Unit 9E, 1999, 2002-2005. Table compiled from ADF&G report (Butler 2010).

Year	Males:100 females	Yearling males:100 females	Calves:100 females	Calf %	Adults	Total Moose	Moose/hour
1999[2]	60	10.77	3	1.89	104	106	27
2002[1]	74	27	20	11	87	97	47
2003[1]	46	10	10	6	131	140	18
2004	*	*	*	*	*	*	*
2005[1]	25	5	22	15	81	95	19

* Not surveyed due to weather factors

[1] Includes some data from the U.S Fish and Wildlife Service

[2] Survey in 1999 conducted in Aniakchak

Threats and Stressor Factors

Stressors identified by NPS staff include moose harvest rates and brown bear predation on neonatal moose. From the mid-1960s to early 1970s, relaxed hunting regulations led to slowed population growth and decreased populations in order to rehabilitate willow stands within Unit 9 (Butler 2006, 2010). Moose population declines in the 1970s were attributed to low calf recruitment rates, liberal hunting regulations, and range damage (Butler 2006, 2008, 2010). Reported/unreported moose harvest in GMU 9 has been estimated at 200-280 moose per year since 2000 (Table 7). Even considering unreported harvest, unit 9 remains within sustainable harvest limits established by the ADF&G (Butler 2010). Butler (2010) suggested that moose harvested within Unit 9 are often not reported by hunters. Closed season hunting and cow moose harvest likely represent a significant percentage of the unreported harvest. Butler (2010) suggests that illegal harvest will only cease with increased community support and law enforcement efforts, which may not be cost-effective. Reported annual moose harvest rates declined between 1998 and 2008 (Table 7).

Table 7. Annual moose harvest in Unit 9, 1998-2008. An additional 100 moose are estimated as harvested but unreported annually. Table compiled from Butler (2006, 2010).

Year	Male	Female	Unknown	Reported Total	Estimated Total
1998	198	2	0	200	300
1999	238	8	7	253	353
2000	176	2	2	180	280
2001	167	8	0	175	275
2002	171	6	2	179	279
2003	177	0	0	177	277
2004	158	3	0	161	261
2005	158	0	2	160	260
2006	124	1	0	125	225
2007	147	0	0	147	247
2008	107	0	0	107	207

Butler (2006, 2010) suggested that recent declines in harvest rates are associated with a decrease in the number of hunters rather than changes in the moose population. Unit 9E moose are hunted from 10-20 September by non-resident hunters. A bag limit of one bull with three brow tines on one antler side or a 50-in (127-cm) minimum spread is permitted. Resident and subsistence hunting is permitted in Unit 9E for 81 days from 20 August to 20 September and 1 December to 30 January. Resident hunters must follow the bull take restrictions of non-resident hunters but are also permitted to take a spike or fork bull. Subsistence hunters are allowed any antlered bull with no antler restrictions. Cow harvest is prohibited in unit 9E. An estimated 100 unreported moose, many of which are assumed to be cows, are harvested each year in Unit 9 (Butler 2010). However, Butler (2010) noted that while current illegal practices likely do not greatly influence overall moose populations in Unit 9, illegal harvest of cows may play some role in limiting moose densities (Butler 2006). Concession hunts are also permitted in ANIA, although the harvest of 58 bulls from 2005-2011 is likely not a stress on the population (Table 8).

Table 8. Concession harvest of moose in ANIA from 2005 to 2010 (Sherri Anderson, KATM Wildlife Biologist, pers. comm., 2012).

Moose Harvest	2005	2006	2007	2008	2009	2010	2011	Total Harvest
Total for Year	6	8	13	7	10	6	8	58

The primary limiting factor of moose populations in Unit 9 was brown bear predation on neonatal moose (Butler 2006, 2010). Predation on calves caused moose density in Unit 9 to decline, even after range conditions improved from relieved browsing pressure in the 1950s and 1960s (Sellers 1990). Neonatal and young of the year moose are exceptionally vulnerable to predators such as bears and wolves, particularly in late winter months when snow hinders a moose's movements. Ballard et al. (1981) found that moose predation by brown bears accounted for 79% of mortalities of collared moose calves. Butler (2010) stated that while conditions have improved since the 1960s and 1970s, recruitment remains low in Unit 9. According to Butler (2010, p. 119), "bear:moose ratios in Unit 9 ranged from >1:1 to 1:10," and in order to achieve significant improvements in calf survival, major reductions in bear densities need to occur. However, this suggestion would run contrary to NPS management policy and, as the authors suggest, this would likely be opposed by the general public. Extremely low calf:cow ratios reported in the 2000s suggest that recruitment may be a further limiting factor of moose densities. Calf:cow ratios were low in GMU 9 even during years of peak population (Butler 2006).

<u>Data Needs/Gaps</u>

The 2012 ADF&G moose management report is not yet available. Therefore, the most current available information from older ADF&G reports was utilized for this assessment. Butler (2008, 2010) and Anderson (pers. comm., 2012) noted that inadequate snow cover, aircraft availability, and poor weather conditions often limit moose population composition surveys in Unit 9, which results in infrequent or incomplete surveys. Moose movements also add variability to population estimates and survey results (Butler 2008, 2010). Butler (2010) noted that sampling variation was introduced into surveys in 2007 and 2008 due to changes in technique. This likely introduced slight variability into the bull:cow ratio estimate.

Moose surveys have not been conducted in ANIA within the past 13 years (NPS 2012). Sherri Anderson (pers. comm., 2012), KATM wildlife biologist, noted that ANIA often cannot be surveyed because of its limited accessibility and frequent poor weather conditions. Future surveys for these locales may provide adequate data for comparison and trend analyses. However, Anderson (pers. comm., 2012) suggested that in order to have successful aerial surveys, weather and flying conditions need to be very good to excellent. Furthermore, snow depth and snow cover must also be at ideal conditions. Marginal conditions in the past, due to inadequate snow depth and lack of snow cover, likely resulted in underreported moose populations.

Overall Condition

Population Size

Limited quantitative data exist that describe the moose population density within ANIA. Therefore, an accurate statement regarding condition cannot be made. However, Butler (2010) indicates that the population density is generally within the ADF&G management goal. Furthermore, the remoteness of the park limits susceptibility to threats and stressors related to human activities.

Population Composition (bull:cow ratio)

Moose density and composition monitoring in Unit 9E suggest that the bull:cow ratio was above the desired range in recent years (25 bulls:100 cows). Moose population composition in unit 9E has remained relatively stable, with slight variations between years. ANIA bull:cow ratio is estimated to be within defined parameters. However, ANIA preserve and monument moose surveys should be conducted to more accurately define moose composition within ANIA park boundaries.

Summary

Reports indicate that moose populations are stable in ANIA and Unit 9E, although they may be trending slightly downward based on recent NPS and ADF&G population reports (Butler 2006, 2008, 2010; NPS 2012). Moose population composition (bull:cow ratio) has been consistently above the recommended level of 25 bulls:100 cows established by the ADF&G, with slight seasonal and annual variability (Butler 2006, 2008, 2010; NPS 2012). Even though human activity is low in ANIA, moose hunting is a primary reason for visitor use in the park. Without current data regarding moose densities within ANIA and the impact that recreational and subsistence hunting has on moose in ANIA, a conclusive statement assessing condition cannot be made.

4.1.6 Sources of Expertise

Sherri Anderson, KATM Wildlife Biologist

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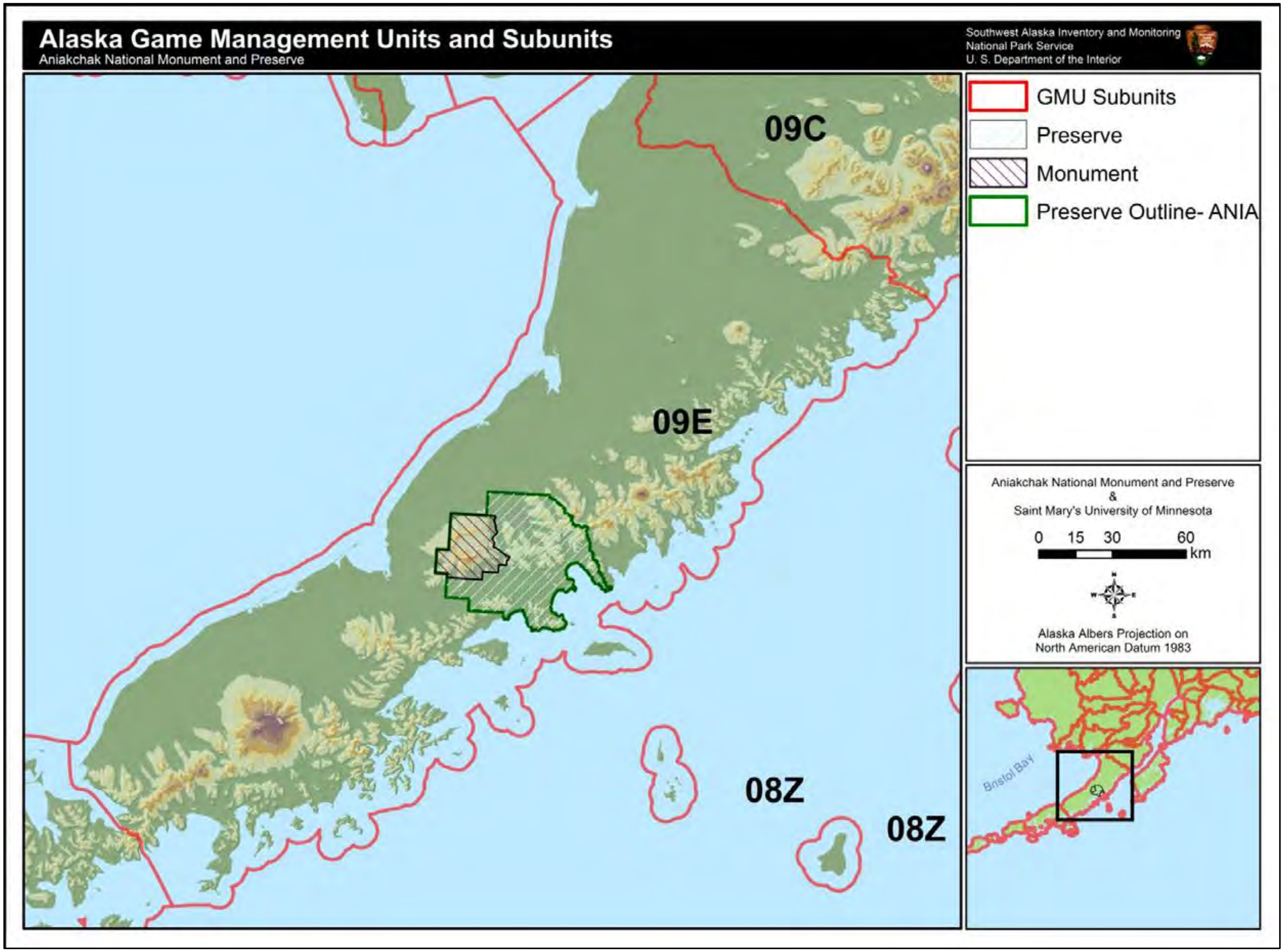

Plate 4. Alaska GMUs and subunits. Subunit 9E contains all of the Aniakchak National Monument and Preserve.

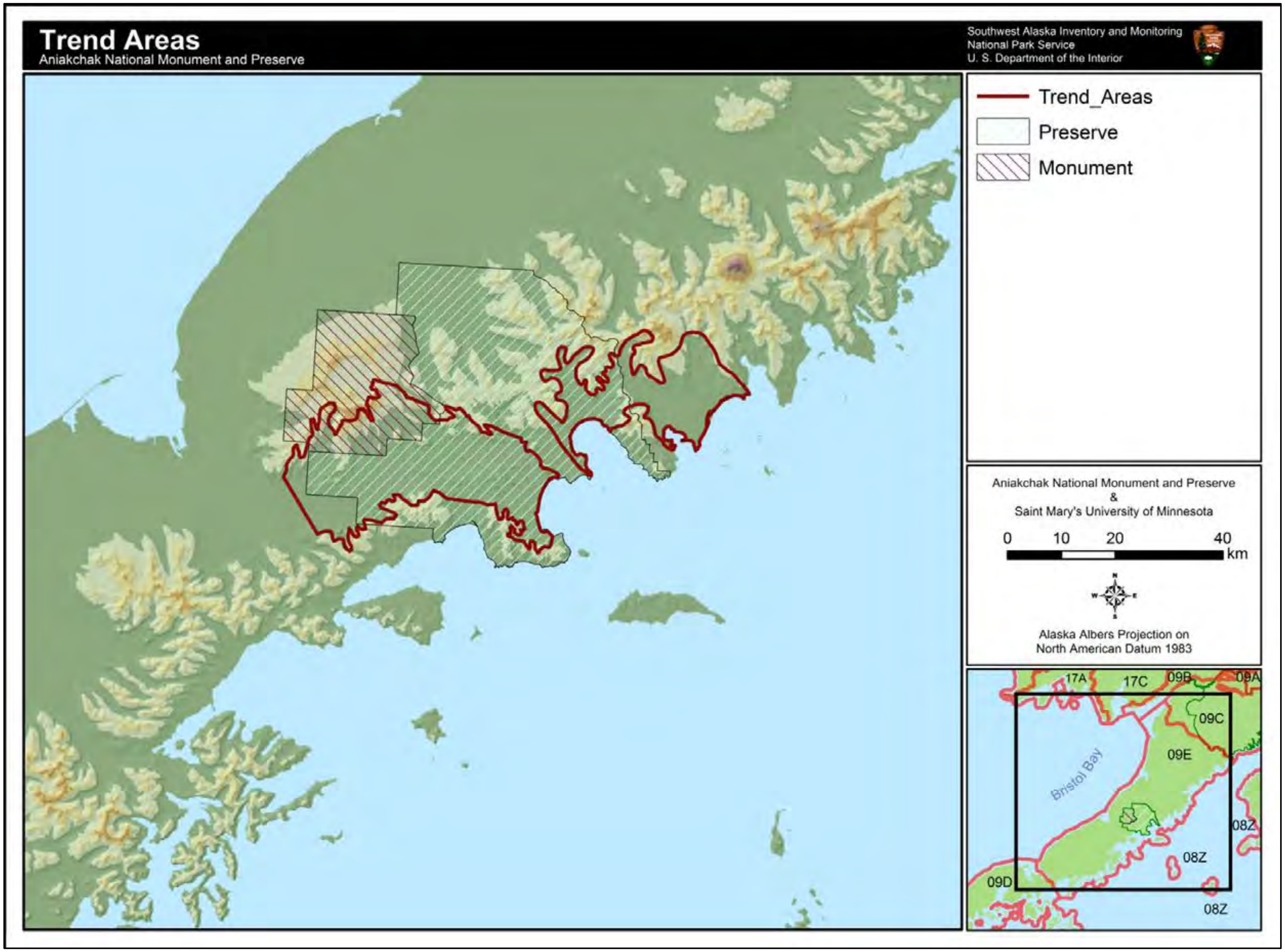

Plate 5. Trend area survey boundaries.

4.2 Bear

4.2.1 Description

Brown bears (*Ursus arctos*) are a prominent mammal species in ANIA (Photo 6). The species is found in ANIA and the surrounding area, with larger concentrations in coastal and lake ecosystems. Brown bears utilize ANIA resources year-round but the population gravitates towards rivers and lakes with available salmon (Sowl 1988).

Photo 6. An Alaskan brown bear sow with three cubs (NPS photo).

Alaskan Peninsula brown bear males average 357 kg (787 lbs) and females average 226 kg (498 lbs) (Miller and Sellers 1992). Brown bears primarily feed on salmon from July through September; sedges, berries, and clams comprise some of their diet in spring/early summer. ANIA brown bears will also consume caribou and moose; juveniles of both species are predominantly targeted (Eide and Miller 2008).

NPS (2003) reports that brown bears den in ANIA on caldera slopes and on the east side of the Aleutian Range. Typically all bears have entered dens by December and most emerge by early May; moderate weather in ANIA facilitates later den entrance and earlier emergence than is typical for its latitude (NPS 2003). Mating generally occurs from May to mid-July, and one to four cubs are typically born in the mid-winter months. Litter intervals for sows are usually three years, and cubs remain with their mother for their first two years (Eide and Miller 2008).

Brown bear populations are protected from sport hunting within the 55,432-ha (137,000-ac) ANM. However, subsistence hunting is legal within ANM. Sport hunting is permitted in the ANP, which comprises 188,179 ha (465,000 ac). Sport hunting is permitted in the spring during even-numbered years, and the fall during odd-numbered years. Alternating seasons established in the 1980s were implemented to stimulate population recovery. Fall brown bear harvest is generally greater than spring harvest; alternating seasons lowers bear harvest, stimulating population growth (Loveless et al. in review).

4.2.2 Measures

- Population density

4.2.3 Reference Conditions/Values

A reference condition for brown bear in ANIA does not exist. Unlike nearby Katmai National Park and Preserve (KATM), where the park’s enabling legislation allows for interpretation of a reference condition, the enabling legislation of ANIA does not provide enough information to define a quantitative reference condition. In addition, the lack of survey data limits the ability to define current condition quantitatively and to derive reference conditions.

4.2.4 Data and Methods

Butler (2009) is the primary source of information for this component. Butler (2009) provided data from surveys at Black Lake, approximately 50 km (30 mi) southwest of ANIA, for the years 1990-2002. In addition, Butler (2009) provides accounts of population density and harvest for all of GMU 9E, which encompasses ANIA.

4.2.5 Current Condition and Trend

Population Density

Quantitative data on the density of brown bears within ANIA do not exist. Overall, little is known about the density of brown bear in GMU 9E (Plate 6). Butler (2009) provides survey data for the Black Lake area of GMU 9E from 1990-2002. Individual surveys at Black Lake from 1999-2002 indicated that the population at Black Lake is stable (Butler 2009). Habitat similar to Black Lake is found in ANIA, with Aniakchak River and Surprise Lake supporting salmon runs and those runs coinciding with observations of brown bear at Surprise Lake (Sowl 1988).

Threats and Stressor Factors

The Alaska National Interest Lands Conservation Act (ANILCA) enables brown bear subsistence hunting opportunities in the preserve and monument portion of ANIA; sport hunting is permitted only in the preserve portion. Proposals have been submitted to the Board of Game requesting that units 9C and 9E increase brown bear harvest (Butler 2009). Local residents cite the Northern Alaska Peninsula caribou herd (NAPCH) decline, a decline caused by brown bear predation of neonatal and young of the year caribou according to caribou mortality studies, as the major reason to increase brown bear harvest (Butler 2009). In ANIA, concession contracts are issued for three different guide areas which have resulted in 94 brown bear harvested from 2005 to 2010 (NPS 2003, Anderson, pers. comm., 2012) (Table 9).

Table 9. Concession harvest of brown bears in ANIA from 2005 to 2010 (Anderson, pers. comm., 2012).

Brown Bear Harvest	2005	2006	2007	2008	2009	2010	2011	Total Harvest
Male	12	14	8	12	9	5	10	70
Female	3	3	3	2	7	2	4	24
Total for Year	15	17	11	14	16	7	14	94

Data Needs/Gaps

Research to assess the brown bear population in ANIA has never been conducted. Therefore, no data exist for population density or any other population parameters.

Overall Condition

Population Density

Reference condition and quantitative data that enable explicit conclusions regarding condition do not exist for this component. Within GMU 9E, surveys at Black Lake in the late 1990s and early 2000s indicate stable populations, but the survey area is approximately 50 km (30 mi) from the park. Fuller (1983) and Sowl (1988) document that brown bear are present in ANIA year round, and that bears congregate near Surprise Lake and other streams and lakes during the fall salmon run, similar to the Black Lake area.

Summary
ANIA brown bears reside year-round in a remote section of the Alaskan Peninsula rarely visited by humans. Therefore, a conjecture can be made that the stressors caused by human interaction affect ANIA brown bears less than other thriving brown bear populations in heavily visited Alaskan parks. However, a primary reason for visitor use of ANIA is for the sport and concession hunting of brown bears. Until more current brown bear population surveys are conducted and assessment of the impact that sport and concession hunting have on the brown bear population is completed, an accurate statement regarding the condition of brown bears in ANIA cannot be made.

4.2.6 Sources of Expertise
Sherri Anderson, ANIA Wildlife Biologist

Troy Hamon, KATM/ANIA Chief of Resources

4.2.7 Literature Cited

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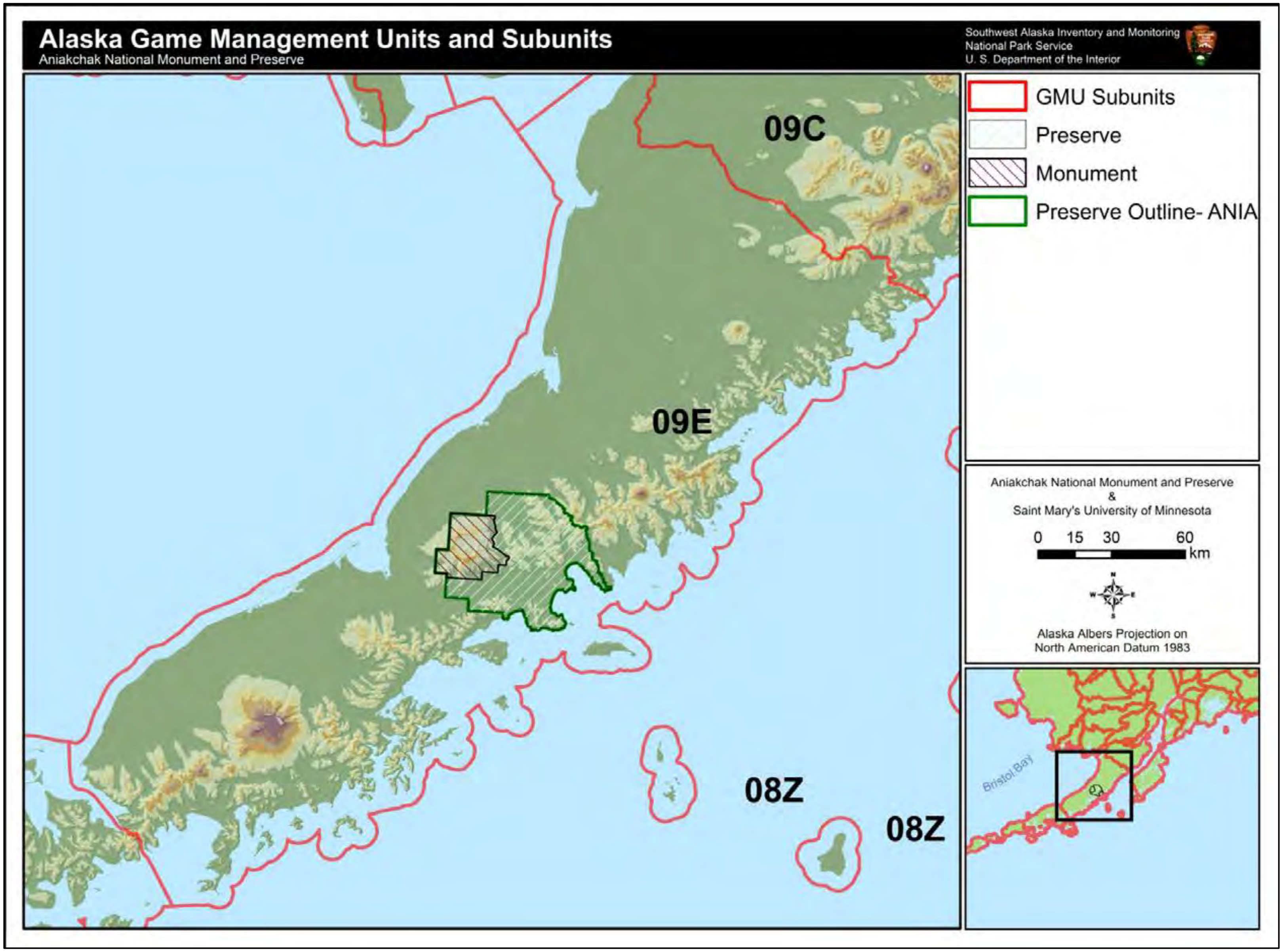

Plate 6. Alaska game management units and subunits. Subunit 9E contains all of the ANIA National Monument and Preserve.

4.3 Caribou

4.3.1 Description

Photo 7. Alaskan caribou bulls in early fall (NPS photo).

Caribou (*Rangifer tarandus*; Photo 7) are a prominent mammal species in ANIA. An Alaskan adult bull caribou can weigh up to 318 kg (700 lbs), but averages between 160-180 kg (350-400 lbs); adult cows weigh on average 80-120 kg (175-225 lbs) (Rausch et al. 2008). Caribou bulls can grow massive antlers. Cows also grow antlers but they are much shorter and smaller. Antlers grow each spring and remain covered in velvet until late August when the antler hardens. Caribou are herbivores, eating willow leaves, sedges, flowering tundra plants and mushrooms in the summer (May-September) and then supplementing their diet with dried sedges, small shrubs, and lichens during the winter (Rausch et al. 2008).

Cows in exceptional condition may breed at 16 months but generally reach sexual maturity at 28 months of age (Rausch et al. 2008). The breeding season or rut starts in early September and peaks towards the end of the month. Fighting between bulls is common but generally brief; occasionally serious bouts unfold and result in injury or death. Cows give birth to a single calf (twins are rare) around early June. Shortly after calving, “post calving aggregations” form which provide protection from predators and insects. Caribou disperse in August to feed heavily before migrating. Caribou herds spend much of the year traveling between summer calving grounds and wintering areas. Migration is thought to be triggered by changing weather patterns, as caribou migrations generally precede cold fronts and snowstorms. Caribou often travel 80 km (50 mi) a day during peak migration times (Rausch et al. 2008).

ANIA caribou are part of the NAPCH, one of the 32 designated herds in Alaska. Herds may intermix at wintering grounds, but calving grounds are separate and historically remain in the same general area; wintering grounds and migration routes have been seen to change suddenly from historic locations to routes and areas with more food (Rausch et al. 2008). Mountainous areas and treeless tundra are preferred caribou habitat year-round, with preference to open coastal areas and mountains for calving areas and boreal forests as wintering grounds (Rausch et al. 2008). Traditional calving grounds of the NAPCH have been between the Bear River and Cinder River that runs through ANIA, and on the Bering Sea Flats. These traditional grounds have been used sparingly since 2004 and calving is now widely dispersed in mountainous terrain between the Meshik River and Katmai National Park.

4.3.2 Measures

- North Alaska Peninsula Herd size

- North Alaska Peninsula Herd composition

4.3.3 Reference Conditions/Values

According to the NPS's enabling legislation, ANIA, like all other NPS managed lands, is to manage animal species in a manner consistent with maintaining a natural and healthy population. NPS policies that support the naturally occurring and healthy population are found in sections 4.4.1 and 4.4.3 of the NPS Management Policies (2006) which state that;

> *The NPS will maintain as parts of the natural ecosystem of parks all plants and animals native to park ecosystems…*
>
> *…preserving and restoring the natural abundances, diversities, dynamics, distributions, habitats, and behaviors of native plant and animal populations and the communities and ecosystems in which they occur…*
>
> *…minimizing human impacts on native plants, animals, populations, communities, and ecosystems, and the processes that sustain them.*
>
> *…the Service* (NPS) *does not engage in activities to reduce the numbers of native species for the purposes of increasing the numbers of harvested species (i.e., predator control), nor does the Service permit others to do so on lands managed by the National Park Service*

Management of the caribou population in ANIA is intended to be implemented through the cooperative efforts of the NPS and the ADF&G . However, when the species in question is a harvested or game species, it should be noted that the NPS management policies may not be congruent with local or state wildlife management policies due to differing management objectives.

Currently, quantitative caribou population metrics have not been established by the NPS that would define a set of caribou population reference conditions (i.e., ranges of natural variability that embody natural and healthy populations). In lieu of NPS established caribou population reference conditions, the following section reports population metrics according to ADF&G defined management goals. While the ADF&G defined management goals are discussed below, it is important to recognize that the NPS goals may differ and that management objectives of the ADF&G do not necessarily represent the management objectives of the NPS.

Two management goals were outlined in the ADF&G caribou management report for GMU 9C and 9E (Plate 7). Management goals are set by the ADF&G for each Alaskan GMU and individual caribou herd. The management goal for population size of the NAPCH is set at 12,000-15,000 caribou (Butler 2009). The management goal for the population composition is the maintenance of October sex ratios of at least 25 bulls:100 cows (Butler 2009).

4.3.4 Data and Methods

ADF&G caribou management reports (Butler 2005, 2007, 2009) provide information on defined management goals. ADF&G conducts population size, age structure, and sex ratio surveys with the aid of radio telemetry, helicopters, and fixed winged aircraft for game management units 9C and 9E.

ADF&G reports also outline other sources of mortality, establish caribou population and composition objectives, and monitor temporal trends in population size and composition (Butler 2005, 2007, 2009).

ADF&G conducts aerial population surveys in late June over post-calving concentrations of caribou, and USFWS surveys the Aleutian Mountains and Pacific Coast. Establishment of bull:cow ratios; percentage of young, medium, and large bulls; and age composition surveys are done in October between the Naknek River and Port Moller (Butler 2009). Parturition surveys occur in early June on the calving grounds to establish pregnancy rates; cows equipped with radio collars are also surveyed at this time to determine age-specific pregnancy rates. The ADF&G and USFWS intend to establish and maintain 25-30 radio collars on caribou in the NAPCH and deploy satellite collars to track caribou migrations (Butler 2009). Wide angle 35-mm still photos were taken from aircraft over areas with large numbers of caribou and later counted to increase accuracy of population, calf:cow ratio, and sex ratio estimates (Butler 2005, 2007, 2009).

4.3.5 Current Condition and Trend

North Alaska Peninsula Herd Size

In the absence of quantitative caribou population metrics from the NPS the following section reports population metrics according to ADF&G defined management goals. While the ADF&G defined management goals are discussed below, it is important to recognize that the NPS goals may differ and that management objectives of the ADF&G do not necessarily represent the management objectives of the NPS.

Butler (2009) notes that the NAPCH fluctuates in population size; peaks were reached at the turn of the century and in the early 1940s with the herd reaching 20,000 caribou. The NAPCH then plummeted to 2,000 caribou by the late 1940s, but again recovered to over 10,000 caribou in 1963 (Skoog 1968). The first population survey aided by radio telemetry occurred in 1981 and estimated the NAPCH at 16,000. A survey in 1984 found the NAPCH had again risen to 20,000 caribou (Butler 2009, Table 10). Traditional wintering grounds south of the Naknek River began to show depletion in lichen availability from over browsing, resulting in a decline of caribou use. Several members of the NAPCH began to cross the Naknek River, assumedly in search of sustainable overwintering habitat, settling between the Naknek River and Lake Iliamna. Butler (2009) found that this new wintering area contained excellent forage able to sustain the NAPCH at its 1986 ADF&G management goal of 15,000 to 20,000 individuals. The NAPCH was managed at the lower end of the management goal (15,000) during the late 1980s, because an estimated 50,000 Mulchatna caribou began utilizing the same wintering grounds between Lake Iliamna and the Naknek River. This caused concern that winter forage in the area would be over browsed (Butler 2009). The NAPCH experienced a slow decline throughout the 1990s. The largest population decrease occurred between 1993 and 1994, when high natural mortality and a record harvest reduced the population size from 16,000 to 12,500 animals (Butler 2007). The NAPCH again began wintering in traditional grounds south of the Naknek River, as only one radio-collared caribou has crossed the river since 2000. Efforts were made to reduce harvest rates with hunting restrictions implemented in 1994, but the NAPCH continued to decline over the next several years. The most recent estimate in 2008 indicates that the herd consists of approximately 2,000 individuals (Butler 2009).

The NAPCH continues to winter south of the Naknek River between Port Heiden and King Salmon, with very few animals observed to cross the Naknek (Troy Hamon, KATM/ANIA Chief of Resources, pers. comm., 2013). Traditional wintering grounds have not been re-established and no defined area for wintering exists within this geographic region. Caribou roam the region in winter, utilizing and congregating based on weather conditions and areas with quality forage during that year (Hamon, pers. comm., 2013).

Table 10. Population size and composition of the NAPCH, 1984, 1990-2008 (reproduced from Butler 2009).

Year	Total bulls: 100 cows	Calves: 100 cows	Calves %	Cows%	Small bulls(% of bulls	Medium bulls (% of bulls)	Large bulls (% of bulls)	Total bulls (%)	Sample size	Estimate of herd size
1984	39	39	22	56	67	16	17	22	1,087	20,000
1990	41	29	17	59	*	*	*	24	1,484	17,000
1991	42	47	25	53	54	34	12	22	1,639	17,000
1992	40	44	24	54	44	38	19	22	2,766	17,500
1993	44	39	21	55	52	29	19	24	3,021	16,000
1994	34	34	20	59	58	28	14	20	1,857	12500
1995	41	24	15	60	49	29	22	25	2,907	12,000
1996	48	38	19	54	71	19	10	26	2,572	12,000
1997	47	27	16	57	54	31	14	27	1,064	10,000
1998	31	30	19	62	57	28	15	19	1,342	9,200
1999	40	21	13	62	58	30	12	25	2,567	8,600
2000	38	18	12	64	59	24	18	24	1,083	7,200
2001	49	28	16	57	61	24	15	28	2,392	6,300
2002	46	24	14	59	57	19	24	27	1,007	6,600
2003	36	11	8	68	46	30	24	24	2,776	*
2004	34	7	5	71	40	34	25	24	1,355	3,400
2005	23	7	6	77	37	41	22	18	1,914	*
2006	26	14	10	72	26	43	31	18	1,725	*
2007	27	7	5	75	29	38	33	20	1,719	*
2008	19	10	8	77	33	25	43	15	1,841	2,000

* Data were not included in Butler (2009).

North Alaska Peninsula Herd Composition

In the absence of quantitative caribou population metrics from the NPS the following section reports population metrics according to ADF&G defined management goals. While the ADF&G defined management goals are discussed below, it is important to recognize that the NPS goals may differ and that management objectives of the ADF&G do not necessarily represent the management objectives of the NPS.

The ADF&G management goal for the NAPCH composition is 25 bulls:100 cows. Butler (2009) states that this ratio is lower than several other Alaskan herds and should be switched to a bull: cow ratio of at least 35:100. The NAPCH maintained a bull:cow ratio of over 35:100 from 1990-2004 when the average ratio was 41 bulls:100 cows. NAPCH bull:cow ratios fell below the ADF&G management goal from 2005-2008. Butler (2009) indicated that poor calf recruitment and the shorter lifespan of bulls compared to cows were primary causes for the decline of the ratio (Table 10). Butler (2009) suggests that managing towards a bull:cow ratio of 35:100 will be a more achievable goal now that the NAPCH is small (2,000 caribou).

ADF&G fall estimates of cow:calf ratios provide insight into changes in population size and help explain trends in bull:cow ratios. During the NAPCH herds steady growth years, from 1970 to 1980, the calf:cow ratio was on average 50:100. When the population size was stable from 1981-1994, calf:cow ratios averaged 39:100. While the herd declined from 1995 to 2002, the average ratio was 26 calves:100 cows (Butler 2009). Since 2003, yearly calf:cow ratios average 9:100; this ratio is a record low for the NAPCH herd according to available data (Butler 2009).

Threats and Stressor Factors

The population size of the NAPCH has been steadily decreasing since 1984, with nutritional stress and habitat condition being cited as possible setbacks (Butler 2009). ADF&G compiled data on the weights of neonatal, young of the year, and adult female caribou from the NAPCH for most years from 1990-1998 (Butler 2009). In comparison to other Alaskan herds, adult, neonatal, and young of the year cows displayed intermediate body size. However, an ADF&G study of NAPCH cow productivity from 1997-2000 concluded that moderate nutritional stress was evident in the herd (Butler 2009). A sample of 32 age-two cows and 18 age-three cows resulted in 33% (six cows) and 0% pregnancy rates, respectively (Butler 2009).

Cow and calf mortality rates have been at all-time highs for the NAPCH, according to an ongoing ADF&G study using telemetry flights to monitor these rates. Since 1998, an average cow mortality rate of 21% has been observed; cow mortality rates from 1980 to 1984 were 7% (Butler 2009). Predation on caribou from wolves and brown bears could also be a contributor to the NAPCH decline and lack of recovery. Brown bear and wolf predation was cited as the likely cause of death for 60% of collared neonatal calves (2 weeks and younger) from 2005 to 2007 (Butler 2009). Although the cause of the mortalities was undocumented, calves between 2 weeks and 4 months of age also continued to show a high mortality rate, at 66% over the same years.

Hunting of the NAPCH is not permitted at this time, but is predicted to reopen again with a bull-only harvest; no specific date for the reinstatement of hunting has been set and will not be set until the herd begins to recover (Butler 2009). Butler (2009, p. 36) reports that a "2005 herd health assessment identified heavy parasite loads, the presence of bovine respiratory disease complex, poor immune response, low levels of micronutrients, and chronic dehydration" in caribou examined from the NAPCH.

Data Needs/Gaps

Butler (2009) suggests that assessment of the NAPCH wintering grounds should be completed, with an aim to define if nutritional limitations are still stressing the herd. This assessment would aid in defining future management goals for the NAPCH and determine if the herd has a chance to recover from a poor health assessment in 2005 (Butler 2009).

Overall Condition

The NAPCH has shown small improvements from 2001 to 2008. Pregnancy rates of cows over 2 years of age have been slowly improving from 2005-2008 with rates of 57%, 63%, 74%, and 78% during those years. However, calf survival remains at an all-time low and the herd has continued to decline. ADF&G Biologists examined the NAPCH from 1999 through the 2000s to define intensive management options and concluded "no viable solutions exist to alter the status of this herd" (Butler 2009, p. 37).

4.3.6 Sources of Expertise

Troy Hamon, KATM/ANIA Chief of Resources

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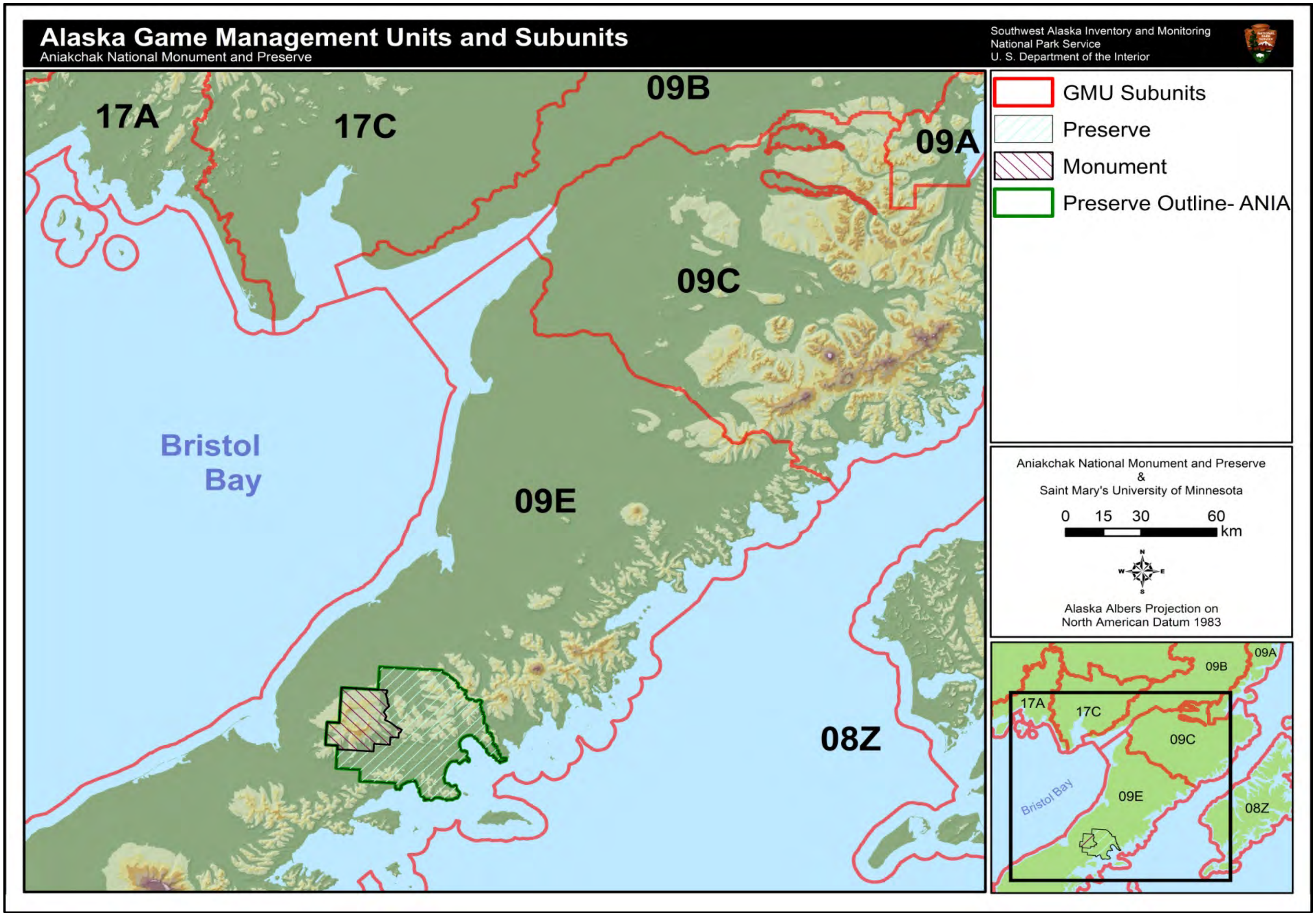

Plate 7. Alaska game management units and subunits. Subunits 9E and 9C include the area utilized by the NAPCH.

4.4 Passerines

4.4.1 Description

Passerines are birds that belong to the Order Passeriformes, commonly referred to as “perching birds”. Bird populations often act as excellent indicators of an ecosystem’s health (Morrison 1986, Hutto 1998, NABCI 2009). Birds are typically easy to observe and identify, and bird communities often reflect the abundance and distribution of other organisms with which they co-exist (Blakesley et al. 2010). When SWAN began conducting biological inventories of vertebrates and vascular plants in the network parks in the early 2000s, land birds were identified as one of the top eight priority groups for study (Kedzie-Webb 2001, as cited in Ruthrauff and Tibbits 2009).

Photo 8. A male snow bunting in ANIA (NPS photo by Bill Thompson).

ANIA provides a wide range of habitats, from coastal to montane, that support a variety of passerines. Forty-four passerine species have been documented in the park, including several species of conservation concern, such as the snow bunting (*Plectrophenax nivalis*, Photo 8) (Rich et al. 2004, NPS 2013).

4.4.2 Measures

- Species richness and diversity
- Species abundance

4.4.3 Data and Methods

The earliest available observations of bird populations in ANIA are from Manski et al. (1987) and Meyer (1987). Manski et al. (1987) documented bird species along the Pacific coast of ANIA in August and September of 1987, while Meyer (1987) reported on birds in the Aniakchak Caldera during July 1987. In the summer of 1988, Starr and Starr (1988) reported bird observations along the ANIA coast, and Sowl (1988) documented species in the caldera. Several years later, Savage (1992, 1993) documented bird species in the park during two summer field seasons.

The most thorough survey of ANIA bird populations, including passerines, occurred during May and June of 2009 (Ruthrauff and Tibbits 2009). The survey utilized stratified random sampling according to land cover type. Crews conducted surveys at 136 points within eight plots; more in-depth surveys took place at six locations with unique habitats or landforms within the park (Ruthrauff and Tibbits 2009; Plate 8).

4.4.4 Current Condition and Trend

Species Richness and Diversity

According to the NPS Certified Species List (NPS 2013), 44 passerine species are present or probably present within ANIA (Table 11). This includes birds that are year-round or seasonal residents as well as species that pass through during migration. Ruthrauff and Tibbits (2009) documented 28 passerine species during a summer landbird survey in 2009, including two species new to the park: the horned lark (*Eremophila alpestris*, Photo 9) and the hoary redpoll (*Carduelis hornemanni*). During the 1992-93 field seasons, Savage (1992, 1993) observed 18 passerine species. Observers during the summers of 1987 and 1988 recorded between nine and 16 species (Table 11). However, some of these observations were limited in geographical scope. For example, Manski et al. (1987) and Starr and Starr (1988) visited only the park's coast, while Meyer (1987) and Sowl (1988) documented birds in Aniakchak Caldera.

Photo 9. Horned lark (USFWS photo by Tim Bowman).

Table 11. Passerines present or possibly present in ANIA (species in bold are of conservation concern). Abundances are from the NPS Certified Species List (NPS 2013), for those species confirmed present in the park. For other sources that recorded abundance, A = abundant, C = common, FC = fairly common, U = uncommon, O = occasional, R = rare, VR = very rare.

Scientific Name	Common Name	Abundance	Ruthrauff & Tibbits 2009	Savage 1992-93	Starr & Starr 1988	Sowl 1988	Meyer 1987	Manski et al. 1987
Alauda arvensis	sky lark	Occasional	x	x				
Eremophila alpestris	horned lark		x					
Cinclus mexicanus	American dipper	Uncommon	x	x		U	U	
Corvus corax	common raven	Common	x	x	C	FC	C	A
Pica hudsonia	black-billed magpie	Uncommon	x	x	C			C
***Calcarius lapponicus*[2]**	**lapland longspur**	Common	x	x		FC	A	
Junco hyemalis	dark-eyed junco							
Melospiza lincolnii	Lincoln's sparrow							
Melospiza melodia	song sparrow				U			
Passerculus sandwichensis	savannah sparrow	Common	x	x	C	C	A	A
Passerella iliaca	fox sparrow	Uncommon	x	x	O			
Plectrophenax hyperboreus	McKay's bunting							
***Plectrophenax nivalis*[2]**	**snow bunting**	Uncommon	x	x		A	A	
Spizella arborea	American tree sparrow	Uncommon	x					
Spizella passerina	chipping sparrow							

[1] Landbird Conservation Plan for Alaska (Boreal Partners in Flight Working Group 1999)

[2] NALCP = North American Landbird Conservation Plan (Rich et al. 2004)

* formerly known as the water pipit, *Anthus spinoletta*.

Table 12 (continued). Passerines present or possibly present in ANIA (species in bold are of conservation concern). Abundances are from the NPS Certified Species List (NPS 2013), for those species confirmed present in the park. For other sources that recorded abundance, A = abundant, C = common, FC = fairly common, U = uncommon, O = occasional, R = rare, VR = very rare.

Scientific Name	Common Name	Abundance	Ruthrauff & Tibbits 2009	Savage 1992-93	Starr & Starr 1988	Sowl 1988	Meyer 1987	Manski et al. 1987
Zonotrichia atricapilla[1]	**golden-crowned sparrow**	Abundant	x	x	C	C	A	A
Zonotrichia leucophrys	white-crowned sparrow	Rare	x	x			R	
Carduelis flammea	common redpoll	Common	x	x	U	FC	A	
Carduelis hornemanni[1,2]	**hoary redpoll**		x					
Carduelis pinus	pine siskin							
Fringilla montifringilla	brambling							
Leucosticte tephrocotis	gray-crowned rosy-finch	Uncommon	x	x		FC	C	R
Pinicola enucleator	pine grosbeak							
Riparia riparia	bank swallow	Uncommon	x	x	A	C	C	U
Tachycineta bicolor	tree swallow	Rare	x		O			
Tachycineta thalassina	violet-green swallow							
Lanius excubitor	northern shrike	Rare	x		O		C	U
Anthus hodgsoni	olive-backed pipit							
*Anthus rubescens**	American pipit	Common	x		U	A	A	A
Motacilla tschutschensis	eastern yellow wagtail							
Poecile atricapillus	black-capped chickadee	Rare	x	x	O			U

[1] Landbird Conservation Plan for Alaska (Boreal Partners in Flight Working Group 1999)

[2] NALCP = North American Landbird Conservation Plan (Rich et al. 2004)

* formerly known as the water pipit, *Anthus spinoletta*.

Table 13 (continued). Passerines present or possibly present in ANIA (species in bold are of conservation concern). Abundances are from the NPS Certified Species List (NPS 2013), for those species confirmed present in the park. For other sources that recorded abundance, A = abundant, C = common, FC = fairly common, U = uncommon, O = occasional, R = rare, VR = very rare.

Scientific Name	Common Name	Abundance	Ruthrauff & Tibbits 2009	Savage 1992-93	Starr & Starr 1988	Sowl 1988	Meyer 1987	Manski et al. 1987
Dendroica petechia	yellow warbler	Rare	x	x	O			
Vermivora celata	orange-crowned warbler	Rare	x	x		VR		
Vermivora peregrina	Tennessee warbler							
Wilsonia pusilla	Wilson's warbler	Uncommon	x	x	U	R	R	
Regulus calendula	ruby-crowned kinglet							
Regulus satrapa	golden-crowned kinglet	Unknown	x					
Troglodytes troglodytes	winter wren	Occasional	x				O	
Catharus guttatus	hermit thrush	Abundant	x		C			
***Catharus minimus*[1]**	**gray-cheeked thrush**	Rare	x	x	O			
Ixoreus naevius	varied thrush							
Turdus migratorius	American robin	Unknown	x					
Contopus sordidulus	western wood-pewee							
Empidonax alnorum	alder flycatcher							
Total species			28	18	16	12	14	9

[1] Landbird Conservation Plan for Alaska (Boreal Partners in Flight Working Group 1999)

[2] NALCP = North American Landbird Conservation Plan (Rich et al. 2004)

* formerly known as the water pipit, *Anthus spinoletta*.

Photo 10. Orange-crowned warbler (Vermivora celata), black-billed magpie (Pica hudsonia) (USFWS photos), and golden-crowned sparrow (Zonotrichia atricapilla) (NPS photo by Kelly Walton).

Species Abundance

Abundance information for passerines in ANIA is primarily anecdotal. Several observers have classified species into categories such as "common", "uncommon", or "rare" (see Table 11). Species consistently reported as abundant or common across surveys include the savannah sparrow (*Passerculus sandwichensis*), golden-crowned sparrow, and common raven (*Corvus corax*).

During the Ruthrauff and Tibbits (2009) landbird survey, four of the five most commonly detected species were passerines: bank swallow (*Riparia riparia*), golden-crowned sparrow, Wilson's warbler (*Wilsonia pusilla*), and hermit thrush (*Catharus guttatus*). However, nearly all the bank swallows occurred in a large flock at one location, and the species was not widely distributed across the park (Ruthrauff and Tibbits 2009). The total number of each passerine species observed and average occurrence (number of individuals/number of points surveyed) in ANIA are presented in Table 12.

Table 14. Number of individuals of each passerine species documented in ANIA, and average occurrence (Ruthrauff and Tibbits 2009).

Species	Individuals	Average Occurrence
black-billed magpie	8	0.059
common raven	16	0.118
horned lark	3	0.022
tree swallow	10	0.074
bank swallow *	187	1.375
American dipper	2	0.015
gray-cheeked thrush	6	0.044
hermit thrush *	114	0.838
American robin	10	0.074
American pipit	45	0.331
orange-crowned warbler *	72	0.529

* Species with the five highest average occurrences (also highlighted in gray).

Table 15 (continued). Number of individuals of each passerine species documented in ANIA, and average occurrence (Ruthrauff and Tibbits 2009).

Species	Individuals	Average Occurrence
yellow warbler	4	0.029
Wilson's warbler *	141	1.037
American tree sparrow	11	0.081
savannah sparrow	45	0.331
fox sparrow	50	0.368
white-crowned sparrow	15	0.110
golden-crowned sparrow *	143	1.051
Lapland longspur	21	0.154
snow bunting	32	0.235
redpoll sp.	10	0.074

* Species with the five highest average occurrences (also highlighted in gray).

Threats and Stressor Factors

Due to limited research, it is unclear if any stressors to passerines are present within the park. However, these species are likely threatened by sources outside ANIA boundaries, such as mining or the development of off-shore oil and gas exploration. For example, several large developments have been proposed in Bristol Bay west of the park, which may influence wildlife in the region (Ruthrauff et al. 2007). Climate change is also a threat to birds, particularly those that rely on alpine habitats, as these areas are likely to become drier and experience shifts in vegetation (Ruthrauff et al. 2007). Additionally, many of the passerines that occur in ANIA are migratory, and face multiple threats during migration and while in their winter habitats.

Data Needs/Gaps

Nearly all of the bird surveys and observations in ANIA have occurred during the summer months. While this is likely the time when most passerines are present and active in the parks, surveys during other seasons (e.g., spring and fall migrations) would contribute to a more thorough understanding of the passerine population (Ruthrauff and Tibbits 2009). Establishment of a regular monitoring program would help NPS staff determine if any changes are occurring within the ANIA passerine population

Overall Condition

It is difficult to assess the overall condition of passerines in ANIA, due to the limited amount of data that are available. Historical information is primarily from incidental observations as opposed to scientifically designed inventories or surveys. As a result, it is not directly comparable to more recent surveys. However, there is no evidence of any cause for concern among the passerine populations, particularly given the relatively pristine and undisturbed condition of the park.

4.4.5 Sources of Expertise

Sherri Anderson, KATM Wildlife Biologist

4.4.6 Literature Cited

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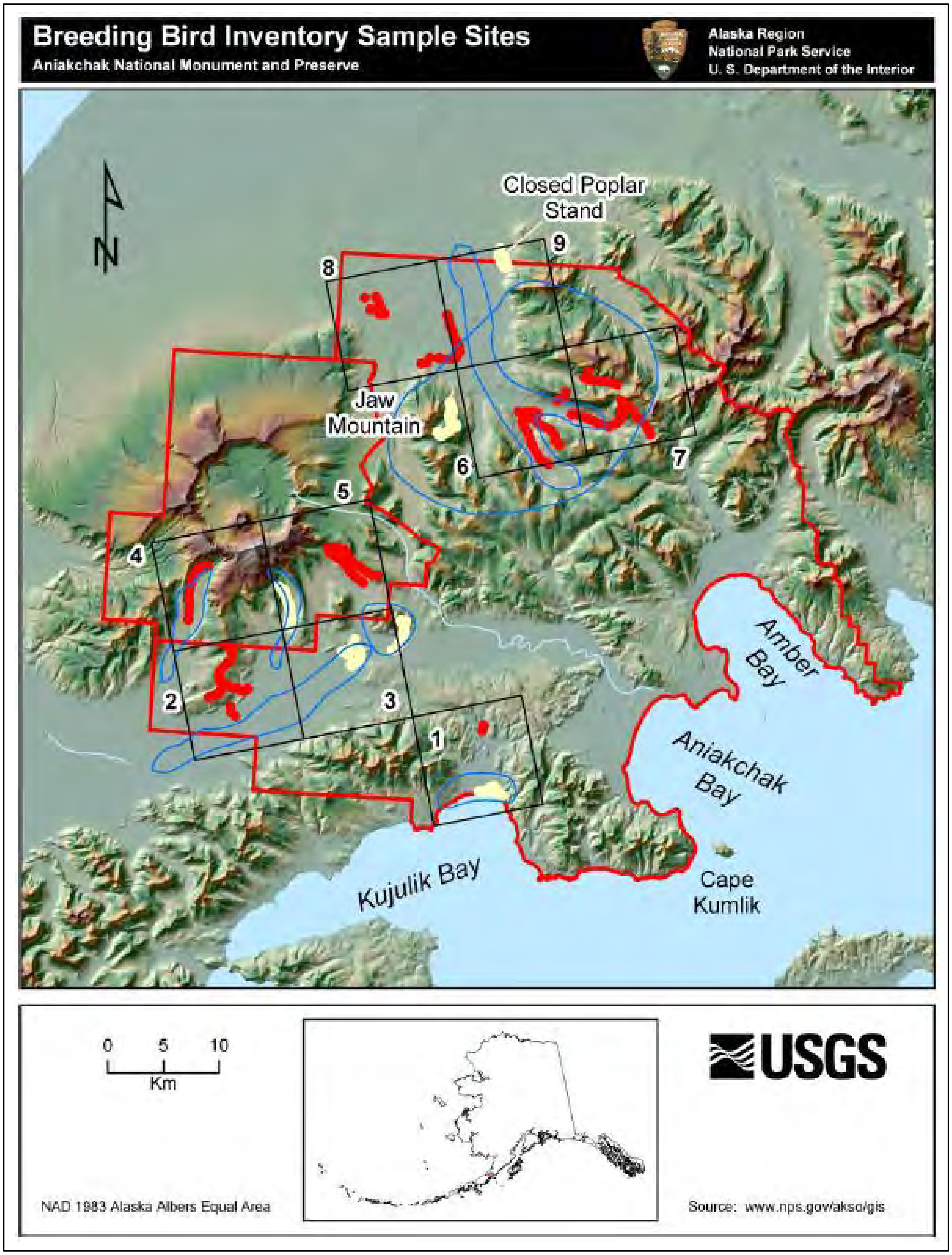

Plate 8. Breeding bird inventory sites within ANIA (from Ruthrauff and Tibbitts 2009). Sample plot boundaries are shown in black and red circles represent point-count survey locations. Areas of special interest are outlined in blue with focal-area inventory locations shown by pale yellow circles.

4.5 Salmon

4.5.1 Description

Sockeye salmon (*Oncorhynchus nerka*) are known to inhabit Surprise Lake within the Aniakchak Caldera, where they have established spawning populations (Mahoney and Sonnevil 1991, Hamon 2000, Hamon et al. 2004). Other salmon species present within the park include Coho (*O. kisutch*), pink (*O. gorbuscha*), chum (*O. keta*), and Chinook salmon (*O. tshawytscha*). A variety of other salmonid species are present within the Aniakchak River and its major tributaries, including Dolly Varden (*Salvelinus malma*) and arctic char (*S. alpinus*) (Lechner 1969, Buck 1979, Mahoney and Sonnevil 1991). Sockeye salmon are an anadromous species that have adapted to adverse conditions within the park, including previously uninhabited areas once covered by receding glaciers, and Surprise Lake, a high-altitude lake within the Aniakchak Caldera, formed nearly 3,500 years ago by volcanic eruptions (Hamon et al. 2004) (Plate 9). According to Hamon et al. (2004, p. 37), sockeye salmon in Surprise Lake are "some of the most recently established natural populations known in southwest Alaska."

Photo 11. A local fisherman drying salmon on a knoll east of the mouth of the Aniakchak River (NPS photo by Keith Trexler).

The Aniakchak Caldera within ANIA contains Surprise Lake, which populated with salmon following a break in the caldera wall and subsequent flood between 1,800 and 3,400 years ago (Hamon 1999). Salmon species have persisted in Surprise Lake since sometime following the historic flood, and have thrived even after another major eruption of the Aniakchak volcano in 1931 (Mahoney and Sonnevil 1991, Hamon 1999). Following geological events such as volcanic eruptions or deglaciation, fish typically colonize new areas or become adapted to this newly available habitat (Hamon et al. 2004). Historically, sockeye salmon inhabited roughly one-third of the eastern shoreline of Surprise Lake (Lechner 1969); currently, three spawning salmon populations are present within ANIA, two within the caldera and one in Albert Johnson Creek, a major tributary of the Aniakchak River (Hamon 1999). During annual spawning runs, sockeye salmon swim up the high-gradient Aniakchak River to Surprise Lake to lay their eggs before they die. ANIA contains several nursery areas for sockeye salmon runs that are considered part of the Bristol Bay and Kodiak/Chignik fisheries (Hamon, pers. comm., 2013).

Hamon (1999) noted that recreational visitor observations, documentation of subsistence use, and aerial counts provided evidence of the presence of sockeye salmon within ANIA and its drainages. Sport fishing is a common visitor activity, although total visitation in 2010 was only 62 visitors (Street 2011). Salmon are frequently harvested by local residents and native tribes for subsistence use (Photo 11) (Deur et al. 2007). ANIA is known for frequently bad weather conditions and costly, unpredictable access; this often discourages visitation and inhibits scientific investigations in the region (Mahoney and Sonnevil 1991, Hamon 1999, 2000). Salmon populations within ANIA have not been well-documented (Hamon 2000); therefore, data regarding escapement, harvest rates, and run timing are either sporadic or non-existent.

4.5.2 Measures

- Escapement
- Percent harvest
- Run timing

4.5.3 Reference Conditions/Values

Management objectives typically correspond to escapements and harvest rates of major salmon species. However, a reference condition was not established by park staff for the ANIA salmon component. Conclusions were drawn from anadromous fish reports, anecdotal accounts, available historical data, and temporal trends.

4.5.4 Data and Methods

Lechner (1969) provided one of the first investigations on sockeye salmon stocks in the ANIA region. Lechner (1969) determined the origin of sockeye salmon stocks harvested in the Cape Kumlik fishery at Aniakchak Bay. Numbers of Chignik sockeye salmon harvested at Aniakchak Bay were recorded using tagging efforts, which provided a basis for management of the cape fishery. Age composition of salmon stocks, time of migration, and the contribution of Aniakchak system sockeye salmon to the cape fishery were also investigated in the study (Lechner 1969).

Mahoney and Sonnevil (1991) conducted the first study investigating the Surprise Lake and Aniakchak River fisheries from 1987-1988, which sampled both fisheries to determine age, length, and weight of adult sockeye salmon at each location (Mahoney and Sonnevil 1991). The study collected various baseline data on fish species composition and distribution (Mahoney and Sonnevil 1991).

Baseline data gathered by Hamon (1999) identified spawning locations and total population estimates within the Aniakchak River drainage. Genetic sampling and body dimension measurements allowed researchers to compare present and historic salmon populations; the study also provided population estimates and a baseline for future ANIA salmon studies (Hamon 1999). Hamon (2000) further studied sockeye salmon populations within the Aniakchak Caldera and the Aniakchak River drainage. The study documented spawning populations, associated habitats, and distribution of spawning aggregations within the park (Hamon 2000).

Hamon et al. (2004) discussed sockeye salmon investigations in ANIA and studied salmon adaptation to geologic upheaval and survivability in harsh environments. Hamon et al. (2004) also studied salmon colonization efforts following the historic Aniakchak flood, escapement within the Chignik and Aniakchak River systems, as well as genetic similarity between three different sockeye salmon populations within ANIA.

4.5.5 Current Condition and Trend

Escapement

Historical accounts (Lechner 1969) reported that sockeye salmon escapement in Albert Johnson Creek was approximately 500 to 1,000 annually. Escapement to Surprise Lake was estimated to be between 3,000 and 5,000 individuals, except in 1962 when 40,000 spawning sockeye salmon were observed (Lechner 1969). The study by Lechner (1969) estimated the spawning population of sockeye salmon in Surprise Lake to be approximately 2,000 fish. An additional 200 sockeye were found spawning in the Aniakchak River, near the edge of the crater (Lechner 1969). Interviewees in the study by Deur et al. (2007, p. 80) noted that "official fish escapement figures represented 'paper numbers' and that the actual escapement numbers for the local fishery were so low that the salmon population was in a steady state of decline."

As of 2007, Albert Johnson Creek, the outlet of Surprise Lake, and the beaches of Surprise Lake all report escapement rates of fewer than 10,000 fish each annually (Pavey et al. 2007). Hamon et al. (2004) noted that Surprise Lake experiences between 5,000 and 50,000 spawning salmon annually. Black Lake, located southwest of ANIA in the neighboring Chignik River system (Plate 9), has an average annual escapement between one and two million fish (Hamon et al. 2004, Pavey et al. 2007). Bristol Bay, located on the northwest border of the Alaskan Peninsula, and its associated fishing districts experience escapement of approximately 11 million sockeye salmon annually on average (Jones et al. 2012).

Percent Harvest

Sockeye salmon populations within ANIA are affected by commercial harvest pressures outside of park boundaries, as well as subsistence harvest within park boundaries (Hamon 1999). The commercial fishing industry is active in the waters surrounding ANIA. However, major concentrations of harvest vessels are typically found in the nearby Chignik district (Hamon et al. 2004). Because of small spawning salmon populations in the ANIA region, harvest of sockeye salmon is typically minimal (Hamon et al. 2004). Generally, weather conditions and the rate of salmon entering Chignik Lagoon were two significant factors that determined harvest rates (Lechner 1969). Recreational harvest along the ANIA coast is typically minimal because of harsh weather conditions. However, fishermen suggest that the shoreline is a "profitable fishing ground" and is often sought out due to low density human populations and protection from harsh winds (Deur et al. 2007). Salmon populations are generally governed by natural processes within ANIA.

Subsistence harvest was present in the area prior to the establishment of ANIA in 1978 (Deur et al. 2007). Chignik villagers harvest modest amounts of salmon, clams, and waterfowl along the ANIA coast (Deur et al. 2007). Historically, harvest occurred in the spring or fall seasons, closely mirroring salmon runs (Deur et al. 2007). Fishermen from other regions, Kodiak Island for example, were known to harvest salmon in the area although exact numbers are unknown (Tuten 1977). Tuten (1977, p. 11, as cited in Deur et al. 2007) suggested that subsistence data for the ANIA coast seem to have a relatively high margin of error due to residents' high sensitivity "to the powerful role of the ADF&G which regulates their commercial salmon industry."

Run Timing

Little data exist regarding run timing for ANIA salmon populations and little is known about salmon run timing for differing geographic locations within ANIA. Salmon runs occur in the spring and fall months, typically beginning in early June and ending in late July to mid-August. According to interviewees in a study by Deur et al. (2007), salmon runs occur at irregular pulses depending on species and are occasionally delayed by inclement weather.

Threats and Stressor Factors

Park staff identified harvest rates as a major stressor to salmon populations within ANIA. Recreational and subsistence fisheries do not influence the salmon population as significantly as the commercial fishery, but often unique salmon stock can be affected. Genetic sampling conducted by Hamon et al. (2004) revealed three distinct spawning populations within ANIA water bodies, all tied to the ANIA fishing industry. A delicate balance exists between escapement and harvest rates in southwest Alaska. For example, historical closings of the Chignik Bay district in order to improve system escapement rates of sockeye salmon resulted in harvest increases in the nearby Cape Kumlik fishery (near ANIA), approximately 97 km (60 mi) to the east (Plate 9) (Lechner 1969). Typically, fisheries are only closed if harvest adversely affects ADF&G escapement goals (Lechner 1969). Tensions between subsistence and commercial harvest exist in the region, which have direct effects on ANIA such as coincidental commercial and subsistence harvests (Deur et al. 2007). Interviewees in the study by Deur et al. (2007, p. 80) expressed concern "that subsistence fishery seasons were not providing enough time to meet the needs of the communities before the commercial season began." Others cited the commercial fishery's preferential catchment of larger fish as a factor contributing to smaller salmon caught for subsistence use (Deur et al. 2007).

Salmon populations in southwestern Alaska are subject to commercial harvest pressures outside of the park, while subsistence and recreational harvest pressures exist within park boundaries (Hamon 1999). Salmon runs within ANIA streams are not as large as other nearby systems, such as those in the Bristol Bay or Chignik Bay region (Hamon et al. 2004). For this reason, it is likely that commercial harvest efforts will remain concentrated in the Bristol and Chignik Bay areas and not dramatically affect smaller runs returning to Surprise Lake and the Aniakchak River through Aniakchak Bay (Hamon et al. 2004). However, Deur et al. (2007) noted that significant declines in species such as salmon and halibut were observed over the past few decades.

Data Needs/Gaps

Because of its frequent poor weather conditions, inaccessibility, and remoteness, salmon populations in and near ANIA have not been well-studied; data regarding escapement, harvest, and run timing are either non-existent or severely lacking (Hamon 1999). Although anecdotal accounts exist, very few scientific studies investigating escapement, harvest, or run timing have occurred in ANIA.

Studies investigating run-timing in ANIA streams would help to address the measure. Comparisons between various other waterbodies, as well as changes over time within the system, would likely help to address temporal shifts in salmon runs; however, complete inventories of anadromous waters would likely be difficult and would not be cost effective.

Overall Condition

Escapement

The measure of escapement is not currently considered an area of management concern. While sockeye salmon escapement within ANIA has not been especially well-documented, populations are generally governed by natural processes. However, escapement rates are likely directly affected by harvest rates, and vice versa. Escapement for Albert Johnson Creek, the outlet of Surprise Lake, and the beaches of Surprise Lake are each estimated at less than 10,000 fish annually (Pavey et al. 2007). Surprise Lake escapement is relatively variable, between 5,000 and 50,000 spawning salmon annually (Hamon et al. 2004). Sockeye salmon escapement within Surprise Lake, Aniakchak Bay, the Aniakchak River, and its tributaries is significantly less than other locations in southwest Alaska (Hamon et al. 2004, Jones et al. 2012).

Percent Harvest

The measure of percent harvest is not currently considered an area of management concern. Commercial, recreational, and subsistence harvest all uniquely contribute to the percent harvest of sockeye salmon within ANIA. Recreational and subsistence fisheries do not heavily influence salmon populations. According to Hamon et al. (2004), it is likely that commercial harvest efforts will remain concentrated in the Bristol Bay and Chignik River districts because of larger salmon populations.

Run Timing

The current run timing in ANIA is unknown as data are not available for the park. Because of its remoteness and frequent poor weather conditions, ANIA is little affected by human activity and generally governed by natural processes (NPS 2009). Future studies examining run timing (e.g., mean day of salmon escapement) and the effects of climate change on salmon runs would be helpful to determine overall condition for this resource?.

Summary

ANIA salmon populations are not well studied. Therefore, significant conclusions cannot be drawn from available data, although anecdotal sources note that populations within ANIA are relatively small, but apparently healthy. According to Hamon et al. (2004, p. 39), “the populations at ANIA, though relatively small, appear to be very healthy and represent adaptations to a unique region.” Harvest rates do not currently have significant impacts on the small sockeye salmon populations within the park.

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Troy Hamon, KATM/ANIA Chief of Resources

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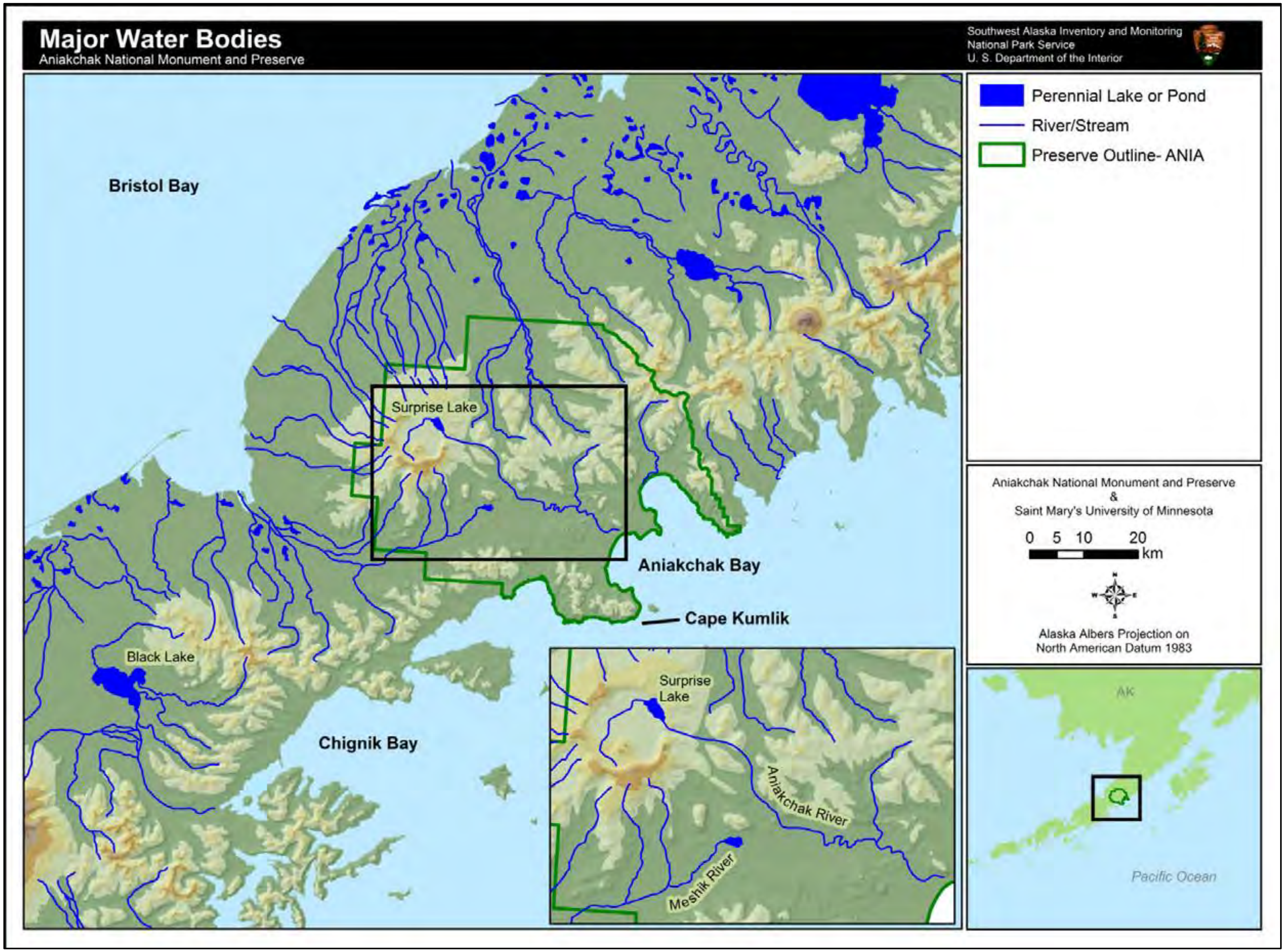

Plate 9. Major water bodies in and near ANIA.

4.6 Native Fish

4.6.1 Description

Twenty-seven anadromous and non-anadromous native fish species are present or probably present in ANIA (Table 13, Miller and Markis 2004, Jones et al. 2005, NPS 2012). Native fish of ANIA have been subjected to major geologic upheaval and flooding events over the past century. Sockeye salmon, coho salmon, and Dolly Varden are the most prevalent species in ANIA, showing an ability to adapt after environment-altering events. Hamon et al. (2004) recognizes salmon as an important source of nutrients for plant and mammal species and a source of subsistence for the native people surrounding ANIA (Krieg et al. 2004). Brown bears rely on fall salmon runs to supplement their diets before hibernation and native fish such as the Dolly Varden (Photo 12) feed heavily on drifting salmon eggs.

Photo 12. An Alaskan Dolly Varden (Photo by Jacob Zanon, SMUMN GSS 2011).

Table 16. NPS certified species list of native fish present or probably present in ANIA (NPS 2012).

Scientific Name	Common Name	Occurrence	Abundance
Catostomus catostomus	longnose sucker	probably present	*
Dallia pectoralis	Alaska blackfish	present in park	uncommon
Gasterosteus aculeatus	three-spined, Alaskan stickleback	present in park	abundant
Pungitius pungitius	ten-spined, nine-spined stickleback	present in park	abundant
Thaleichthys pacificus	eulachon	probably present	*
Lampetra tridentata	Pacific lamprey	probably present	*
Lethenteron japonicum	Arctic lamprey	probably present	*
Platichthys stellatus	starry flounder	present in park	unknown
Oncorhynchus gorbuscha	pink salmon	present in park	abundant
Oncorhynchus keta	chum salmon	present in park	abundant
Oncorhynchus kisutch	coho salmon	present in park	abundant
Oncorhynchus mykiss	steelhead, rainbow trout	present in park	rare
Oncorhynchus nerka	sockeye salmon	present in park	abundant
Oncorhynchus tshawytscha	king salmon, chinook salmon	present in park	uncommon
Prosopium cylindraceum	round whitefish	probably present	*
Salvelinus malma	Dolly Varden	present in park	abundant
Thymallus arcticus	Arctic grayling	probably present	*
Cottus aleuticus	coastrange sculpin	present in park	uncommon
Platichthys stellatus	starry flounder	present in park	uncommon

* Indicates that information regarding the abundance of the species is not available.

Table 13 (continued). NPS certified species list of native fish present or probably present in ANIA (NPS 2012).

Scientific Name	Common Name	Occurrence	Abundance
Leptocottus amatus	Pacific staghorn sculpin	present in park	uncommon
Lota lota	burbot	probably present	*
Salvelinus namaycush	lake trout	probably present	*
Esox lucius	northern pike	probably present	*
Artedius fenestralis	padded sculpin	probably present	*
Hypomesus olidus	pond smelt	probably present	*
Prosopium cylindraceum	round whitefish	probably present	*
Cottus cognatus	slimy sculpin	probably present	*

* Indicates that information regarding the abundance of the species is not available.

4.6.2 Analysis

Existing data and literature sources for this component were compiled and reported. Data for this component are minimal.

4.6.3 Reference Conditions/Values

Reference condition for this component is not available.

4.6.4 Data and Methods

Due to the lack of reference conditions for this component, the primary purpose of this portion of the NRCA is to provide park management with summarized data and information for future use. To fulfill this goal, data and literature provided by SWAN and ANIA staff were compiled and summarized.

Mahoney and Sonnevil (1987, 1991) completed a fisheries investigation of Surprise Lake and its tributaries, conducting three sampling efforts over two consecutive years (July 1987, August-September 1988). Fishery sampling efforts were reported in two water body groups: stream sampling and lake sampling efforts. Fisheries collection methods included minnow traps, backpack electrofishing, gill netting, hook and line, and dip netting.

Miller and Markis (2004) conducted a fisheries survey of ANIA water bodies with the goal to document species classified as probably present in ANIA. Water bodies were sampled in August 2002 and May-July 2003. Fisheries collection methods included minnow traps, hoop traps, minnow seines, beach seines, fyke nets, gill nets, and hook and line (Miller and Markis 2004). Jones et al. (2005) surveyed ANIA water bodies with a similar goal: to seek species listed as probably present and confirm those already present.

Manski et al. (1988) conducted a brief water quality sampling and fisheries survey of Surprise Lake. Methods of fisheries sampling included backpack electrofishing, minnow traps, hook and line, and gill nets (Manski et al. 1988).

4.6.5 Current Condition and Trend

Harvest and Angler Pressure Data

Dolly Varden and sockeye salmon were the only species reported in Surprise Lake (Mahoney and Sonnevil 1987, 1991; Table 14). Manski et al. (1988) confirms that only two species are found in Surprise Lake, adding that since the last major volcanic eruption in 1931, non-anadromous species such as stickleback have not yet been able to re-populate. Dolly Varden ranged from 1-11 years of age; several fish sampled over 4 years of age were found to be anadromous (Mahoney and Sonnevil 1987, 1991). The 1988 study sampled selected streams branching off of the Aniakchak River, resulting in more species being reported than the previous year (Plate 9, Table 15). The presence of juvenile sockeye salmon indicates that Surprise Lake supports sockeye salmon reproduction (Mahoney and Sonnevil 1987, 1991).

Table 17. Fisheries survey of Surprise Lake and Surprise Lake Tributaries. Table compiled from Mahoney and Sonnevil (1987).

ANIA fish survey 1987	Dolly Varden	sockeye (juvenile)	sockeye (adult)	pink salmon	chum salmon	coho salmon	three-spined stickleback
Surprise Lake/Tributaries	92	175	11	0	0	0	0

Table 18. 1987 & 1988 fisheries survey of Surprise Lake, Surprise Lake Tributaries, and Aniakchak River Tributaries. Table compiled from Mahoney and Sonnevil (1991).

ANIA fish survey 1988	Dolly Varden	sockeye (juvenile)	sockeye (adult)	pink salmon	chum salmon	coho salmon	three-spined stickleback
Surprise Lake	86	175	45	0	0	0	0
Tributary 5	15	0	0	0	0	0	0
Albert Johnson Creek	69	2	1	19	2	30	2
N. Fork ANIA River	9	0	0	A*	0	94	1

* A - Indicates that pink salmon were observed in large numbers but no effort to gather numerical data was made.

Miller and Markis (2004) were successful in documenting three species in ANIA: Alaska blackfish, coastrange sculpin, and nine-spined stickleback, all of which were labeled probably present before 2003. Miller and Markis (2004) confirmed that only two species: sockeye salmon and Dolly Varden, were present in Surprise Lake. The Aniakchak River was found to have the highest species diversity in the area with nine sampled species (Table 16, Miller and Markis 2004). Jones et al. (2005) identified 11 native fish species from ANIA water bodies, with two species confirmed that had previously been labeled as probably present.

Table 19. Species and number of fish sampled (2002 – 2003) in ANIA water bodies. Table compiled from Miller and Markis (2004).

Species	Albert Johnson Creek	Aniakchak River	Surprise Lake	Iris Creek	Willow Creek	Meshik Lake	Meshik River	Total
Expected undocumented species								
Alaska blackfish	0	0	0	0	0	0	1	1
coastrange sculpin	0	3	0	9	1	0	0	13
ninespine stickleback	56	4	0	0	0	3	2	65
Previously documented species								
coho/silver salmon	700	880	0	148	0	189	408	2,325
Dolly Varden	63	52	942	572	2	3	67	1,701
Pacific staghorn sculpin	0	100	0	0	0	0	0	100
pink salmon	0	1	0	0	0	0	0	0
rainbow trout/ steelhead	0	0	0	39	0	0	0	39
sockeye salmon/ red	0	17	1,264	0	0	679	16	1,976

Table 20. Species and number of fish sampled (2002 – 2003) in ANIA water bodies. Table compiled from Miller and Markis (2004).

Species	Albert Johnson Creek	Aniakchak River	Surprise Lake	Iris Creek	Willow Creek	Meshik Lake	Meshik River	Total
starry flounder	0	81	0	1	0	0	0	82
threespine stickleback	1	13	0	1	4	756	15	790

Threats and Stressor Factors

Salmon extirpation or the discontinued use of ANIA water bodies by salmon (especially sockeye salmon) would threaten the existence of several native fish species. Salmon supply essential nutrients from their eggs and flesh to the native fish of ANIA; without these nutrients many native fish species would become stressed. ANIA is also susceptible to another large volcanic eruption or other ecological disturbance, which could again alter native fish distribution.

Data Needs/Gaps

Unlike nearby KATM, data from ADF&G statewide mail-in surveys and guide logbooks do not exist for ANIA. Overall, information regarding native fish studies in ANIA is limited and outdated. Future sampling efforts would benefit the ability to describe condition in the future.

Overall Condition

Given the remoteness of the Aniakchak River and its tributaries, Surprise Lake, and other water bodies in ANIA, natural processes should be the primary driver of fish population dynamics and the condition of this resource is assumed to be good. However, without frequent and recent monitoring data, condition is only speculative.

4.6.6 Sources of Expertise

Troy Hamon, KATM/ANIA Chief of Resources

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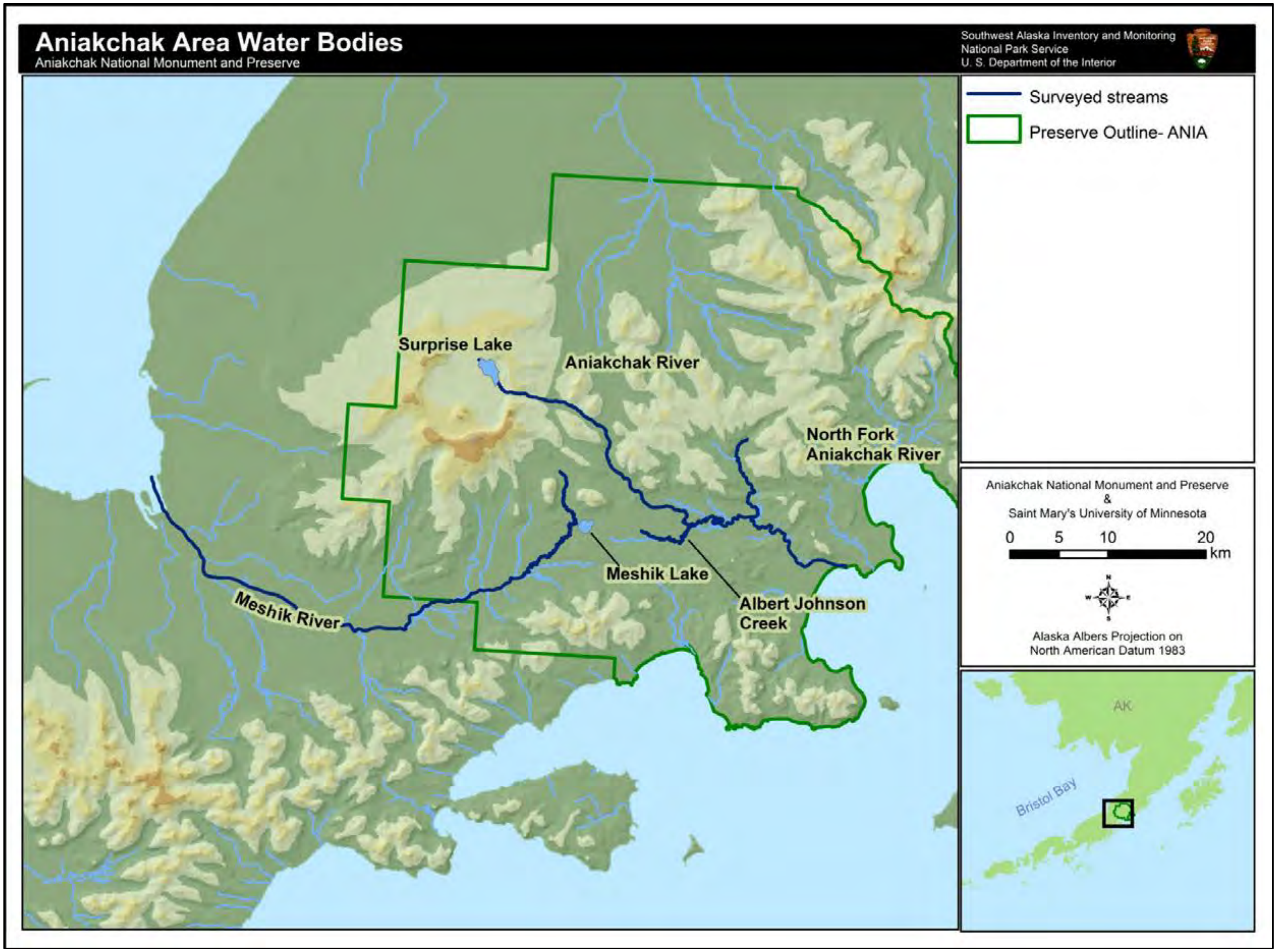

Plate 10. Area waterbodies of interest in Aniakchak National Monument and Preserve.

4.7 Seismic Activity

4.7.1 Description

ANIA is located in the Aleutian volcanic arc, one of the most volcanic and seismically active regions of the world, due to the northward movement of the Pacific Plate in relation to the North American plate (Page et al. 1991). The Aleutian volcanic arc is geographically described as a curving chain of volcanoes from the far western end of the Aleutian Islands, extending up the southwest Alaskan peninsula, and terminating in south-central Alaska (Simkin and Siebert 1994).

Photo 13. Aerial photograph of Aniakchak Caldera with landforms and deposits labeled (Coombs and Bacon 2012).

The Aniakchak Caldera (Photo 13), deemed a National Natural Landmark, has been the subject of several geologic studies because of its unique geologic features, formation history, and volcanic characteristics. The caldera is, on average, 10 km (6 mi) wide and over 600 m (2,000 ft) deep, making it one of the largest explosive craters in the world (Coombs and Bacon 2012). The caldera was formed from the collapse of Aniakchak Volcano after a catastrophic eruption around 3,400 years ago in an eruption larger than the Novarupta-Katmai eruption in 1912 (Coombs and Bacon 2012).

Visits to the caldera are rare and usually involve geologic and fisheries studies or water quality sampling. These teams are drawn to Surprise Lake and prime examples of lava flows, cinder cones, and explosion pits contained within the interior of the caldera (Brooks 2012). One of the most intriguing facets of the caldera, caused by its topography and location, is its ability to generate its own weather (Brooks 2012).

Earthquakes and volcanic eruptions within ANIA are a result of the interaction of the Pacific and North American plates along the Aleutian volcanic arc and are capable of drastically changing the landscape. Major alterations to the flora and fauna of a region can occur tens of kilometers from an epicenter or major eruption (Page et al. 1991). These alterations occur through a variety of mechanisms such as uplift or subsidence, tsunamis, mass movements or mass wasting events (e.g., snow avalanches, landslides), lava flows, and fallout debris which can cover the landscape with a thick layer of ash (Hoyer 1971, Crowell and Mann 1998, and AVO 2001).

Fierstein (2012, p. 15) states that “understanding the eruptive history of a volcano provides the best clues as to when, how, and on what scale that volcano may erupt in the future.” By analyzing the juxtaposition of lava flows, ash deposits, and other deposits as well as utilizing radiometric dating, estimates can be made regarding the frequency and magnitude of historic volcanic eruptions produced by the volcano in question (Fierstein 2012).

Photo 14. AVO seismic monitoring station in ANIA (Image courtesy of AVO/USGS).

Generally, an increase in seismic activity will accompany a volcanic eruption. A seismic swarm of volcano tectonic (VT) earthquakes is a common disturbance before an eruption occurs (Umakoshi 2001). Low frequency earthquakes are thought to be an even more diagnostic seismic signal, as their occurrence often indicates the movement of fluid or gasses (James Dixon, USGS Geophysicist, pers. comm., 2013). A large scale volcanic eruption can cause massive destruction to landscapes, personal property and result in wide-spread casualties. The ability to predict if an observed seismic event is the precursor for an eruption can provide an opportunity to set plans into action to save human lives through the evacuation of an area in danger.

The Alaska Volcano Observatory (AVO) operates a seismograph station network to monitor seismic activity across the Aleutian volcanic arc (Photo 14). AVO inherited 22 seismograph stations in 1988 and added the majority of the existing seismograph stations between 1996 and 2006 (AVO 2013). In 2011, the AVO seismic monitoring network had expanded to include 205 seismograph stations across 33 AVO seismically-monitored volcanoes located within the Aleutian volcanic arc (Dixon et al. 2012).

4.7.2 Measures

- Summary of recorded seismic history
- Summary of major seismic events

4.7.3 Reference Conditions/Values

Long-term trends defining geologic or seismic background for a region are difficult to achieve, as the factors that produce the frequency and magnitude of events are many and unpredictable. Regional trends could possibly be derived from consistent long-term monitoring of the seismic activity in a region with a constant number of functioning seismic stations. Discussion regarding the seismic activity of ANIA is limited to the time in which the seismic monitoring system has been operational. Due to the fact that a consistent number of seismic monitoring stations have only been operational since 2003, an accurate reference condition cannot be determined, as a sample size of a decade is extremely short when compared to the time between eruptions or great earthquakes.

4.7.4 Data and Methods

AVO (2013) monitors and records the daily seismic activity of the 33 volcanoes actively monitored by the observatory. Information is also presented regarding the seismic station and volcano latitude and longitude locations within ANIA, descriptions of each volcano, recorded seismic histories, and recorded volcanic activity.

4.7.5 Current Condition and Trend

Summary of Recorded Seismic History

Within ANIA, the Aniakchak Crater is the only volcano monitored by AVO (Table 17; Plate 11). AVO maintains six seismic monitoring stations in the Aniakchak subnetwork in an effort to record the daily seismic activity, predict eruptions, and develop historical seismic activity data (Table 18; Plate 12; Dixon et al. 2012). The only volcanic activity in the caldera recorded over the past 200 years is the six-week long eruption of Aniakchak Crater in 1931 (Neal et al. 2001). Scientists have worked to unravel the volcanic history of ANIA in an effort to better understand the past eruptions of the region. Half Cone, Blocky Cone, and Vent Mountain, all located within the Aniakchak Crater, were identified to have erupted explosively about 400 years ago (Coombs and Bacon 2012).

Table 21. Volcano located in ANIA (AVO 2013).

Name	Latitude (DD)	Longitude (DD)	Elevation (ft)	Seismically Monitored	Type
Aniakchak Crater	56.906	-158.209	4,400	Yes	Stratovolcano with intracaldera domes, vents, and cones

Table 22. Seismic monitoring stations located within ANIA (AVO 2013).

Station	Latitude (DD)	Longitude (DD)	Elevation (ft)	Seismometer	Open Date
ANNE	56.913	-158.059	214	L4	07/18/1997
ANNW	56.966	-158.215	248	L4	07/18/1997
ANON	56.92	-158.172	135	L22	07/10/2000
ANPB	56.802	-158.281	200	L4	07/18/1997
ANPK	56.842	-158.126	296	L4	07/18/1997
AZAC	56.895	-158.231	322	L4	07/12/2003

Aniakchak Crater was one of only seven AVO monitored volcanoes to show an increase in regional seismic activity in 2011 from recorded 2010 levels (Dixon et al. 2012). AVO located 12 earthquakes within the Aniakchak volcano subnetwork in 2010 and 55 in 2011. Over the last eight years, AVO seismic stations have located, on average, 24 earthquakes/year at Aniakchak.

Summary of Major Seismic Events

The 1931 eruption from the new vent within the Aniakchak Caldera produced egg-sized rock projectiles observed to travel over 30 km (19 mi) (Coombs and Bacon 2012). The eruption began 1 May and continued into the middle of June, with the most violent activity reported during the first 10 days. This eruption was unique in regards to the chemical makeup of the magma emitted, and type of projectiles ejected (Coombs and Bacon 2012). Fragments of pumice with estimated diameters of 5 cm (2 in) landed in Meshik, approximately 25 km (15 mi) away. Ash fallout about the size of a sand grain was nearly 10 m (32 ft) deep near the Aniakchak Caldera; however, fallout was observed to be only a dusting at distances greater than 100 km (62 mi) (Neal et al. 2001).

Threats and Stressor Factors

Threats and stressors regarding the seismic activity of the ANIA region are undefined.

Data Needs/Gaps

Roman and Cashman (2006) state that VT swarms that are observed but do not result in an eruption are largely not understood. This is mainly due to the fact that only VT swarms that result in a volcanic eruption are of interest and, therefore, thoroughly studied. Approximately half of observed VT swarms occurring on or near a volcanic center lead to an eruption (Benoit and McNutt 1996). Dixon and Power (2009) stress the need and importance to study VT swarms that do not result in volcanic eruption. A more thorough understanding of these VT swarms is important for the quick and decisive assessment of future VT swarms and the probability that they may cause a volcanic eruption.

Overall Condition

Within ANIA, one volcano is monitored by six seismic monitoring stations maintained by AVO. Seismic stations surrounding the Aniakchak Crater have recorded an average of 24 earthquakes/year over the past eight years. Aniakchak Crater was one of only seven AVO monitored volcanoes to show an increase in regional seismic activity from recorded 2010 levels (Dixon et al. 2012). AVO located 12 earthquakes within the Aniakchak volcano subnetwork in 2010 and 55 in 2011, more than double the eight-year average for the region. This seismic increase has been attributed to low frequency events which occur at depths greater than 10 km (6 mi) and in short activity bursts (Dixon et al. 2012). The presence of these low frequency events indicates that an active source underlies the Aniakchak Caldera (Dixon, pers. comm., 2013).

Volcanologists predict, through the piecing together of historic geological evidence, that eruptions of the same scale as the 1931 eruption of the Aniakchak Caldera, are to be expected (Neal et al. 2001).

4.7.6 Sources of Expertise

James Dixon, USGS Geophysicist

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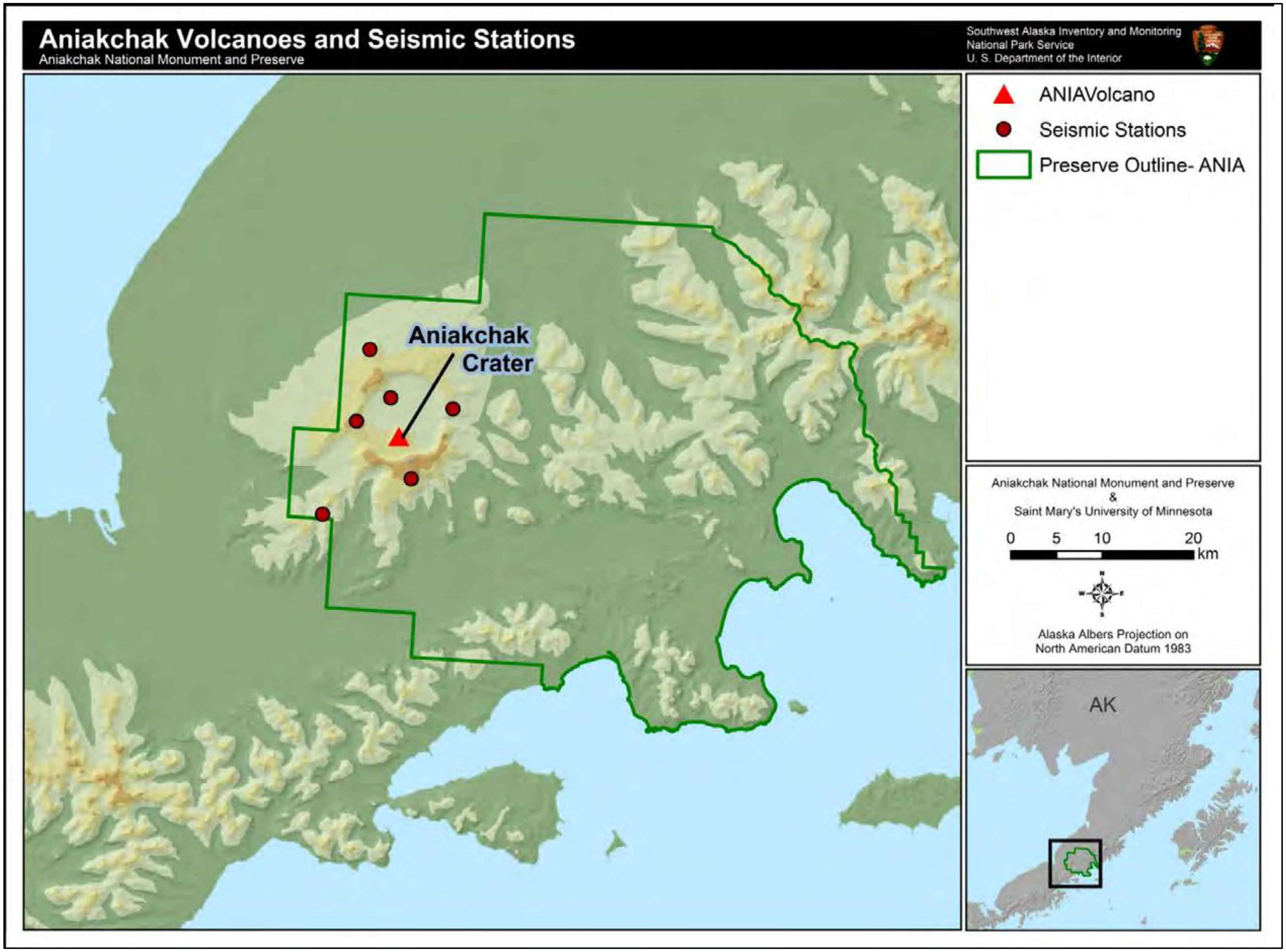

Plate 11. Seismically monitored volcano and seismic stations within ANIA.

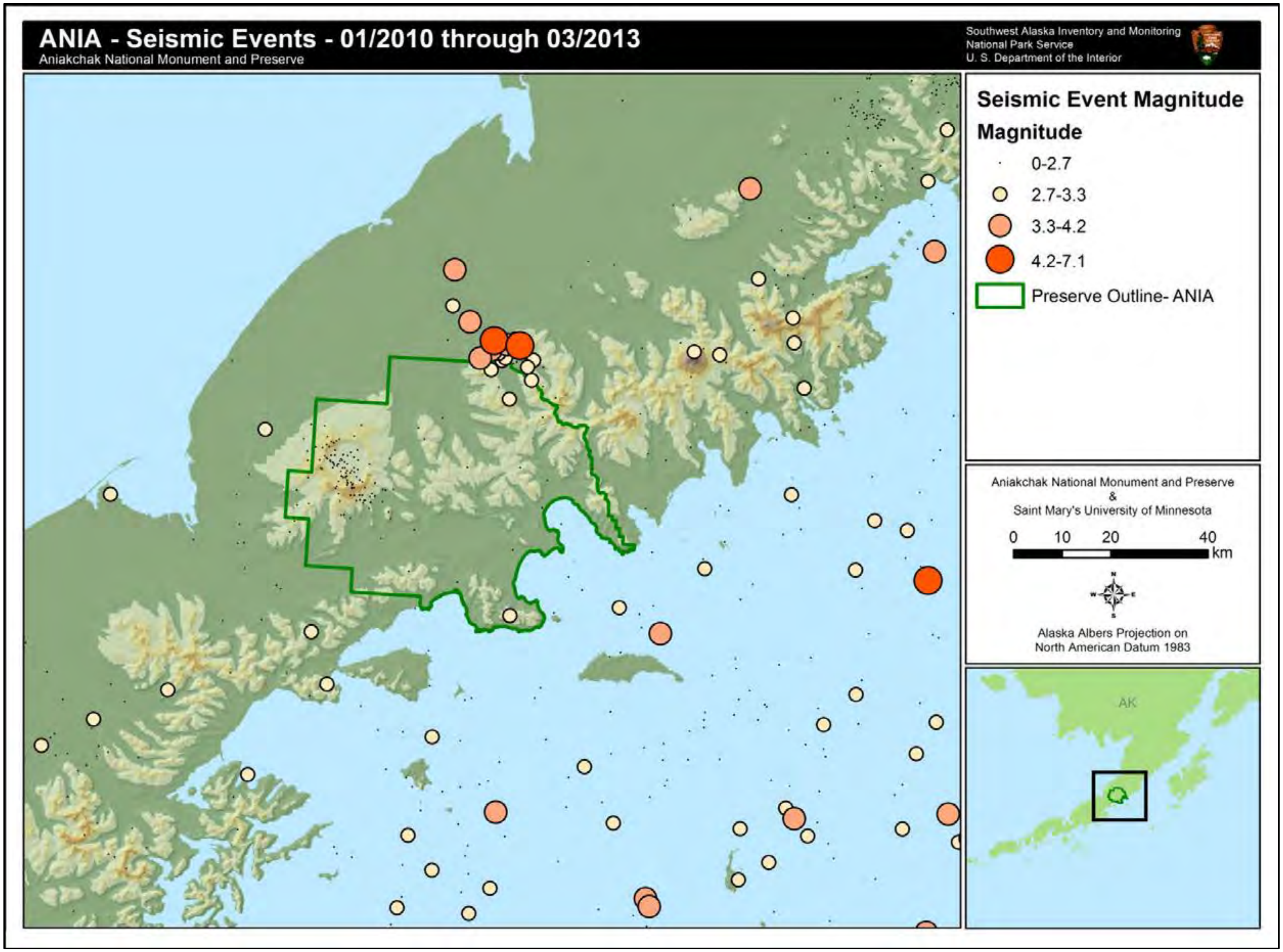

Plate 12. Distribution and magnitudes of recorded seismic events of the KATM region (NCEDC 2013).

4.8 Climate

4.8.1 Description

Climate is widely recognized as one of the most fundamental drivers of ecological condition and ecological change, particularly in Alaska (NPS 2011). As a primary driver of many other ecosystem components (vegetation, wildlife, disturbance regime, etc.), climate also has numerous management consequences and implications. Climate was selected by the SWAN I&M program as a high-priority Vital Sign for southwest Alaska parks (Davey et al. 2007). ANIA's climate is described as "transitional between polar (tundra climate) and maritime (maritime subarctic)" (Lindsay 2013, p. 1). Winter temperatures are cold, while summer temperatures are somewhat moderated by nearby open water (e.g., Bering Sea and Gulf of Alaska) (Lindsay 2013).

The climate of ANIA and southwest Alaska as a whole is influenced by its high latitude, varying topography, and location near the ocean, as well as atmospheric and oceanic circulation patterns (NPS 2011). Two patterns of particular importance are the Aleutian Low and the Pacific Decadal Oscillation (PDO) (Lindsay 2013). The Aleutian Low is a "semi-permanent low pressure center" in the Gulf of Alaska that influences storm tracks and, therefore, variability in precipitation (Lindsay 2013, p. 2; Bennet et al. 2006). The PDO, which is related to sea surface temperatures in the northern Pacific Ocean, affects atmospheric circulation patterns and alternates between positive and negative phases (Wendler and Shulski 2009). A positive phase is associated with a relatively strong low pressure center over the Aleutian Islands, which moves warmer air into the region, particularly during the winter (Wendler and Shulski 2009). Some of the variation in Alaska's climate over time can be explained by major shifts in the PDO which occurred in 1925 (negative to positive), 1947 (positive to negative), and 1977 (negative to positive) (Mantua et al. 1997). Hartmann and Wendler (2005) found that much of the warming that occurred in Alaska during the last half of the twentieth century was influenced by the PDO shift in 1976-77. Temperatures in southwestern Alaska are also influenced by the El Niño Southern Oscillation (ENSO) (Lindsay 2013).

4.8.2 Data and Methods

No weather or climate monitoring stations have ever operated in ANIA (Davey et al. 2007). The nearest available climate data is from two Remote Automated Weather Stations (RAWS) approximately 21 km (13 mi) northeast of the park. One of the stations (Yantarni Bay) was not established until 2010; the other (Mother Goose) operated for several years in the early 2000s and was re-established in 2010. Climate data for these stations were obtained through the Western Regional Climate Center website (WRCC 2013). In the past, climate conditions in the ANIA region were estimated using data from an Automated Weather Observing System (AWOS) monitoring station at Port Heiden, approximately 20 km (12.5 mi) west of the park. Temperature data for this station from 2008-2011 was provided by the NPS.

The NPS also provided GIS climate data for Alaska from the Parameter Regression on Independent Slopes Model (PRISM). PRISM was developed "to address the extreme spatial and elevation gradients exhibited by the climate of the western U.S." (Davey et al. 2007, p. 20). The model is initialized using climatological normals from stations where actual data are available. It incorporates the "scale-dependent effects of topography" into estimates of climate metrics (i.e., temperature and precipitation) and can be useful in remote areas where little or no climate data has been gathered (Davey et al. 2007, p. 20). The available PRISM data provides temperature and precipitation means for the period 1971-2000.

Lindsay (2013) provides weather information for the SWAN region in 2012, comparing it to longer term climate patterns in the area. The status of climate patterns (e.g., PDO, ENSO) and their potential influence on weather variables are also discussed as well. Lindsay (2013) also raises concerns regarding the collection of winter (November - April) precipitation data at RAWS stations. These stations utilize unheated tipping buckets to collect precipitation and are only accurate in measuring liquid precipitation, not snow or snow water equivalent (Lindsay 2013). Sometimes ice or snow that has been stored in the gauge for weeks or even months suddenly melts, resulting in a “delayed” report of precipitation. Buckets can also shake during high winds and cause false precipitation reports. Lindsay (SWAN Physical Scientist, email communication, 28 March 2013) believes that precipitation readings taken when the temperature is below -0.5°C (31.1°F) or when the wind is above 126 km/hr (78 mi/hr) are likely not reliable.

4.8.3 Current Condition and Trend

Temperature

The mean annual temperatures in the ANIA region for the period 1971-2000, according to PRISM data, are presented graphically in Plate 13. It is important to remember that these values are based on modeling rather than actual ground observations. Mean annual temperatures within the park boundary ranged from approximately -3.2°C to 4.4°C.

Monthly mean temperature data for the AWOS station at Port Heiden and for the two RAWS stations near the park are presented in Table 19 - Table 21. An overall mean for each month during the period of data collection is also included. The final column of each table shows the monthly mean temperatures for each location according to 1971-2000 PRISM data (PRISM 2010). Monthly mean temperatures across all stations ranged from -7.5°C at Port Heiden in January to 11.6°C at Yantarni Bay in August (WRCC 2013). The coldest temperature recorded during the period of record was -31.7°C at Mother Goose in January 2012, while the highest temperature (23.3°C) was observed at Yantarni Bay in June 2012. The minimum and maximum temperatures for each monitoring station during the period of record are shown in Table 22.

Table 23. Port Heiden monthly mean temperature (°C) by year and the mean from Oct. 2008-Sept. 2011, according to AWOS data (NCDC 2010, 2013). The final column shows 1971-2000 monthly means according to PRISM data (PRISM 2010).

Month	2007	2008	2009	2010	2011	2012	Mean (2007-12)	1971-2000 Mean
Jan.	-5.1	-9.1	-7.8	-6.2	-3.3	-13.2	-7.5 *	-4
Feb.	-1.1	-9.1	-4.2	-3.9	-3	-1.5	-3.8	-4.6
Mar.	-11.2	-6.1	-5.8	-7	-3.7	-9.5	-7.2 *	-2.3
Apr.	2.6	-1.8	-0.2	-1.4	0.2	0.2	-0.1	0.7
May	4.1	4.1	4.2	3.4	5.6	2.1	3.9 *	5
June	4.5	6.9	8.4	7.5	7.6	5.5	6.7 *	8.6
July	8.5	8.9	11.5	9.6	9.2	8.7	9.4 *	11.1
Aug.	11.5	9.7	10.3	10.4	10.3	10.8	10.5 *	11.7
Sept.	8.1	8.6	8.6	9.4	8.6	7.7	8.5	9.1
Oct.	3.3	1.9	4.8	3.3	4.9	2.9	3.5	3.6
Nov.	0.9	-3.9	-2.8	-0.2	-2.5	-3.4	-2.0 *	-0.4
Dec.	-1.7	-1.9	-0.4	-7.6	-1.3	-7.3	-3.4	-2.6

* Indicates months where recent AWOS data means are 1° colder than PRISM means (also highlighted in dark grey).

Table 24. Yantarni Bay monthly mean temperature (°C) by year and the mean over all years of available RAWS data (WRCC 2013).

Month	2010	2011	2012	2013	Mean (2010-13)	1971-2000 Mean
Jan.	--	0.4	-9.3	0.2	-2.9	-2.0
Feb.	--	-1.8	-1.0	-0.6	-1.1 [1]	-2.3
Mar.	--	-0.3	-5.9	--	-3.1 *	-0.6
Apr.	--	1.3	2.9	--	2.2	2.7
May	--	5.9	4.8	--	5.3	6.3
June	--	8.3	9.9	--	9.1	9.6
July	--	10.3	10.4	--	10.3 *	12.0
Aug.	11.8	--	11.5	--	11.6	12.4
Sept.	9.9	7.2	8.1	--	8.4 *	9.9
Oct.	4.2	5.2	3.8	--	4.4	4.9
Nov.	0.7	-2.2	-2.5	--	-1.3 *	1.2
Dec.	-4.9	-2.2	-4.2	--	-3.8 *	-1.3

* Indicates months where recent AWOS data means are 1° colder than PRISM means (also highlighted in dark grey).

[1] Indicates months where recent AWOS data means are 1° warmer than PRISM means (also highlighted in light grey).

Table 25. Mother Goose monthly mean temperature (°C) by year and the mean, 2010-2013 (WRCC 2013).

Month	2010	2011	2012	2013	Mean (2010-13)	1971-2000 Mean
Jan.	--	-2.3	-16.8	-1.1	-6.7	-7.2
Feb.	--	-3.9	-1.7	-2.2	-2.6 [1]	-6.9
Mar.	--	-3.8	-8.5	--	-6.2 *	-3.6
Apr.	--	0.2	1.2	--	0.7	0.3
May	--	6.1	3.8	--	4.9 *	6.0
June	--	7.8	7.7	--	7. 7 *	9.3
July	10.5	--	10.1	--	10.3 *	12.0
Aug.	11.2	--	11.4	--	11.3	12.2
Sept.	9.7	6.4	8.0	--	8.1	9.1
Oct.	2.9	4.8	2.7	--	3.5 [1]	2.1
Nov.	-1.0	-4.0	-6.8	--	-3.9 *	-1.9
Dec.	-10.1	-3.3	-7.6	--	-7.0 *	-5.9

* Indicates months where recent AWOS data means are 1° colder than PRISM means (also highlighted in dark grey).

[1] Indicates months where recent AWOS data means are 1° warmer than PRISM means (also highlighted in light grey).

Table 26. Minimum and maximum temperatures (°C) recorded at each of the climate monitoring stations near ANIA, along with the month in which they occurred (NCDC 2010, WRCC 2013).

	Port Heiden	Yantarni Bay	Mother Goose
Minimum	-28.9 (Jan 2009)	-19.4 (Feb 2012)	-31.66 (Jan 2012)
Maximum	22.2 (July 2009)	23.3 (June 2012)	22.2 (June & Aug 2012)

A comparison of recent RAWS and AWOS data from the three stations near ANIA to the modeled temperature means from PRISM (1971-2000) shows that monthly means during the RAWS/AWOS period of record were often colder than PRISM means (see Table 19 - Table 21). However, it is unclear if this is due to actual change in temperatures over time or simply because of differences in methodology (i.e., RAWS/AWOS data are actual on-the-ground measurements while PRISM data are based on modeling). The amount of data used in calculating means also has an influence; PRISM means are for a 30-year period while RAWS/AWOS means in this document are based on just 3-6 years of data.

According to Lindsay (2011), the SWAN region in 2010 was warmer and slightly drier in comparison to climatological normals (1971-2000), perhaps due to El Nino conditions. However, the region was then colder than average in 2012. Temperatures at weather stations throughout the region were 1.5-2.2°C cooler than the most recent 30-year climatological normals (1981-2010) (Lindsay 2013). These cooler conditions may be related to a negative phase in the PDO, causing colder sea surface temperatures in the Bering Sea and Gulf of Alaska, as well as a weak La Niña event (part of the ENSO circulation pattern) in early 2012 (JISAO 2013, NWS Climate Prediction Center 2013). Evidence suggests that temperatures in Alaska are typically lower than normal, particularly in the winter, during La Niña events (Papineau 2001). Monthly minimum, maximum, and mean temperatures at the Port Heiden AWOS station in 2010 and 2012 are presented in Table 23.

Table 27. Mean minimum, mean maximum, and overall mean monthly temperatures (°C) at Port Heiden during the 2010 and 2012 hydrologic years (Oct.-Sept.) (Lindsay 2011, 2013).

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Year
2010													
Min	2.1	-5.8	-1.9	-9.0	-6.4	-10.5	-4.8	1.0	4.3	7.4	8.1	6.2	-0.7
Max	7.4	-0.1	2.7	-3.5	-2.2	-3.6	1.6	6.4	11.0	12.3	13.1	12.4	4.8
Mean	4.9	-2.8	0.2	-6.1	-3.9	-6.9	-1.4	0.7	7.6	9.6	10.4	9.4	2.1
2012													
Min	2.0	-5.8	-4.7	-17.2	-4.3	-12.1	-2.6	-0.5	2.8	6.4	8.2	4.6	-1.9
Max	7.4	0.8	0.5	-9.2	0.9	-6.6	3.7	4.7	8.5	11.5	14.1	10.3	3.9
Mean	4.8	-2.5	-1.6	-13.2	-1.9	-9.2	0.3	2.2	5.6	8.8	10.8	7.7	1.0

Precipitation

Mean annual precipitation in the ANIA region for the period 1971-2000, according to PRISM data, are presented graphically in Plate 14. Again, it should be noted that these values are based on modeling rather than actual ground observations. Mean annual precipitation within the park boundary ranged from 475 mm (19 in) to 2,420 mm (95 in) (PRISM 2010).

Monthly precipitation data for each year available, as well as an overall mean, are presented for the RAWS stations in Table 24 - Table 25 (the AWOS station at Port Heiden did not collect precipitation data). The final column of each table shows the monthly mean precipitation for these locations according to 1971-2000 PRISM data (PRISM 2010). Yantarni Bay was generally wetter than Mother Goose, averaging nearly 2,000 mm (78.7 in) of precipitation a year during the period of record, compared to Mother Goose's approximately 1,200 mm (47.2 in) (WRCC 2013). The wettest monthly measurement on record was January 2013, when Yantarni Bay received 1,514 mm (59.6 in) of precipitation. However, this reading may not be accurate, due to the issues with measuring winter precipitation discussed earlier in the data and methods section.

Substantial differences exist between the monthly precipitation means from recent RAWS data and modeled means from PRISM. As with temperature means, it is unclear if this is due to actual changes in precipitation over time or differences in methodology (i.e., actual measurements vs. modeling). It is also important to keep in mind that winter precipitation data from RAWS stations may also be inaccurate, due to their ability to measure only liquids (Lindsay 2013).

Table 28. Yantarni Bay monthly precipitation (mm) by year and the mean over all years of available RAWS data (WRCC 2013). The final column shows 1971-2000 monthly precipitation according to PRISM data (PRISM 2010). Annual totals were not calculated for years with missing monthly data.

Month	2010	2011	2012	2013	Mean (2010-13)	1971-2000 Mean
Jan.	--	266.7	51.6	1,514.0	610.8	130.9
Feb.	--	121.7	162.3	172.0	152.0	102.1
Mar.	--	30.7	27.4	--	29.0	98.9
Apr.	--	218.4	120.9	--	169.7	80.4
May	--	300.2	122.4	--	211.3	100.6
June	--	209.0	33.3	--	121.2	65.7
July	--	6.4	118.6	--	62.5	72.5
Aug.	9.4	--	91.2	--	50.3	101.5
Sept.	222.5	33.8	202.2	--	152.8	155.8
Oct.	135.9	205.7	92.5	--	144.7	142.1
Nov.	90.4	113.8	107.9	--	104.0	169.6
Dec.	52.8	240.5	183.1	--	158.8	142.4
Annual total	--	--	1,313.4	--	1,967.1	1,362.6

Table 29. Mother Goose monthly precipitation (mm) by year and the mean over all years of available RAWS data (WRCC 2013). The final column shows 1971-2000 monthly precipitation according to PRISM data (PRISM 2010). Annual totals were not calculated for years with missing monthly data.

Month	2010	2011	2012	2013	Mean (2010-13)	1971-2000 Mean
Jan.	--	223.3	37.3	538	266.2	57.3
Feb.	--	215.6	11.9	58.7	95.4	38.8
Mar.	--	36.8	0	--	18.4	44.7
Apr.	--	462.0	0	--	231	40.2
May	--	163.1	0	--	81.6	47.8
June	--	32.3	0	--	16.1	52.5
July	2.3	--	69.9	--	36.1	57.6
Aug.	0.5	--	65.5	--	33.0	68.9
Sept.	60.5	189.7	121.4	--	123.8	99.5
Oct.	136.1	139.4	19.1	--	98.2	93.4
Nov.	48.8	101.1	26.9	--	58.9	70.3
Dec.	50.6	193.0	99.6	--	114.4	64.4
Annual total	--	--	414.3	--	1,173.1	735.5

During the 2010 hydrologic year (Oct. 2009-Sept. 2010), the SWAN region was slightly drier than normal, receiving 75-97% of the typical annual precipitation (Lindsay 2011). In the 2012 hydrologic year (Oct. 2011-Sept. 2012), the southern part of the SWAN region experienced above average precipitation, with 126-142% of typical annual precipitation (Lindsay 2013). According to the Alaska Climate Research Center (ACRC 2012), much of southern Alaska experienced record-high snowfall during the winter of 2011-2012.

Threats and Stressor Factors

There is a scientific consensus that human activities, particularly those that produce greenhouse gasses (e.g., fossil fuel burning), have contributed to a general warming trend in global climate (IPCC 2010). Climate models predict that change will be greatest at higher latitudes, like in Alaska (NPS 2011). In the ANIA region, temperatures are projected to increase approximately 1°F (about 0.6°C) per decade over the next century (SNAP et al. 2009). Winter temperatures may change more dramatically, increasing by 10°F (about 6°C) by 2080 (SNAP et al. 2009). Precipitation is predicted to increase, yet increased evapotranspiration due to warmer temperatures and a longer growing season will likely lead to an overall drier climate (SNAP et al. 2009). Potential impacts of these changes in southwest Alaska parks include reduced snowpack and a longer growing season, which could affect plant phenology and productivity, wildlife distribution and mating cycles, water availability, and recreational and subsistence activities (e.g., hunting, fishing) (SNAP et al. 2009, NPS 2011).

Data Needs/Gaps

No climate data have been collected within ANIA boundaries. Establishing a climate monitoring station within the park would provide data that are more reliable and accurate, as opposed to relying on data from nearby monitoring stations that may not reflect the specific climate within the park. However, if this is not feasible, it will be important to continue gathering data from the two RAWS stations just northeast of the park. This information will help identify the range of climate variability in the area and if any changes are occurring over time, perhaps in connection with global climate change. Further studies may be needed explore how changes in climate will impact other park resources (e.g., vegetation and wildlife, water regime, etc.).

Overall Condition

Due to a lack of climate data collected within ANIA boundaries it is difficult to assess the current condition of climate in the park. Data from just outside the park and the greater region suggest that temperatures have been slightly cooler over the last decade in comparison to 30-year normals, perhaps due to a negative phase in the PDO. However, climate models predict that Alaska will become warmer and drier over the next century, which is a cause for concern regarding the effects on resources in the park.

4.8.4 Sources of Expertise

Chuck Lindsay, SWAN Physical Scientist

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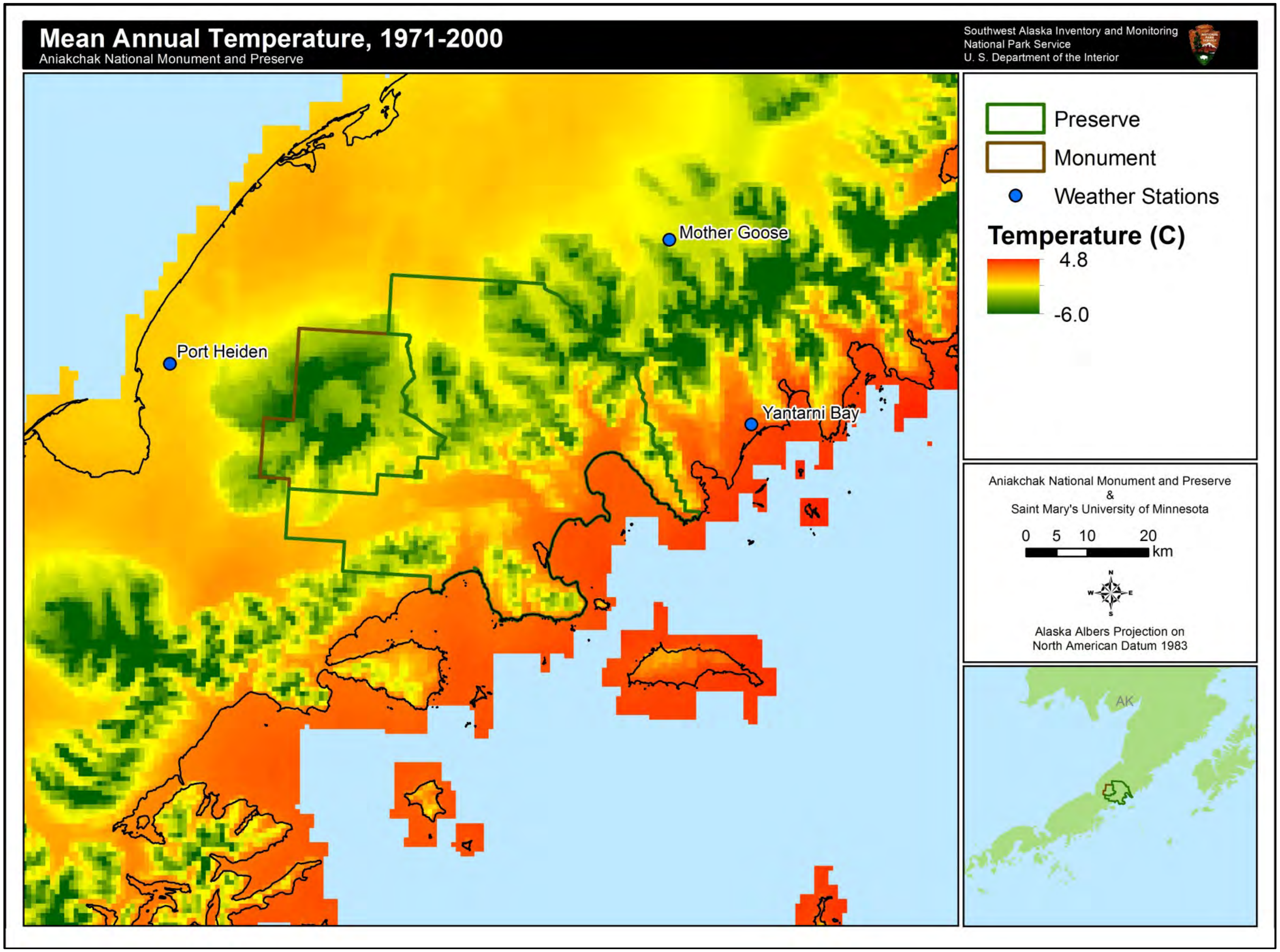

Plate 13. Mean annual temperatures in the ANIA region, 1971-2000, according to PRISM data (PRISM 2010).

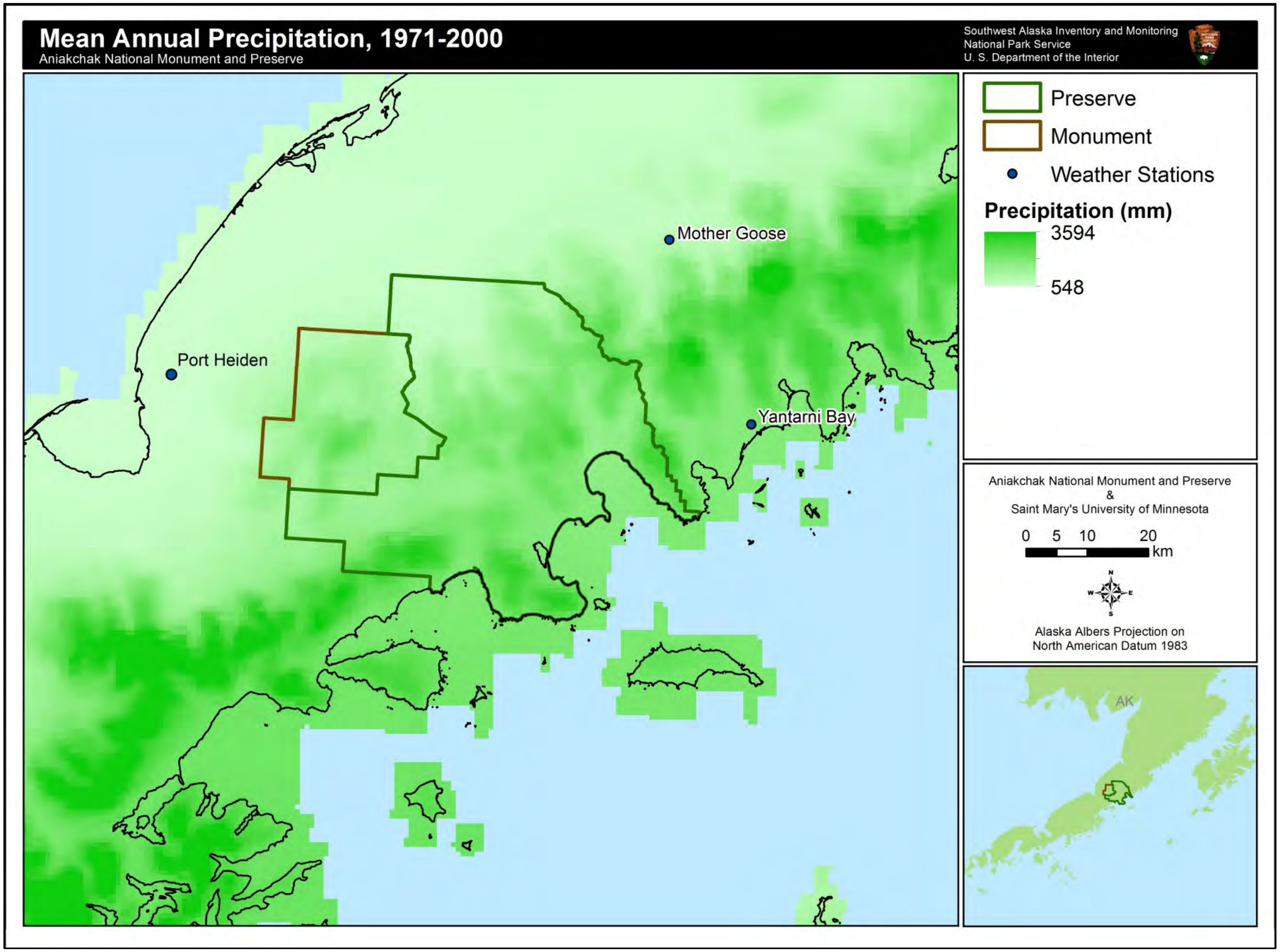

Plate 14. Mean annual precipitation in the ANIA region, 1971-2000, according to PRISM data (PRISM 2010).

4.9 Human Activity

4.9.1 Description

ANIA is one of the least visited national parks. NPS (2013) reports that on average, less than 500 individuals visited ANIA each year since 1989. In the last five years, the average annual visitation was less than 40 individuals (NPS 2013). Low visitation is primarily due to the remoteness of the park. Access to the park is restricted to aircraft or boat, as there are no roads within park boundaries. In addition, NPS does not maintain facilities or trails within the park. Whitewater rafting from the Aniakchak Caldera to the ocean is one of the most common activities within the park (Photo 15).

Photo 15. Rafting the Aniakchak River (NPS photo by Troy Hamon).

4.9.2 Specific Analysis

For this component, available datasets were used to provide an overview of visitor use in the park. The Commercial Use Authorization (CUA) database was the primary source of information for this analysis (NPS 2012). In addition, data available online via the NPS Integrated Resource Management Application (IRMA) (NPS 2013) provided general summaries of park usage.

4.9.3 Data and Methods

Queries were developed to extract data from the CUA database to better understand location of human activities within ANIA. Queries were dynamic when possible, to enable future use. Queried data were linked to ArcGIS via a SQL Server connection. Data were joined to Visitor Use Location GIS data received from SWAN. Using linked data, appropriate maps were developed to display visitor use patterns in the park.

4.9.4 Current Condition and Trend

Yearly Visitation by Park Location

Visitation in ANIA is extremely limited (Table 26); the park consistently ranks among the five least visited sites out of more than 350 NPS units (NPS 2013). To date, NPS (2013) has recorded a maximum of 1,638 visitors to ANIA during any year; this occurred during 1992. During multiple years, NPS (2013) indicates that no visitors have utilized the park. From 2006-2012, fewer than 100 visitors used park resources each year.

SWAN NPS visitor use data include four distinct visitor use areas in ANIA where the CUA database identifies visitor use during 2005-2012: Amber Bay, Aniakchak Bay, Aniakchak Caldera, and Cinder River (Plate 15). According to the CUA database, the Aniakchak Caldera received the most visitor days from 2005-2012, followed by Amber Bay and Aniakchak Bay (Table 27, Plate 16). Of identified activities in CUA records, sport fishing was the activity that visitors to the park engaged in most, with 95 visitor days from 2005-2012. Unspecified activities was the second most prevalent category of visitor use according to the CUA database from 2005-2012 (Table 28).

Table 30. ANIA yearly visitation, 1989-2011 (NPS 2013).

Year	Number of Visitors
1989	853
1990	967
1991	1,469
1992	1,638
1993	1,593
1994	1,193
1995	0
1996	0
1997	0
1998	209
1999	377
2000	251
2001	206
2002	241
2003	154
2004	285
2005	285
2006	60
2007	26
2008	10
2009	14
2010	62
2011	57
2012	19

Table 31. Yearly visitor days, by park location, from SWAN CUA database (NPS 2012).

Location Name	2012	2011	2010	2009	2008	2007	2006	2005
Amber Bay	-	-	-	4	22	39	8	-
Aniakchak Bay	-	-	-	46	-	2	15	-
Aniakchak Caldera	-	-	22	53	4	7	14	146
Cinder River	-	-	-	-	-	-	7	-
Meshik River	-	-	-	-	9	-	-	-
Other	-	-	-	18	-	-	5	-

Table 32. Total visitor days, by activity, from SWAN CUA database, 2005-2012 (NPS 2012).

Location Name	Not Specified	Sport Fishing	Photography	Bear Viewing	Boating Trip	Backpacking/ Camping	Air Taxi
Amber Bay	-	47	-	22	-	-	2
Aniakchak Bay	12	21	-	-	-	8	19
Aniakchak Caldera	48	20	4	-	-	12	40
Cinder River	-	7	-	-	-	-	-
Other	-	-	-	5	12	-	3

Regarding seasonality of park visitation, the months of June through September are the only months with visitation on record, according to the CUA database. Of those, September is the month with the highest visitation, totaling 165 visitor days in the park from 2005-2012 (NPS 2012).

Table 33. ANIA visitor days by month from SWAN CUA Database, 2005-2012 (NPS 2012).

Location Name	June	July	August	September
Amber Bay	-	-	-	73
Aniakchak Bay	12	5	25	21
Aniakchak Caldera	18	85	95	48
Cinder River	-	4	-	3
Meshik River	-	-	-	9
Other	12	-	-	11
Total	**42**	**94**	**120**	**165**

Threats and Stressor Factors

Threats and stressors do not apply to this topic.

Data Needs/Gaps

Data are currently sufficient for this component.

Overall Condition

Overall, visitation and human activity are minimal in the park.

4.9.5 Sources of Expertise

Troy Hamon, KATM/ANIA Chief of Resources

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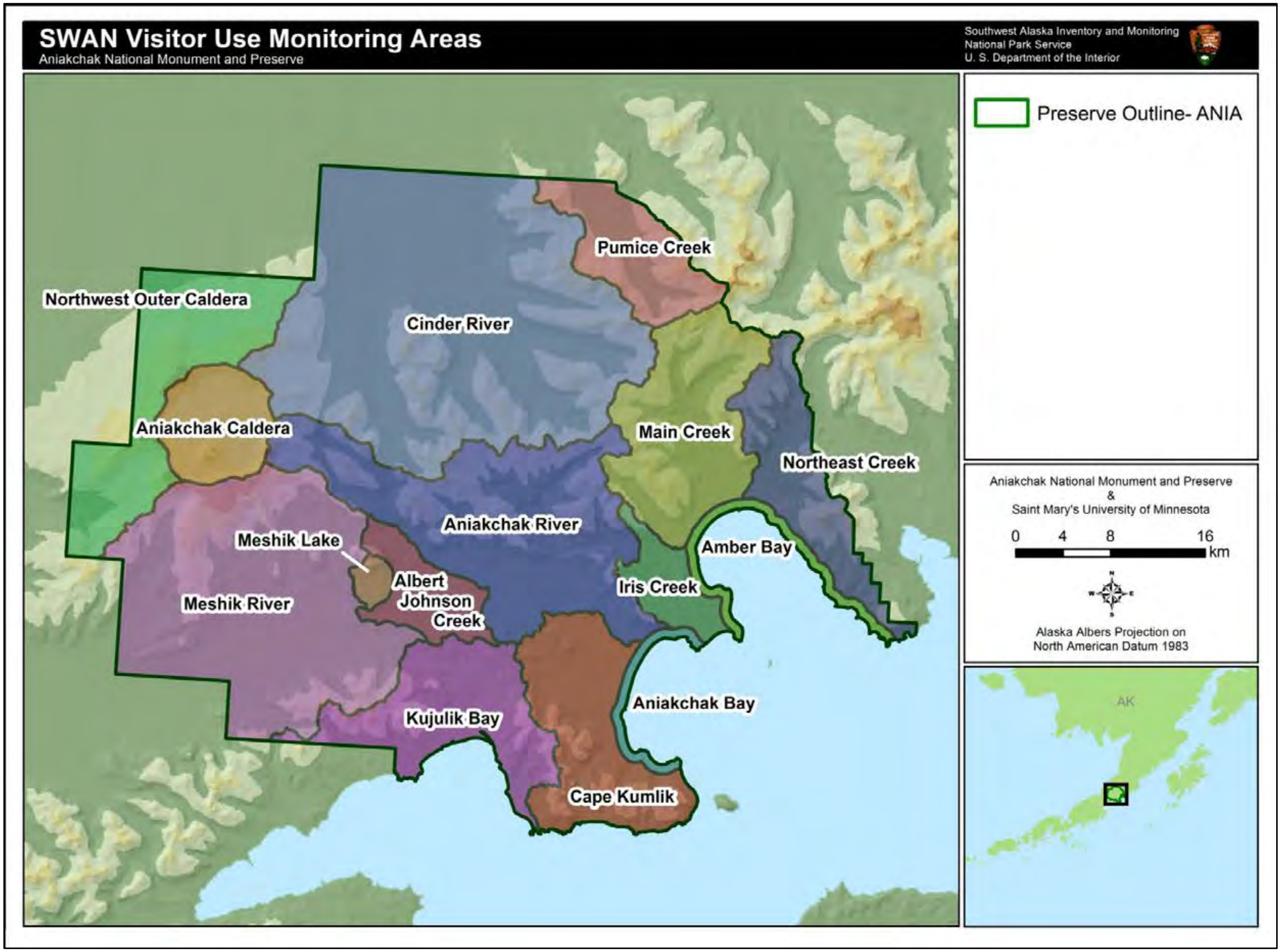

Plate 15. SWAN visitor use monitoring areas.

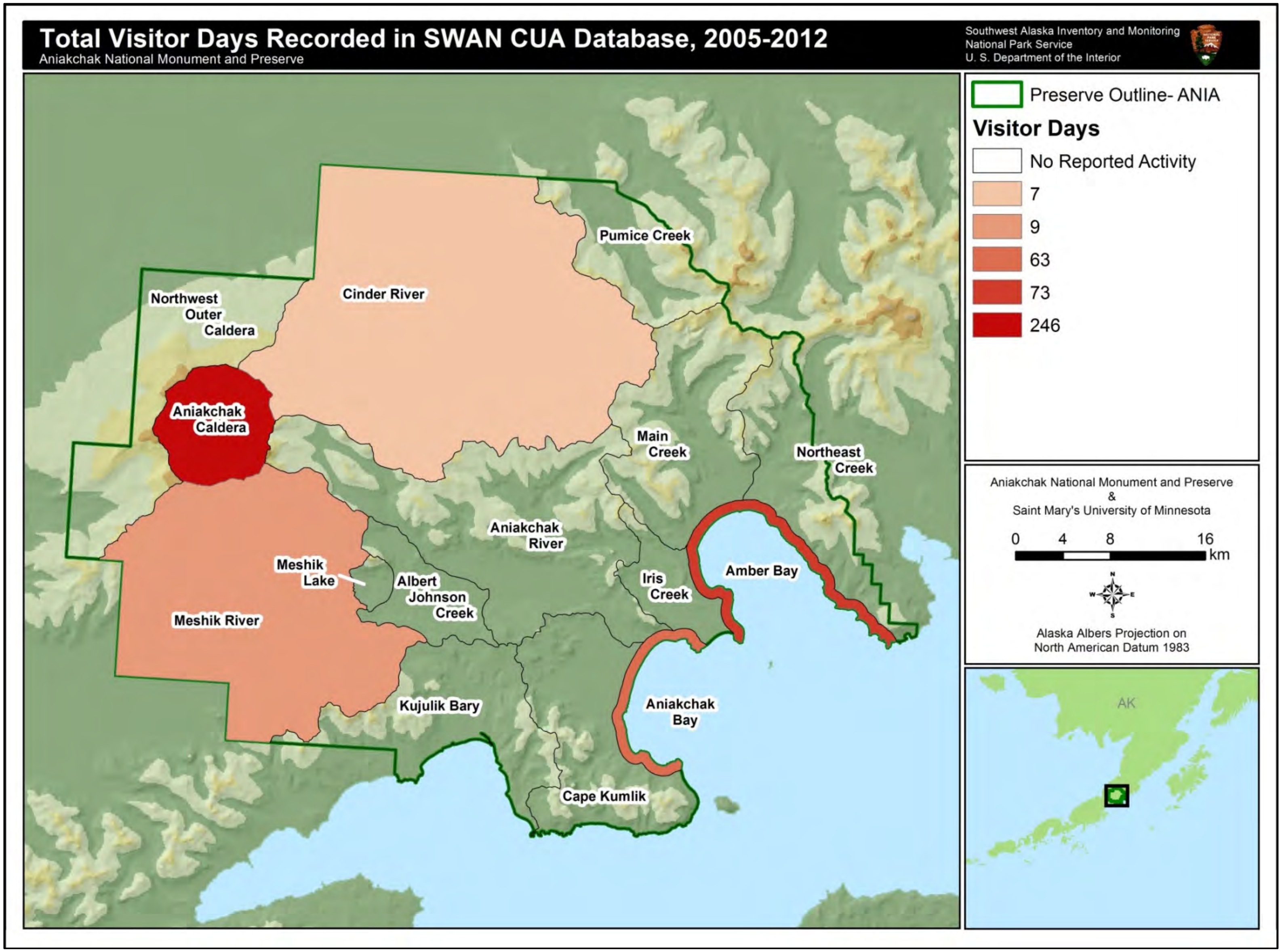

Plate 16. Total visitor days by park location from SWAN CUA Database, 2005-2012 (NPS 2012).

4.10 Glaciers

4.10.1 Description

Glaciers are large persistent bodies of ice that flow under the influence of gravity (Marshak 2005). The formation of a glacier requires three conditions: abundant snowfall, cool summer temperatures, and the gravitational flow of ice (NPS 2010). Glaciers occur in ANIA but are not considered to be a significant land cover type in the park (Giffen and Lindsay 2011). Giffen and Lindsay (2011, p.8) describe the glaciers in ANIA to be "small hanging/cirque glaciers of very limited extent that occur inside the Aniakchak crater on the very steep north aspect of the southern portion of the crater" (Photo 16, Plate 17). Arendt et al. (2012) confirms that the ice fields in the Aniakchak Caldera are the only permanent ice fields found in ANIA.

Photo 16. The Aniakchak Caldera area in ANIA (NPS photo).

Glaciation begins with the accumulation of fresh, loosely packed snow containing 90% air, due to the space created by its hexagonal crystals (Marshak 2005). As new layers of snow accumulate on top of the old snow, pressure increases from the weight, squeezing out air pockets and, over time, transforming the snow into a packed granular material called firn, which contains only 25% air (Marshak 2005). As melting occurs, water recrystallizes in the spaces between grains until the firn is transformed into a solid mass of glacial ice containing only 20% air (Marshak 2005).

Glacier mass balance studies determine the difference between the annual accumulation (all processes that add to the mass, i.e., snowfall) and ablation (all processes that remove mass, i.e., sublimation, melting, and calving) of a glacier during a mass balance year (Veins 1995, NPS 2010, Cogley et al. 2011). Mass balance studies can provide information on the stability of glaciers, runoff predictions, and a measurement of climatic variation and trends (Muirhead 1978). A mass balance year is 12 months long, beginning during the accumulation season and lasting until the end of the ablation season (Cogley et al. 2011). A mass balance year is dependent upon elevation and some glacial areas in southwest Alaska can experience ablation until late November and accumulation into late August; for simplicity a mass balance year is often tied into the water year (Lindsay, pers. comm., 2012). If the rate of accumulation is higher than that of ablation, the glacier will thicken, advance, or both. However, if the rate of ablation is higher than that of accumulation, the glacier will retreat (Marshak 2005). The accumulation zone is the area on a glacier where more mass is gained than lost, whereas the area where more mass is lost than gained is known as the ablation zone (Figure 1, Cogley et al. 2011). The accumulation area ratio (AAR) represents the ratio of the accumulation zone to the area of the glacier at the end of a mass balance year (Cogley et al. 2011).

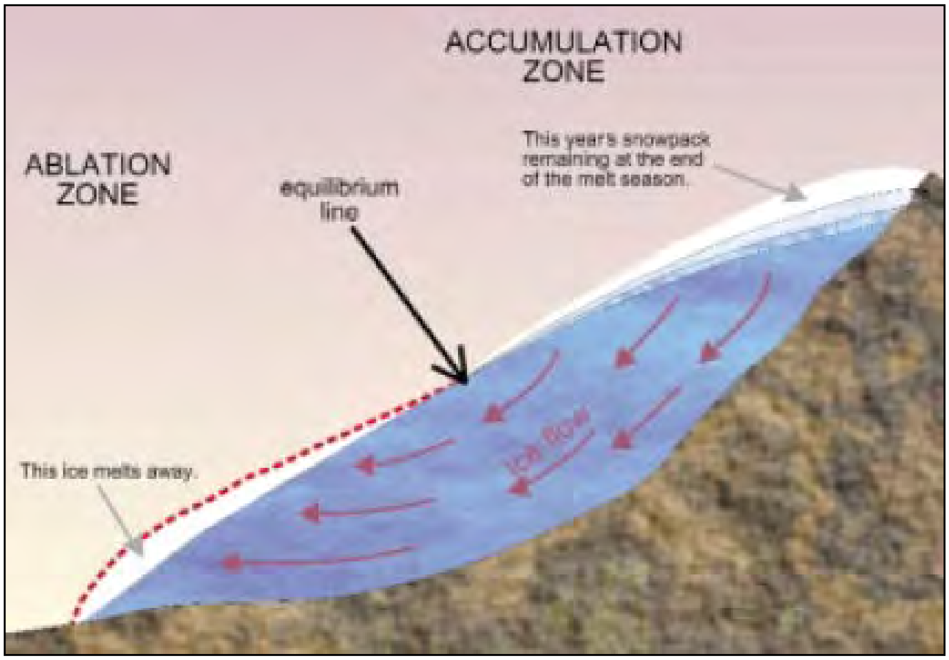

Figure 1. Illustration of a glacier showing the accumulation zone, ablation zone, and equilibrium line (Valentine et al. 2004).

Glacier firn lines define the boundary between the melting ablation zone and the snow-covered accumulation zone. Late summer is the end of the ablation season, and during this time, the late summer firn line reaches its highest elevation, called the annual firn line. The annual firn line is closely related to the equilibrium line, which separates the accumulation zone from the ablation zone (Figure 1, Muirhead 1978). The equilibrium line altitude (ELA) is the spatially averaged altitude of the equilibrium line at the end of a mass balance year (Cogley et al. 2011). The position of the firn line varies depending on the season. During winter, snow covers the entire glacier. As spring thaw occurs, the firn line moves up the glacier. The amount of accumulation, combined with the ablation rate, determine how far the firn line will move up the glacier before the cycle repeats (Muirhead 1978).

4.10.2 Measures

- Area
- Rate of terminus movement

4.10.3 Reference Conditions/Values

IKONOS imagery taken in 2005 provides a reference of the glacial areas in ANIA (Robertson 2011).

4.10.4 Data and Methods

Giffen and Lindsay (2011) provide a general description of the glacial area in ANIA. IKONOS imagery was taken over ANIA in 2005 in an effort to define the glacial areas in the park (Giffen and Lindsay 2011).

Loso et al. (2012) provides the first quantitative data for glaciers in ANIA. Interpolation of historic map data from 1957 to 1962 provides a benchmark for comparison to the glacial extent data collected in fulfillment of this publication.

4.10.5 Current Condition and Trend

Area

General glacial areas in ANIA were defined using IKONOS imagery in 2005 (Giffen and Lindsay 2011). Personal observation from area experts estimate that glacial extent in ANIA does not exceed 2 km^2 (0.8 mi^2) (Bruce Giffen, NPS Alaska Region Geologist, pers. comm., 2012). According to Giffen and Lindsay (2011), the only know glaciated area was inside the caldera within the monument portion of ANIA. Loso et al. (2012) report the glacial coverage in ANIA to be minimal as well, covering approximately 4.4 km^2 (1.7 mi^2) (Table 30). Glacial areas continue to be small and located on shaded, north-facing slopes of the caldera (Loso et al. 2012). The glaciers within the caldera grew or were not mapped originally, based on the most resent glacial extent report for ANIA. Very small glacial areas located outside the caldera on the eastern side of ANIA retreated since the 1950s (Loso et al. 2012). Imagery from Loso et al. (2012) indicates that no tidewater glaciers are present in ANIA and most of the glacial area in ANIA is comprised of a single 3-km^2 glacier.

Table 34. Extent of glaciers located in ANIA (Loso et al. 2012).

Time Period	Number of Glaciers	Total Glacier Area (km^2)	Estimated Volume* (km^3)
Historic Map Date (1957-1962)	29	4.1	0.5
Modern (post-2000)	19	4.4	1.1
Absolute Change	-10	0.3	0.5
Percent Change	-34%	8%	106%

* Volumes and volume changes are preliminary and subject to change. They are derived from area/volume scaling (Bahr et al. 1997) using coefficient/exponent values of 0.2055/1.375 from Radic and Hock (2010).

Glacial recession in ANIA and other SWAN parks on the Southwest Alaskan Peninsula has been observed in recent glacial extent reports. Above average yearly temperatures and the predictions that these average temperatures will continue to increase in the SWAN parks region is a threat to the longevity of the small glaciated areas in ANIA.

Rate of Terminus Movement

Study of the rate of terminus movement defines the behavior of the glaciers in a particular region. Terminus movement data help quantitatively define the implications of climate change on the glaciers of a region. No data regarding rate of terminus movement are available for glaciers in ANIA.

Threats and Stressor Factors

Climate Change

Climate is one of the most important factors influencing ecosystems. In Alaska, climate is constantly fluctuating on multiple temporal scales, including several natural cycles. One climate fluctuation of particular importance in Alaska is the Pacific Decadal Oscillation (PDO) (Lindsay 2011). Mantua et al. (1997) formally identified this pattern of climate variability in a study relating climate oscillation to salmon production. The PDO, which is related to sea surface temperatures in the northern Pacific Ocean, affects atmospheric circulation patterns and alternates between positive and negative phases (Wendler and Shulski 2009). A positive phase is associated with a relatively strong low pressure center over the Aleutian Islands, which moves warmer air into the state, particularly during the winter (Wendler and Shulski 2009). Some of the variation in Alaska's climate over time can be explained by major shifts in the PDO which occurred in 1925 (negative to positive), 1947 (positive to negative), and 1977 (negative to positive) (Mantua et al. 1997). Hartmann and Wendler (2005) found that much of the warming that occurred in Alaska during the last half of the twentieth century was likely due to the PDO shift in 1976-77.

Over the time period of 1949 to 2008, an increase of summer and winter temperatures was reported from two different long-term climate stations located in SWAN park regions (Lindsay 2011). The mean annual temperature over this time period has increased by 2.1°C (3.8°F) in King Salmon, Alaska and 2.2°C (4.0°F) in Homer, Alaska (Lindsay 2011). The SWAN park region average annual temperatures are predicted to continue increasing by about 0.56°C (1.0°F) per decade (SNAP 2008).

Data Needs/Gaps

Glacier mapping is scheduled to be repeated every 10 years in other SWAN parks on the Southwest Alaskan Peninsula to monitor the glacial extent of the region (Arendt et al. 2012). Arendt et al. (2012) did not visit the glaciers of ANIA during the previous status and trend assessment of Alaska National Park Glaciers; therefore, ANIA glaciers were not studied until the most recent publication from Loso et al. (2012).

Overall Condition

Given that minimal quantitative data exist regarding the glaciers of ANIA, the condition of this component cannot be assessed at this time. An increase in average yearly temperature has been identified and is predicted to continue in the SWAN parks region. Since no previous quantitative data exist for the glaciers in ANIA, the effects of regional temperature increases cannot be calculated. Trends identified by Loso et al. 2012 indicate that the glaciers located on the north-facing slopes of the caldera have shown advance since the historic mapping period while glaciers located outside the caldera of ANIA have retreated during that time.

4.10.6 Sources of Expertise

Bruce Giffen, NPS Alaska Regional Office Geologist

Chuck Lindsay, NPS Physical Science Technician

4.10.7 Literature Cited

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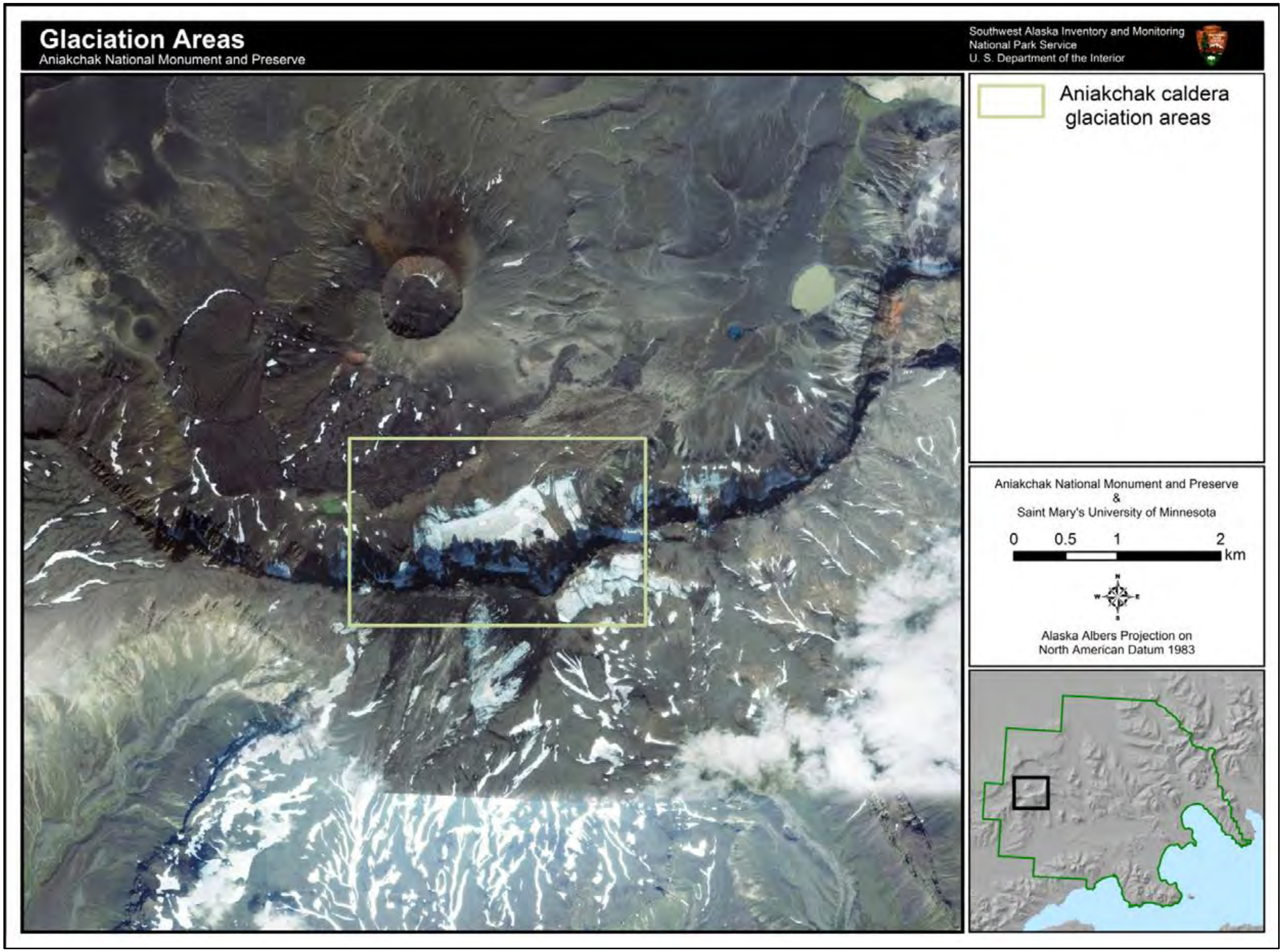

Plate 17. Glaciated areas of the Aniakchak Caldera in ANIA.

4.11 Water Quality

4.11.1 Description

Aquatic systems within SWAN units are remote and pristine; this results in an opportunity for researchers to examine the effects of man-made disturbances, namely climate change and atmospheric pollutants, on intact systems. Currently, water quality data for SWAN units such as ANIA are minimal, but a monitoring plan exists. Specifically, SWAN intends to examine lake water quality parameters (Photo 17), both physical and chemical, along with data regarding other Vital Signs (e.g., surface hydrology, lake ice phenology, and glacial extent) to develop a more complete understanding of watershed dynamics (NPS 2012).

Photo 17. Water quality data collection in an Alaskan water body (NPS photo).

Water quality analysis of physical and chemical characteristics can be important in understanding the aquatic community of a water body (NPS 2012). Researchers may use water quality analysis to explain the absence or extirpation of fish communities in habitats that appear suitable to sustain productive fish communities. Many ANIA fisheries investigations involved water quality data collection as well. Most water quality data for ANIA come from sampling efforts at Surprise Lake, and the Meshik Lake/Meshik River Drainages. However, the data pool for these areas is sparse and water quality sampling has not been conducted in most of the drainages in ANIA. Surprise Lake, located in the Aniakchak Caldera, is hydrothermally active, a characteristic also shared by several of its tributaries. The unique nature of the Surprise Lake region has contributed to more frequent water quality investigations in this area than in other ANIA water bodies.

Prior to analysis of this component, SWAN aquatic ecologist Claudette Moore (pers. comm. 2012) suggested that gathering existing data sources and producing data tables for future use was the most useful exercise for the NRCA. Through data and literature searches, past water quality reports for ANIA were collected and data were input into tables according to guidance by NPS. Within this component section, a summary of data sources and tables are provided for the reader. Because recently collected data are minimal, an assessment of condition is not provided for this component.

4.11.2 Measures

This assessment does not focus on specific metrics for assessing water quality. Rather, literature sources for ANIA that include water quality parameters are summarized individually to provide the reader with a history of water quality data collection in the park. These results are presented in the Data and Methods section.

4.11.3 Data and Methods

Bennett (2004) collected baseline information regarding physical and chemical water quality characteristics in ANIA as part of an initiative by the NPS I&M Vital Signs program to collect data in areas that have been largely unstudied. Water quality analyses were performed on samples from the following areas during a fisheries investigation to help explain the lack of fish production in seemingly suitable habitat: Surprise Lake and Aniakchak River and major tributaries (29 May 2003-13 June 2003); Meshik River, Albert Johnson Creek Headwaters, and Meshik Lake (16 June 2003-24 June 2003); and coastal streams and the lower Aniakchak River (12 July 2003-21 July 2003). Bennett (2004) presents tables and figures for several parameters including temperature, dissolved oxygen, specific conductance, pH, alkalinity, nutrients, chlorophyll, major ions and trace elements, discharge, and turbidity; parameters were sampled using surface waters and a YSI 6600 multi-parameter sonde unit. Discharge and flow measurements were taken with a Marsh McBirney Flo-Mate 2000. Parameters for lab analysis included total suspended solids, total dissolved solids, major ions, nutrients, alkalinity, and trace metals. Bennett (2004) attempted to re-visit the sample sites defined in Cameron and Larson (1992); however, the sites were not georeferenced so sites were re-visited as close to the original locations as possible utilizing plotted maps.

Data presented in Bennett (2004) are not historic (collected before 2000), and are well presented in the original document. Therefore, data from Bennett (2004) are not presented in this NRCA.

Cameron and Larson (1993) present data collected regarding trace element concentrations at stream inflow sites around Surprise Lake in July and August of 1988 and 1989 (Table 31, Table 32). Various water quality parameters as well as chlorophyll data were also collected in Surprise Lake over these sampling dates (Table 33). Field analyses were performed to determine hardness, pH, conductivity, and total alkalinity. The values for conductivity and pH were cross-referenced with readings taken in the field with a Hydrolab 4000 series. Conductance, dissolved oxygen, and pH readings were recorded in Surprise Lake at stations WS1, WS2, RS1 and ML1 over 1-meter depth intervals.

Cameron and Larson (1992) performed an inventory of the aquatic resources of the monument area in ANIA. Surprise Lake (Photo 18) and its inlet streams were sampled to determine if nine chemicals were within EPA standards for drinking water (Table 34). Surprise Lake was also sampled to track changes in temperature, dissolved oxygen (percent saturation), conductance, pH, and percentage of light penetration at depth (Table 34-Table 56).

Table 35. Late July and August,1988-1989, trace element concentrations of inlet streams and warm spring 14 at the point of entry into Surprise Lake. Data presented in minimum–maximum values (Cameron and Larson 1993). Numbers in parentheses indicate sample size.

Variable	**Units**	**Inlet 1- 4 (7)**	**Inlet 8 (1)**	**Inlet 9 (1)**	**Inlet 10 (4)**	**Inlet 11 (4)**	**WS 14 (1)**
Ca	mg/L	2.67-3.54	6.93	7.87	17.23-38.18	42.44-54.48	100.55
Mg	mg/L	0.4-1.76	3.67	4.45	8.65-19.47	30.96-41.25	118.07
K	mg/L	BD-1.43	1.56	1.96	4.04-7.16	10.49-11.56	12.36
Na	mg/L	4.86-10.04	14.22	12.29	32.15-64.31	110.18-130.25	207.48
S	mg/L	.94-1.94	0.75	1.41	3.26-7.48	7.67-10.20	65.05
Si	mg/L	3.35-12.83	10.63	13.83	10.92-27.66	8.61-15.8	25.74
Fe	µg/L	BD	BD	BD	BD	60-166	46
Mn	µg/L	BD	9	14	54-97	435-534	1249
B	mg/L	BD-.04	0.06	0.19	.86-1.87	4.25-5.40	2.58
Cu	mg/L	BD	BD	BD	BD	BD	BD
Sr	µg/L	BD-17	15	27	39-140	166-193	309

BD = parameter was below the detection limit

Table 36. Late July and August,1988-1989 trace element concentrations in Surprise Lake at the Warm Spring stations (WS1 and WS2), reference station (RS1), and the mid-lake station (ML1 at 1 and 14 m). Warm Spring and reference station samples taken at a depth of 1 m. Data presented as minimum-maximum values of three samples (Cameron and Larson 1993).

Variable	**Units**	**WS1**	**WS2**	**ML1-1m**	**ML1-14m**	**RS1**
Ca	mg/L	19.95- 27.27	15.01-21.35	8.80-21.67	12..74- 29.31	14.83- 22.78
Mg	mg/L	15.10- 23.64	15.08-19.36	15.04-17.91	14.94 - 26.43	15.46- 18.70
K	mg/L	4.14- 6.16	4.03- 4.83	4.11- 4.56	4.16- 5.82	4.13- 4.75
Na	mg/L	42.03- 67.05	41.04-51.98	41.26-48.21	40.99- 65.75	42.91- 49.70
S	mg/L	7.64- 10.66	7.98- 9.18	8.00- 9.14	7.93- 14.10	6.07- 9.83
Si	mg/L	16.21- 24.90	12..11-24.01	17.36-21.25	15.50- 24.97	16.93- 24.97
Fe	mg/L	BD	BD	BD	BD	BD
Mn	µg/L	16 -146	33 -76	6-71	16 - 74	26 -101
B	mg/L	0.95- 1.82	0.89- 1.34	.90-1.08	0.89- 1.47	0.92- 1.29
Cu	mg/L	BD	BD	BD	BD	BD
Sr	µg/L	55 -103	60 -71	39-80	48 -108	59 - 72

Table 37. Water quality and chlorophyll data from Surprise Lake (Cameron and Larson 1992).

Variable	Unit	Surprise Lake	Surprise Lake
Date	N/A	Aug-31-1988	Jul-30-1989
pH	standard	7.3	7.5
Alkalinity	mg/L	162	180
Hardness	mg/L	126	132
Conductivity	µmhos/cm	380	391
Turbidity	N/A	2.6	3.2
TP	µg/L	24.9	19.2
TFP	µg/L	8.5	7.7
FRP	µg/L	24.4	6.3
TKN	µg/L	44.7	31.2
NH3 + NH4	µg/L	N/A	16.4
NO3 + NO2	µg/L	N/A	N/A
Ca	mg/L	16.6	8.8
Mg	mg/L	15.1	15.8
K	mg/L	4.3	4.1
Na	mg/L	41.3	42.9
S	µg/L	8	8.2
Si	mg/L	17.4	18.6
Fe	mg/L	<.01	<.01
Cu	µg/L	<.01	<.01
Mn	µg/L	71	6
Chlorophyll	µg/L	2.32	1.69

Table 38. Concentrations of chemicals measured in µg/L that exceed drinking water standards developed by the U.S. EPA in the inlets of Surprise Lake (Cameron and Larson 1992).

Chemical	EPA Standard	Cold Inlets	Intermediate Inlets	Warm Inlets	Surprise Lake
Arsenic	50	+	+	+	+
Cadmium	10	+	+	+	+
Chromium	50	+	+	+	+
Iron	300	+	+	3,282	436
Lead	50	+	+	+	+
Manganese	50	+	64	577	62
Nickel	13	+	+	+	+
Nitrate	10,000	+	+	+	+
Zinc	5,000	+	+	+	+

Photo 18. Surprise Lake in the Aniakchak Caldera (NPS photo).

Table 39. Temperature (°C), dissolved oxygen (percent saturation), therapeutic pH (units), and conductance (mS/cm at 25° C) measured with a hydrolab in the inlet streams of Surprise Lake, Aniakchak National Monument, Alaska (Cameron and Larson 1992).

Date	Inlet	Stream Section	Temperature	Dissolved Oxygen	pH	Conductance
8/13/1988	I1 E fork	upper	7.1	98	6.8	141.3
8/13/1988	I1 W fork	upper	9.2	96.7	6.7	147.5
8/13/1988	I1	upper	9.5	91.9	6.5	101.9
8/13/1988	I1	middle	15.7	99.3	6.6	85.4
8/13/1988	I1	lower	10.2	79	6.3	90.9
8/13/1988	I1	mouth	8.3	87.9	6.2	97.9
8/13/1988	I2	source	1.8	96.9	7.2	144.7
8/13/1988	I2	middle	6.4	99.1	6.9	117.8
8/13/1988	I2	mouth	7.5	100.7	6.7	112.9
8/13/1988	I3	upper	3.2	98.7	6.7	97.3
8/13/1988	I3	middle	3.7	98.5	6.8	95.7
8/13/1988	I3	lower	4.3	94.4	7	115.4
8/13/1988	I3	mouth	4.7	98.6	7.1	117.7
8/13/1988	I4	source	2.8	98	6.9	127.1
8/13/1988	I4	middle	3.1	99.2	7.1	125.2
8/13/1988	I4	mouth	3.2	98	7.6	123.9
8/13/1988	I5	source	2	98.2	6.9	126.6
8/13/1988	I5	upper	3.1	99.6	6.9	122.6
8/13/1988	I5	middle	4.4	97.5	7	115.1
8/13/1988	I5	mouth	5.2	99.5	7	109.8

Table 35 (continued). Temperature (°C), dissolved oxygen (percent saturation), therapeutic pH (units), and conductance (mS/cm at 25° C) measured with a hydrolab in the inlet streams of Surprise Lake, Aniakchak National Monument, Alaska (Cameron and Larson 1992).

Date	Inlet	Stream Section	Temperature	Dissolved Oxygen	pH	Conductance
8/18/1988	I8	lower	4.9	98.4	7	261.3
8/18/1988	I9	lower	9.1	97.4	6.9	231.2
8/18/1988	I10	lower	9	90.8	6.3	494
8/18/1988	I11	lower	21.3	13	5.6	1130
8/18/1988	WS4	WP1	23.9	5.1	5.5	1118.5
8/18/1988	WS4	WP2	20.6	4.7	5.5	1118
8/18/1988	WS4	WP3	19.9	5.8	5.5	1101.3
8/13/1988	WS14	source	15.4	10.5	5.8	1468.8
8/13/1988	WS15	source	15.7	7.9	5.8	1501.8
8/13/1988	CS2	source	2.1	97.9	7.1	130.9
8/13/1988	CS2	middle	2.5	100.7	7.1	126.4
8/13/1988	CS2	mouth	3.2	103.1	7.2	124.9
8/13/1988	CS2	marsh	2.9	104.2	7.2	123.4
8/13/1988	CS3	source	2	98.6	7.2	127.2
8/13/1988	CS3	middle	2.4	99.6	6.9	125.5
8/13/1988	CS3	mouth	3.5	103.4	6.9	121.3
8/13/1988	CS3	marsh	2.7	101.2	6.9	121.6
8/13/1988	CS23	mouth	8.4	93.5	6.9	101.1
8/13/1988	CS23	marsh	9.7	98.3	6.2	105.7
8/13/1988	CS24	middle	9.6	82.5	6.5	121.7
8/13/1988	CS24	mouth	9.2	101.2	6.8	120.8
8/13/1988	CS25	middle	7.8	91.3	6.9	101.6
8/13/1988	CS25	mouth	10.1	96	6.5	92.7
8/13/1988	CS26	mouth	11.3	106.4	6.5	109.7

Table 40. Temperature (°C) measured with a Bacharach thermometer in the inlet streams of Surprise Lake, Aniakchak National Monument, Alaska (Cameron and Larson 1992).

Date	I1	I2	I3	I4	I5	I6	I8	I9	I10	I11	WP1
06/181988	N/A	N/A		2.2					7.2	12.2	N/A
7/10/1988				-					7.8	18.1	17.5
7/19/1988				2.8						N/A	N/A
7/28/1988				3.3					8.9	22.2	23.9
8/8/1988				-			6.7	11.1	10	21.1	N/A
8/9/1988				3.9						N/A	25.6
8/12/1988				3.9						N/A	N/A

Table 36 (continued). Temperature (°C) measured with a Bacharach thermometer in the inlet streams of Surprise Lake, Aniakchak National Monument, Alaska (Cameron and Larson 1992).

Date	I1	I2	I3	I4	I5	I6	I8	I9	I10	I11	WP1
8/13/1988	8.3	7.5	4.7	3.3	5.4		5.2	8.9	8.9	22.1	N/A
8/18/1988	10	6.7	5	3.3			4.9	9.1	9	21.3	23.9
8/31/1988				3.3					7.5	22.2	24.4
7/30/1989				3.3					8.3	21.1	24.4
8/1/1989	6.7	5.6	6.1	3.3		6.7	6.1	10	8.9	21.1	N/A

Table 41. Change in temperature (°C) with depth measured with a hydrolab at Station ML1 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	6/18/1988	7/10/1988	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	9.7	12	13.4	12	11.7	12.9	9.7	11.6
0.5	9.5	11.5	12.8	11.9	11.7	12.7	9.8	11.5
1	9.4	11.4	12.6	11.9	11.7	12.4	9.9	11.5
2	9.3	11.2	12.4	11.8	11.6	11.7	9.9	11.5
3	9.3	11.1	12.3	11.5	11.5	11.6	9.9	11.5
4	9.2	10.8	11.8	11.5	11.4	11.5	9.9	11.5
5	8.8	10.5	11.6	11.4	11.4	11.4	9.9	11.4
6	8.6	10.4	11.1	11.4	11.4	11.4	9.9	11.4
7	8.5	10.4	11.1	11.3	11.3	11.4	9.9	11.4
8	8.3	10.3	10.8	11.2	11.3	11.3	9.9	11.4
9	8.2	10.3	10.6	11.2	11.3	11.3	9.9	11.4
10	8.2	10.2	10.6	11.2	11.3	11.3	9.9	11.4
11	8	10.1	10.5	11.2	11.3	11.3	9.9	11.4
12	8	10.1	10.5	11.2	11.3	11.2	9.9	11.4
13	8	10.1	10.4	11.2	11.3	11.2	9.9	11.4
14	7.9	10	10.4	11.1	11.3	11.1	9.9	11.4
15	7.9	9.9	10.4	11.1	11.3	11.1	9.9	11.4
16	7.8	9.9	10.3	11.1	11.2	11.1	9.9	11.3
17	7.8	9.8	10.3	11	11.1	11	9.9	11.3
18	7.8	9.6	10.2	10.9	11	10.9	9.9	11.2
19	7.7	9.5	10	10.9	11	10.7	9.9	11

Table 42. Change in temperature (°C) with depth measured with a hydrolab at station RS1 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	13.8	11.8	11.5	11.2	11.6	11.9
0.5	13.1	11.8	11.4	12.3	11.1	11.7
1	13	11.8	11.4	11.8	11	11.5
2	12.6	11.7	11.4	11.4	10.9	11.4
3	12.3	11.6	11.4	11.3	10.8	11.4
4	12	11.6	11.4	11.3	10.7	11.3
5	11.8	11.6	11.3	11.2	10.2	11.3
6	11.2	11.4	11.3	11.2	10.2	11.3
7	10.9	11.4	11.3	11.2	10.1	11.2
8	10.7	11.4	11.3	11.2	10	11.2
9	10.6	11.4	11.3	11.1	9.9	11.2
10	10.6	11.4	11.2	10.9	9.9	11.2
11	10.5	11.4	11.2	10.9	9.9	N/A

Table 43. Change in temperature (°C) with depth measured with a hydrolab at station WS1 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	15.2	14.7	12.7	14.9	12
0.5	15.2	14.6	12.8	13.2	12
1	14.7	14.6	11.8	12.5	11.9
2	14.1	13.4	11.5	11.7	11.6
3	13.5	12.6	11.5	11.5	11.5
4	12.8	12.1	11.4	11.4	11.5
5	12.1	11.9	11.4	11.4	11.4
6	12	11.8	11.3	11.3	11.3
7	11.7	11.7	11.3	11.3	11.3
8	10.8	11.5	11.2	11.3	11.3
9	10.8	11.4	11.2	11.3	11.3
10	10.6	11.4	11.2	11.2	11.3
11	10.5	11.4	11.2	11.2	11.3
12	N/A	N/A	N/A	N/A	11.2
13	N/A	N/A	N/A	N/A	11.2

Table 44. Change in temperature (°C) with depth measured with a hydrolab at station WS2 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	14.5	12.5	11.7	14.2	11	12.9
0.5	14.4	12.6	11.8	13	10.9	12
1	14.4	12.6	11.8	12.6	10.9	11.6
2	13.2	12.6	11.8	12.7	10.8	11.5
3	12.8	12.6	11.8	11.5	10.3	11.5
4	12.6	12	11.8	11.5	10.3	11.4
5	12	12	11.7	11.6	10.2	11.4
6	11.8	11.9	11.9	11.4	10.1	11.3
7	11.8	11.7	11.9	11.3	10.1	11.3
8	11.4	11.6	11.6	11.3	10.1	11.3
9	11.3	11.6	11.4	11.3	10.1	11.3
10	11.3	11.6	11.6	11.4	10.3	11.3

Table 45. Change in conductance (mS/cm at 25°C) with depth measured with a hydrolab at Surprise Lake station ML1 Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	6/18/1988	7/10/1988	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	476.8	465.8	444.4	459.1	454	446.9	475.8	478
0.5	481.7	467.1	452	460.4	454	448.2	477.2	484
1	486.2	466.3	454.3	460.8	452	451.1	477.6	485
2	487.5	469.7	458	462.5	452.6	458.6	477.5	485
3	489.3	469.9	459.3	465	452.1	459.8	477.5	484
4	490	476.8	465	465.6	451.7	461.5	477.5	485
5	494.3	479.1	468	466.3	452.3	462.1	478.1	485
6	497	478.6	473	466.9	452.4	462.7	478.1	485
7	498.4	478.6	472	468.1	452.9	462.7	478.1	485
8	502.3	478.8	474.6	467.6	452.4	463.3	477.5	485
9	504.8	478.8	477.2	468.3	451.9	464.3	477.5	484
10	504.5	480.1	477.2	468.3	451.9	462.3	476.9	484
11	505.5	483.5	477.4	467.7	451.5	462.9	476.9	483
12	505.5	482.4	477.4	467.2	451.5	463.5	476.4	483
13	505.5	480.3	478.6	467.2	450.9	460.4	475.8	482
14	506.3	480.5	477.5	466.8	450.4	461	475.8	482
15	506.5	480.8	477.5	466.3	449.8	460	475.3	482
16	506.6	478.1	477.8	466.9	448.9	459	475.3	482
17	506.6	478.2	476.7	466.9	447.5	458.6	474.8	481
18	506	481.4	476.9	467.6	447.5	459.2	474.8	480
19	505.1	483.7	477.3	467.6	447.1	463.7	475.3	477

Table 46. Change in conductance (mS/cm at 25°C) with depth measured with a hydrolab at Surprise Lake station RS1 Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	434.2	459	450.7	451.5	471	475
0.5	439.3	459.5	450.7	451.6	463.7	480
1	438.8	459.5	450.7	458.4	464.9	483
2	443.2	460.7	450.7	462.7	466.2	484
3	447.2	462.8	450.8	462.3	466.8	485
4	453.5	463.4	450.3	462.3	466.5	486
5	459.4	463.4	448.8	463	477.5	486
6	462.5	465	448.3	463.5	477.5	485
7	470.8	465.3	450.4	463	479.4	485
8	472.7	465.3	449.4	463.6	476.2	485
9	475	165.3	449.4	463.7	476.4	484
10	475	464.6	450.5	465	474.7	484

Table 47. Change in conductance (mS/cm at 25°C) with depth measured with a hydrolab at Surprise Lake station WS1 Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	503.9	572	428.1	517	610.8	520
0.5	484.7	569.5	477.6	490.1	544.5	521
1	477.5	555.2	469.2	480.2	483.8	520
2	519	506.5	462.5	474.6	460.7	497
3	527.4	477.4	460.4	468.2	471.2	485
4	457	473.2	458	467.9	485	484
5	457	466.5	455.4	466.9	490	481
6	468.3	471.3	455	468.5	484.5	481
7	483.3	477.1	451.9	469.6	479.8	481
8	445.2	465.2	451	469.1	473.3	481
9	451.8	464.2	448.9	471.7	469	481
10	453.9	464.2	447.9	467.2	468.5	482
11	455.1	464.2	448.9	463	468.1	484
12	N/A	N/A	N/A	N/A	N/A	481
13	N/A	N/A	N/A	N/A	N/A	480

Table 48. Change in conductance (mS/cm at 25°C) with depth measured with a hydrolab at Surprise Lake station WS2 Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	436.5	458.3	458.6	467.3	465.9	559
0.5	437.6	458.3	458	471.6	467.1	494
1	441.9	458.3	461	491.3	467.1	488
2	463.4	458.3	460.6	470.4	470	490
3	465	461.3	466.2	471.2	477	490
4	470.3	470.4	470.3	473.9	483.2	488
5	474.5	494.9	470.4	501.6	482.9	491
6	481	501.2	498.7	477.8	482.4	486
7	516	487.4	477.1	477.4	481.4	482
8	496	484.5	480.9	482.5	481.9	482
9	509.1	491.7	471.7	492.4	487.3	482
10	N/A	N/A	N/A	N/A	N/A	480

Table 49. Change in pH with depth measured with a hydrolab at station ML1 Surprise Lake, Aniakchak National Monument, Alaska,1988 and 1989 (Cameron and Larson 1992).

Depth (m)	6/18/1988	7/10/1988	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	6.5	6.8	6.3	6.4	6.7	6.7	6	6.2
0.5	6.7	6.9	6.5	6.6	6.8	6.8	6.3	6.5
1	6.7	6.9	6.6	6.7	6.8	6.8	6.5	6.6
2	6.8	7	6.7	6.8	6.9	6.9	6.7	6.7
3	6.9	7.1	6.7	6.8	6.9	6.9	6.7	6.8
4	6.9	7	6.8	6.8	6.9	7	6.8	6.8
5	6.9	7.1	6.8	6.9	6.9	7	6.9	6.9
6	6.9	7	6.8	6.9	7	7	6.9	6.9
7	6.9	7.1	6.8	6.9	7	7	7	6.9
8	6.9	7.1	6.8	6.9	7	7	7	6.9
9	7	7.1	6.8	6.9	7	7.1	7	6.9
10	7	7	6.8	6.9	7	7	7	6.9
11	7	7	6.8	6.9	7	7.1	7	6.9
12	7.1	7	6.8	6.9	6.9	7	7	6.9
13	7.1	7	6.9	6.9	6.9	7	7	6.8
14	7.1	7	6.8	6.9	6.9	7	7	6.8
15	7.1	7	6.8	6.9	6.9	7	7	6.8
16	7	6.9	6.8	6.9	6.9	7	7	6.8
17	7	6.9	6.8	6.9	6.9	7	7	6.8
18	7	6.7	6.7	6.8	6.8	6.8	7	6.7
19	7	6.6	6.7	6.8	6.8	6.8	6.9	6.6

Table 50. Change in pH with depth measured with a hydrolab at station RS1 Surprise Lake, Aniakchak National Monument, Alaska,1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	6.2	6.3	6.8	6.9	6.7	6.5
0.5	6.7	6.6	6.8	7	6.8	6.6
1	6.8	6.7	6.9	7	6.9	6.7
2	6.9	6.8	6.9	7	7	6.8
3	6.9	6.8	6.9	7.1	7	6.8
4	6.9	6.9	7	7.1	7.1	6.9
5	7	6.9	7	7.1	7.1	6.9
6	7	6.9	7	7.1	7.1	6.9
7	6.9	6.9	7	7.1	7.2	7
8	6.9	6.9	7.1	7.1	7.1	7
9	7	6.9	7.1	7.1	7.1	7
10	6.9	6.9	7	7	7	6.9

Table 51. Change in pH with depth measured with a hydrolab at station WS1 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	6.1	5.9	6.2	6.3	5.8	6
0.5	6.1	6	6.1	6.2	6	6.2
1	6.2	6	6.2	6.3	6.2	6.3
2	6.5	6.2	6.4	6.5	6.4	6.4
3	6.6	6.3	6.5	6.6	6.5	6.6
4	6.6	6.5	6.6	6.7	6.6	6.6
5	6.7	6.6	6.7	6.8	6.6	6.7
6	6.6	6.6	6.7	6.8	6.6	6.7
7	6.6	6.6	6.8	6.8	6.7	6.7
8	6.7	6.7	6.8	6.8	6.7	6.8
9	6.7	6.7	6.9	6.8	6.7	6.8
10	6.7	6.8	6.9	6.8	6.7	6.8
11	6.7	6.8	6.8	6.8	6.8	6.8
12	N/A	N/A	N/A	N/A	N/A	6.7
13	N/A	N/A	N/A	N/A	N/A	6.7

Table 52. Change in pH with depth measured with a hydrolab at station WS2 Surprise Lake, Aniakchak National Monument, Alaska,1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	6.6	6.1	6	6.5	6	6
0.5	6.7	6.4	6.3	6.5	6.4	6.3
1	6.7	6.5	6.4	6.4	6.6	6.3
2	6.6	6.6	6.5	6.6	6.7	6.5
3	6.7	6.7	6.5	6.7	6.8	6.6
4	6.7	6.7	6.5	6.8	6.7	6.7
5	6.7	6.7	6.6	6.7	6.8	6.7
6	6.6	6.6	6.5	6.7	6.8	6.8
7	6.6	6.6	6.5	6.7	6.8	6.9
8	6.5	6.6	6.6	6.7	6.8	6.9
9	6.5	6.6	6.6	6.7	6.8	6.9
10	N/A	N/A	N/A	N/A	N/A	6.9

Table 53. Change in dissolved oxygen (percent saturation) with depth measured with a hydrolab at station ML1 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	6/18/1988	7/10/1988	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	105.8	104	106	102	98.5	98.9	99.3	95
0.5	101.4	103	106	99	98	97.4	97.7	94
1	97.1	103	107	97	99	96.8	96.4	94
2	95.5	102	105	97	98.4	95.4	95.5	94
3	96.1	97	105	98	97.8	95	95.1	94
4	95.7	96	105	97	96.2	94.8	94.6	93
5	94	95	104	97	95.7	94.7	94.6	93
6	93.1	95	100	97	95.1	94.6	94.2	93
7	92.9	93	98	95	94.9	94.6	93.7	93
8	92.4	92	97	94	95.4	93.5	93.7	93
9	92.2	92	97	94	94.9	93.5	93.7	92
10	92.1	92	97	94	95.4	93	93.2	92
11	91.8	92	97	94	95.3	93.4	93.7	92
12	91.8	91	95	94	94.3	92.8	93.2	92
13	91.8	89	95	91	94.8	92.3	93.2	91
14	91.5	88	95	91	94.3	92.1	93.2	91
15	91.4	88	95	91	94.3	91.6	92.8	91
16	90.9	88	95	91	94.1	92.1	92.8	91
17	90.3	88	94	91	92.9	91.9	92.5	91
18	90	85	93	87	92.4	90.7	92.5	91
19	88.4	85	85	87	91.9	88.5	91.8	90
20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	89

Table 54. Change in dissolved oxygen (percent saturation) with depth measured with a hydrolab at station RS1 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	88	83	93	93	80.6	96
0.5	90	80	95.6	92	85	96
1	93	82	95.5	91.5	88	94
2	98	84	93.9	93.3	92.3	94
3	99	95	94.4	95.9	90.6	93
4	99	94	94.7	94.1	89.7	92
5	95	98	94.7	93.6	88.5	92
6	94	90	94.9	93.5	88.2	92
7	89	89	94.9	92.5	88.5	92
8	92	94	94.3	92.4	89	91
9	91	94	94.3	91.5	89	91
10	92	94	94.3	91.3	89	91
11	90	92	93.8	91.3	88.9	N/A

Table 55. Change in dissolved oxygen (percent saturation) with depth measured with a hydrolab at station WS1 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	106	103	99.6	101.8	94.6	94
0.5	106	102	98.6	99.6	93.9	93
1	105	101	99.5	96.5	93.8	93
2	102	99	99.5	96	93.5	94
3	104	98	98.4	95.9	92.4	93
4	104	98	99.4	95.3	92.6	93
5	104	98	96.7	95.2	91	93
6	100	98	96.3	94.7	90.5	93
7	99	95	95.3	94.3	88.9	92
8	96	95	95.3	94.1	87.9	92
9	96	97	94.8	92	88.6	92
10	94	97	94.7	91.2	86.9	92
11	N/A	N/A	N/A	N/A	N/A	92
12	N/A	N/A	N/A	N/A	N/A	91
13	N/A	N/A	N/A	N/A	N/A	91

Table 56. Change in dissolved oxygen (percent saturation) with depth measured with a hydrolab at station WS2 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.1	106	110	101.6	95.1	100.5	92
0.5	102	107	102.2	95.1	97.3	96
1	100	105	91.6	93.3	97.3	95
2	95	105	102.2	94.4	94.7	94
3	96	102	99.3	93.9	94.1	94
4	98	98	97.9	93.8	92.1	94
5	95	96	96.3	91.1	91	93
6	92	92	93.9	91.2	90.9	93
7	86	96	94.9	90.6	90.4	93
8	86	96	86.9	90.6	89.9	93
9	86	95	93.6	89.6	90.9	93
10	N/A	N/A	N/A	N/A	N/A	93

Table 57. Change in light (% of light measured just below the lake surface) with depth measured with a hydrolab at station ML1 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	6/18/1988	7/10/1988	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.05	100	100	100	100	100	100	100	100
0.5	80	73.3	78.3	63.8	80.4	85.3	79.7	61.1
1	64	55	58.7	39.7	60.7	64.7	59.3	46.7
2	40	30.8	32.6	26.4	33.9	38.2	30.5	25.6
3	24	17.5	18.1	12.6	21.4	20.6	16.8	15.6
4	14.7	10	10.1	8.5	11.4	12.1	9.2	8.8
5	8.8	5.8	5.8	5.2	6.8	7.4	4.9	4.9
6	6.4	3.5	3	2.8	4.1	4.4	3.1	2.7
7	3.5	2	1.6	1.9	2.5	2.6	1.8	2
8	2.1	1.3	0.92	1.2	1.5	1.7	1	1.2
9	1.3	0.76	0.52	0.76	0.95	0.97	0.63	0.6
10	0.84	0.45	0.29	0.38	0.52	0.56	0.39	0.4
11	0.56	0.28	0.2	0.31	0.38	0.38	0.27	0.2
12	0.37	0.18	0.12	0.29	0.23	0.24	0.19	0.1
13	0.24	0.11	0.07	0.14	0.14	0.15	0.13	0.1
14	0.16	0.07	0.05	0.09	0.09	0.1	0.1	0.04
15	0.1	0.04	0.03	0.06	0.05	0.06	0.09	0.02
16	0.07	0.03	0.02	0.04	0.04	0.04	0.08	0.01
17	0.04	0.02	0.01	0.03	0.02	0.03	0.08	0.003
18	0.03	0.01	0.01	0.02	0.02	0.02	0.07	0.001
19	0.02	N/A	N/A	0.01	0.01	0.01	0.07	N/A

Table 58. Change in light (% of light measured just below the lake surface) with depth measured with a hydrolab at station RS1 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.05	100	N/A	100	100	100	100
0.5	88.9	N/A	82.9	78.4	81.3	76.7
1	54.2	N/A	62.9	62.7	68.8	56.7
2	36.1	N/A	37.1	37.3	40.6	30
3	19.4	N/A	22.9	21.6	14.4	17
4	11.4	N/A	14	12.6	8.1	9.7
5	6.3	N/A	8.9	7.7	4.3	5.7
6	3.8	N/A	5.7	4.5	2.8	3.2
7	2.2	N/A	3.7	2.9	1.6	1.9
8	1.3	N/A	2.2	1.8	0.94	1.1
9	0.72	N/A	1.3	1.1	0.56	0.63
10	0.43	N/A	1	0.65	0.34	0.35
11	0.28	N/A	N/A	N/A	0.23	0.22
12	N/A	N/A	N/A	N/A	N/A	0.17

Table 59. Change in light (% of light measured just below the lake surface) with depth measured with a hydrolab at station WS1 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.05	100	N/A	100	100	100	100
0.5	81.5	N/A	77.6	73	81.3	93.8
1	59.3	N/A	55.1	59.5	59.4	53.1
2	32.6	N/A	30.6	29.7	31.3	21.9
3	17	N/A	15.5	15.4	17.5	10.6
4	11.9	N/A	9	8.7	9.7	6.3
5	6.3	N/A	5.3	4.6	4.7	3.1
6	3.3	N/A	2.9	2.7	2.5	1.9
7	1.4	N/A	1.6	1.6	1.3	1
8	0.67	N/A	0.92	0.95	0.72	0.56
9	0.41	N/A	0.55	0.57	0.41	0.32
10	0.33	N/A	0.31	0.27	0.22	0.19
11	0.21	N/A	0.18	0.22	0.13	0.09
12	0.16	N/A	0.14	N/A	N/A	0.04

Table 60. Change in light (% of light measured just below the lake surface) with depth measured with a hydrolab at station WS2 Surprise Lake, Aniakchak National Monument, Alaska, 1988 and 1989 (Cameron and Larson 1992).

Depth (m)	7/17/1988	7/28/1988	8/5/1988	8/14/1988	8/31/1988	7/30/1989
0.05	100	N/A	100	100	100	100
0.5	83.6	N/A	68.9	82.9	83.3	76
1	64.2	N/A	48.9	68.6	65.2	48
2	35.8	N/A	22	54.3	36.2	21.6
3	17.9	N/A	11.6	20.9	21.2	12
4	8.5	N/A	7.8	11.4	10.2	6.4
5	4.8	N/A	4.7	6.6	5.6	3.8
6	2.2	N/A	2.8	3.7	3.2	2
7	1	N/A	1.7	2.2	1.8	1.1
8	0.46	N/A	1.1	1.2	1	0.64
9	0.24	N/A	0.69	0.63	0.55	0.36
10	0.16	N/A	0.44		0.3	0.2
11	N/A	N/A	0.27	N/A	0.17	0.2
12	N/A	N/A	0.14	N/A	N/A	N/A

Mahoney and Sonnevil (1991) performed water quality measurements on Surprise Lake and selected tributaries in July of 1987. These data, including a vertical profile of water quality measurements taken every 2 m (6.6 ft) in Surprise Lake, and other water quality parameters taken in Surprise Lake and some tributaries were compiled and are presented in Table 57-Table 59.

Stream discharge was measured at selected sites using a Marsh McBirney flow meter, top setting wading rod, and meter tape. Conductivity, dissolved oxygen (DO), pH, and temperature were measured just below the stream surface at all stream discharge measurement sites. Conductivity (μS/cm), DO concentration (mg/L), pH, and temperature (°C) measurements were taken at six Surprise Lake locations at depths ranging from 0.9-18.3 m (3.0-60.0 ft) using a hydrolab 4000 series instrument. Secchi disk readings were taken in conjunction with the water quality measurements.

Table 61. Water depth, depth of measurement and water quality parameters for six sampling locations in Surprise Lake, Aniakchak National Monument and Preserve, Alaska, 26 July 1987 (Mahoney and Sonnevil 1991).

Sample Site	**A**	**B**	**C**	**D**	**E**	**F**
Total depth (m)	13.7	18.6	1.8	1.4	15.9	2
Depth of measurement (m)	10	16	1.4	0.9	10	1.8
Secchi disk depth (m)	2.6	2.9	1.7	1.4	2.3	2
Conductivity (µS/cm)	394	390	789	369	390	386
Dissolved oxygen (mg/l)	10.4	10.1	8.5	9.7	10.2	10.4
pH	6.8	6.8	6.2	6.7	6.8	6.7
Temperature (°C)	10	9.4	12.6	10.1	9.6	11.4

Table 62. Calculated stream discharge and water quality measurements of tributaries to Surprise Lake and the Aniakchak River, Aniakchak National Monument and Preserve, Alaska, 24-26 July 1987 (Mahoney and Sonnevil 1991).

Tributary	Discharge Site	Discharge (m^3/s)	Stream width (m)	Mean velocity (m/s)	Maximum depth (m)	Minimum depth (m)	Conductivity (µS/cm)	Dissolved oxygen (mg/L)	pH	Temperature (°C)
Tributary 1	Site 1	*	*	*	*	*	101	10.8	6.8	11.4
	Site 2	2.54	8.5	1.01	0.9	0.03	289	10.4	6.15	9.8
	Site 3	1.95	17.3	0.5	0.5	0.1	288	10.5	6.2	8.9
Tributary 2	Warm Water Springs	0.38	5.7	0.22	0.3	0.1	901	2.5	5.25	19.4
Tributary 3	Tributary 3	0.25	4.5	0.16	0.2	0.1	58	12.7	7.9	4.4
Tributary 4	Waterfall Creek	2.48	7.3	1.41	0.5	0.2	43	13.4	7.45	2.4
	Aniakchak River	6.71	19.9	1.85	1.2	0.1	N/A	N/A	N/A	N/A

Table 63. Vertical profile of water quality measurements taken at two meter intervals in Surprise Lake, Aniakchak National Monument and Preserve, Alaska, 26 July 1987 (Mahoney and Sonnevil 1991).

Depth (m)	Conductivity (µS/cm)	Dissolved oxygen (mg/L)	pH	Temperature (°C)
0.2	387	10.4	6.9	11.1
3	388	10	7	10.9
5	389	10.1	7	10.5
7	390	8.7	7.1	10.3
9	393	10	7.1	9.9
11	393	9.1	7.2	9.8
13	392	9.3	7.2	9.5
15	392	9.2	7.2	9.3
17	392	9.6	7.1	9.2
19	394	8.7	7.1	9.1

4.11.4 Current Condition and Trend

Threats and Stressor Factors

Nagorski et al. (2007) cites that oil spills, pollutants transferred through the atmosphere and biological processes, and climate change have negatively affected ANIA water quality in the past and are likely to continue to in the future. Approximately two-thirds of the ANIA coastline was oiled after the Exxon Valdez spill in 1989, which still affects water quality and biotic communities of the region. Billions of barrels in crude oil are pumped, transported, and processed close enough to the park for swift currents to quickly deposit spills of all scales in ANIA waters (Nagorski et al. 2007). The ANIA region has been exposed to the recent warming trend identified as beginning in the mid-1970s. Climate change can upset the natural balance of snow pack accumulation in the winter, resulting in streams with higher winter flow rates and lower summer flow; this could alter the number of streams and lakes in ANIA (Nagorski et al. 2007). Natural water quality degradations caused by geothermal springs in ANIA have caused the parameters of pH, metals, and temperature to measure outside the allowed state and federal water quality standards (Nagorski et al. 2007).

Data Needs/Gaps

Water quality data do not exist for most drainages in ANIA. The available data collected in ANIA include gaps of several years, and are inconsistent with regards to the time of year the sampling was conducted. Previous sampling locations have not been revisited again or often enough to develop trends and conclusions. Jones et al. (2005) reports that flow and water quality characteristics in many SWAN park water bodies including ANIA are completely unknown, making ecological evaluations of these water bodies difficult.

Overall Condition

Condition is unknown at this time due to lack of reference condition and limited data.

4.11.5 Sources of Expertise

Claudette Moore, SWAN Aquatic Ecologist

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Chapter 5. Discussion

Chapter 5 provides an opportunity to summarize assessment findings and discuss the overarching themes or common threads that have emerged for the featured components. The data gaps and needs identified for each component are summarized and the role these play in the designation of current condition is discussed. Also addressed is how condition analysis relates to the overall natural resource management issues of the park.

5.1 Component Data Gaps

The identification of key data and information gaps is an important objective of NRCAs. Data gaps or needs are those pieces of information that are currently unavailable, but would help to inform the status or overall condition of a key resource component in the park or would allow the park to develop a more thorough understanding of the topic in order to inform possible management decisions. Data gaps exist for most resource components assessed in this NRCA. Table 60 provides a detailed list of the data gaps identified in this assessment by component. Each data gap or need is discussed in further detail in the individual component assessments (Chapter 4).

Table 64. Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Moose	Current population and sex survey information available only from 1999 survey data. Data variability likely introduced due to differing collection techniques.
	Population and sex survey data absent from ANIA.
Bear	No quantitative data exists for bears within ANIA. Limited site specific (Black Lake) area population survey from 1999-2002.
Caribou	Assessment of NAPCH wintering grounds should be conducted to determine if herd has recovered from poor health assessment in 2005.
Passerines	Bird observation and surveys predominately occur during summer. Surveys during other seasons and a regular monitoring program would contribute to a more thorough understanding of passerines.
Salmon	Salmon run data (e.g., escapement, harvest) severely lacking or non-existent.
	Studies addressing run timing in ANIA streams would be beneficial.
Native Fish	Data very limited and outdated. Future sampling is needed.
Seismic Activity	Need to study VT swarms that do not result in volcanic eruption.
Climate	Establish a climate monitoring station inside the park if possible.
	Continue to gather climate data from stations northeast of the park.
	Study how changes in climate will impact other park resources (e.g., vegetation and wildlife, water regime, etc.)
Human Activity	To allow for future comparison, yearly updates of the CUA database are important for maintaining the integrity and quality of the database.

Table 60 (continued). Identified data gaps or needs for the featured components.

Component	Data Gaps/Needs
Glaciers	Decadal glacier mapping for monitoring must continue.
Water Quality	Water quality data do not exist for most drainages in ANIA.
	Existing data collection methods/times are inconsistent.

Many of the park's data needs involve the challenge of determining ways to effectively sample and monitor biological phenomena in order to increase statistical confidence and to ensure long-term monitoring techniques are possible. To increase statistical confidence, sampling techniques of existing survey efforts could be strengthened and improved, or in some cases, entirely different approaches in terms of long-term data collection could be designed. Some statistical confidence will increase by simply repeating the existing surveys consistently to increase the total number of samples (e.g., years), as some sampling methods have only been repeated for a few consecutive years.

The sampling and monitoring efforts in ANIA are complicated given the remote location of the park, as well as potentially extreme environmental conditions. Techniques for large mammal surveys (aerial) often require ideal weather during the survey period. Moose surveys are frequently impacted by a lack of snow cover, inadequate snow depth, and less than optimal flying conditions. Weather and sampling conditions also impact other population surveys in ANIA including passerines, salmon, and bear. A consistent but opportunistic and flexible approach to population surveys is necessary to gather data and improve analyses.

5.2 Park-wide Component Observations

5.2.1 Biotic Composition

Mammals

Moose

Moose are common within ANIA. Originally scarce on the Alaskan peninsula (prior to 1900), moose populations grew exponentially until they peaked in the late 1960s (Butler 2010). Natural predators of moose within ANIA include wolves and brown bears. Limited hunting is also allowed within ANP. While current survey trends in ANIA indicate declining populations, overall, populations are considered to have been stable for the past 30 years (Butler 2008, 2010). Consistent moose population/sex ratio surveys would aid in obtaining a more complete picture of the moose population in ANIA.

Bear

Brown bears are a prominent mammal species in ANIA. The species is found throughout the surrounding area, with larger concentrations in coastal and lake ecosystems. Brown bears utilize ANIA resources year-round but the population gravitates towards rivers and lakes with available salmon (Sowl 1988).

Quantitative data on the density of brown bears within ANIA do not exist. Overall, little is known about the density of brown bear in GMU 9E. Sport hunting is permitted in the ANP, which comprises

188,179 ha (465,000 ac). Sport hunting is permitted in the spring during even-numbered years, and the fall during odd-numbered years.

Caribou

Caribou are also a prominent species in the park. ANIA caribou are part of the NAPCH, one of the 32 designated herds in Alaska. Mountainous areas and treeless tundra are preferred caribou habitat year-round, with preference to open coastal areas and mountains for calving areas and boreal forests as wintering grounds (Rausch et al. 2008). Traditional calving grounds of the NAPCH have been between the Bear River and Cinder River that runs through ANIA, and on the Bering Sea Flats.

The NAPCH population has ranged from a high of 20,000 animals to the current low of approximately 2,000 individuals (Butler 2009). Butler (2009) suggests that assessment of the NAPCH wintering grounds should be completed, with an aim to define if nutritional limitations are still stressing the herd. This assessment would aid in defining future management goals for the NAPCH and determine if the herd has a chance to recover from a poor health assessment in 2005 (Butler 2009).

<u>Birds</u>

Passerines

Bird populations can be an important indicator species as they often reflect an ecoystem's health (Morrison 1986, Hutto 1998, NABCI 2009). Forty-four species of passerines have been observed in ANIA (NPS 2013a). Abundance information for passerines in ANIA is primarily anecdotal. Several observers have classified species into categories such as "common", "uncommon", or "rare".

Nearly all of the bird surveys and observations at ANIA have been during the summer months. While this is the most likely time for passerines to be present and active, surveys during other seasons (migratory behavior) would be beneficial in understanding the passerine population.

<u>Fish</u>

Salmon

Sockeye salmon are known to inhabit Surprise Lake within the Aniakchak Caldera, where they have established spawning populations (Mahoney and Sonnevil 1991, Hamon 2000, Hamon et al. 2004). Other salmon species present within the park include Coho, pink, chum, and Chinook salmon.

Surprise Lake was populated with salmon following a break in the caldera wall and subsequent flood between 1,800 and 3,400 years ago (Hamon 1999). Salmon species have persisted in Surprise Lake since some time following the historic flood, and have thrived even after another major eruption of the Aniakchak volcano in 1931 (Mahoney and Sonnevil 1991, Hamon 1999).

ANIA salmon populations are not well studied. Therefore, significant conclusions cannot be drawn from available data, although anecdotal sources note that populations within ANIA are relatively small, but apparently healthy. According to Hamon et al. (2004, p. 39), "the populations at ANIA, though relatively small, appear to be very healthy and represent adaptations to a unique region."

Harvest rates do not currently have significant impacts on the small sockeye salmon populations within the park. Run timing data are also virtually non-existent for ANIA streams.

Native Fish

Twenty-seven anadromous and non-anadromous native fish species are present or probably present in ANIA (Miller and Markis 2004, Jones et al. 2005, NPS 2013a). Unlike nearby KATM, data from ADF&G statewide mail-in survey and guide logbooks do not exist for ANIA. Overall, information regarding native fish studies in ANIA is limited and outdated. Future sampling efforts would benefit the ability to describe condition in the future.

Given the remoteness of the Aniakchak River and its tributaries, Surprise Lake, and other water bodies in ANIA, natural processes are likely the primary driver of native fish population dynamics. Hamon et al. (2004) states that even though sockeye salmon populations in ANIA are "relatively small they appear to be very healthy and represent adaptations to a unique region." Given the remoteness of the park and lack of stressors, condition of this resource is assumed good.

5.2.2 Environmental Quality

Human Activity

ANIA is one of the least visited national parks. NPS (2013b) reports that on average, less than 500 individuals visited ANIA each year since 1989. Access to the park is restricted to aircraft or boat, as there are no roads within park boundaries and the NPS does not maintain facilities or trails within the park. Whitewater rafting from the Aniakchak Caldera to the ocean is one of the most common activities within the park. To allow for future comparison, yearly updates of the CUA database are important for maintaining the integrity and usefulness of the database.

Water Quality

Aquatic systems within SWAN are remote and pristine, providing researchers with an opportunity to examine the effects of man-made disturbances such as climate change and atmospheric pollutants on intact systems. Currently, water quality data for SWAN NPS units such as ANIA are minimal, but a monitoring plan for ANIA exists.

Nagorski et al. (2007) notes that oil spills, pollutants transferred through the atmosphere and biological processes, and climate change have negatively affected ANIA water quality in the past and are likely to continue to in the future. Water quality data do not exist for most drainages in ANIA. The available data collected in ANIA include gaps of several years, and are inconsistent with regards to the time of year the sampling was conducted. Previous sampling locations have not been revisited again or often enough to develop trends and conclusions. Jones et al. (2005) reports that flow and water quality characteristics in many SWAN park water bodies including ANIA are completely unknown, making ecological evaluations of these water bodies difficult.

5.2.3 Physical Characteristics

Seismic Activity

Located in the Aleutian volcanic arc, ANIA has experienced considerable seismic and volcanic activity throughout its history. The Aniakchak Caldera, deemed a National Natural Landmark, has been the subject of several geologic studies because of its unique geologic features, formation history, and volcanic characteristics. The caldera is on average 10 km (6 mi) wide and over 600 m (2,000 ft) deep, making it one of the largest explosive craters in the world (Coombs and Bacon 2012).

Earthquakes and volcanic eruptions within ANIA are a result of the interaction of the Pacific and North American plates along the Aleutian volcanic arc and are capable of drastically changing the landscape. Major alterations to the flora and fauna of a region can occur tens of kilometers from an epicenter or major eruption (Page et al. 1991).

Within ANIA, one volcano is monitored by six seismic monitoring stations maintained by AVO. Seismic stations surrounding the Aniakchak Crater have located an average of 24 earthquakes/year over the past eight years. Aniakchak Crater was one of only seven AVO monitored volcanoes to show an increase in regional seismic activity in 2011 from recorded 2010 levels. Volcanologists predict, through the piecing together of historic geological evidence, that an eruption of the same scale as the 1931 eruption of the Aniakchak Caldera can be expected (Neal et al. 2001). An event that large, however, would have an extremely low probability for many centuries to come simply due to the rarity of such large events (Neal et al. 2001).

Climate

As a primary driver of many other ecosystem components (vegetation, wildlife, disturbance regime, etc.), climate has numerous management consequences and implications. Climate was selected by the SWAN I&M program as a high-priority Vital Sign for southwest Alaska parks (Davey et al. 2007). The ANIA climate is described as "transitional between polar (tundra climate) and maritime (maritime subarctic)" (Lindsay 2013, p. 1). Winter temperatures are cold, while summer temperatures are somewhat moderated by nearby open water (e.g., Bering Sea and Gulf of Alaska) (Lindsay 2013).

There is a scientific consensus that human activities, particularly those that produce greenhouse gasses (e.g., fossil fuel burning), have contributed to a general warming trend in global climate (IPCC 2010). Climate models predict that change will be greatest at higher latitudes, indicating that Alaska is at high risk (NPS 2011). In the ANIA region, temperatures are projected to increase approximately 1°F (about 0.6°C) per decade over the next century (SNAP et al. 2009).

Glaciers

Glaciers occur in ANIA but are not considered to be a significant land cover type in the park (Giffen and Lindsay 2011). Giffen and Lindsay (2011, p. 8) describe the glaciers in ANIA as "small hanging/cirque glaciers of very limited extent that occur inside the Aniakchak crater on the very steep north aspect of the southern portion of the crater". Loso et al. (2012) report the glacial coverage in ANIA to be minimal, covering approximately 4.4 km^2 (1.7 mi^2).

An increase in average yearly temperature has been identified and predicted to continue in the SWAN parks region. Since no previous quantitative data exist for the glaciers in ANIA, the effects of regional temperature increases cannot be calculated. Trends identified by Loso et al. (2012) indicate that the glaciers located on the north-facing slopes of the caldera have shown advance since historic map data while glaciers located outside the caldera of ANIA have retreated during that time.

5.2.4 Park-wide Threats and Stressors

Several stressors were identified as threatening multiple resources within the park. Anthropogenic impacts from tourism to ANIA are extremely low. From 2008-2012, annual park visitation averaged less than 35 people (NPS 2013b). Indirect anthropogenic impacts however, are a long-term threat to ANIA and include airborne pollutants and climate change.

Climate change has begun to alter ANIA resources, but the extent of future impacts is uncertain. The average temperatures have risen 2.2°C (4°F) since the 1950s and are predicted to continue to increase by 2.8-10°C (5–18°F) by 2100 (Nagorski et al. 2007). A warming climate will most seriously impact water resources, especially at high altitudes (Hall 1988, Serreze et al. 2000), by affecting snow cover, glaciers, and sea/lake ice cover (Nagorski et al. 2007). Warmer winters will cause the snowpack to decrease while increasing rain events (Nagorski et al. 2007). This will result in a drier spring environment. Drier conditions may then cause an increase in the fire regime.

For biological resources analyzed in this assessment, concerns also stem from climate change (warming). Salmon may experience decreased survival of eggs and fry, slowed growth, premature smolting, and shifts in onsets of runs (Alderice and Velsen 1978). Other potential impacts of a warmer climate include reduced snowpack and a longer growing season, which could affect plant phenology and productivity, wildlife distribution and mating cycles, water availability, and recreational and subsistence activities (e.g., hunting, fishing) (SNAP et al. 2009, NPS 2011).

Another threat to resources in ANIA is human-caused disaster such as oil spills. The Exxon Valdez oil spill in the spring of 1989 was one of the most environmentally devastating (human-caused) events to affect the park (NPS 1990, as cited by Nagorski et al. 2007). The eastern two-thirds of the park shoreline was contaminated by the spill (NPS 1990, as cited by Nagorski et al. 2007). Marine wildlife, including mammals, fish, and seabirds, were most adversely affected by the spill. A restoration plan was created in 1994 by the Exxon Valdez Oil Spill Committee to restore the resources lost or damaged in the area. The plan contains actions to rehabilitate the environment by replanting intertidal plant species to prespill conditions, and limiting human use in the park and surrounding areas until populations stabilize (EVOS Council 1994).

This assessment serves as a review and summary of available data and literature for featured natural resources in the park. Much of the information presented here may serve as a baseline against which any changes in condition of components in the future may be compared. Establishing baseline information, for many of these resources, can help managers prioritize management objectives and better focus conservation strategies to maintain the health and integrity of these ecosystems.

5.2.5 Literature Cited

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