National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Arctic Network Vital Signs Monitoring Plan

Natural Resource Report NPS/ARCN/NRR—2009/088



ON THE COVER

Clockwise from top right:

Arctic ground squirrel (*Spermophilus parryii*). Photo by Franziska Kohl, Institute of Arctic Biology, University of Alaska Fairbanks.

Chuck Racine measuring vegetation changes 28 years after fire at the Uchugrak site in Noatak National Preserve. Photo by Jennifer Allen, National Park Service.

Walker Lake, located along the southern edge of the Brooks Range, is the largest lake in the Gates of the Arctic National Park and Preserve and is easily accessible by float plane from Bettles. National Park Service photo.

A maar lake in Bering Land Bridge National Preserve. National Park Service photo.

A view of Tasaychek Lagoon in Cape Krusenstern National Monument. National Park Service photo.

Moose (*Alces alces*). National Park Service photo.

Remnant fireweed (*Epilobium angustifolium*) from the Kugururok burn of 1972 in Noatak National Preserve. Photo by Andrew Stinchfield, National Park Service.

Tors above Serpentine Hot Springs in Bering Land Bridge National Preserve. National Park Service photo.

Arctic Network Vital Signs Monitoring Plan

Natural Resource Report NPS/ARCN/NRR—2009/088

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Executive Summary

Chapter 1, Introduction and Background

The Arctic Network (ARCN) includes five National Park Service (NPS) system units:

- Bering Land Bridge National Preserve (BELA),
- Cape Krusenstern National Monument (CAKR),
- Gates of the Arctic National Park and Preserve (GAAR),
- Kobuk Valley National Park (KOVA), and
- Noatak National Preserve (NOAT).

Collectively these units represent approximately 19.3 million acres, or roughly 25% of the land area of NPS-managed units in the United States.

Administratively, the parklands in ARCN are managed as two units:

- Western Arctic Parklands (WEAR), which consists of one monument (CAKR), one park (KOVA), and two preserves (BELA and NOAT), and is managed by a superintendent in Kotzebue and an office in Nome; and
- GAAR, which is managed by a superintendent in Fairbanks, with field offices in Bettles and Coldfoot.

The park headquarters for all five parks are outside the park boundaries, and the parks themselves are accessible only by airplane, boat, or on foot.

The ARCN parks contain a broad array of the ecosystems typical of the subarctic (boreal forest or taiga), and arctic (tundra) biomes of northwestern North America. The boundary, or ecotone, between these two biomes is also represented in many different phases. Because these parks encompass large areas of mountainous terrain, including a major portion of the Brooks Range, they also include examples of virtually every type of alpine situation to be found in northern Alaska.

The intent of the NPS monitoring program is to track 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. These resources and process are termed “vital signs.” This subset of resources and processes is part of the total suite of natural resources that park managers are directed to preserve “unimpaired for future generations.” The broad-based, scientifically sound information obtained through natural resource monitoring will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources.

Chapter 2, Conceptual Ecosystem Models

Conceptual models should:

- describe our current understanding of system components and processes,
- identify linkages and interactions between those components, and
- identify gaps in our knowledge (Gross 2003).

With the help of experts from a broad array of specialties, ARCN developed several conceptual models that describe key features and processes within the ARCN parks. In some cases, additional descriptive models were developed in order to highlight unique ecosystems of interest (e.g., arctic lagoons, spring streams) and provide additional details about key ecosystem processes or components of interest. A series of nested models describing current and future threats to ARCN ecosystems and potential consequences of those threats is also presented. Special areas of management concern for ARCN parklands (e.g., global climate change, air toxins, invasive species) are also addressed using conceptual models.

Our hope is that the models developed during the initiation of this monitoring effort will:

- help to describe the complex ecosystems of ARCN,
- elucidate current and potential stressors to ARCN ecosystems,
- suggest potential mechanisms by which these stressors could impact ARCN ecosystems, and
- help lay the foundation for monitoring critical aspects of the environment of the parks.

Chapter 3, Vital Signs

The Arctic Network has identified 28 vital signs through a multistep process, including scoping sessions, interviews with park superintendents, literature reviews, ecosystem workshops, a vital signs workshop, vital signs selection meetings, and finally, a presentation to the network Board of Directors. The network plans to implement monitoring or develop a monitoring plan for 19 of these vital signs in the next three to five years (Table ES.1). An additional nine vital signs will be monitored if additional resources become available.

Of the vital signs slated for implementation, four vital signs relate to air and climate (Wet and Dry Deposition, Air Contaminants, Climate, and Snowpack), two relate to geology and soils (Coastal Erosion and Permafrost), three relate to water (Lagoon Communities and Ecosystems, Lake Communities and Ecosystems, and Stream Communities and Ecosystems), one relates to human use (Subsistence/Harvest), two relate to ecosystem pattern and processes (Fire Extent and Severity and Terrestrial Landscape Patterns and Dynamics), and seven relate to biological integrity (Landbirds, Yellow-billed Loons, Brown Bears, Caribou, Dall's Sheep, Muskox, and Terrestrial Vegetation and Soils). The network developed this list through a process of meetings and ranking exercises.

Table ES.1. Arctic Network vital signs under the Vitals Signs Framework, as developed by the National Park Service Vital Signs Monitoring program. Only vital signs that will be implemented in the next 3–5 years are listed.

Level 1 Category	Level 2 Category	Level 3 Category	ARCN Vital Sign
Air and Climate	Air Quality	Wet and Dry Deposition	Wet and Dry Deposition
		Air Contaminants	Air Contaminants
	Weather and Climate	Weather and Climate	Climate
			Snowpack
Geology and Soils	Geomorphology	Coastal/Oceanographic Features and Processes	Coastal Erosion
	Soil Quality	Soil Function and Dynamics	Permafrost
Water	Water Quality	Water Chemistry	Lagoon Communities and Ecosystems
			Lake Communities and Ecosystems
			Stream Communities and Ecosystems
Biological Integrity		Birds	Landbirds
			Yellow-billed Loons
		Mammals	Brown Bears
			Caribou
			Dall's sheep
			Muskox
		Terrestrial Complex	Terrestrial Vegetation and Soils
Human Use	Consumptive Use	Consumptive Use	Subsistence/Harvest
Landscapes	Fire and Fuel Dynamics	Fire and Fuel Dynamics	Fire Extent and Severity
	Landscape Dynamics	Land Cover and Use	Terrestrial Landscape Patterns and Dynamics

Chapter 4, Sampling Design

ARCN is composed of large and remote park areas. This presents a daunting challenge for designing a statistically valid sampling strategy. Practical considerations, such as accessibility and cost, limit design alternatives that can realistically be implemented in these park units. In addition, sample design needs to be flexible enough to allow continued sampling within a range of areas or sites if funding drops to levels too low to support the full program.

Whenever possible we will use a common probabilistic design for monitoring vital signs. By sharing a common design, we will be able to colocate and covisit locations to gather data for a number of vital signs. Nonetheless, an overarching sample design that can be used for all vital signs and metrics is not possible given the different fundamental types of sampling required by each monitoring effort.

It is not realistic to collect high-resolution data for all vital signs on a network-wide scale. Therefore, even though our target population may be found throughout the network, the actual areas of inference (sampled population) may be much smaller, especially for vital signs requiring on the ground sampling. In those situations where network-wide sampling is unfeasible, we will incorporate accessibility and prioritization components into our designs.

Three fundamentally different schemes for collecting measurements in the field were adopted for the ARCN monitoring studies. The first scheme (grid-based sampling) constructs a grid of either points or cells to use as sample units and draws a probability sample. The second scheme (list-based sampling) constructs a list of sample units and either draws a probability sample or attempts to census all units. The third scheme collects information on areas or at points (index sites) that were hand-picked by lead investigators to yield adequate data on a particular vital sign.

Chapter 5, Sampling Protocols

The key to a credible long-term monitoring program is consistency in how data are collected, managed, analyzed and reported (Oakley et al. 2003). This consistency is achieved by using monitoring protocols. Well-written protocols ensure that the quality of data collected is consistent and credible and that programmatic goals, such as detecting change over time, are met. In this chapter we present the measurable objectives associated with ARCN's 28 vital signs and a timeline for development and implementation of sampling protocols for each vital sign.

Monitoring protocols identify methods for gathering information on a vital sign, outline a process to collect information, and establish how information will be analyzed and reported. Protocols are detailed study plans that are necessary to ensure that changes detected by monitoring actually are occurring in nature and do not stem from measurement variability introduced when different people or methods are used (Oakley et al. 2003).

Protocol development for the ARCN parks has proceeded with a view to ensuring compatibility with other natural resource monitoring efforts in the region and with other inventory and monitoring networks within the Alaska region to facilitate information exchange and sharing. Protocol development summaries include the vital signs to be monitored, a justification for monitoring, a list of sampling objectives, and a description of the sample frame and revisit schedule for the parks where the protocol will be implemented. The full protocol development summaries are provided in Appendix 15.

Chapter 6, Data Management

An integrated program of inventory and monitoring of natural resources is multidisciplinary and requires programmatic data and information management strategies for success. Data management fulfills this role by providing expertise in the technical aspects of inventory and monitoring, including relational databases and software development, metadata generation, web development, and geographic information systems. By expressing up-front support for data management, the Inventory and Monitoring Program is not only publicly committing to a culture of good data management practices but also expressing pride in the program's resulting technical products. The Arctic Network's main data management goals are:

- acquire, store, manage, and archive Arctic Network data;
- ensure high data quality;
- document and disseminate data and information; and
- ensure long-term access to and utility of data.

Chapter 7, Data Analysis and Reporting

Efficient data analysis can be achieved by careful planning. Aspects of the planning process include setting clear and measurable goals and designing effective sampling strategies to meet these goals. The Arctic Network strategy for analysis is:

- well-structured data management,
- prompt summarizing and reporting of results,
- in-depth analysis (e.g., trends, model building), and
- in some instances, forecasting and interpolation across space.

Reporting of results will occur at regular intervals and will use a variety of media. Data will be reported in short concise segments as well as longer, more detailed reports. Outlets that the Arctic Network will use to report findings include:

- informal communication with superintendents and NPS staff,
- informal communication with staff from other natural resource agencies,
- staff meetings,
- public presentations (talks and posters),
- newsletters,
- reports (annual reports, project specific reports, analysis and synthesis reports, state of the park reports),
- journal articles,
- ARCN website (including publications, data, and interactive maps),
- podcasts, and
- public radio.

The principal audience of the Inventory and Monitoring Program will be park managers. Other audiences may include environmental educators and scientists. One of the challenges of building a long-term monitoring program is that data from this program will likely be used for a variety of purposes.

Chapter 8, Administration and Implementation of the Monitoring Program

Key components of the administrative process of the Arctic Network are the Board of Directors, Technical Committee, and the Arctic Network staff. In this chapter we describe the makeup of these groups and the process by which decisions are made. We also describe how the network will integrate with other park operations, staff, and collaborators from outside of the NPS. Periodic review of the network's program provides the opportunity to adjust network resources to better meet the objectives of the Vital Signs Monitoring Program. Three levels of review will be used to keep the ARCN on track. On an annual basis, the Annual Administrative Report and Work Plan provides the opportunity for input. Every two years, the network will hold a symposium to more fully review the program. Every five years, an in-depth review of the overall program will occur.

Chapter 9, Schedule

The transition from defining the program to having a functional monitoring program requires planning to ensure that financial and staffing resources are not over-committed. The Arctic Network's strategy for sustainability is to stagger the timing of implementation of monitoring the network's identified vital signs.

There are some tasks associated with all vital signs identified by the Arctic Network that need to be addressed before monitoring occurs. In all cases, a thorough investigation of existing methodologies and data sets associated with the vital sign needs to be made. Explicit decisions regarding spatial and temporal extent of monitoring need to be made. Pilot studies may be necessary to inform these decisions. Following completion of these tasks, protocols and standard operating procedures have to be written, and explicit decisions need to be made regarding data management and mechanisms for future review of the monitoring effort's effectiveness.

Monitoring of different vital signs in ARCN will be performed on various temporal schedules. In many instances, sampling is restricted to specific seasons. Sampling within a designated time period can minimize between-year variability. The frequency of monitoring is often governed by the scale of resolution being monitored and the rate of change expected. Differences in timing and sampling frequency need to be recognized to ensure the availability of resources.

Chapter 10, Budget

Funding for the Arctic Network comes from the Natural Resource Challenge program. In FY 2009, the network anticipates receiving $145,100 from the NPS Water Resources Division and $1,559,680 from the I&M Program for vital signs monitoring. Budget figures are reported once a year in a standard format in the Annual Administrative Report and Work Plans submitted to Congress. In FY 2009, approximately 43% of the network budget will be committed to staff salaries and approximately 15% will support protocol development and testing through cooperative agreements and contracts. Annual operations and equipment will comprise 33% ($668,000) of the budget. To make the model of a centralized staff successful, 3% ($49,000) of the budget will be spent on travel funds. Travel funds will be used to maintain close communication between network and park staff, the Board of Directors, and the Technical Committee.

Chapter 1
Introduction and Background

"Sentiment without action is the ruin of the soul.
One brave deed is worth a thousand books."

—Edward Abbey

1.1 Park Stewardship and Natural Resource Monitoring

The Arctic Network (ARCN) is composed of Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Preserve. ARCN is one of the 32 networks included in the Servicewide Inventory and Monitoring program (Figure 1.1) and one of four networks in Alaska (Figure 1.2). Park units within the ARCN contain approximately 19.3 million acres, or roughly 25% of the land area of National Park Service (NPS)-managed units in the United States. The purpose of the Vital Signs Monitoring Program in the National Park Service relates directly to the purposes of the national park system.



Figure 1.1: National Inventory and Monitoring Networks

1.1.1 *Justification for Integrated Natural Resource Monitoring*

Knowing the condition of natural resources in national parks is fundamental to the ability of NPS to manage park resources "unimpaired for the enjoyment of future generations." National park managers across the country are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a basis for making decisions and working with other agencies and the public for the benefit of park resources. For years, managers and scientists have sought a way to characterize and determine trends in the condition of parks and other protected areas to assess the efficacy of management practices and restoration efforts and to provide early warning of impending threats. The challenge of protecting and managing a park's natural resources requires a multiagency, ecosystem approach because most parks are open systems, with threats such as air and water pollution or invasive species originating outside of the park's boundaries. An ecosystem approach is also needed because no single spatial or temporal scale is appropriate for all system components and processes; the appropriate scale for understanding and effectively managing a resource might be at the population, species, community, or landscape level, and in some cases may require a regional, national, or international effort to understand and manage the resource. National parks are part of larger ecosystems and must be managed in that context.

Natural resource monitoring provides site-specific information needed to understand and identify changes in complex, variable, and imperfectly understood natural systems and to determine whether observed changes are within natural levels of variability or may be indicators of unwanted human influences. Thus, monitoring provides a basis for understanding and identifying meaningful change in natural systems characterized by complexity, variability, and surprises. Monitoring data help to define the normal limits of natural variation in park resources and provide a basis for understanding

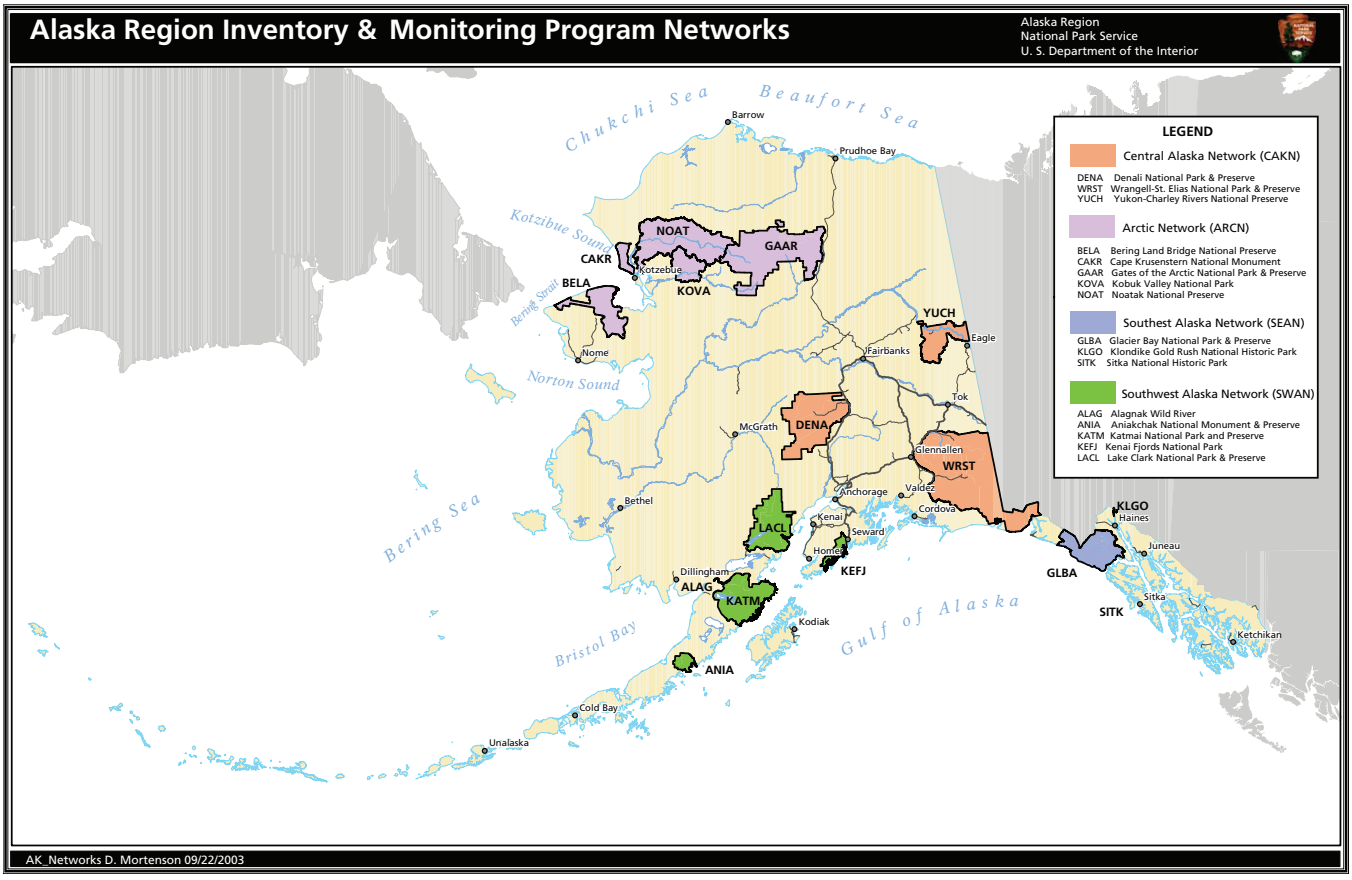


Figure 1.2: Alaska Region Inventory and Monitoring Program networks

observed changes; monitoring results may also be used to determine what constitutes impairment and to identify the need to initiate or change management practices. Understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate ecological threats to these systems (Roman and Barrett 1999).

The intent of the NPS monitoring program is to track 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. This subset of resources and processes is part of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on these resources. In situations where natural areas have been so highly altered that physical and biological processes no longer operate (e.g., control of fires and floods in developed areas), information obtained through monitoring can help managers understand how to develop the most effective approach to restoration or, in cases where restoration is impossible, ecologically sound management. The broad-based, scientifically sound information obtained through natural resource monitoring will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources.

1.1.2 Federal Legislation, Policy, and Guidance

National park managers are directed by federal law and National Park Service policies and guidance to know the status and trends in the condition of natural resources under their stewardship, in order to fulfill the NPS mission of conserving parks unimpaired (see Appendix 1). This specific direction on the monitoring of resources in national parks was not in the early policies of the NPS. Since 1978, legislation and guidance have evolved such that the 2001 NPS Management Policies specifically directs the service to inventory and monitor natural systems (see Appendix 1 for more detail). It is evident from even a cursory reading of relevant laws, policy, and guidance that a substantial framework is in place for the establishment of the Vital Signs Monitoring program for the ARCN as well as the other NPS networks.

1.1.3 ARCN Parks Legislation and Guidance

All of the NPS units within the ARCN parks (Figure 1.2) are relatively recent additions to the national park system. Portions of BELA, CAKR, and GAAR were initially created by presidential proclamation in 1978. All five units were redesignated or created with their present boundaries by the Alaska National Interest Lands Conservation Act (ANILCA) in 1980. The recent origin of these remote and difficult-to-access units, coupled with limited natural resource staffing levels, has left the natural resources in these units relatively under-studied.

Although ANILCA was passed before the inauguration of the NPS Inventory and Monitoring program, the act contains language that describes the need for an ecological monitoring program. The passage of ANILCA had, and will continue to have, large ramifications for national parks in Alaska. It is important to understand the intent of this law and its effect on management of Alaska national parks. Title I, Section 101(b) of ANILCA states that:

> it is the intent of Congress in this Act to preserve unrivaled scenic and geological values associated with natural landscapes;

to provide for the maintenance of sound populations of, and habitat for, wildlife species of inestimable value to the citizens of Alaska and the Nation, including those species dependent on vast relatively undeveloped areas;

to preserve in their natural state extensive unaltered arctic tundra, boreal forest, and coastal rainforest ecosystems, to protect the resources related to subsistence needs;

to protect and preserve historic and archeological sites, rivers, and lands, and to preserve wilderness resource values and related recreational opportunities including but not limited to hiking, canoeing, fishing, and sport hunting, within large arctic and subarctic wildlands and on freeflowing rivers;

and to maintain opportunities for scientific research and undisturbed ecosystems.

Clearly, the information gained from an ecological monitoring program is integral to the ability of ARCN park managers to steward the land in a manner consistent with enabling legislation, primarily ANILCA. Although each ARCN park preserves unique areas, these parks share common purposes of protecting fish and wildlife habitat and populations, providing for recreation and subsistence, preserving scenic and geologic formations, and maintaining extensive areas of undisturbed arctic and boreal forest ecosystems. These common purposes unify the network. This unity in underlying purposes is a great help to the network as it establishes itself. Because parks have traditionally operated as independent entities, a major challenge in creating a multipark monitoring network is overcoming these tendencies. The ARCN parks are fortunate in sharing broad goals, providing a solid foundation for "thinking like a network."

1.2 Monitoring Goals and Strategies

The first section of this chapter addressed the broad goals of monitoring in the context set by the enabling legislation for national parks generally and for ARCN parks specifically. In this section, we first discuss the importance of inventory, monitoring, and research in stewarding natural resources. We then present our current thinking about goals and objectives for ARCN monitoring, summarize our progress to date, and describe the next steps in program development. This section is intended as a status report on the development of the overall ARCN program, including network-specific goals and objectives.

1.2.1 Role of Inventory, Monitoring, and Research in Resource Management

Monitoring is a central component of natural resource stewardship in the National Park Service and, in conjunction with natural resource inventories and research, provides the information needed for effective, science-based managerial decision-making and resource protection (Figure 1.3; see also Appendix 2). The NPS strategy to institutionalize inventory and monitoring throughout the agency consists of a framework (see Appendix 3) having three major components:

1. completion of 12 basic resource inventories upon which monitoring efforts can be based;

2. evaluation of alternative monitoring designs and strategies using a network of 11 experimental or "prototype" long-term ecological monitoring (LTEM) programs begun in 1992; and

3. implementation of operational monitoring of critical parameters (i.e., "vital signs") in approximately 270 parks with significant natural resources that have been grouped into 32 vital sign networks linked by geography and shared natural resource characteristics.

The network approach facilitates collaboration, information sharing, and economies of scale in natural resource monitoring and provides parks with a minimum infrastructure for initiating natural resource monitoring that can be built upon in the future. Nine of the 32 networks include one or two prototype LTEM programs, which were established as experiments to learn how to design scientifically credible and cost-effective monitoring programs in ecological settings of major importance to a number of NPS units. Because of higher funding and staffing levels, as well as U.S. Geological Survey (USGS) involvement and funding in program design and protocol development, the prototypes serve as "centers of excellence" that are able to do more extensive and in-depth monitoring and continue research and development work to benefit other parks.

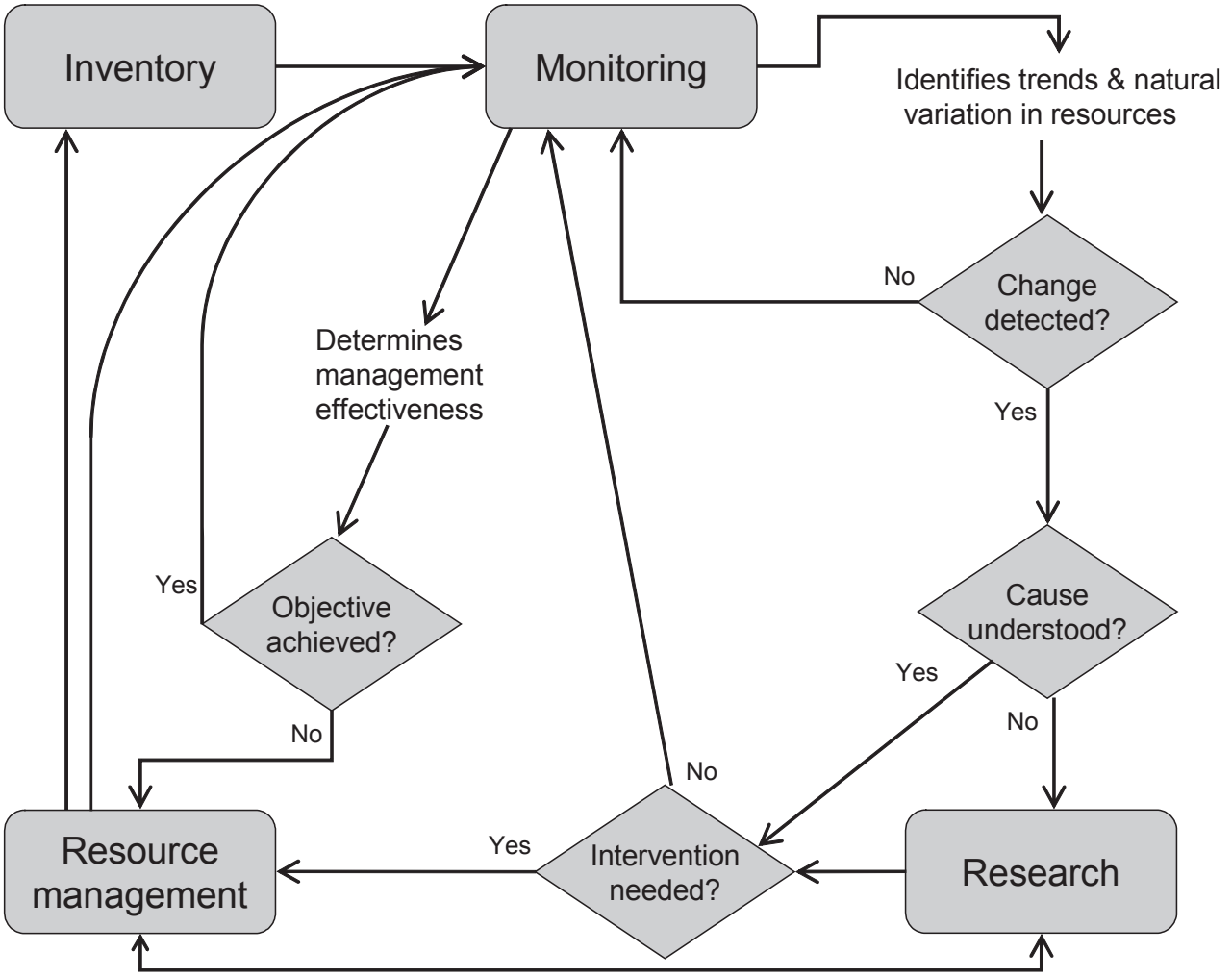


Figure 1.3: Relationships between monitoring, inventories, research, and natural resource management activities in national parks

1.2.2 Goals for Vital Signs Monitoring

Servicewide goals for vital signs monitoring for the National Park Service are as follows:

1. determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources;

2. provide early warning of abnormal conditions and impairment of selected resources to help develop effective mitigation measures and reduce costs of management;

3. provide data to improve understanding of the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments;

4. provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment; and

5. provide a means of measuring progress towards performance goals.

1.2.3 ARCN Program Focus

The ARCN recognizes the National Park Service Monitoring Program as a unique opportunity to advance our understanding of the ecosystems that encompass our network of parks. This understanding will come in the form of the monitoring data that are collected, analyzed, interpreted, and reported. Further, we recognize that while scientific work has been conducted in each of the network parks, this information needs to be incorporated with our monitoring efforts to improve our understanding of the functioning of ecosystems within our network. An understanding of ecosystem function is important because it allows us to fulfill the legislative mandate to manage parks in a manner that leaves them "unimpaired for the enjoyment of future generations." At the most basic level, we cannot evaluate appropriate ecosystem function when the bounds of natural variability are not known because we cannot identify when conditions are outside an expected range of variation. Similarly, in this situation, reliable identification of resource trends is also difficult.

We have specifically chosen to focus the ARCN monitoring program on general ecological function because our parks are relatively pristine and unstudied. In so doing, the ARCN program falls predominantly under servicewide goals #1, #3, and #4 (see section 1.2.2 above). These goals concern determining status and trends of ecosystem condition, understanding the dynamics of park ecosystems, and providing data to meet legal mandates. As mentioned in the previous section, ecological vital signs may occur at any level of ecological organization, thus several of the vital signs we monitor are of a large-scale ecological scope. While many long-term ecological monitoring programs have focused on anthropogenic causes of change, direct human effects tend to be more limited in our systems. However, scientists expect global climate changes to register first in northern climes; moreover, arctic and subarctic environments may be especially vulnerable to even slight shifts in temperature regimes (National Assessment Synthesis Team 2000). Because of their size, remote and protected status, and resultant near-pristine condition, few regions offer the environmental monitoring opportunity and promise that is possible in the arctic and subarctic parks of Alaska, even though there are zones of intensive disturbance, primarily due to mining activity. The relatively untouched nature of these vast parklands provides ARCN with important baselines to measure and evaluate the direction and magnitude of changes brought about by human influences on regional, national, and global scales.

The focus of Arctic Network is to build a unified picture of change across the ecosystems of the network. Specifically, we desire to:

- monitor ecosystems to detect change in ecological components,
- detect change in the relationships among those components, and
- minimize bias in measurements so that inference from our efforts is sound.

Our network is also highly committed to establishing the foundation of a monitoring program that will last in perpetuity. We anticipate that over time the information gained from the monitoring program will provide valuable data that will aid appropriate management decisions in the network parks. Thus management issues should be considered in the design of the monitoring program, yet those issues should not limit the program because management issues change. A well-designed monitoring program will be applicable to future issues, including ones that we cannot foresee.

1.2.4 The Integration of Water Quality with Monitoring

The ARCN parks have an extensive and diverse array of aquatic ecosystems that are relatively undisturbed by human activity. Key features of the landscape are the large freshwater lakes, seemingly endless miles of river networks, large expanses of wetlands, unique isolated spring systems, and large coastal lagoons. There are seven designated wild and scenic rivers in the ARCN. All of the rivers of the ARCN are free of man-made impoundments. There are a few glacial streams that originate in the Brooks Range and several spring-fed streams. Currently, there are no waters in ARCN listed as impaired under Section 303(d) of the Clean Water Act. The NPS Government Performance and Results Act (GPRA) goal for water resources requires that parks report on "impaired waters" as defined by section 303(d) of the Clean Water Act.

The ARCN has recognized from the beginning that the water resources of the network, whether in the form of precipitation or in water bodies, are a primary component of all the network ecosystems. Therefore, we have sought to fully integrate the monitoring of water into the framework of the entire Vital Signs Monitoring Program. Scoping workshops on Freshwater Ecosystems and Coastal Influenced Ecosystems were held in 2004 to help define monitoring objectives for water resources in the ARCN.

Ecosystems function as a continuum of land to water, rather than a line of demarcation. For any ecosystem, the abundance and distribution of water is probably one of the strongest driving forces of ecological change. For purposes of approaching water monitoring in a manageable context, we categorize our water resources into nonmoving water systems and moving water systems. In this context, the network has decided, first, to approach monitoring water quality by focusing not just on the chemical "health" of the water but also on the abundance and distribution of water on the landscape. Second, we consider our monitoring of these resources from remote-sensed options and from actual in situ monitoring.

For nonmoving water systems, ARCN will monitor shallow lakes, deep lakes and coastal lagoons (see Appendices 5 and 6 for details on some of these resources). Lakes and lagoons in the ARCN provide important habitat for aquatic primary producers, zooplankton, macroinvertebrates, and secondary consumers such as fish and waterfowl. Because these lakes are important to wildlife, subsistence users, and the scenic quality of the park, the NPS Organic Act and ANILCA mandate that their value and status be understood and protected. Monitoring lakes and lagoons is fundamental to understanding

the availability of aquatic habitats and to the biophysical characteristics of the ARCN park environment. Water quality is important to the survival, growth, and reproduction of aquatic organisms. The network is interested in the biota living in, near, and dependent on water-dominated parts of the landscape. We will monitor these systems with remote sensing technology and also physically visit some lakes for in situ measurements (see Protocol Development Summary, Lake Communities and Ecosystems and Lagoon Communities and Ecosystems in Appendix 15 for more detail).

Moving water systems represent the other large category of water resources that the network plans to incorporate into the Vital Signs Monitoring program. National Wild and Scenic Rivers in ARCN include the Noatak, Salmon, Kobuk, Alatna, John, Tinayguk, and North Fork of the Koyokuk rivers. The Noatak River, which originates in GAAR, flows into NOAT, where the river and its surrounding watershed have been designated as an internationally recognized Biosphere Reserve (UNESCO). As with lakes the network's strategy will be to measure water quality metrics at a few sites on select rivers on a rotating basis and use remote sensing for wider network inferences (see Appendix 15, Protocol Development Summary, Stream Communities and Ecosystems, for more detail).

1.2.5 The Integration of Air Quality with Monitoring

Under the Clean Air Act, park managers have a responsibility to protect air quality and related values from the adverse effects of air pollution. Protection of air quality in national parks requires knowledge about the origin, transport, and fate of air pollution as well as its impacts on resources. To be effective advocates for the protection of park air resources, NPS managers need to know the air pollutants of concern, existing levels of air pollutants in parks, park resources at risk, and the potential or actual impact on these resources. Through the efforts of park personnel, support office staff, and the NPS Air Resources Division, the NPS meets its clean air affirmative responsibilities by obtaining critical data and using the results in regulatory-related activities.

Within the NPS, air quality monitoring is managed nationally through participation in several established programs, each targeting a specific aspect of air quality. ARCN will use data from the newly established Bettles site to monitor air quality in the network. The network will monitor concentrations of compounds known to be generated by industrial activities and to act as pollutants (e.g., sulfate), in both wet and dry deposition. The network will also monitor composition and concentrations of particulates that affect visibility. Because ARCN is part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) program in the Air Resources Division, ozone concentrations will be monitored as well. The mercury levels in precipitation will be monitored as part of the Mercury Deposition Network.

1.2.6 ARCN Approach to Program Development

The ARCN has followed the NPS National Vital Signs Monitoring program guidance (http://science.nature.nps.gov/im/monitor/index.cfm) and developed the monitoring program in a stepwise fashion such that we implement sections of the program one at a time as we build the program. Obviously, it is impossible to monitor all attributes of our systems at once; thus our program will evolve over time as we document change and patterns of variation in our ecosystems. This evolution will be slow and adaptive in that we will evaluate the results of our monitoring at regular intervals (annually and at 5 and 10 year intervals). Our initial focus on baseline information will build the foundation of our understanding. Such an approach allows us to build a robust knowledge of ecosystem change and the patterns of variation in system resources.

To provide a starting point for the development of a monitoring plan, ARCN held a series of workshops. In 2004, ARCN held a Freshwater Ecosystems workshop and a Coastal-Influenced Ecosystems workshop, and in 2005 a Terrestrial Ecosystems workshop. These workshops developed strategies for monitoring particular ecosystem components. Strategies developed during these workshops served as the starting point for a fourth workshop (Land-Water-Air Linkages) held in January 2006. During the fourth workshop, participants worked on fitting the components of the ecosystem monitoring program together. The objectives developed during the workshops as well as well as compiled discussions and models from these workshops are available on line at http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm.

By the conclusion of Land-Water-Air Linkages workshop, we had received excellent input from invited experts who helped refine subject area objectives and approaches to the program. The most important feedback from participants concerned the need to integrate the program across disciplines if attaining a large-scale picture of ecosystem function was a primary goal of the program. This input caused the Technical Committee to recognize the corresponding importance of an integrated approach for designing a sampling strategy across vital signs that would be applicable across the entire network. Besides the myriad statistical advantages conferred by an integrated sample design, it would also allow us to appropriately link spatial scales of monitoring components for extensive and intensive objectives.

Given the above, we focused our work during 2006 on developing the framework of the monitoring program. We did this through regular Technical Committee meetings and through a series of focused working group meetings. Meetings that focused on particular aspects of the monitoring program included working groups on Weather and Climate, Vegetation Monitoring, and Bird Monitoring. Participation by the members of the Technical Committee in these working groups helped to ensure that the fundamental information parks need to gain from the monitoring program was appropriately represented.

During 2007 and spring 2008, the Technical Committee evaluated the products from the various workshops and worked on constructing the “short list” of vital signs and their implementation in a three-to-five-year time frame. This short list was approved by the ARCN Board of Directors. Further details of the development of the ARCN program appear in Appendix 4. The ARCN vital signs and their objectives appear in Table 1.1.

Table 1.1: Vital signs and objectives for the Arctic Network under the National Park Service Monitoring Framework. Table 1.1 includes only those vital signs slated for short-term implementation by ARCN within the next five years (see section 3.1).

National Ecological Monitoring Framework Level 3 Categories	ARCN Vital Sign	Objectives
Wet and Dry Deposition	Wet and Dry Deposition	• Establish baseline and long-term framework for monitoring concentrations of airborne Pb, Zn, Cd, Cu, Cr, Hg, Al, B, Fe, Ti, Total S, Total N, NO_3^-. • Calibrate elemental concentrations in *Hylocomium splendens* with concentrations in passive air sampler devices in order to be able to use moss concentrations to predict true deposition values on a landscape level. • Determine current levels of Hg in piscivorous freshwater fish and relate these levels to fish age and lipid content. • Link *Hylocomium splendens* tissue sampling with surveys of lichen community structure currently conducted by Vegetation vital sign. This permits a linkage between observed pollutant levels and changes in community structure. • Monitor changes in deposition of Pb, Cd, and Zn along the Red Dog haul road and link deposition levels with changes in sensitive nonvascular plant communities.
Air Contaminants	Air Quality	• Determine levels of air pollutants in parks and correlate to observed effects. • Identify and assess trends in air quality. • Determine compliance with National Ambient Air Quality Standards. • Provide data for the development and revision of national and regional air pollution control policies. • Provide data for atmospheric model development and evaluation. • Use information to inform the public about conditions/ trends in national parks • Determine which air pollutants in parks contribute to visibility impairment.
Weather and Climate	Climate	• Determine long and short term trends in climate by recording weather parameters at sites that capture the primary climate gradients within ARCN. • Provide monthly and annual summaries of climate data and identify any extreme climatic conditions.
	Snowpack	•Determine long-term patterns of snowpack extent, depth, and duration within ARCN parks by working with the USDA-Natural Resources Conservation Service (NRCS) to establish seasonal snowpack monitoring snow courses and aerial snow markers with in ARCN parks. • Determine long-term trends in total annual precipitation and daily accumulation patterns with high accuracy by working with the USDA-NRCS to establish recording precipitation gages in each ARCN park as part of the telemetry (SNOTEL) network.

Coastal/ Oceanographic Features and Processes	Coastal Erosion	• Determine long-term trends and variation of coastline accretion, erosion, and bluff retreat. • Determine long-term trends in area, volume, or mass fluxes at long-term monitoring sites along the coastline. • Detect changes in nearshore vegetation and landcover. • Link coastline monitoring sites and methods with those for the permafrost, and lagoons protocols.
Soil Function and Dynamics	Permafrost	• Detect permafrost related surface disturbance (e.g., thermokarst, solifluction) and determine long-term trends in degradation rates. • Identify and map permafrost-related features in ARCN parks and monitor trends in the distribution and abundance of these features. • Determine long-term temperature trends in existing boreholes gathered by researchers near ARCN parks.
Water Chemistry	Lagoon Communities and Ecosystems	• Determine seasonal and long-term trends in dissolved oxygen, salinity, conductivity, and pH on a semiannual basis in the coastal lagoons of CAKR. • Determine long-term trends in water level in each CAKR lagoon. • Determine long-term trends in nutrient concentrations (total N and total P), zooplankton biomass, and phytoplankton biomass in CAKR lagoons. • Detect changes in the hydrologic structure (open or closed to oceanic inputs) and surface area of CAKR coastal lagoons. • Identify the resident fish species and determine the contaminant load of key subsistence fish resources, and determine long-term trends in contaminant load for each identified species. • Identify subsistence activities in the lagoons and determine long-term trends in human use patterns.
	Lake Communities and Ecosystems	• Detect decadal scale changes in water level in shallow lakes. • Determine long-term trends in water level and surface water inputs and outputs of deep lakes. • Determine long-term trends in surface water temperature in shallow lakes. Determine long-term trends and seasonal variation in water temperature in deep lakes. • Determine long-term trends in turbidity, light penetration, pH, dissolved oxygen, specific conductivity, and nutrients in deep and shallow lakes. • Determine long-term trends in community composition of phytoplankton and resident fish in deep lakes.
	Stream Communities and Ecosystems	• Determine long-term trends in water temperature, pH, conductivity, dissolved oxygen, flow/stage/level, total N, total P, and chlorophyll a in selected wadable streams and large receiving rivers in ARCN parks. • Determine variability and long-term trends in species composition of macroinvertebrate and diatom communities in ARCN streams and rivers.

Birds	Landbirds	• Determine biennial long-term trends in density and frequency of occurrence of 6 common passerine species in selected sites across ARCN during the breeding season (June). • Determine biennial long-term trends in landbird species composition and distribution in selected sites across ARCN during the breeding season. • Improve understanding of breeding bird-habitat relationships and climatic changes on bird populations by correlating changes of 6 common passerine species to changes in habitat and climate variables.
	Yellow-billed Loons	• Determine triennial trends in occupancy of yellow-billed loons in selected sites during the breeding season (June). • Determine triennial status and trends in density estimates of yellow-billed loons in selected sites during the breeding season. • Monitor the types and levels of common contaminants (e.g., Hg, PCPs) present in yellow-billed loons in selected sites during the breeding season.
Mammals	Brown Bears	• Determine statistically defensible estimates of brown bear populations. • Develop models of brown bear presence and absence. • Incorporate human development metrics into occupancy modeling of brown bears. • Determine long-term trends in brown bear abundance in the ARCN.
	Caribou	• Determine long-term trends in caribou distribution and movements using GPS locations. • Determine long-term trends in physical condition of WAH caribou either by recording body weights and measurements (as outlined by CARMA protocol) or by stable isotope analysis. This monitoring question will be addressed cooperatively with the Alaska Department of Fish and Game. • Determine long-term trends in habitat condition by evaluating plant communities and forage availability. • Determine long-term trends in sex and age composition of WAH caribou. This monitoring question will be addressed cooperatively with the Alaska Department of Fish and Game.
	Dall's Sheep	• Determine status and long-term trends in Dall's sheep abundance across ARCN where there is available sheep habitat. • Determine status and trends in Dall's sheep sex and age composition at two areas of high management concern in ARCN. • Determine long-term trends in Dall's sheep diets in the Itkillik Preserve, GAAR, and the Baird Mountains, NOAT.
	Muskox	• Determine long-term trends in muskoxen sex and age composition and how they potentially relate to herd productivity. This monitoring question is currently being addressed cooperatively with the Alaska Department of Fish and Game.

Terrestrial Complex	Terrestrial Vegetation and Soils	• Determine long-term trends in plant community structure (species cover, diversity, biomass, tall shrub and tree density) at selected focal areas. • Determine long-term trends in active layer depth, organic layer thickness, and heavy metal inputs to soils. • Determine major trends in soil temperature.
Consumptive Use	Subsistence/Harvest	• Summarize harvest data from studies and databases maintained by the Alaska Department of Fish and Game, the Federal Subsistence Board, regional and local Native corporations and organizations, and other resource management entities. • Establish outreach venues whereby information about subsistence resources that is gathered by the ARCN is reported back to local residents.
Fire and Fuel Dynamics	Fire Extent and Severity	• Work with the NPS Fire Management Program in the Alaska Region to determine annual variation and long term trends in fire frequency, average fire size, maximum fire size, and total area affected by fire in ARCN parks. • Work with the NPS Fire Management Program in the Alaska Region to determine the trends and variability in burn severity on fires larger than 300 acres in ARCN. • Work with the NPS Fire Management Program in the Alaska Region to determine the effects of fire and burn severity on vegetation species composition (species and % cover), vegetation structure (tree diameters and heights), and ground cover (% cover and depth) of varying vegetation types.
Land Cover and Use	Terrestrial Landscape Patterns and Dynamics	• Develop landcover maps that can be integrated with other vital signs monitoring programs, specifically the Surface Water Dynamics and Distribution, Permafrost, Terrestrial Vegetation, Fire Extent and Severity, and various mammal and bird vital signs. • Determine trends in major indicators of vegetation phenology and productivity that can be tracked by remote sensing: maximum and seasonally integrated NDVI, date of green-up, date of senescence, total days of greenness; beginning and end of snow melt, and date of first total snow cover. • Determine landscape-scale trends in tree and shrub cover and height.

1.3 Overview of Arctic Network Ecosystems

The ARCN parks contain a broad array of the ecosystems typical of the subarctic (boreal forest or taiga) and arctic (tundra) biomes of northwestern North America. The boundary, or ecotone, between these two biomes is also represented in many different phases. Because these parks encompass large areas of mountainous terrain, including a major portion of the Brooks Range, they also include examples of virtually every type of alpine situation to be found in northern Alaska.

The nature of boreal and arctic ecosystems is often profoundly influenced by climate, especially weather, and to what degree the climate is maritime or continental. The climate of the ARCN parks varies from the extreme continentality of interior Alaska to the more maritime coastal areas of the parks bordering the Chukchi Sea. However, this maritime climate is somewhat modified by the presence of pack ice, which minimizes the moderating effect of the sea during the six to nine months it is

present. Thus winters, even in coastal areas, are intensely cold and have relatively moderate precipitation and snow cover.

The Arctic Network contains geomorphic and ecological features that are either unique or are found in very few of the nation's national parks. Permafrost, glaciers, granitic outcroppings, tors, pingos, taliks, springs, glacial-fed streams, coastal lagoons, large meandering rivers, maar lakes, lagoons, tundra lakes, and ponds are all parts of the northern Alaska landscape. A sampling of interesting features in ARCN parks includes the Lost Jim lava cone and other lava flows near Imuruk Lake, Serpentine Hot Springs, the coastal lagoons of BELA and CAKR, the sand dunes and Onion Portage in KOVA, and the Noatak River watershed in GAAR and NOAT. A summary of some of the ecological features that have been recognized by national and international programs can be found in Appendix 7.

1.3.1 Air and Climate

Although current air quality in ARCN parks is considered pristine by national standards, ARCN recognizes that air pollution from global and regional industrialization is a potential driver of ecosystem change in network parks. Air quality in ARCN parks is also affected by wildland fires. Air quality was designated a vital sign for the network because of its importance as both an anthropogenic and natural driver of change.

The climate of northwest Alaska is characterized by long, cold winters and cool, wet summers. The entire region receives continuous sunlight during the summer for at least 30 days. While the coastal area experiences a predominantly maritime climate, the interior has a more continental climate, with greater seasonal variations in temperatures and precipitation. Mean summer temperatures for the northwest region range from ~0 °C in the higher mountains to as high as 12 °C in the Mission Lowlands. Mean winter temperatures for the region range between –17 and –28 °C.

The coastal areas of ARCN typically receive regular high winds. The most extreme winds are associated with winter storms. Wind speeds are somewhat less in the interior than at the coast. Rainfall in this area usually increases as the summer months progress, typically peaking in August. Annual snowfall ranges from 114 cm in the southwest to more than 250 cm at higher elevations in the east. Freeze-up of surface waters generally occurs from early to mid October, and breakup occurs in mid to late May.

The climate of the Seward Peninsula and Bering Land Bridge National Preserve shows both maritime and continental influences. When surrounding marine waters are ice-free (mid June to early November), temperatures are moderate, humidity is high, and skies are typically cloudy, especially near the coast. Interior sections, even during this summer period, are somewhat drier and less cloudy and therefore have greater heat buildup during daytime hours and a greater daily temperature change. Summer is the wettest period.

1.3.2 Geology and Soils

The national parks, preserves, and monuments of ARCN contain

- most of the western half of Alaska's Brooks Range,
- both hilly and low terrain on the northern Seward Peninsula,
- broad lowlands draining major river systems approaching the coast of the Chukchi Sea, and
- coastal lowlands and bluffs.

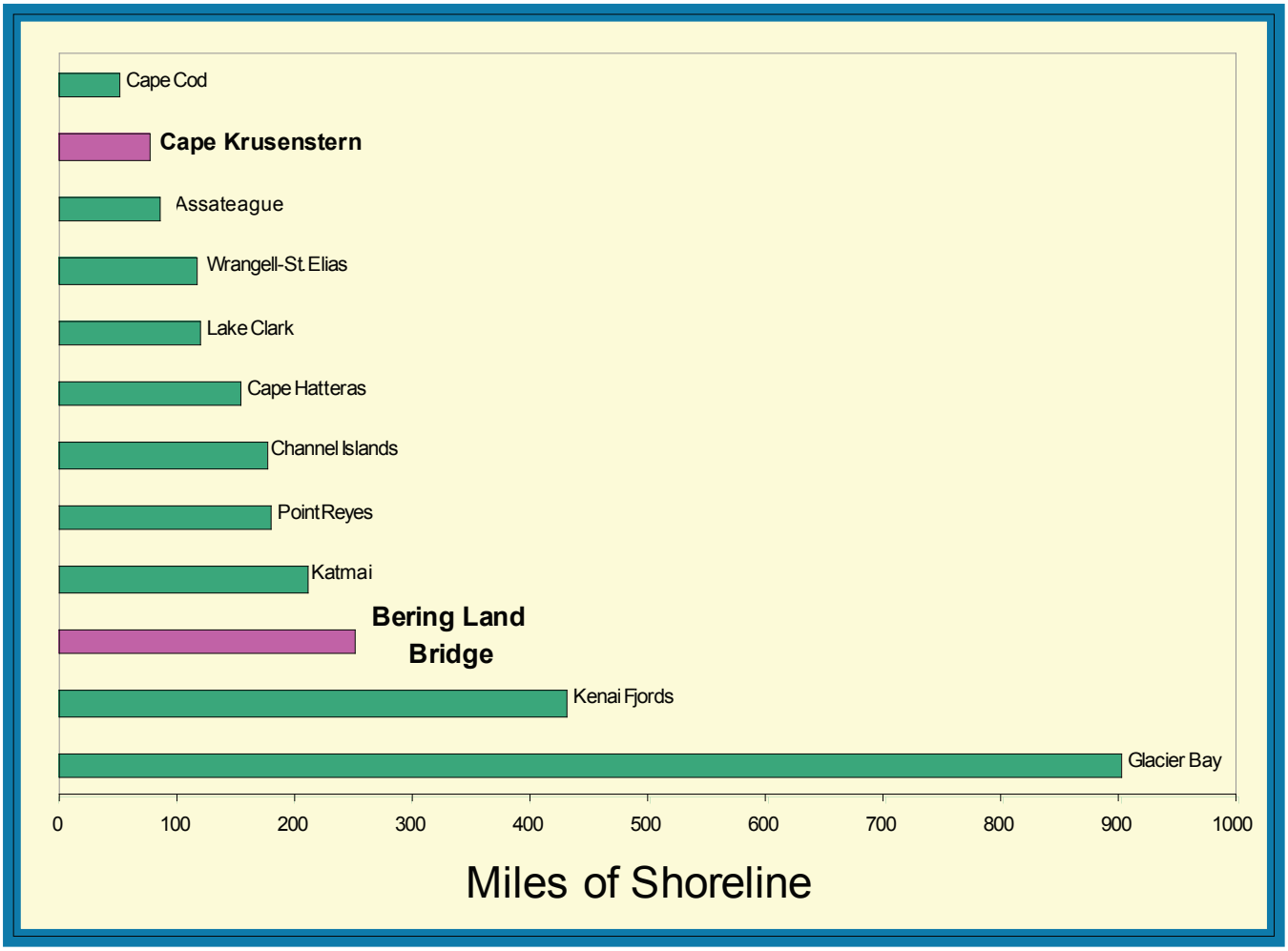


Figure 1.4: Miles of shoreline in ARCN in comparison to other NPS lands with coastal areas

Collectively, the processes responsible for the landforms, bedrock, and soils within ARCN are a complex suite spanning all three geologic eras, from the late Paleozoic to the present. Maritime, lacustrine, palustrine, lotic, aeolian, glacial, and volcanic and tectonic processes have all left prominent evidence of their influence throughout the ARCN region, with many interesting and often unique subtexts within each park unit.

Geologic formations within ARCN span much of Earth's geologic history. The southern flank of the Brooks Range includes sedimentary rock dating to the late Precambrian Era, while the volcanic deposits on the Seward Peninsula date to as recently as 1,000 years ago. The Brooks Range itself is a collection of subranges with igneous, sedimentary, and metamorphosed rocks added at different times, often through tectonic movement bringing terranes from distant origins. Many episodes of uplift, deformation, and intrusion have arranged the geologic substrata into several major synclines and anticlines with complex patterns of folding, fracturing, and thrust blocks. A comprehensive description of Brooks Range geology is beyond the scope of this report, but several noteworthy details may be found in Appendix 8 and help to illustrate its essential character.

Landforms and soils within Arctic Network units are mainly products of glacial, periglacial, fluvial, and eolian processes during the Cenozoic Era. Late Pleistocene glaciations exerted the most prominent, lasting influence throughout the region, by reshaping mountains formed by prior uplift, scouring broad valleys, and depositing boulder-to-silt-sized sediments through a variety of processes. Most of

the network is within the zone of continuous permafrost, which has major implications for hydrologic process and produces unique landforms and patterned ground.

Soils within ARCN are diverse and range from thin layers of coarse-grained material over bedrock to thick loamy and organic deposits. Heavily vegetated areas usually have an organic surface horizon and permafrost within a meter of the surface. Lowlands with a high density of lakes, estuaries, and freshwater wetlands, common in the western units, have thick layers of peat and fine-grained material. High-elevation soils are coarse-grained, with sparse alpine tundra vegetation and much exposed rock. Glacial and fluvial deposits near flowing water contain a mixture of grain sizes and are continually reorganized through hydrologic processes on streams and rivers.

1.3.3 Water Resources

The ARCN parks have an extensive and diverse array of freshwater ecosystems that are relatively undisturbed by human activity. Key features of the landscape are the large freshwater lakes, seemingly endless miles of river networks, large expanses of wetlands, unique isolated spring systems, and coastal lagoons. There are seven wild and scenic rivers in the ARCN, including the Noatak, Salmon, Kobuk, Alatna, John, Tinayguk, and North Fork of the Koyukuk. All of the rivers of ARCN are free-flowing and run clear most of the year. There are a few glacial streams that originate in the Brooks Range and several spring streams, including tributaries of the Reed River, Kugrak River, and Alatna River. Additional information on the freshwater resources of the ARCN may be found in Appendix 5.

Coastal ecosystems are a dominant feature within ARCN. Of the approximately 370 km (230 miles) of shoreline in ARCN, 120 km (75 miles) are in Cape Krusenstern National Monument and 250 km (155 miles) are in Bering Land Bridge National Preserve. The total shoreline, including bay and barrier island ecosystems surrounded by BELA, reaches approximately 450 km (280 miles). Together these parks make up the third largest block of coastline managed by the National Park Service (Figure 1.4). Details regarding the coastal ecosystem of the ARCN can be found in Appendix 6.

1.3.4 Terrestrial Biological Resources

Terrestrial Vegetation

A conspicuous feature of northwestern Alaska is treeline, or northward or coastward limit of conifer forests. The forest reaches its northwesternmost limit in North America in the vicinity of the eastern border of Cape Krusenstern National Monument and the western edge of the Noatak National Preserve (Young 1974), but treeline forms a complex and convoluted boundary through much of the three more eastern parks. A number of other organisms have ranges strongly associated with the presence of conifers: red squirrels, porcupines, certain typically understory plants, some tree-nesting birds, and some epiphytic lichens are examples.

Western and northwestern Alaska has long been recognized as having the richest array of vascular plants of any region in the circumpolar north (Hultén 1937, 1968). This is due to a number of factors, the most important of which are as follows. First, the area was never totally glaciated during the later Pleistocene. This means that populations of many species of plants were presumably able to survive in situ throughout the period that most of the rest of northern North America was repeatedly glaciated (e.g., Hopkins et al. 1982). During much of this time Alaska was connected directly with Asia by the Bering Land Bridge, allowing Asian species to colonize the area. A second important factor is the location of the area at a place where many of the major mountain ranges of the world converge. The

Brooks Range extends thousands of kilometers southward as part of the Rocky Mountains, while similar connected mountain ranges extend deep into central Asia. Thus, the Beringian region has probably long served as a "staging area" for alpine plants that are slowly colonizing the Arctic (Young 1971). Finally, the complex local topography and history of local glacial advance and retreat have created great variety in local habitats in terms of substrate, soils, microclimates, and disturbance. A listing of vascular plant species of concern may be found in Appendix 9.

Lichens and bryophytes are a conspicuous and ecologically important element in Alaska's arctic parks. Nonvascular plants are likely to represent 75 to 80% of ARCN's flora (Neitlich and Hasselbach 1998). In many cover types, these plants constitute a co-dominant portion of the biomass (Viereck et al. 1992, Swanson et al. 1985). Because of their fragility, ecological importance as forage, and high sensitivity to impacts from pollution (Nash 1988, Pegau 1968), the inventory and monitoring of lichens and bryophytes is a priority statewide.

Lichens are extremely fragile, slow-growing, and sensitive to air pollution (Richardson 1992). Because of slow growth and poor dispersal ability of lichens, attainment of late-successional terrestrial or epiphytic lichen communities can take up to 250 years in boreal and arctic environments (Black and Bliss 1978, Christiansen 1988). Lichens rely entirely on atmospheric inputs of water and nutrients for growth and have evolved to uptake atmospheric inputs readily without barriers of specialized tissue. Because of this, they are extremely susceptible to injury by S and N-based pollutants and acidification (McCune 1988, Richardson 1992).

Terrestrial Fauna

The monitoring of terrestrial fauna in ARCN focuses on birds and mammals. Most birds found in ARCN are summer nesters or migrants, with only about a dozen species overwintering within the network. There is evidence supporting the presence of 177 bird species in ARCN, with individual parks containing between 114 and 132 species (NPSpecies 2008; Appendix 11). Northwest Alaska provides important bird habitat because it is a major breeding area for migratory birds from as far away as Antarctica. This region encompasses a zone of interchange between the flyways of Asia and North America, and it includes important transitional habitat between boreal forest, coastal lands, and tundra.

More than 25 species of waterfowl inhabit the network's wetland areas. Four loon species are found in the Noatak drainage. The lagoons between Cape Krusenstern and Sheshalik are heavily used by migrating waterbirds. This area is also an important subsistence hunting area for waterfowl and an egg gathering area. It is an important fall staging area for thousands of geese, ducks, shorebirds, and gulls. Prime waterfowl nesting areas also occur in the extensive wet lowlands in the Kobuk Valley. In BELA and CAKR, the marine/estuarine habitat, together with extensive freshwater ponds and lakes, provides resting, nesting, feeding, and molting grounds for large populations of migrating geese, ducks, and shorebirds. The salty grasslands and marshes at the mouths of the Nugnugaluktuk, Pish, and Goodhope rivers and Cape Espenberg are especially important for waterfowl adapted to estuarine conditions.

Approximately 42 species of terrestrial mammals are believed to occur within the boundaries of ARCN (NPSpecies 2008; Appendix 12), ranging in size from the tiny shrew (Sorex yukonicus) to brown bears (*Ursus arctos*) and moose (*Alces alces*). Many northern mammal populations, such as lynx (*Lynx canadensis*), snowshoe hare (*Lepus americanus*), caribou (*Rangifer tarandus*), and lemmings (*Dicrostonyx* spp. and *Lemmus* spp.), are characterized by local, seasonal, or cyclic abundance. Distribution and abundance data are almost nonexistent except for animals hunted for subsistence.

Ecological and distribution information about northern mammals is scant compared to that of parks in the contiguous U.S., where small changes in species' ranges are being tracked at a fine scale as species move north and up in altitude, in a possible response to global climate change (Burns et al. 2003). Recent inventory and monitoring field inventories have demonstrated the paucity of knowledge of even the presence of the few species in the Arctic by providing vouchers for 12 mammal species not previously documented in one or more of the ARCN parks. By park unit, the number of new mammal species documented during inventory fieldwork from 2001 to 2003 were five in GAAR, two in NOAT, eight in KOVA, four in BELA, and six in CAKR. Additional literature searches have located more obscure documentation of an additional 10 species that were not previously thought present in one or more of the ARCN parks. Overall, recent efforts have increased the number of mammal species known to be present in ARCN parks by 19.

In addition to the terrestrial mammals, it is estimated that more than 13 species of marine mammals use the waters of the Chukchi Sea and Kotzebue Sound adjacent to Cape Krusenstern National Monument and Bering Land Bridge National Preserve. Both BELA and CAKR have mandates for the protection of marine mammal habitat (jurisdiction ends at the high-tide line). Polar bears and seals make dens or have haul-outs on the mainland, and many are frequently sighted in estuarine environments or small bays.

1.3.5 Human use

The dominant human activities in the ARCN can be characterized as industrial activity, subsistence activities, or recreation visitation.

ARCN has the largest lead and zinc mine in the world (Teck Cominco Red Dog Mine) located just outside the borders of Cape Krusenstern National Monument. Impacts of the mine to surrounding park ecosystems include ore spills, haul-road dust, dust palliatives, fuel spills, power plant and combustion engine emissions, and heavy metal accumulation. Teck Cominco operates an industrial road and an ore storage facility within the boundaries of CAKR. Additional mining and oil exploration and development has been proposed just north of NOAT.

The enabling legislation for ARCN parklands (ANILCA Public Law 96-487) provides for the traditional subsistence use of resources by 21 neighboring and resident zone communities. Environmental quality and game and fish populations are important to local communities and must be managed, protected, and preserved. Resources that may be harvested include but are not limited to: fish, wildlife, timber (for subsistence cabins and firewood), water, and berries and other edible plant material. Also, Noatak National Preserve, Bering Land Bridge National Preserve, and the preserve portions of Gates of the Arctic are open to sport hunting. We expect that access to the parks will improve over time and status and condition of harvested resources will need to be monitored.

Recreational visitors to ARCN parks can have unexpected and significant effects on ecosystems and ecosystem processes. Information about the spatial and temporal distribution of visitor use can help managers identify potential recreation-related threats to the natural resources. In ARCN parks, documentation of visitor impacts is difficult because of the remoteness of ARCN's nearly 19 million acres of parklands and the dispersed presence of visitors at any one time. Also, not all visitors stop at designated visitor centers in Fairbanks, Nome, Kotzebue, Bettles, Anaktuvuk Pass, or Coldfoot before entering the parks. Most visitors access these parks by commercial float plane or by walking in from resident zone communities or the Dalton Highway. No rigorous methods or protocols exist to determine park visitation.

1.3.6 Landscape

Many of the interesting landscape dynamics that occur in the ARCN have been summarized in our description of Geology and Soils (section 1.3.2) and Terrestrial Biological Resources (section 1.3.4). One landscape level disturbance not previously discussed is the fire regime of the Arctic Network. Climate, terrain, and vegetation strongly influence the occurrence and extent of fires within ARCN. The subarctic boreal forests and low arctic tundra biomes are subject to periodic fires. Over the last 50 years, greater than 1.2 million acres have burned within and around ARCN park units (NPS Fire Records 1956–2005). The frequency and extent of the fires is variable within the park units (Table 1.2). Fires can exert landscape-scale controls on vegetation structure and composition, permafrost dynamics, nutrient cycling, carbon loss/gain, primary productivity, and biodiversity (Racine et al. 2004).

Table 1.2: Acreage burned in and around ARCN from 1956–2005. Data include all fires that have started within the park units, although not all acres are contained within the administrative boundary of the units. Fire information is based on NPS fire records.

	BELA	CAKR	GAAR	KOVA	NOAT	Total
Total acres	289,670	4,285	314,215	202,158	430,405	1,240,732
Average acres/year	5,793	86	6,284	4,043	8,608	24,815
Total # fires	36	5	145	60	135	364
Average # fires/year	0.7	0.1	2.9	1.2	2.7	
Average fire size (acres)	7,828	857	2,228	3,485	3,188	

1.4 Resource Concerns for ARCN

For the monitoring program to be relevant, it must provide data useful to protection of park resources, now and in the future. To ensure relevancy over time, the monitoring program needs to address broad concerns and not be limited to the issues of today, because the issues will change (McDonald et al. 1998).

The national program has created a NPS Ecological Monitoring Framework that is a systems-based, hierarchical, organizational tool for promoting communication, collaboration, and coordination among parks, networks, programs, and agencies involved in ecological monitoring. Although Arctic Network Parks are relatively pristine, there are a myriad of resource concerns, and many of these are shared throughout the national Inventory and Monitoring Network (Table 1.3).

We found the resource preservation concerns of all five parks were similar. We therefore present the broad-scale concerns affecting the network parks.

1.4.1 Broad-Scale Concerns of all Network Parks

The resource protection concerns of Arctic Network parks fall into two main categories:

1. Concerns stemming from global industrialization. These include climate change, long-distance air pollution, species additions and losses (biodiversity), and effects on migratory birds and fish when they are not present in network parks.

2. Concerns relating to human activities and development in the parks and neighboring regions.

We discuss each of these categories of concern in the following sections. The concerns are not independent from one another, and relationships among the concerns are discussed in Chapter 2, which includes a conceptual model of the resource preservation concerns. In this section, we provide a general overview of the concerns.

Global Industrialization

In 1997, Vitousek et al. (1997) presented a short but sobering picture of human domination of the earth's ecosystems. Human population growth, and growth in use of resources by humanity, is maintained by agriculture, industry, fishing, and international commerce. These activities change the earth's surface with two major effects:

1. changes in major biogeochemical cycles, and

2. adding or removing species.

These alterations to the functioning of the Earth's ecosystems are driving global climatic change and the irretrievable loss of biological diversity. This conceptual model of humanity's role in the earth's ecosystem, circa 2000, provides a general context for considering the resource protection concerns of Arctic Network parks. Although remote and presumably pristine, these parks are surrounded by a world that is changing so quickly due to human activities that a broad perspective is needed.

Climate Change: Overall climate warming trends documented elsewhere are also being detected in much of Alaska (Juday 2000). Dramatic melting of snow and ice in Alaska has been occurring over the past few decades due to warmer climate. Warming has caused thawing of permafrost and permanent snowfields as well as a reduction in seasonal snowfall and shorter seasons of river, lake, and sea ice. Continued warming will cause further reductions in snow cover and permafrost and a corresponding shift in landscape processes. Changes to the network park ecosystems due to climate change include decreases in useable moisture for plant growth, increases in fire occurrence and intensity, thawing of permafrost layers reducing slope stability, changes in glaciers, and changes in the rate and extent of coastal erosion.

Many of these changes could contribute to a shift in vegetative community types. Models predict community shifts from tundra to forest, black spruce to deciduous forest, and forest to grasslands, bogs, and wetlands (Starfield and Chapin 1996). Warmer temperatures will result in a longer growing season, and changes in precipitation and community types will result in changes in vertebrate distribution and habitat use. Riparian areas, wetlands, dry habitats, and areas with discontinuous permafrost are the most vulnerable to warming temperatures and will provide the best signals of change (Weller and Lange 1999).

One of the most important changes that could occur in network parks from climate change is a change in the wildfire regime. Wildfire is one of the most influential environmental processes in tundra and taiga ecosystems and is a dominant process in Arctic Network parks. The current vegetation mosaic and habitat diversity in these areas reflect the complex effects of fires that have occurred over the past. The frequency and intensity of wildland fires are dependent on long-term climate conditions. There has been an increase in the number of fire starts and acres burned as Alaska experiences a climate warming and drying trend. This has caused landscape-scale changes to vegetation, soils, and underlying permafrost, creating a dynamic mosaic within the ecosystem.

Table 1.3: Potential resource concerns in the context of the National Ecological Monitoring Framework (X indicates a potential resource concern for the park, preserve, or monument, – indicates low likelihood of a resource concern for the park, preserve, or monument). Specific concerns of high pertinence to any or all parks in the Arctic Network are listed in the last column.

NATIONAL ECOLOGICAL MONITORING FRAMEWORK			POTENTIAL RESOURCE CONCERNS					SPECIFIC CONCERNS
Level 1 Category	**Level 2 Category**	**Level 3 Category**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**	**Any or All Parks**
Air and Climate	Air Quality	Ozone	–	–	–	–	–	–
		Wet and Dry Deposition	X	X	X	X	X	Persistent Organic Pollutants (POPs), Metals, Nitrates, Sulfates
		Visibility and Particulate Matter	X	X	X	X	X	Arctic Haze
		Air Contaminants	X	X	X	X	X	Arctic Haze
	Weather and Climate	Weather and Climate (Climate Change)	X	X	X	X	X	Climate Change
Geology and Soils	Geomorphology	Windblown Features and Processes	X	X	X	X	X	Kobuk Dunes Ecosystem
		Glacial Features and Processes	–	–	X	–	X	Glacier Retreat
		Hillslope Features and Processes	X	X	X	X	X	Erosion, Solifluction
		Coastal/Oceanographic Features and Processes	X	X	–	–	–	Sea Ice
		Marine Features and Processes	X	X	–	–	–	Prevailing Currents, Marine–derived Food Sources
		Stream/River Channel Characteristics	X	X	X	X	X	
		Lake Features and Processes	X	X	X	X	X	Thermokarst, Drainage, Eutrophication, Water Quality
	Subsurface Geologic Processes	Geothermal Features and Processes	X	–	X	–	–	Unique Microhabitats, Human Use/Development
		Cave/Karst Features and Processes	–	–	–	–	–	
		Volcanic Features and Processes	–	–	–	–	–	
		Seismic Activity	–	–	–	–	–	
	Soil Quality	Soil Function and Dynamics	X	X	X	X	X	Thermokarst, Nutrient Cycling/ Sequestration
	Paleontology	Paleontology	X	X	X	X	X	Paleoresource Protection
Water	Hydrology	Groundwater Dynamics	X	X	X	X	X	Permafrost, Groundwater Dynamics
		Surface Water Dynamics	X	X	X	X	X	Permafrost, Surface Water Dynamics
		Marine Hydrology	X	X	–	–	–	
	Water Quality	Water Chemistry	X	X	X	X	X	Eutrophication, Water Quality
		Nutrient Dynamics	X	X	X	X	X	Nutrient Dynamics
		Toxics	–	X	–	–	X	Pollution, Human Waste/ Chemical Spills
		Microorganisms	X	X	X	X	X	
		Aquatic Macroinvertebrates and Algae	X	X	X	X	X	

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NATIONAL ECOLOGICAL MONITORING FRAMEWORK			POTENTIAL RESOURCE CONCERNS					SPECIFIC CONCERNS
Level 1 Category	**Level 2 Category**	**Level 3 Category**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**	**Any or All Parks**
Biological Integrity	Invasive Species	Invasive/Exotic Plants	–	X	X	–	–	
		Invasive/Exotic Animals	–	–	–	–	–	
	Infestations and Disease	Insect Pests	X	X	X	X	X	Vectors, Transmission Mechanics, Outbreaks
		Plant Diseases	X	X	X	X	X	Vectors, Transmission Mechanics, Outbreaks
		Animal Diseases	X	X	X	X	X	Vectors, Transmission Mechanics, Outbreaks
	Focal Species or Communities	Marine Communities	–	–	–	–	–	
		Intertidal Communities	X	X	–	–	–	
		Estuarine Communities	X	X	–	–	–	
		Wetland Communities	X	X	X	X	X	Lagoon Ecology
		Riparian Communities	X	X	X	X	X	
		Freshwater Communities	X	X	X	X	X	
		Sparsely Vegetated Communities	X	X	X	X	X	Rare, Unique Microhabitats, Distribution/Area
		Cave Communities	–	–	–	–	–	
		Desert Communities	–	–	–	–	–	
		Grassland/Herbaceous Communities	X	X	X	X	X	
		Shrubland Communities	X	X	X	X	X	
		Forest/Woodland Communities	X	–	X	X	X	
		Marine Invertebrates	–	–	–	–	–	
		Freshwater Invertebrates	X	X	X	X	X	
		Terrestrial Invertebrates	X	X	X	X	X	
		Fishes	X	X	X	X	X	Resident Fish, Subsistence
		Amphibians and Reptiles	–	–	–	–	–	
		Birds	X	X	X	X	X	
		Mammals	X	X	X	X	X	
		Vegetation Complex	X	X	X	X	X	
		Terrestrial Complex	X	X	X	X	X	
	At-risk Biota	Threatened and Endangered Species and Communities	X	X	X	X	X	
Human Use	Point Source Human Effects	Point Source Human Effects	–	X	X	–	X	Mining/Industrial Pollution, Human Waste, All Terrain Vehicles, Trash
	Nonpoint Source Human Effects	Nonpoint Source Human Effects	X	X	X	X	X	Arctic Haze, Industrial Pollution, Bioaccumulation
	Consumptive Use	Consumptive Use	X	X	X	X	X	
	Visitor and Recreation Use	Visitor Use	X	X	X	X	X	
	Cultural Landscapes	Cultural Landscapes	X	X	X	X	X	

(continued on next page)

NATIONAL ECOLOGICAL MONITORING FRAMEWORK			POTENTIAL RESOURCE CONCERNS					SPECIFIC CONCERNS
Level 1 Category	Level 2 Category	Level 3 Category	BELA	CAKR	GAAR	KOVA	NOAT	Any or All Parks
Landscapes (Ecosystem Pattern and Processes)	Fire and Fuel Dynamics	Fire and Fuel Dynamics	X	X	X	X	X	Habitat, Thermokarst
	Landscape Dynamics	Land Cover and Use	X	X	X	X	X	Development, National Petroleum Reserve Alaska, Coal, Oil, Mining, RS 2477 Roads, Treeline, Plant Community Distribution
	Extreme Disturbance Events	Extreme Disturbance Events	X	X	X	X	X	Fire, Coastal Erosion
	Soundscape	Soundscape	–	–	X	–	–	
	Viewscape	Viewscape/Dark Night Sky	–	–	–	–	–	
	Nutrient Dynamics	Nutrient Dynamics	X	X	X	X	X	Carbon Sequestration/Release
	Energy Flow	Primary Production	X	X	X	X	X	

Little is known about the management implications of a potential increase in the burn cycles in interior Alaska. Alaska currently uses Canadian fire behavior models to determine the intensity and conditions under which fire will burn. Ecosystem level information would be useful in developing an Alaska-based model for predicting wildland fire behavior. Understanding the role fire plays in soils (permafrost), vegetative succession, animal movements, erosion, and tree line movement will better prepare fire managers for fire season decision-making.

One of the more dramatic effects of a warming Arctic is a strong negative trend in the summertime arctic sea ice extent. Sea ice extent was at an all-time low in 2007, the second lowest sea ice extent record is for 2008, and the third lowest was the 2006 season. Sea ice is a major component driving the state of coastal park ecosystems. Sea ice can have a large impact on predator-prey relationships of both sea and terrestrial mammals as well as on subsistence activities. Sea ice affects broad-scale climatic factors, including basic ranges of temperature and precipitation as well as feedback loops driven by prevailing weather patterns, cloudiness, and albedo. Changes in broad-scale climatic factors in turn influence the spatial arrangement of animals and plants.

The extent of sea ice also influences coastal erosion processes by altering the timing and the extent to which the coastline is exposed to waves and ocean currents. Shoreline erosion is becoming a severe issue to communities in the Bering Strait and Chukchi Sea and may adversely affect the stability of unique coastal habitats including lagoons, estuaries, and near-shore riverbanks. From a monitoring perspective it may be important to quantify the variability of these processes and to better understand their consequences to park resource values, particularly since they are demonstrably sensitive to climate trends.

Long-distance Air Pollution: Long-distance transport of air pollutants is another major concern of Arctic Network parks stemming from global industrialization. Asiatic and global long-range pollutants deliver significant amounts of airborne contaminants each year to the North American Arctic. Much of this pollution comes in the form of arctic haze, a combination of sulfate, particulate matter,

nitrate, heavy metals, black carbon, and other minor constituents. Other global pollutants include mercury and semivolatile organic compounds. The ecological effects of these particular air pollutants in Alaska ecosystems are currently unknown. The addition of the air quality station at Bettles, Alaska, by the Arctic Network in September 2008 will provide a substantial amount of new information to park managers about this concern.

Effects on Biodiversity: The potential for non-native invasive species of plants and animals to become established in network parks is another concern stemming from global industrialization. Species additions and losses due to the expansion of human commerce around the globe is one of the biggest ecological problems worldwide, and even remote Alaska parks need to be aware of this potential problem.

Effects on Migratory Species When They are Not in the Parks: All network parks provide habitat for migratory birds and fish. Industrialization elsewhere on the globe could adversely impact migratory birds of network parks. Most of the bird species that breed in network parks are migrants who spend most of the year elsewhere in North, Central, or South America; Asia; or at sea in the North Pacific. One species, the arctic warbler, winters in southeast Asia, and another, the northern wheatear, winters in central Africa. While global industrialization may not affect the breeding habitat of these species in network parks, the same may not be true of their migratory paths or wintering habitats. Adverse impacts could include reduced overwinter survivorship and increased contaminant levels.

Similarly, global industrialization could affect the anadromous fish of network parks. Arctic char and salmon that spawn and rear young in the streams and rivers of network parks spend most of their lives at sea. Changes in the oceanic environment due to global industrialization could affect the number of fish returning to network parks. Fish are an important subsistence resource and transport marine nutrients into terrestrial ecosystems. Changes in fish populations could affect ecosystem processes and subsistence users in some areas of network parks.

In addition to protecting important habitat for reproduction and overwintering, it is important that Arctic Network parks track and call attention to population changes in migratory species. Providing information on status and trends of migratory species in protected habitats can help influence conservation actions elsewhere.

Human Activities and Development In and Near Network Parks

Activities in and near the parks are another source of resource protection concern for park managers. These include consumptive uses of park resources (primarily fish and wildlife), recreational uses, private land development in and near parks, and resource management.

Consumptive Uses: This category addresses consumptive uses of fish and wildlife—a major issue for all ANILCA parks due to the underlying philosophy of this key piece of legislation. ANILCA specifically allowed for consumptive use of wildlife resources (i.e., hunting, trapping, and fishing) within national preserves and for subsistence uses by local rural residents in both national parks and preserves. ANILCA also requires the National Park Service, in cooperation with the Alaska Department of Fish and Game, to manage for "healthy" populations of fish and wildlife species within national preserves and "natural and healthy" populations in national parks.

Historically, the Alaska Department of Fish and Game managed both sport and subsistence harvests of wildlife within network parks. In 1990, however, the State of Alaska was ruled to be out of compliance with the subsistence sections of ANILCA, and responsibilities for managing subsistence harvest of wildlife within national parks were delegated to the parks. Under the current legal situation, the

Alaska Board of Game establishes regulations for hunting and fishing seasons, harvest limits, and methods and means for nonfederally qualified subsistence users in the national preserves. The Federal Subsistence Board establishes regulations for hunting and fishing seasons and harvest for federally qualified subsistence users in parks and preserves.

The complexity of the fish and wildlife management scheme requires current, accurate information on fish and wildlife populations, their habitat needs, and prey base for effective decision-making. To ensure good stewardship and consistency with national park purposes and management policies of fish and wildlife resources, basic population and distribution information, harvest tracking, and consistent monitoring are essential. These data allow managers to determine if management objectives for the populations are being met. With information of this type, managers can propose any necessary changes to state and federal harvest regulations to protect resources from excessive harvest.

Most of the concerns related to fish and wildlife management in network parks have to do with large mammals subject to human harvest for subsistence and for sport. Management of consumptive uses of fish is also important in the network. The heart of the most difficult management issues regarding consumptive uses of fish and wildlife lies in the difference between management objectives among agencies. Alaska, like most states, manages for sustained yield of fish and wildlife species. Under the sustained yield paradigm, harvested species are more valuable than nonharvested species or predators of the harvested species. This paradigm directly contradicts NPS policy to preserve fundamental biological and physical processes, as well as individual species, features, and plant and animal communities. The NPS maintains, as parts of parks, all native plants and animals in their natural abundance (NPS management policies 2001, 4.1).

Fish and wildlife management concerns of network parks are not limited to consumptive uses. Also of concern are effects on wildlife species stemming from park visitation. These concerns include habituation of wildlife species, particularly those species that readily adapt to human presence. A related concern is bear-human interactions. These concerns require active management on the part of parks to prevent and minimize negative interactions and creation of nuisances involving wildlife.

Recreational Use: Increased visitation presents three resource concerns. The visitors themselves impact resources in ways we have yet to understand and quantify. As visitation increases there is pressure to provide new trails and access opportunities into these large wilderness parks. There is also a very strong push to make these very large wilderness parks more accessible by ground transportation. Finally, nonlocal recreational visitors may impact local rural residents and how they recreate and subsist in these parks. Changes in recreational activity have cultural ramifications in the region.

Private Land Development In and Near Network Parks: Private land development is a major concern for all of the Arctic Network parks. The western Brooks Range is rich in mineral deposits and the North Slope of Alaska has substantial oil and gas deposits (see Network Maps). The Teck Cominco Red Dog Mine, the largest lead and zinc mine in the world, is located just outside the borders of Cape Krusenstern National Monument, and the mine operates a road and ore storage facility within the borders of Cape Krusenstern. Active exploration and assessment of gold deposits is occurring near the borders of all five parks. There is also substantial interest in the coal deposits to the north of Cape Krusenstern. Exploratory drilling for gas and oil is occurring to the north of both Noatak National Preserve and Gates of the Arctic National Park and Preserve. These activities could have substantial impacts on the environment in the ARCN.

Resource Management: Resource management is a general category that includes a variety of activities in and near parks. These are activities of the NPS and other land and resource managers (e.g., the

Alaska Department of Fish and Game); these activities include implementation of plans to protect, develop, or manage resources.

One of the most significant resource management activities of concern to network parks is management of access. Access is probably the largest underlying issue and one that is related to many of the other concerns. Transportation and access into all five parks is largely undeveloped by current standards. ANILCA requires that the parks established under its authority provide adequate and feasible access to inholdings within the parks. Access to inholdings and mineral development sites can be challenging to resolve in a manner consistent with other uses and values of the park.

Managing access to prevent resource degradation is a major challenge for all network parks. This challenge is complicated in ARCN parks because there is no way to count visitors as they enter the park or to know where they are going. This situation makes it very difficult to quantify and predict visitor impacts upon resources. Impacts from access can include habitat loss and fragmentation, creation of edge effects, impediment to movement corridors or disturbance of normal activity patterns of wildlife, changes in hydrologic regimes, introduction of exotic plants, introduction of contaminants, and air and water quality degradation.

Like other ANILCA parks, ARCN parks are required to provide adequate and feasible access to inholders and subsistence users. Access onto park-managed lands is usually accomplished with all-terrain vehicles or snowmobiles.

All-terrain vehicles (ATVs) are ubiquitous in the 21 neighboring and resident zone communities of the Arctic Network parks. All-terrain vehicle use may cause adverse impacts to park lands, including shifts in species composition, decreased frequency and cover of plant species, thermokarsting, erosion, and increased trail width (Cook 1990). Of particular concern are trails that traverse wetlands, permafrost soils, and steep slopes. Research in other arctic areas shows that sites will continue to degrade if the organic mat has been destroyed, even if use ceases (Rickard and Brown 1974, Sparrow et al. 1978, Walker et al. 1987).

In the winter, inholders and subsistence users may use snowmobiles (also known as snowmachines) to access Arctic Network parks. Snowmachine noise and traffic may impact resident wildlife species at a time of year when forage availability is low and energy demands are high. Snowmachines are becoming more powerful and reliable. As a result, snowmachines are accessing progressively remoter areas

1.4.2 Looking to the Future

If we have analyzed the current resource preservation concerns of network parks correctly, we will be in a position to design a long-term monitoring program to provide information that will help current and future park managers preserve resources. But what if the issues change? Is there something obvious we have overlooked? For the program to be robust to future information needs, we need to put some effort into thinking about what future issues might be. By taking a long view, we can build a program that will work despite our uncertainty about future events.

Vitousek et al. (1997) suggested that human changes in the earth's ecosystems were of two broad types: changes in biogeochemical cycles and adding or removing species. A recent analysis by the National Academy of Sciences reached similar conclusions (National Academy of Sciences 2001). They urged efforts to understand the relationship between biodiversity and ecosystem functioning, which they felt would be of great practical significance.

In terms of the current resource concerns of Arctic Network parks, the perspective provided by these strategic analyses of global issues suggests that we should also be thinking about the potential for invasive species to become established in these parks. The question of invasive species is an aspect of an overall biodiversity question and suggests that continuing to gather information about species present in the parks is important. The role of climate change in facilitating introduction of invasive species also needs to be kept in mind.

With increasing population growth and demand for mineral resources, one can picture visitation and demand for services for park visitors conflicting with demand for private land development within the parks. Increases in either visitation or private land development could interfere with consumptive uses of fish and wildlife, especially subsistence uses. Providing future resource managers with information that could help address these converging trajectories of increasing human uses would be a valuable contribution of the monitoring program. As the selection of monitoring attributes for the Arctic Network program continues, we should continually ask ourselves, "How will the data help with these types of concerns?"

1.5 Past and Current Monitoring in ARCN Parks and Their Neighbors

The Natural Resource Challenge (NRC) represents the first service-wide effort to fund long-term monitoring. While the Inventory and Monitoring portion of the NRC is an opportunity to establish new facets of an ecological monitoring program, it is important to examine past and current monitoring conducted by parks and their neighbors also. Doing so will allow us to build upon those efforts and gain the maximum amount of understanding of park natural resources.

No task could be more important to developing a monitoring program than a thorough review of existing literature and prior inventory and monitoring efforts. The Arctic Network has made progress in assembling a knowledge base that will be valuable in designing a monitoring plan. Our data mining efforts have focused on two fronts:

1. assembling a natural resource bibliography, and

2. identifying sources of high-quality inventory and monitoring data and collaborations.

In 2004 we made great progress on populating NatureBib, the national Inventory and Monitoring bibliography, with publications about the arctic parks ecosystem. This effort has yielded thousands of references that will be a significant resource on the arctic biome. We also began data mining efforts with the goal of identifying present and historical resource inventories and monitoring efforts. We expect this effort will continue through the life of the program. Thus far, we have made a preliminary list of agencies, programs, existing ecological inventories, and long-term studies that may be of value to ARCN. This list is not exhaustive but highlights prominent, large-scale, and relevant data resources. The matrix in Table 1.4 also hints at significant data gaps for ARCN.

Details about the datasets used to generate the matrix in Table 1.4 are described in Appendix 13, including their administrative agency, website URL, data categories, level two vital sign designation, and a summary.

Much of the knowledge of how arctic terrestrial and aquatic ecosystems respond to change has been generated at large, long-term research stations that facilitate multi- and interdisciplinary science (e.g., Toolik Lake Long Term Ecological Research Site). As the Arctic continues to undergo dramatic

changes in climate and human land use, there is a paramount need to further understand how arctic ecosystems outside these long-term research stations will be impacted and how these changes will influence the future state of the Arctic and Earth systems. Many integrated monitoring and research networks are already in place or under development throughout the Arctic. Throughout the last decade, there have been a number of major international research and monitoring initiatives of significance to ARCN. In order for ARCN to develop a successful monitoring program, participation in national and international initiatives such as the International Polar Year (IPY) and the National Ecological Observatory Network (NEON) High Latitude Ecological Observatory (HLEO) will be of the utmost importance. Appendix 14 summarizes some of the most relevant science initiatives taking place in the Arctic.

Table 1.4: Number of major inventory and monitoring efforts in ARCN

Category	BELA	CAKR	GAAR	KOVA	NOAT
Air Chemistry	1	1			
Amphibians	1	1	1	1	1
At-Risk Populations/Biota	1	1			
Baseline/Long-Term Plots					
Biodiversity	2	2	2	2	2
Biogeochemical Processes	1				
Birds	5	5	5	5	5
Climate/Weather/Climate Change	3	2	3	2	3
Contaminants	1	2			
Disease/Parasites	1	1	1	1	1
Disturbance/Fragmentation					
Fire	3	2	3	3	3
Fish	3	3	3	3	3
Food Webs/Trophic Interactions					
Fungi					
Geology	1	1			
Geomorphology/Landform Processes					
Geographic Information System (GIS) Datasets	1	1	1	1	1
Glacial Features and Processes					
Groundwater Dynamics					
Hillslope Features and Processes					
Human Use Activities/Subsistence	1				
Ice Processes and Dynamics/Snow					
Invasive Species	1	1	1	1	1
Invertebrates					
Lagoons					
Lake Features and Processes	2	2	2	2	2
Land Use/Landcover Change	6	7	4	6	4
Large Mammals	4	5	5	4	5
Management Concern	3	3	2	2	2
Marine Features and Processes					
Marine Hydrology					
Marine Mammals					
Microorganisms/Microbes					
Nonvascular Plants					
Nutrient Dynamics/Cycling					
Paleoecology/Paleontology					
Permafrost					
Phenology					
Primary Production					
Remote Sensing					
Small Mammals	3	3	3	3	3
Soils (Chemistry, Erosion)	1	3	1		
Stream/River Channel Characteristics	2	2	2	2	2
Surface Water Dynamics					
Vascular Plants	2	2	3	2	3
Vegetation (General)	3	4	3	3	3
Visitor Usage					
Water Quality/Biota/Chemistry	1	1	1	2	1
Wetland (Distribution and Abundance)	3	3	3	4	3
Windblown Features and Processes	1				

Chapter 2
Conceptual Ecosystem Models

"Everything should be made as simple as possible, but not one bit simpler."

Albert Einstein

2.1 Introduction: Framework for Conceptual Model Development

Conceptual ecosystem models are an excellent way to convey information about complex ecosystems to resource managers and the public. Conceptual models can also be used to help describe our current understanding of anthropogenic sources of disturbance to those ecosystems and the processes or components of the ecosystem impacted by that disturbance (Jenkins et al. 2003). Conceptual models should:

1. describe our current understanding of system components and processes,
2. identify linkages and interactions between those components, and
3. identify gaps in our knowledge (Gross 2003).

Early in the process of developing a monitoring program, visual models provide a framework for discussing the ecosystems of interest. While the National Park Service's Monitoring Program "does not intend to develop quantitative ecosystem models or dictate management policy, constructing a set of realistic, focused conceptual models is an important starting point for designing effective management policies" (Gross 2003). To this end, ARCN developed several conceptual models that describe key features and processes within the ARCN parks. In some cases, additional descriptive models were developed in order to highlight unique ecosystems of interest (e.g., arctic lagoons, spring streams) and provide additional details about key ecosystem processes or components of interest. A series of nested models describing current and future threats to ARCN ecosystems and potential consequences of those threats is also presented. Special areas of management concern for ARCN parklands (e.g., global climate change, air toxins, invasive species) are also addressed using conceptual models.

2.2 The Arctic Network Strategy for Conceptual Model Development

The Arctic Network held three scoping workshops, which were designed, in part, to help network staff develop a set of conceptual models of the natural and anthropogenic features and processes of the enormous areas included in the parks. Each of the three workshops tackled one of three areas of interest to ARCN: freshwater, coastal-influenced, and terrestrial ecosystems. Workshop participants received a workshop notebook before each of the scoping workshops. Before attending the workshops,

technical committee members and outside experts attending each of the meetings were asked either to create models in their area of expertise or to comment on earlier versions of draft models. On day two of the workshops, participants split up into small working groups to further revise models. All hand-drawn draft models from each of the workshops were reproduced in a computer graphics program and placed in workshop output summary documents (see Phase 1 workshop appendices 4–6 at http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm). Information from the workshops was then interpreted and summarized into conceptual models. These models were included in the post-workshop output summary documents. The output documents were placed on the ARCN website for workshop participants to review. Models were revised where appropriate. A subset of these models appear in this chapter.

Our hope is that the models will

1. help to describe the complex ecosystems of ARCN,

2. elucidate current and potential anthropogenic stressors to ARCN ecosystems,

3. suggest potential mechanisms by which these anthropogenic stressors could impact ARCN ecosystems, and

4. help lay the foundation for monitoring critical aspects of the environment of the parks.

Just as ecosystems are fundamentally dynamic, the conceptual models that describe them should be as well. For this reason, the conceptual models presented in this chapter reflect only our current understanding of ecosystem dynamics and should be considered works in progress.

2.2.1 Conceptual Models and the Issue of Scale

Conceptual models should demonstrate the linkages between environmental stressors, ecosystem components, and expected consequences to that system (Figure 2.1; Noon 2003, Thornton et al. 1993). However, this approach is problematic because the boundaries between spatial, temporal, and ecological scale are indistinguishable in nature (O'Neill et al. 1986). Therefore all models are an artificial representation of reality as continuous phenomena are dissected into discrete categories.

A successful monitoring program must be based on a solid understanding of the cumulative processes responsible for driving change and the spatial and temporal scale at which this change is reflected in the ecosystem of interest. In addition, if the wrong ecosystem indicator or vital sign is selected or monitored at an inappropriate temporal or spatial scale, the inference from stressor to ecosystem consequence may be wrong (Figure 2.1).

2.2.2 Spatial Scale

Monitoring can usefully occur in situations as geographically limited as a single thaw pond, mountain slope, or heavily used fishing location; it is likely to be most useful if observations on this scale are incorporated into a broader perspective. In a sense, all larger scale monitoring plans are composed of local sampling schemes, with information obtained, collected, and interpreted to provide a broader picture. Not only does monitoring within the parks in our study area provide information on the condition of the park itself, but it may also be significant on a scale as large as the whole circumpolar north. Thus, while the primary function of long-term monitoring may be seen as providing useful information to be used in managing parks, or areas within parks, we should not lose sight of

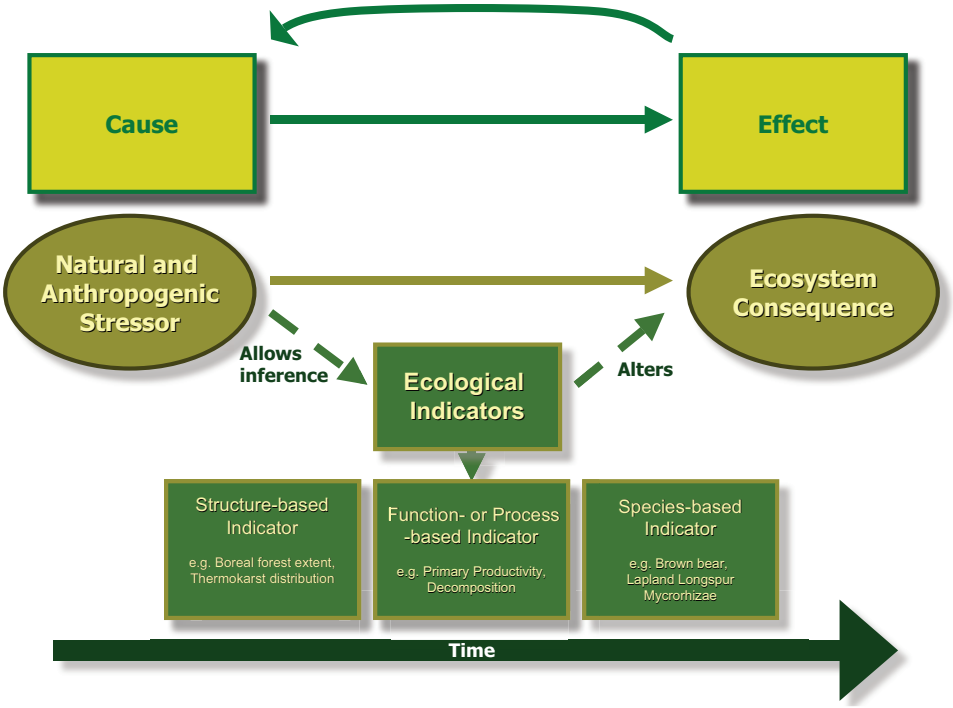


Figure 2.1: Simplified model showing the NPS approach to monitoring and the emphasis on indicators or vital signs, which should represent the cumulative effects of environmental degradation to ecosystems of interest. Redrawn and revised from Noon 2003.

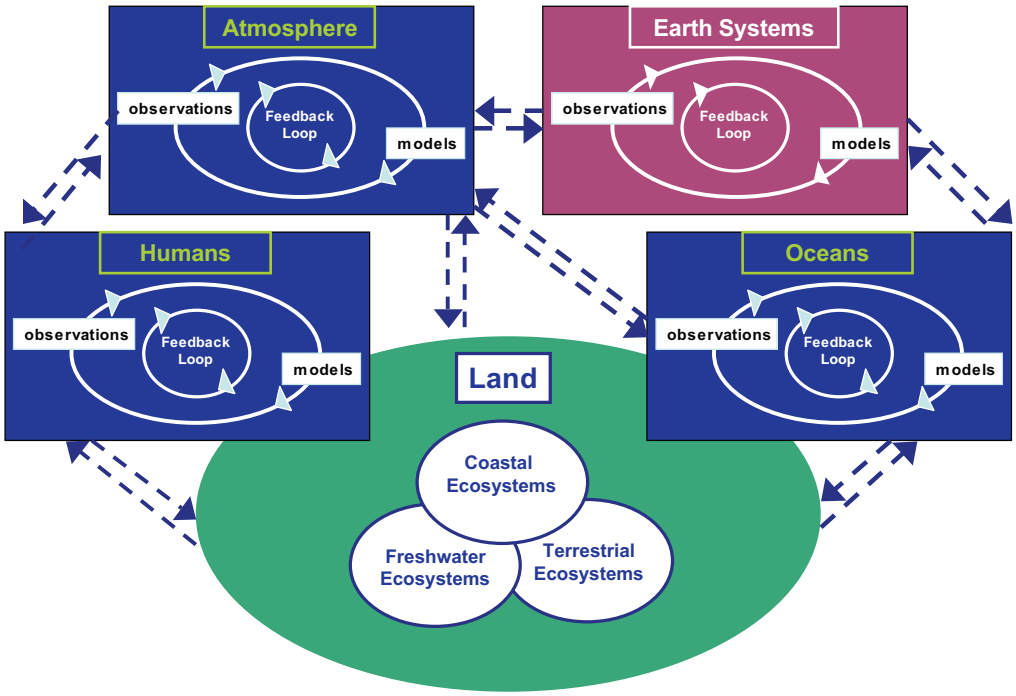


Figure 2.2: Although the ARCN Monitoring Program will focus on ecosystems found within the park boundaries (the "land" portion of this diagram), it is important to realize that changes to park ecosystems may be manifestations of larger scale phenonema occurring in the circumpolar north or world in general. For this reason, collaboration among scientific peers working in other disciplines will be crucial in laying the foundation for any long-term monitoring program in the Arctic. Figure modified from Hinzman and Vörösmarty 2001.

the potential for NPS-sponsored monitoring to improve our overall understanding of the northern environment.

Although the ARCN Monitoring Program will focus on ecosystems found within the park boundaries, it is important to realize that changes to park ecosystems may be manifestations of larger scale phenomena (Figure 2.2). For this reason, collaboration amongst scientific peers working in other disciplines (e.g., anthropologists studying cultural dynamics or economic changes in local villages or earth system scientists studying the global water balance and its implications for arctic ocean circulation) will be crucial in laying the foundation for any long-term monitoring program in the Arctic. To this end, many circumpolar initiatives have or are being proposed for monitoring in the Arctic (see Chapter 1 and Appendix 14).

2.2.3 *Finding an Appropriate Scale to Consider Anthropogenic Stressors in the Arctic*

Human impacts to ARCN come at varying spatial scales. At the largest spatial scale, national and international politics, laws, and treaties could have an impact on arctic ecosystems (Figure 2.3). Although NPS may not have the resources or staff to directly affect legislation or treaty status, these global stressors must be considered when thinking about how arctic ecosystems might be changing. For example, it should be acknowledged that persistent organic pollutants (POPS), which are accumulating in the Arctic, are coming from other parts of the world. The presence of these pollutants could be having an effect on the fecundity, reproduction, and survivorship of large mammal species living in arctic ecosystems (Arctic Monitoring and Assessment Programme 1997, Jepson et al. 1999, Wiig et al. 1998). A large suite of human activities in the circumpolar Arctic may also have a direct impact on ARCN ecosystems (Figure 2.4). For example, circumpolar feedbacks caused by human-induced

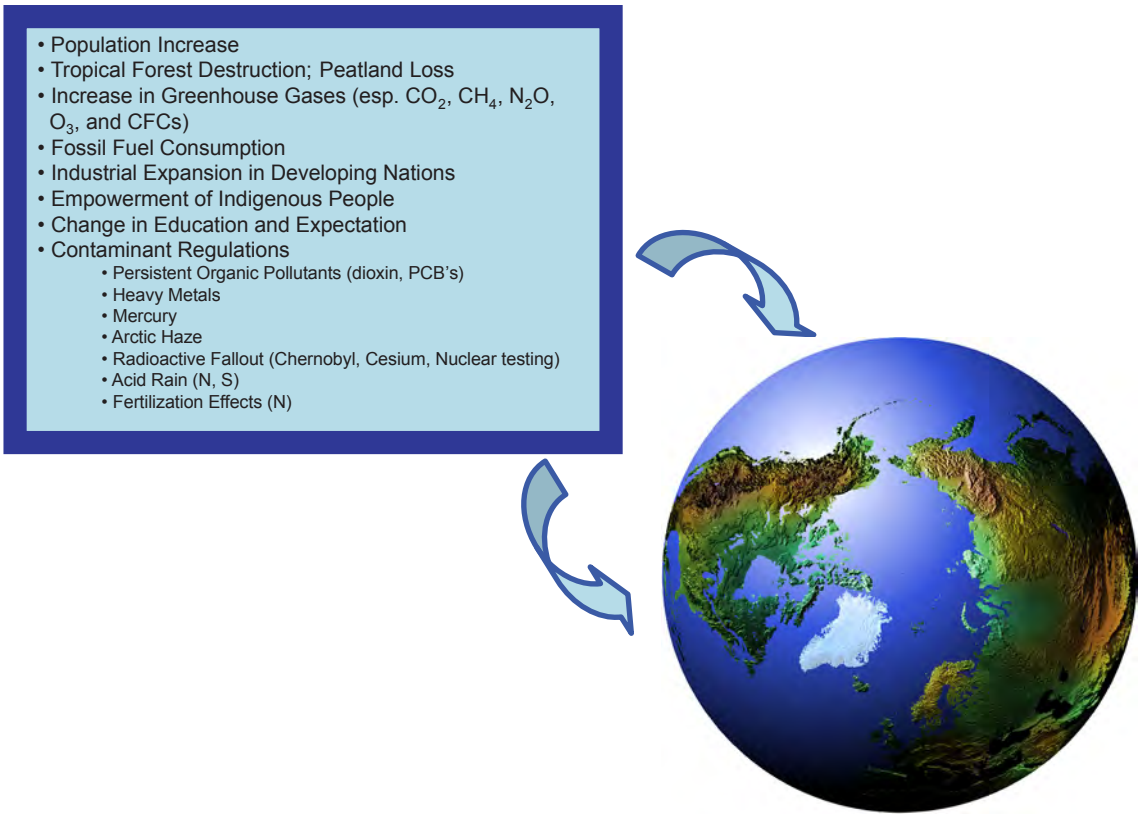


Figure 2.3: Global stressors to ARCN ecosystems

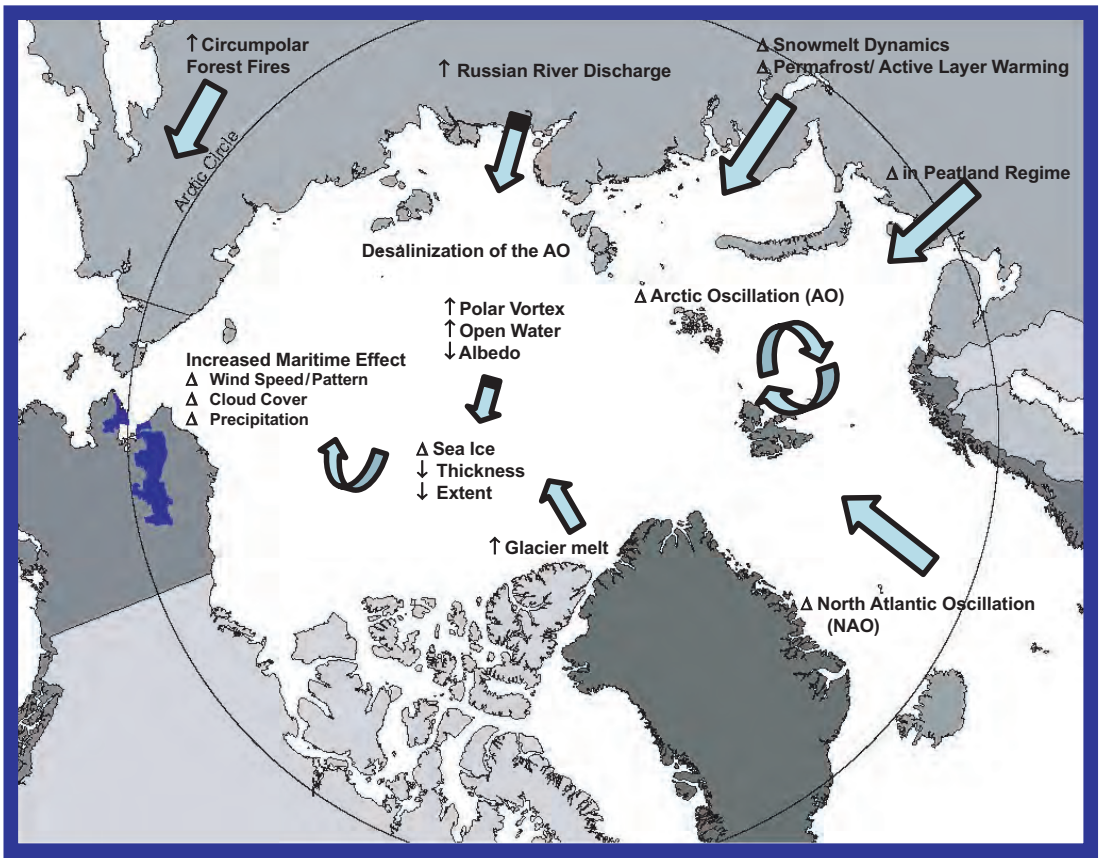


Figure 2.4: Circumpolar drivers to ARCN ecosystems

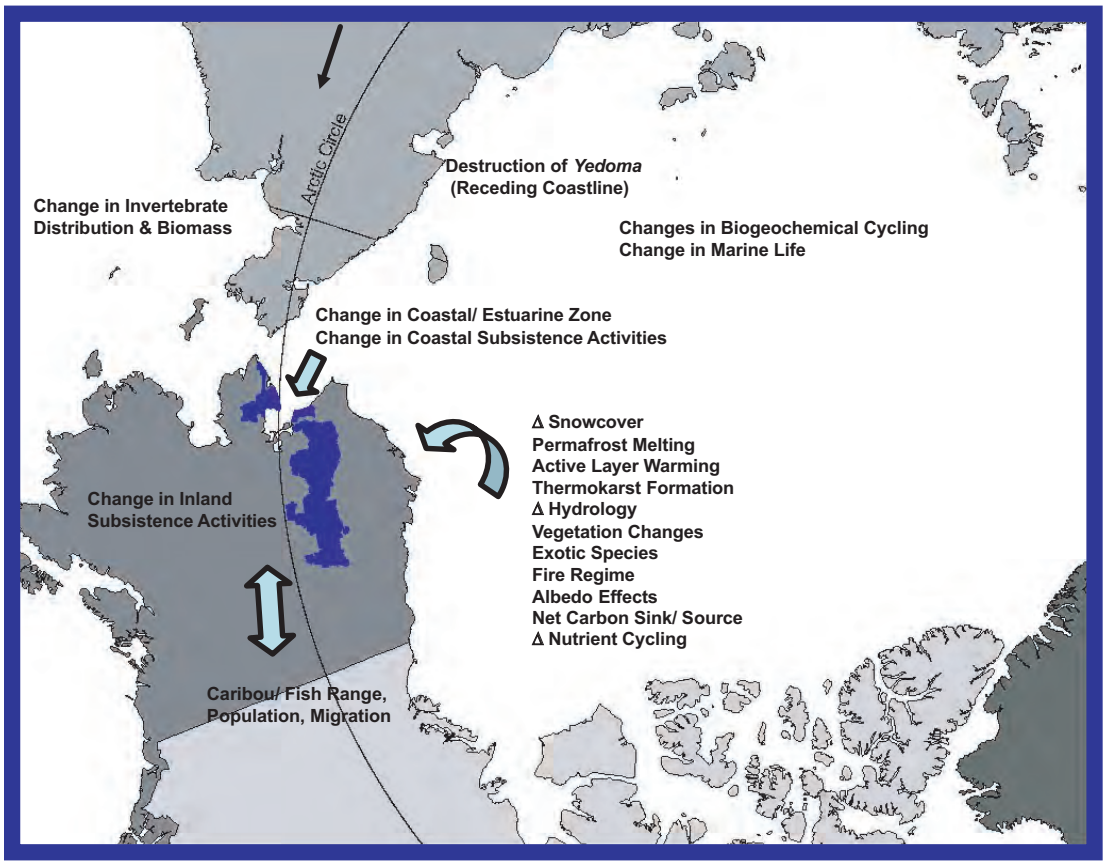


Figure 2.5: Regional drivers to ARCN ecosystems

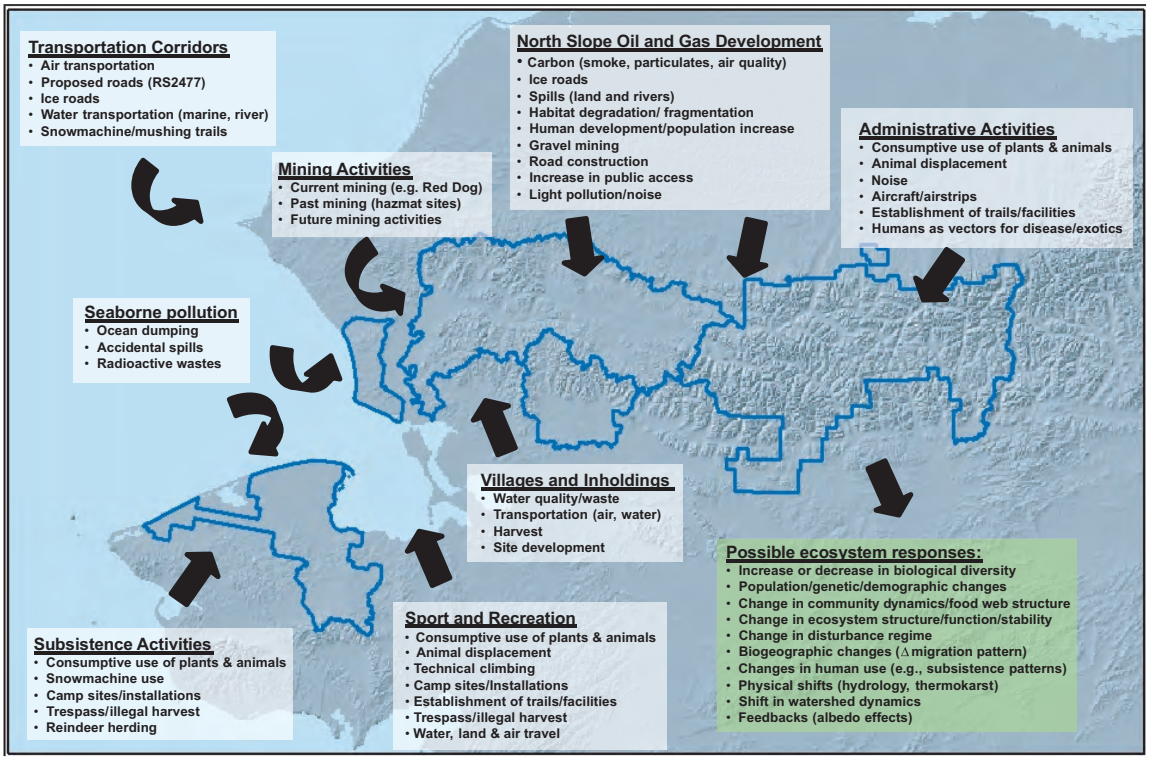


Figure 2.6: Regional anthropogenic stressors to ARCN ecosystems (within or adjacent to park boundaries)

climate change and its effect on arctic sea thickness and extent could have an impact on weather and climate in arctic ecosystems. This, in turn, could have an impact on the coastal ecosystems of ARCN and local subsistence practices (Figure 2.5). Local anthropogenic stressors within or adjacent to ARCN park boundaries could also have a direct impact on ARCN ecosystems (Figure 2.6). For example, the cumulative effects of oil and gas development on the North Slope could directly impact ARCN ecosystems in a variety of ways (National Research Council 2003). Possible ecosystem responses to anthropogenic stressors include things like changes in disturbance regime (e.g., increased fire), physical shifts in the landscape (e.g., thermokarst formation), decreases in ecosystem stability and resilience (e.g., decrease in biodiversity), or population shifts of certain species (e.g., invasive species).

2.2.4 Time Scale and Monitoring in ARCN

Northern and western Alaska, perhaps even more than most regions of the world, have undergone enormous changes in the relatively recent geological past. To understand the region's current array of organisms and the processes that maintain their interactions with the environment, it is necessary to approach them from a historical perspective (Figure 2.7). In particular, we must recognize that the current environmental situation results from the interaction of many processes taking place over greatly varying time scales. For purposes of discussion, we suggest the following time scales:

Long-term geological: dealing with events that have occurred over millions of years, such as mountain building, the distribution of certain substrates, etc.

Late Quaternary: changes that have been important in the late Pleistocene and Holocene, especially the roughly 20,000 years since the last glacial maximum. These would include the termination of continental glaciation over much of the Northern Hemisphere, the submergence of huge areas of conti-

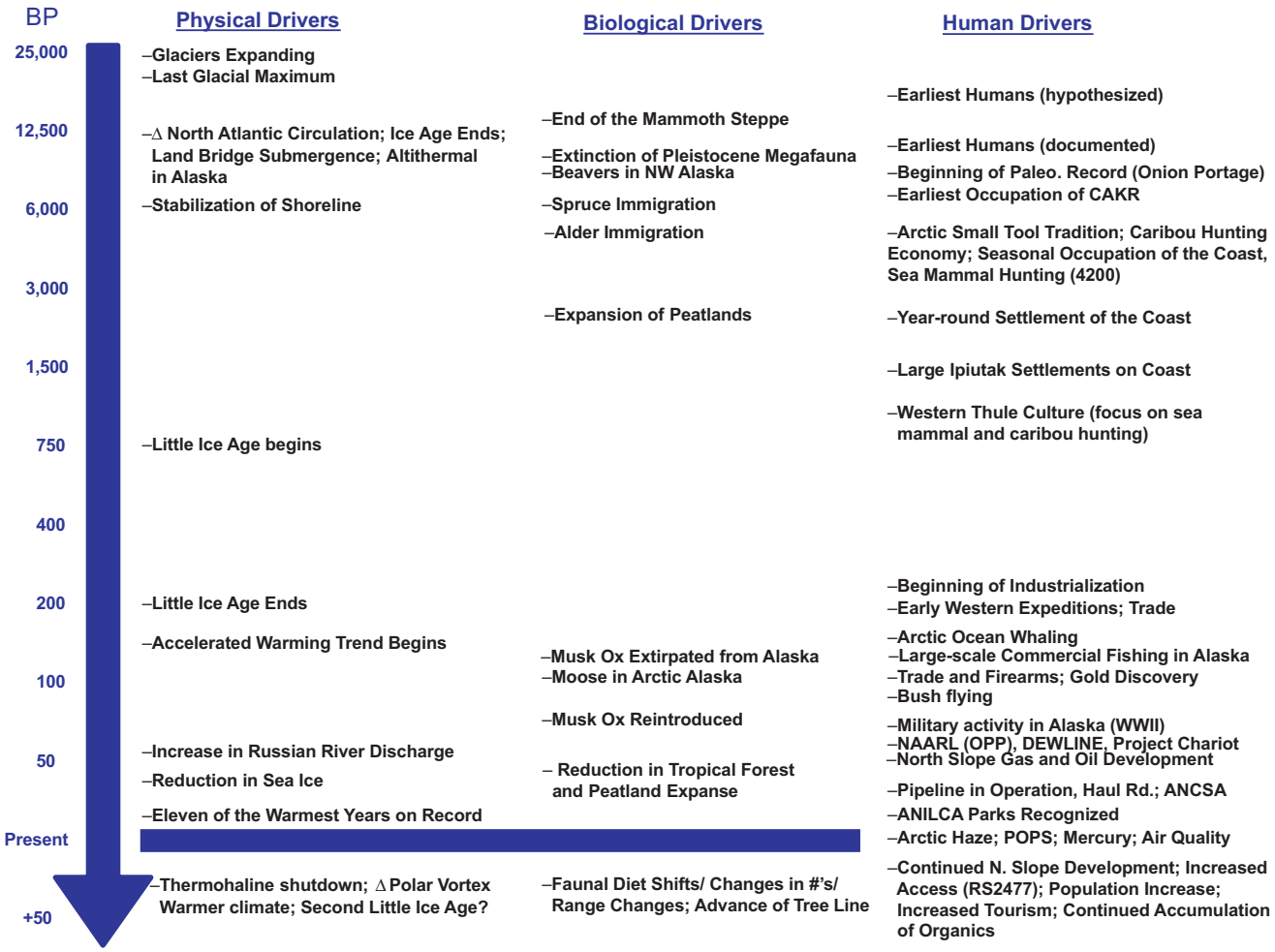


Figure 2.7: Significant physical, biological, and human drivers in the Arctic in the last 25,000 years before present

nental shelf (especially the Bering Land Bridge), the extinction of many important megafaunal species, and the earliest activities of humans within our area.

Early-mid Holocene: changes primarily in vegetation and fauna associated with the emergence of modern ecosystems. Beginning of establishment of modern coastal features, such as the beach ridges of Cape Krusenstern and Cape Espenberg. Stabilization of many terrestrial features such as dunes and loess deposits.

Prehistoric: the emergence of the ancestors of the indigenous cultures of the area and the increasing importance of archaeological sites and materials as sources of data on the nature of the environment.

Historic-current: the time including the influence of Western industrial society on the environments and peoples of our area, beginning soon after 1,800 C.E.

Short term: many of the phenomena with which we are concerned may be evident in the course of a very few years. They may be individual, recurrent, or cyclical.

2.3 Terrestrial Ecosystems of the Arctic Network

It is convenient, although not altogether precise, to divide the terrestrial ecosystems of ARCN into upland and lowland elements. Upland environments are characterized by extensive areas of exposed bedrock; shallow, unstable soils; steep slopes; and small, high-energy streams. Lowland areas have little relief, gentle slopes, often deep alluvial deposits, and, in ARCN, usually heavily permafrost- and ice-rich soils and substrates. They often contain, or are associated with, large, slow-moving watercourses with extensive sandbars and other alluvial deposits. Upland (montane or alpine) situations may occur at almost any elevation within ARCN, since the traditional lower boundary for alpine regions, the treeline, is never more than 500 to 700 m above sea level. Much of ARCN lies beyond the arctic (latitudinal) treeline, so that even the lowlands are tundra covered and have many of the aspects of alpine situations in more temperate regions. The distinguishing features between uplands and lowlands, then, depend on the amount of relief and whether erosional or depositional processes dominate the landscape. It is possible to cross from upland to lowland environments within a few meters and with little or no elevation change, so much of ARCN is a complex mosaic of the two.

Figures 2.8 and 2.9 provide models of the array of landscapes and ecosystems generally associated with uplands and lowlands. They also show graphically the complex interrelationship between the two elements.

2.4 Mountain and Upland Ecosystems of ARCN

Upland ecosystems in ARCN are areas that contain higher elevations and moderate to high relief along with narrower and more sinuous river valleys (Figure 2.8).

Underlying geology is a key feature of the landscape to consider when thinking about ecosystem drivers within the arctic parks. The nature of the bedrock can affect or control the nature of the ecosystems in several ways. Exposed, resistant bedrock is often characterized by steep slopes and minimal soil development. Certain kinds of rock are often associated with particular geomorphic features. For example, granitic outcrops are the basis for spectacular alpine features found in the Arrigetch Peaks and Mt. Igikpak regions in GAAR. In other areas, especially BELA, granite exposures are responsible for the formation of clusters of tors. Lava flows of comparatively recent age, such as are found widely in BELA, form extensive rocky barrens and are associated with features such as Marr Lakes. The chemical nature of the underlying bedrock may also have a profound effect on the vegetation. This is particularly evident in the case of the extensive areas of limestone and other carbonate rocks, such as those found in CAKR and locally in the other parks.

The steep slopes and high elevations characteristic of mountainous terrain provide the basis for many characteristic geomorphic features. Prominent among these are features associated with past and present glaciation. At various times during the earlier Pleistocene, a considerable portion of ARCN was covered by large ice sheets. However, during the latest glacial maximum, about 20,000 years ago, large glaciers were much more localized and occurred mainly in the central Brooks Range. Local glaciers did, however, expand far beyond their present limits in the western Brooks Range and the Seward Peninsula. Currently, glaciers are limited in extent and occur mainly in GAAR.

Aside from the tectonic processes that created the mountains, glacial action is the most significant geomorphic process in virtually all the montane areas in the cool temperate and polar regions. In ARCN, the major features of the landscape of GAAR are of glacial origin.

The more conspicuous geomorphic features of glaciated mountain regions are erosional: cirques, horns, and glacial valleys, for example. Glaciation also produces an array of depositional features such as moraines and valley trains. Many of the features lying well beyond the mountain ranges, such as the rolling terrain of the middle Noatak Valley, are glacial deposits. Glacial action has also been the prime source of sediments for many of the stream deposits throughout much of ARCN. The shrinkage or disappearance of glaciers can remove the main source of sediments from streams and rivers.

Glaciers are uniquely sensitive to changing climate; they are important sources of data in climatic studies. While glaciers normally retreat during warming periods, warmer climates may, paradoxically, cause glaciers to expand because of increased snowfall. The presence of glaciers can have profound effects on stream hydrology, since maximum stream flow from glaciers occurs during warm, sunny periods of maximum melt, rather than times of high precipitation.

In addition to true glaciers, there are extensive areas of late-lying or perennial snow and ice in the mountainous regions of ARCN. These affect the environment in a number of ways: they provide moisture sources during dry periods in summer, and they often shorten the growing season and inhibit the presence of many forms of vegetation. Snowbeds and overflow ice (aufeis) fields are perhaps even more sensitive to climate change than are glaciers.

Periglacial phenomena are characteristic of unglaciated portions of cold regions; they include permafrost and a wide variety of features associated with intense freeze-thaw cycles. Some of the most complex phenomena associated with permafrost occur in deep, unconsolidated sediments on lowlands;

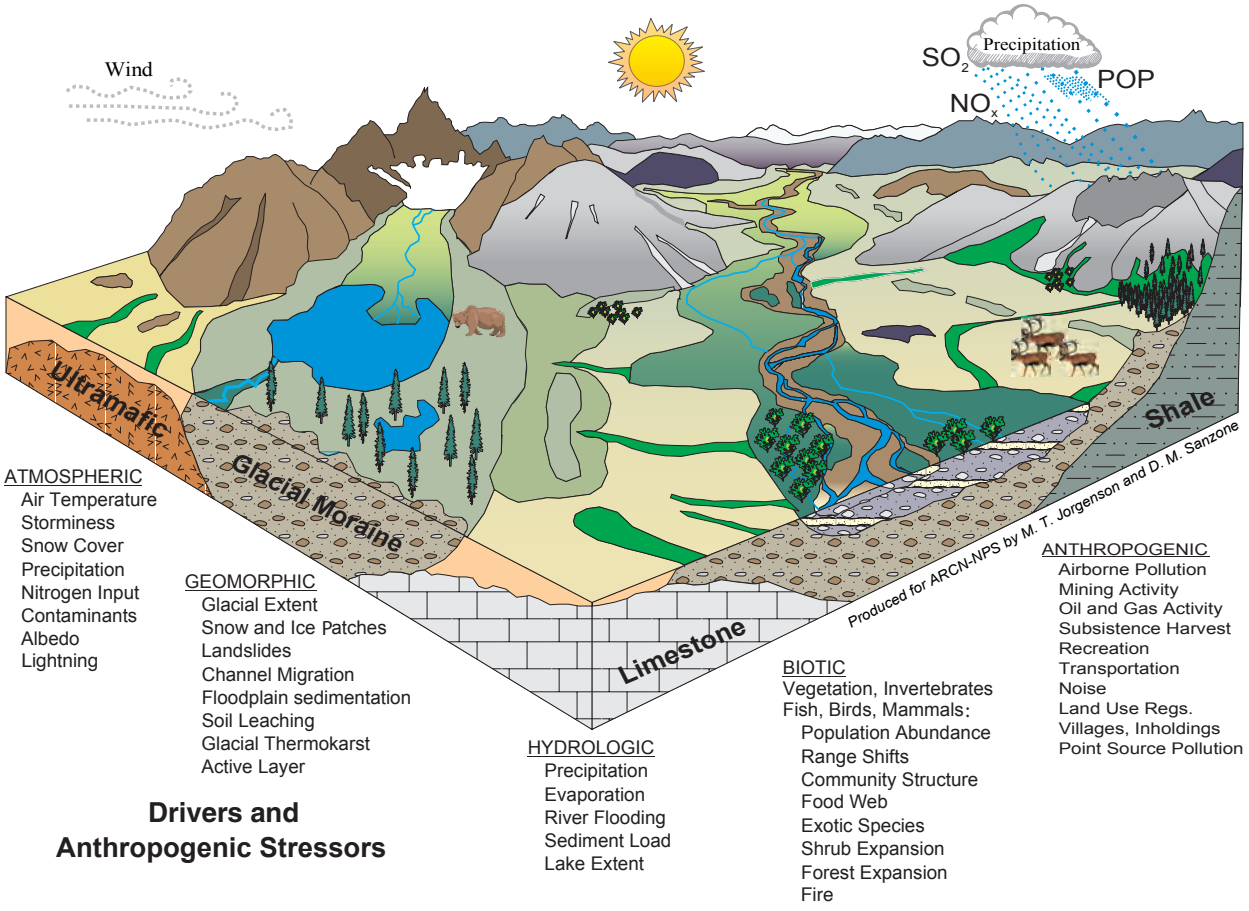


Figure 2.8: Mountain and upland ecosystems of ARCN

they are treated in the next section (section 2.4.1). In montane environments, important periglacial phenomena involve frost wedging and cracking of bedrock and outcrops and boulders and various forms of mass wasting. Retreating glaciers leave oversteepened slopes on the sides and headwalls of cirques and valleys. Frost wedging of the steep walls results in deep and unstable deposits of debris at the bottom of cliffs and crags, and these are subject to landslides. Solifluction often occurs on vegetated slopes. This is the process by which soil creeps downslope in summer, when the top layer is unfrozen and saturated with meltwater.

In the mountainous regions of ARCN, vegetation communities range from the polar desert of the high, barren summits through various forms of alpine tundra to extensive brushlands and, in the more inland areas, upper reaches of boreal forest formed mainly of white spruce (*Picea glauca*). Polar desert communities in ARCN are similar in composition to those found in high arctic regions such as the northern Canadian Arctic Archipelago. Vascular plants are almost entirely herbaceous and mainly circumpolar species. Moss patches are extensively developed in moist areas. Much of the bare rock faces are heavily covered with lichens. Areas that are snow free for only a few weeks in late summer are sparsely vegetated.

Alpine tundra is a broad category; it includes a great variety of local vegetation dominated by herbaceous plants and low shrubs. Some of the variation is associated with altitude, some with slope steepness and exposure, some with soil and substrate structure and chemistry, and some with moisture availability. The number of potential species available is high, and many of the rarer species of plants within ARCN are found in alpine tundra locations, where they may be locally abundant but widely separated from other colonies. Alpine tundra provides important foraging areas for large herbivores such as Dall's sheep (at higher elevations), caribou, and, where they occur, muskox. Some smaller herbivores, such as marmots, are largely confined to alpine tundra. Changes over time in alpine tundra tend to be subtle, and the relevance of the changes to broader scale events is usually difficult to understand. Some of the greatest diversity in alpine tundra species composition occurs in seepage areas, and these are usually related to late-lying snow beds, so changes in snow cover regime may well be correlated with changes in distribution and composition of certain alpine tundra communities. Alpine tundra generally becomes richer in shrubs at lower elevations and merges with shrubland. Alternatively, it may grade more or less imperceptibly into the tussock tundra and wet meadows characteristic of lowland tundra.

Shrubland is characteristic of the lower slopes of mountains throughout ARCN but is especially well developed immediately above (or beyond) treeline in the Brooks Range. The species composition of shrubland varies widely but is often correlated with the direction of slope exposure. Cooler, moister slopes are generally dominated by dense alder (*Alnus crispa*) thickets. These may occur in other situations as well, especially on glacial moraines and outwash plains. Several species of willow (*Salix*) occur widely in shrubland, and the exact species compositions seems to depend on a variety of factors such as elevation, moisture availability, soil type, slope stability, and history.

Boreal forest is an important component of the vegetation at low elevations in KOVA and GAAR south of the Brooks Range. Spruce (*Picea glauca* and *P. mariana*) and birch (*Betula papyrifera*) are the most common tree species, with aspen (*Populus tremuloides*) and poplar (*P. balsamifera*) present locally. The boreal forest occurs in a complex mosaic of stands with different species and unforested areas as a result of site conditions and fire effects. Near arctic treeline, white spruce stands are found along the lower reaches of some of the watercourses. Isolated individual trees are found in the lower reaches of brushland, where trees may be advancing. There has been a great deal of study of the advance and retreat of treeline over time in various parts of the north, and these studies provide important evidence for long-term climatic trends. In addition to spruce forest, there are often small stands of cottonwood

occurring well beyond or above the conifer treeline. In some areas there are also small riparian poplar woodlands. These may host isolated populations of species of insects and nesting birds that are otherwise typical of the boreal forest.

2.4.1 Arctic Lowland Ecosystems

Lowlands are generally areas of low relief and low elevation (Figure 2.9). Within ARCN we define them on the basis of their substrate, which is mainly the result of depositional factors. With the exception of recent lava flows within BELA, there is little exposed bedrock. As mentioned above, exposed bedrock in the form of isolated crags and tors creates a montane environment, even when they occur at low elevations.

The geomorphic features of lowland areas are generally the result of direct glacial deposition (moraine), alluvial deposits associated with streams, mass wasting downslope, and aeolian deposits, most of which are now stabilized. Thus, most lowland ecosystems are developed on landscapes that feature deep deposits of unconsolidated material. Since the mean annual temperatures throughout ARCN are well below freezing, water contained in this material is usually frozen; most of ARCN lies within the zone of continuous permafrost. Although permafrost is defined as soil that is frozen for two or more years, permafrost landscapes on unconsolidated deposits are often quite dynamic. In addition to the

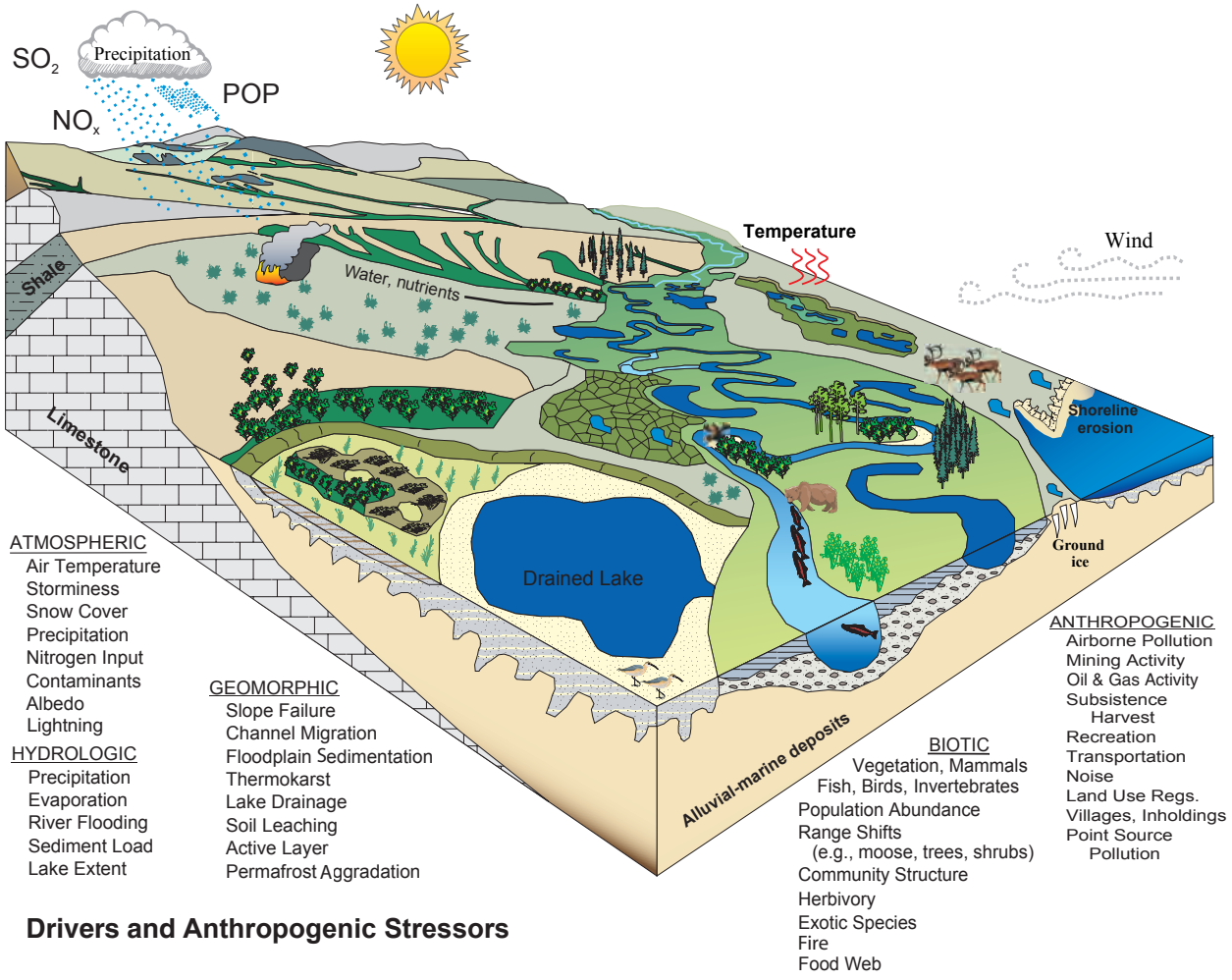


Figure 2.9: Arctic lowland ecosystems of ARCN

active layer—the seasonally thawed soil above the permafrost—there are a number of situations in which freezing and thawing processes create major alterations and instabilities in permafrost terrain. These include ice-wedge polygon formation and other types of processes that form patterned ground. Of particular interest are thermokarst processes. These are the result of the thawing of ice-rich frozen ground; they often result in soil slumps, the creation of ponds and migration of drainage channels, and the draining of older thaw lakes. Thermokarst processes are known to be increasingly active in many polar regions in recent decades due to climate change.

Permafrost action is less conspicuous in active stream floodplains and sand dunes. In these situations drainage is better, the active layer is deeper or permafrost is absent, and redeposition of materials by stream action tends to mask the more slowly acting permafrost processes. Sand and gravel bars cover large areas of the lowlands, because even small streams often carry heavy sediment loads during some seasons of the year.

Within the lowland ecosystems of the Arctic Network, the subarctic boreal forests and low arctic tundra biomes are subject to periodic fires. The frequency extent and severity of the fires is governed by vegetative, geographic, and climatic factors. One of the major uncertainties regarding the effects of climate change on terrestrial ecosystems in the Arctic is how warming will affect the extent and frequency of tundra and subarctic boreal forest wildfires and what effects such fire disturbance would have on these ecosystems. Tundra and taiga fires generally accelerate carbon loss due to both direct burning and to subsequent warming of soils causing higher rates of decomposition.

Boreal forest covers broad areas of lowlands in KOVA and GAAR, some parts of NOAT, and almost none of BELA and CAKR. The main vegetative component of the boreal forest is spruce (*Picea* spp.), and the distribution of this species is closely associated with temperatures during the growing season. The migration of spruce forest into the surrounding tundra areas is the subject of several current studies; the results generally indicate that this is occurring, although not in a uniform or entirely predictable fashion. The presence or absence of spruce forest is important for several reasons. Many animal species are more or less dependent on spruce; these include red squirrels, spruce grouse, snowshoe hare, and Canadian lynx. Spruce forest also affects the landscape in that it changes the albedo and reduces soil temperature by shading the ground surface and modifying snow accumulation.

Various kinds of brushland are widespread in the lowlands of ARCN. Many of these are willow thickets associated with streams and comprised of many species, often depending on such factors as stream size and bank stability. Other types of scrub vegetation involving willow species and dwarf birch (*Betula nana* and *B. glandulosa*) are widespread. Alder (*Alnus crispa*) stands are more common on slopes and moist valley sides, usually in the foothills of the mountains.

The most widespread type of vegetation in most lowland situations is sedge meadow, and it generally consists of two types: wet meadows and tussock tundra. Tussock tundra covers enormous areas of rolling terrain, such as occurs throughout the middle Noatak drainage. The dominant plant species is a cottongrass (*Eriophorum vaginatum*), which forms dense, peaty tussocks, each surrounded by a moist, shaded moat. These areas provide important habitat for caribou during much of the year. They are also populated by a wide array of small mammals.

Wet meadows are usually associated with flat, poorly drained terrain with permafrost. The vegetation consists largely of sedges (*Carex* spp.). Water stands on these meadows during much of the year, and they form a transition between aquatic and terrestrial environments. Wet meadows are often the areas most profoundly affected by changes in the permafrost regime. These include natural cycles that tend to create and drain lakes and ponds, as well as anthropogenic changes. Many of the lowland areas

have been extensively investigated for potential petroleum development; others have served as corridors for moving heavy equipment to mineral exploration sites. These activities often affect the tundra surface to such an extent that they cause changes in the permafrost regime, resulting in extensive anthropogenic thermokarst. Roads from established mines, such as the Red Dog mine near CAKR, cross lowland areas. Heavy vehicle traffic affects not only the roadbed itself but the surrounding environment from dust, exhaust products, and the deposition of heavy metal residues.

Most of the villages within ARCN are located in lowland areas, especially near rivers, so many subsistence activities take place in the surrounding lowlands. Caribou and moose spend much of the year in lowland areas, and they are an important component of the subsistence diet, as are waterfowl and some small game. Lowlands near villages are often subject to heavy traffic from snowmobiles and ATVs.

2.5 Freshwater Ecosystems of ARCN

2.5.1 The Circumpolar Hydrologic Cycle and its Implications for ARCN

The hydrologic cycle figures prominently into the dynamics of arctic ecosystems (Figure 2.10). In the Arctic, this tightly coupled system links land, ocean, and atmospheric components together. The contrast between summer and winter water cycles over the arctic land mass is extreme. During the

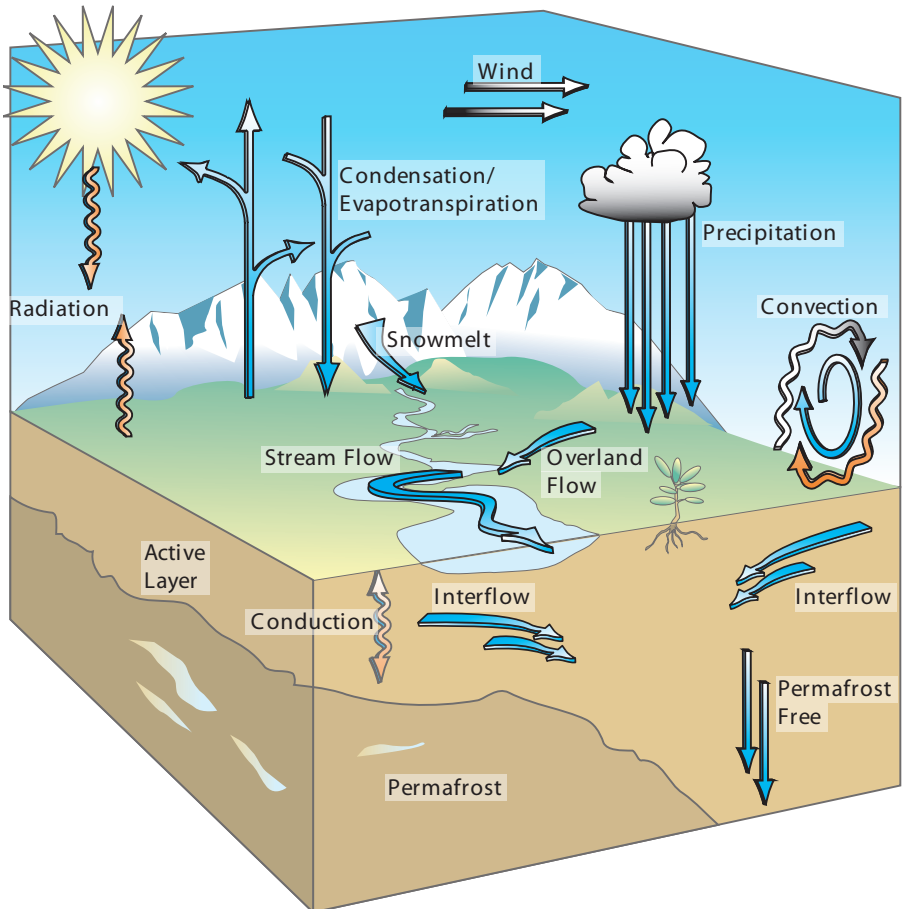


Figure 2.10: Conceptual model of the land surface component of the arctic hydrologic cycle and related water cycle dynamics. From the Arctic Community-wide Hydrologic Analysis and Monitoring Program (Arctic-CHAMP) Strategy Model (Vörösmarty et al. 2001).

summer months, the flux of mass, energy, and nutrients downstream is concentrated in a single sharp peak flow event that brings moisture to terrestrial arctic ecosystems, eventually ending up in the ocean. Surface flow, ponding, and cycles of freeze-thaw are the primary drivers of erosion and geomorphic change (Vörösmarty et al. 2001). In winter, ice and snow radically transform the land surface, increasing surface albedo and reducing the amount of solar energy absorbed. A unique feature of the arctic hydrologic cycle is the presence of permafrost and its associated active layer. Permafrost limits the amount of subsurface water storage, which in turn is largely controlled by surface heat flux. Although ARCN will focus its monitoring effort on the land component (Figure 2.2) of this tightly coupled land-ocean-atmosphere system, it is necessary to point out that the surface water and energy balance is ultimately linked to the pan-arctic water cycle and all of its various feedbacks.

2.5.2 Large Rivers of the Arctic Network

ARCN contains many large river systems, including the Noatak and Kobuk rivers that drain west into the Kotzebue Sound and Chukchi Sea. Large rivers in ARCN usually meander through broad valleys and contain numerous side channels and sloughs (Figures 2.8 and 2.9). The structure of these large river floodplains allows for the lateral transfer of nutrients and energy throughout the valley bottom. Although few studies have been conducted on the surface-subsurface dynamics of these large arctic river systems, this exchange between surface and hyporheic waters may nonetheless be important to the functioning of these systems.

Many of the tributaries to these large rivers originate in the Brooks Range as clear-water or silt-rich glacier-fed streams. These large river systems serve as conduits for carbon, nutrient, and trace metal transport, connecting the surrounding watershed with areas further downstream. In addition, many anadromous fish, riparian birds, and large mammals use these large river corridors for migration or foraging, providing yet another opportunity for exchange of energy and nutrients up or downstream (Oswood 1997).

Historically, much of the gravel used for construction of roads and pads in arctic Alaska has been obtained from deposits within the floodplains of large rivers. Gravel mining in floodplains of large rivers has been shown to substantially alter flow regimes of large river systems (Joyce 1980). The Alaska Department of Natural Resources (DNR) has identified hundreds of potential RS 2477 rights-of-way on federally managed land in the state of Alaska; RS 2477 rights-of-way allow construction for some type of public access, often a road. In 1998, the state legislature declared 600 routes as RS 2477 rights-of-way by public use, and DNR continues to identify more each year. In 13 national parklands in Alaska, the State of Alaska has claimed 112 potential roads totaling 2,272 miles. To date, 21 possible RS 2477 rights-of-way have been identified by the State of Alaska in the ARCN parks (NPS, personal communication). Road development in ARCN parks could have a detrimental impact to many of the large river systems because the construction and use of gravel roads could interrupt or alter stream flow.

2.5.3 Headwater Streams of the Arctic Network

Three main types of headwater streams have been identified in the Alaska Arctic: mountain, tundra, and spring-fed streams (Craig and McCart 1975).

In ARCN there are two types of mountain streams: glacier-fed mountain streams that originate as cirque glaciers high in the Brooks Range and streams fed mainly by precipitation and snowmelt. Mountain streams in ARCN drain north, south, and west out of the Brooks Range. Tundra streams are found in the foothills and coastal plain areas of ARCN, are fed mainly by snowmelt and precipitation,

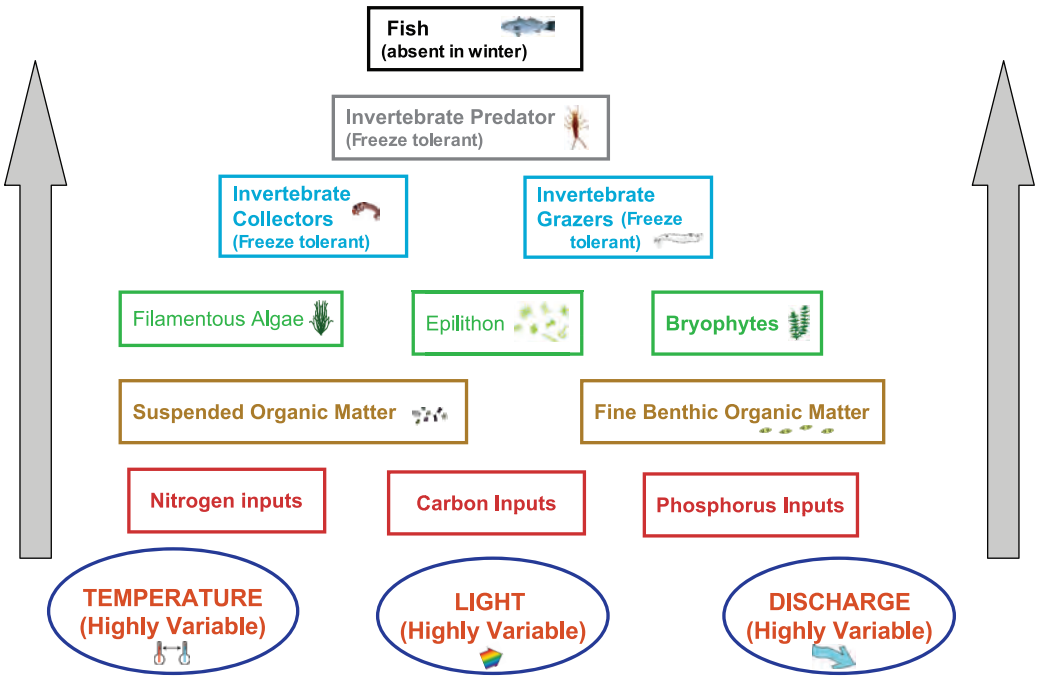


Figure 2.11: Simplified mountain or tundra stream food web. Physical disturbances and extreme fluctuations in temperature, light, and discharge exert control of these food webs. Circles indicate physical drivers, boxes represent standing stocks, and arrows represent general direction of energy flow.

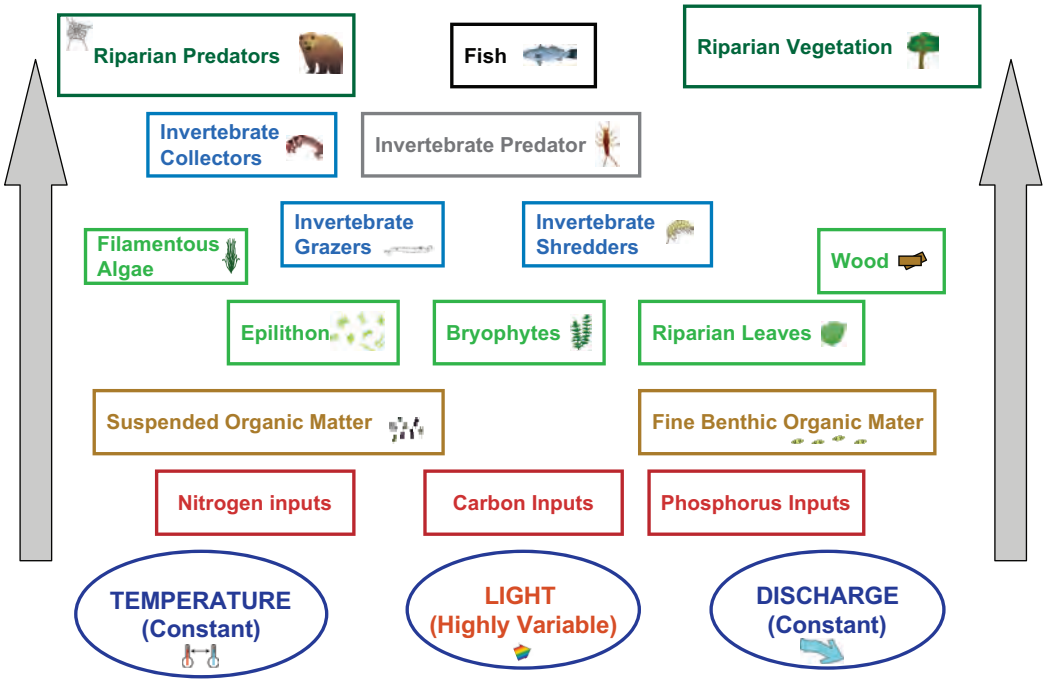


Figure 2.12: Simplified arctic spring-fed stream food web. Extreme physical disturbances are much less common in these streams than arctic mountain or tundra streams because water temperatures and discharge remain relatively constant throughout the year. However, communities in these streams do experience extreme variation in light regimes. Circles indicate physical drivers, boxes represent standing stocks, and arrows represent general direction of energy flow.

and are underlain by peat. Mountain and tundra streams experience extreme fluctuations in flow, with discharge highest in spring and early summer and little or no flow in winter when runoff ceases and most or all of the water column freezes. Mountain and tundra streams that experience extreme physical disturbances such as spring snowmelt and winter freezing are common in high-latitude climates. These streams tend to have low species diversity and secondary production because few aquatic species are adapted to tolerate such extreme physical changes in their environment (Figure 2.11).

Spring-fed streams, which are fed by groundwater below or within the permafrost layer or by deep lakes, flow year round. In many spring-fed streams in the Arctic, water temperatures exceed 5 °C all year long (Craig and McCart 1975). These perennial streams are distributed throughout ARCN, contain a large number of aquatic species, and most likely serve as refugia for taxa that are not tolerant to freezing (Figure 2.12).

2.5.4 Lakes of the Arctic Network

There are many lakes of varying sizes in ARCN (Figures 2.8 and 2.9). Many of the large, deep lakes such as Chandler, Selby, Feniak, and Matcharak are well known in this region; however, thousands of shallow lakes and wetlands are distributed throughout the parks. Water from large freshwater lakes is often used to build ice roads for winter travel and oil exploration in the Alaska Arctic. "For lakes that do not support wintering fish, there is essentially no current regulation of winter water withdrawals, and the amount estimated to be present during summer is typically set as the withdrawal limit—[which] essentially allows withdrawal of all remaining unfrozen water in the lake at the time of withdrawal" (National Research Council 2003). Since little baseline data on the lakes of ARCN has been collected, it will be hard to monitor the actual impacts of water withdrawal on these ecosystems if additional ice road corridors are built within or abutting ARCN parklands.

2.6 Coastal Ecosystems of ARCN

Coastal ecosystems in ARCN are confined to CAKR, whose central feature is the extensive lagoon and barrier beach system that encompasses most of the southern portion of the monument, and BELA, much of whose northern boundary is the Chukchi Sea and Kotzebue Sound coast of the Seward Peninsula. ARCN does not include any offshore waters, but the boundary between marine and coastal ecosystems is less distinct biologically than it is geographically. Marine processes and events strongly affect the coastal environment, and vice versa. This is particularly true within ARCN, since the surrounding seas are shallow; the sea bed was emergent as recently as the terminal Pleistocene, roughly 10,000 years ago. Rising sea levels during the Holocene have been instrumental in shaping the landscape and ecosystems of the coastal regions of ARCN, and this continues in the present.

Polar marine ecosystems are recognized as being extraordinarily sensitive to environmental change. Reductions in sea ice cover can have profound effects on ice-dependent species such as polar bears and ringed seals. The long food chains of the seas encourage the biological concentration of various pollutants at the higher trophic levels. Heavy exploitation of marine resources, especially groundfish, seems to have the potential to disrupt long-established ecosystems to the point that they change their essential nature. These changes may be, for all practical purposes, permanent. Fundamental changes seem to be occurring in the nature of the Bering Sea, within a few hundred kilometers of ARCN. The marine environment immediately adjacent to ARCN is thus of great interest to monitoring programs within the study area.

Coastal ecosystems within ARCN can, somewhat arbitrarily, be divided into four categories, which we have shown graphically as Figures 2.13, 2.14, 2.15, and 2.17. Rocky coastlines (Figure 2.13) are relatively rare within ARCN. More extensive are shorelines where the sea borders low-lying tundra developed on unconsolidated sediments (Figure 2.14). Lagoon and barrier beach systems are extensive and important in both CAKR and BELA (Figure 2.15). Delta ecosystems are also an important habitat in coastal areas of ARCN (Figure 2.17).

2.6.1 Rocky Shores

Rocky shores occur mainly along the Kotzebue Sound coast of BELA. These shores are generally low-lying and are formed from lava flows of various ages (Figure 2.13). Above the inshore limit of storm beaches and beach deposits, the vegetation is often affected by salt carried onshore by wind; a few species of lichens and vascular plants are encouraged by or confined to saline situations. Near the eastern boundary there are some sea cliffs that support small colonies of cliff-nesting seabirds. Except for seabirds, few if any species of vertebrates are found primarily along rocky shores. Benthic communities of rocky substrates are poorly known in this area, and further study is needed.

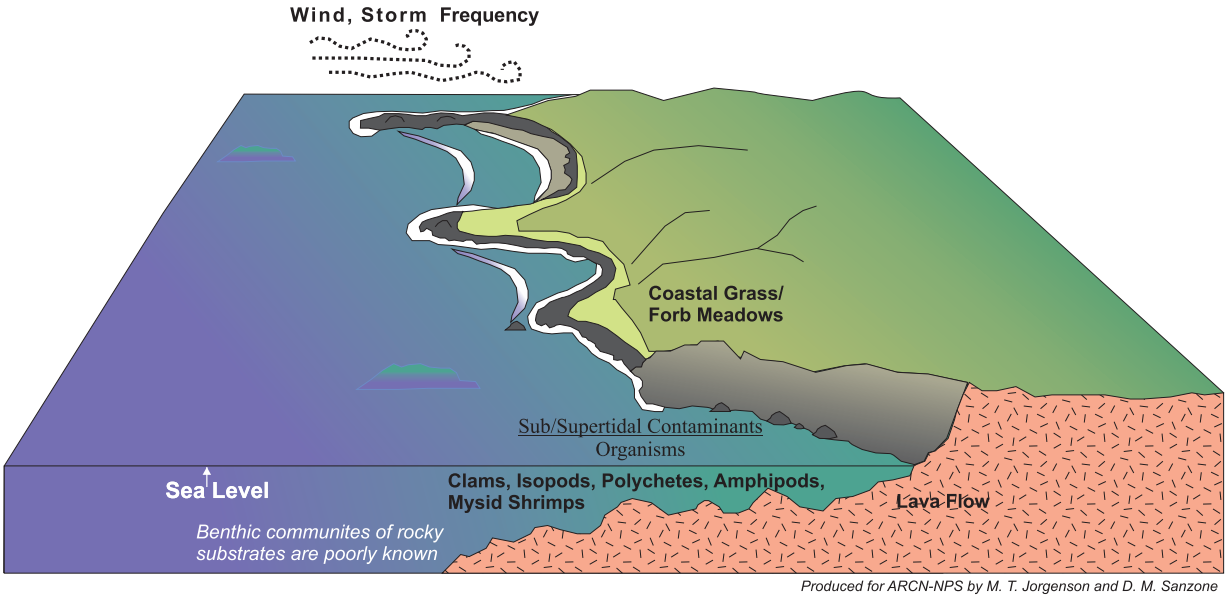


Figure 2.13: Rocky cliff shorelines of ARCN

2.6.2 Exposed Tundra Coastlines

In areas where lagoon and barrier beach systems have not developed, the coastal environment is often confined to a relatively narrow strip of beach (Figure 2.14). In some cases, the sea may even undercut deep deposits of ice-rich unconsolidated sediments, so that the interface between the sea and the terrestrial environment is a narrow zone of collapsing bluffs. In situations where the bluffs are low, no more than a meter or two high, sea ice may actually override the tundra during winter storms, leaving sea ice and detritus lying on the land surface.

Within ARCN, tundra coastlines are generally receding. The main phenomena associated with the incursion of the sea is the loss of terrestrial material and the dispersal into the sea of sediments and

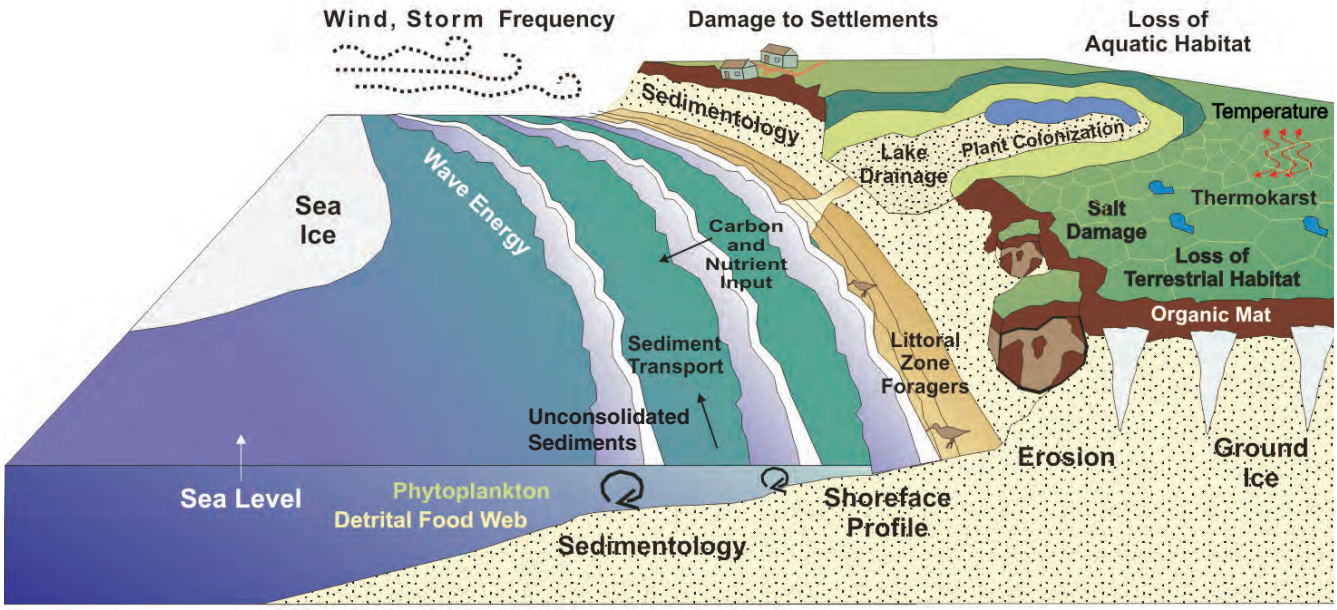


Figure 2.14: Exposed tundra coastline

nutrients that have been contained in the largely frozen terrestrial environment. The spread of saline conditions inland from salt spray and encroaching sea ice may also be important.

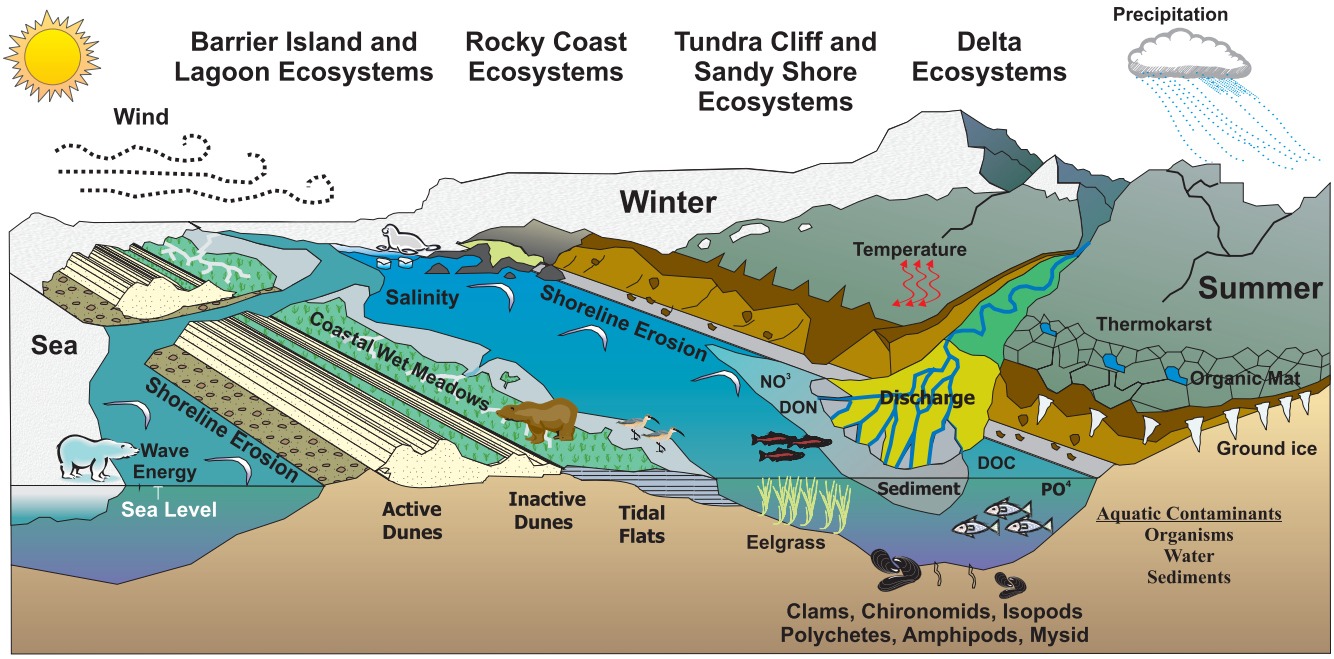
Another feature associated with encroaching seas is the drainage of coastal lakes and thaw ponds. Even shallow tundra ponds have generally existed for long periods of time—hundreds or thousands of years, and the presence of surface water that does not freeze to the bottom in winter allows the degradation of permafrost under the lake bed. When the encroaching seashore intersects the unfrozen and unconsolidated material of the lake bed and shore, a drainage channel may appear suddenly and the lake may drain over a short time. This provides a new, often well-drained, and enriched soil surface for colonization by plants. Much of the surface sediment and nutrients of the lake bed may be discharged into the nearby marine ecosystem. Ultimately, a new permafrost regime will be initiated in the old lake bed, which is no longer insulated from the extreme cold of winter.

Since the actual area included in tundra coastlines is small and generally unstable, there are few vertebrate species specifically associated with this habitat type. It is often used by migrating waterfowl and shorebirds, and the often large quantity of detritus and carcasses of marine mammals and birds often attracts scavengers such as arctic foxes (*Alopex lagopus*) and ravens (*Corvus corax*).

Tundra shorelines are subject to a good deal of anthropogenic disturbance, mainly because they are heavily used corridors for travel during the summer by ATVs. The narrowness of both the beaches and the dry edges of the tundra bluffs confines vehicle travel to this restricted strip, and heavy erosion may result. Although there is also heavy winter travel by snowmobile, damage is less when the ground is frozen and snow-covered.

2.6.3 Lagoon and Barrier Beach Systems

Lagoon and barrier beach complexes (Figure 2.15) encompass most of the northern (Chukchi Sea) coast of BELA and are extensively developed along the coast of CAKR, especially in the southern portion. Cape Krusenstern itself is formed by an ancient and extensive barrier beach formation that is of enormous archaeological significance; this was central to the selection of CAKR as a national monument.



Produced for ARCN-NPS by M. T. Jorgenson and D. M. Sanzone

Drivers and Anthropogenic Stressors

ATMOSPHERIC	OCEANOGRAPHIC	GEOMORPHIC	HYDROLOGIC	BIOTIC	ANTHROPOGENIC
↑ Air Temperature	↑ Air Temperature	↑ Shoreline Erosion	Δ Precipitation	Vegetation, Invertebrates	↑ Airborne Pollution
↑ Storminess	↑ Sea Level	Δ Barrier Island Migration	Δ Evaporation	Fish, Birds, Mammals	Δ Mining Activity
↓ Snow Cover	↑ Storm surges	Δ Marine Sedi. Transport	Δ River Discharge	Δ Population Abundance	Δ Oil and Gas Activity
Δ Precipitation	↓ Sea Ice	Δ Land Sediment Deposit	Δ Lake Extent	Δ Range Shifts	Δ Subsistence Harvest
↑ Nitrogen Input	↑ Fetch Length	Δ Dune Formation/Scouring	Δ Nutrient Load	Δ Community Structure	Δ Recreation
↑ Contaminants	↑ Wave Energy	↑ Thermokarst	Δ Sediment Load	Δ Foodweb	Δ Transportation
↓ Albedo		↑ Active Layer		Δ Exotic Species	Δ Noise
					Δ Land Use Regs.
					Δ Villages, Inholdings
					Δ Pollution
					Δ ATV Use

Figure 2.15: Lagoon and barrier beach ecosystem

In contrast to tundra coastlines, barrier beaches are often aggrading, and many have been doing so for several thousand years, since the time when sea level reached nearly its present elevation. At Cape Krusenstern, over 150 separate beach ridges have been identified. The oldest to youngest are found in sequence from farthest inland to the presently active coast. This provides a time sequence similar to that more typically found in vertically stratified sites.

Barrier beach complexes may be as much as one kilometer or more wide; the ridges are separated by shallow backshore swales that parallel the ridges. The ridgetops generally support thin stands of vegetation, with lyme grass (*Elymus arenarius*) the dominant species. In areas of dunes, lyme grass stands are especially well developed. The swales are variable; some are water filled during much or all of the year, others are mostly dry. They provide a wide variety of habitats and are especially important as breeding grounds for shorebirds and terns. They may also support populations of various microtine rodents; these are preyed upon by foxes and predatory birds such as short-eared owls and northern harriers (*Circus cyaneus*). Some of the deeper, more stable hollows contain dense willow thickets.

Although many barrier beaches have been stable for thousands of years, others are subject to very active shoreline erosion as well as aggradation. Wave action may actually breach the barriers, endangering coastal settlements and archaeological sites and radically changing the nature of associated lagoons.

Inland from the backshore may lie an extensive lagoon system. These lagoons are also highly variable, especially in terms of salinity. Some are actually open to the sea by way of passages through the

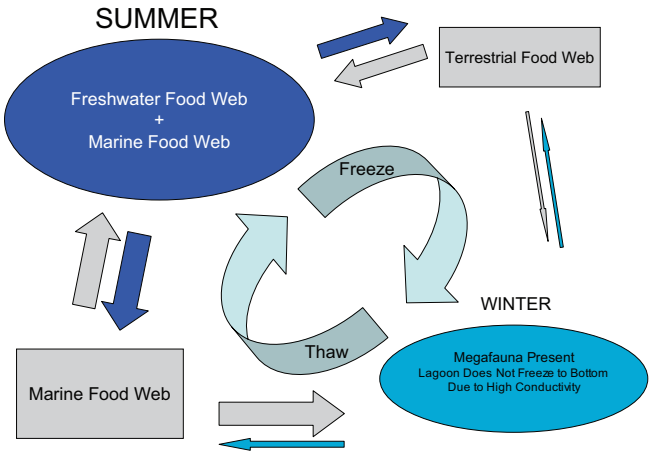


Figure 2.16a: Open lagoon systems of ARCN

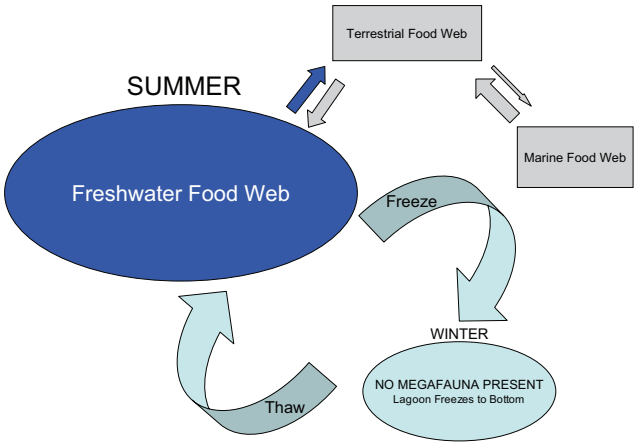


Figure 2.16b: Closed lagoon ecosystems of ARCN

barrier beach complex, and the waters are highly saline, modified only by the inflow of streams (Figure 2.16a). Other lagoons are generally only slightly brackish, their salinity derived from exceptional tides sending sea water up their discharge channels or, if the barrier beach is narrow, waves washing over it (Figure 2.16b). Lesser amounts of salt arrive from sea winds, and probably in some cases by percolation through the coarse sediments of the barrier beaches.

The shores and shallow portions of lagoons support extensive wet meadows; these are often punctuated by small ponds. This is an important habitat for many species of shorebirds and waterfowl. Certain species (e.g., red phalarope, *Phalaropus fulicaria*) are mostly confined as breeding species to coastal ponds. Waterfowl often congregate there in great numbers during molt and migration.

The inland shores of lagoons are also quite variable. In some cases they merge imperceptibly into adjacent wet coastal tundra. In others, they may border an eroding shoreline comparable to coastal tundra shorelines; these are usually less active, since there is less wave and tide action. Lagoons are also fed by streams originating inland; these may carry sediments and nutrients into the lagoon environment. The streams often form small estuaries, with extensive marshes and overflow channels.

Lagoons are relatively little used by large mammals. An exception is large, open lagoons, which may be important hauling areas for seals and may be visited by beluga whales. After winter freeze-up, coastal marshes may supply some fodder for herbivores. Caribou, moose, and muskox may visit barrier beaches at various times of the year. On-shore breezes may make them particularly attractive to caribou, because the wind keeps insects away.

Barrier beaches are subject to the same pressures from ATVs as tundra coastlines. The traveled corridors may be a bit wider and damage less obvious. During warmer seasons, when the ice is off the lagoons, they may receive some hunting and fishing pressure. Lagoons are extremely sensitive to point-source pollution from their shores or feeder streams, since they are largely closed systems.

2.6.4 Delta Ecosystems

The distinction between estuaries and lagoons is not always clear. Most streams that pass through lowland areas before entering the ocean are associated with complexes of beaches and other sediment deposits that form at least rudimentary lagoon systems. The features and processes that generally dis-

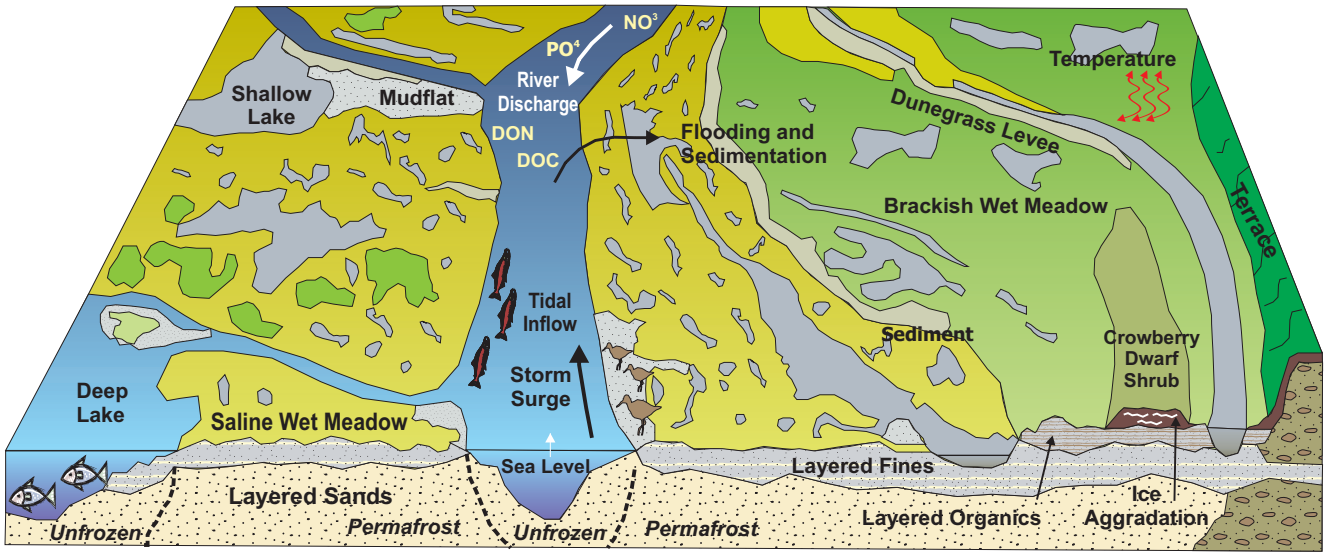


Figure 2.17: Delta ecosystems of ARCN

tinguish delta systems are significant river discharge and sediment load, strong effects of tidal influx, major rapid changes in water level and salinity, strong effects of ice from rivers and/or the sea, often extensive mud flats, and marshes with highly salt-tolerant plant species (Figure 2.17). All of these vary greatly within the system, depending on factors such as microtopography and distance from the river shore and sea coast. Overall, estuarine systems are more dynamic, higher energy, and generally richer in nutrients and species of plants and animals than other coastal environments.

Estuaries are generally associated with sizeable streams, and these carry sediments from far inland. The higher energy streams may provide coarser sediments of sands and silts. Siltation may encourage mudflats in low-lying areas that might otherwise be heavily vegetated marshes. The high sediment load may also result in relatively high nutrient levels in the shallow waters and marshes. Association with larger streams also encourages the presence of anadromous fish. The estuaries and lower reaches of the feeder streams may provide important habitat for young salmonids.

As in the case of lagoons, estuaries are especially heavily frequented by birds, especially shorebirds and waterfowl. Estuarine shores are particularly well known as resting places for migrating shorebirds; their productivity and diversity provides a wide variety of invertebrates and small fish—high-energy food for birds that travel long distances.

Estuarine ecosystems are often heavily used by subsistence hunters and both subsistence and commercial fishermen. Small runs of salmon, especially pink and chum salmon, occur in several of the river systems within coastal ARCN. Waterfowl are abundant. Terrestrial vertebrates are generally uncommon in estuarine environments, especially in summer when insect swarms are heavy. Estuaries are affected by a variety of pollutants, both chemical and physical. Upstream activities may increase silt loads of streams, spills from boats and nearby hunting and fishing camps may be common, and some sea-borne organic pollutants may be locally significant. Because the most significant estuarine ecosystems occur within a meter or so above or below mean high tide level, estuarine ecosystems are strongly affected by minor changes in sea level.

2.7 Special Areas of Management Concern for ARCN

2.7.1 Conceptual Framework for Considering Climatic Change

It is generally accepted that global warming is occurring and that it is especially evident in high-latitude regions. While it is generally assumed that warming is a process that will continue into the foreseeable future, it is not inconceivable that cooling trends could develop. This is especially true over the very long (centuries or millennia) term, when orbital forcing or other factors could theoretically terminate the current interglacial. In the following model, we consider the potential effects of climatic cooling as well as warming. In the case of either warming or cooling trends in arctic environments, there are feedback mechanisms that suggest that some results of either process are counterintuitive. Scenarios based on regional warming or cooling trends that consider only annual means do not take into account changes in the seasonality that may occur. Increased seasonality, often associated with increased continentality, means, under a warming trend, warmer summers; decreased seasonality means warmer winters. Thus, a warming trend that involves increased winter temperature may increase precipitation, resulting in greater snowfall, delayed onset of the growing season, and quite possibly increased cloud cover during summer. A consequence of this could actually be lowered air and soil temperatures at ground level. The result of a warming trend might then appear at the vegetation level as stress on "warm climate" plants: those that require certain levels or duration of warmth during the growing season. Over the long term, this could result in the retraction or fragmentation of the ranges of "low arctic" species in areas such as the North Slope of the Brooks Range. This concept leads directly to concerns of range extension and retraction, such as the location of the treeline (see section 2.7.2).

The example developed above is obviously simplified and isolated from many related factors. It also says little about the scale of time and space over which effects might be visible. For example, a long-term warming trend would probably result in a thinning of the sea ice cover, so that open water near the north and west coast of Alaska would extend farther from the shore and remain open for more months of the year. This might set up a feedback loop in which additional warming was encouraged by the lowered albedo of the open sea as opposed to pack ice. On the other hand, increased open water could increase precipitation and cloudiness over the land, tending to reverse the warming trend. This in turn would depend at least partially on wind and other weather patterns; these are notoriously difficult to predict, and there is usually wide variation between results when only slight modifications are made in the parameters that are fed into climatic models.

2.7.2 A Conceptual Framework for Considering Changing Plant Distribution Patterns in the Arctic Network: Northward Movement of Treeline

Long-term changes in climate are associated with changes in the distributions of various organisms (Figure 2.18). In the North, the most conspicuous and well-studied expression of this is the location of the treeline, often defined as the poleward or seaward limit of coniferous forest. The correlation of the location of treeline with summer temperature is well known (Young 1989), and it is generally accepted that the location of the northernmost forests closely approximates the location of the 10 ˚C isotherm for the warmest month of the year (July in most parts of the North). However, this is only a rough correlation. The array of physiological processes that facilitate or limit the northward spread of certain tree species must operate at a microclimatic level, there may be more than a single set of limiting factors, and different sets of factors may be relevant under different climatic conditions and in different geographic areas.

For example, the limiting factor in some situations might be the production of viable seed, which would require certain conditions of intensity and duration of warmth in the upper portions of mature trees during the growing season. On the other hand, germination and establishment of seeds might be the weak link in the chain, in which case temperatures at the soil surface would probably be critical. In this case, factors such as depth and duration of snow cover and/or shade from nearby mature trees might become dominant in determining reproductive success and, over time, the advance or retreat of the forest. An additional complexity, of course, is the consideration that necessary conditions need to be met only often enough to allow successful reproduction occasionally during the long life span of plants such as conifer trees. Thus, a cooling but unstable climatic regime with an occasional unusually warm summer could conceivably facilitate the spread of trees more effectively than a slightly warmer but more stable climate.

Even this brief consideration of one type of distribution pattern points out the complexity of factors that are implicated in controlling the advance or retraction of the ranges of plants and animals. It will be noted that we have not mentioned the role of dispersal mechanisms and their effectiveness. For a variety of organisms, range expansion could be quite dependent on effective dispersal mechanisms.

Finally, we might note that the presence or absence of conspicuous organisms such as forest trees is easily established, and the changes in their distributions can be monitored by such means as aerial photography. Even ancient ranges can be provisionally plotted on the basis of fossil evidence. This be-

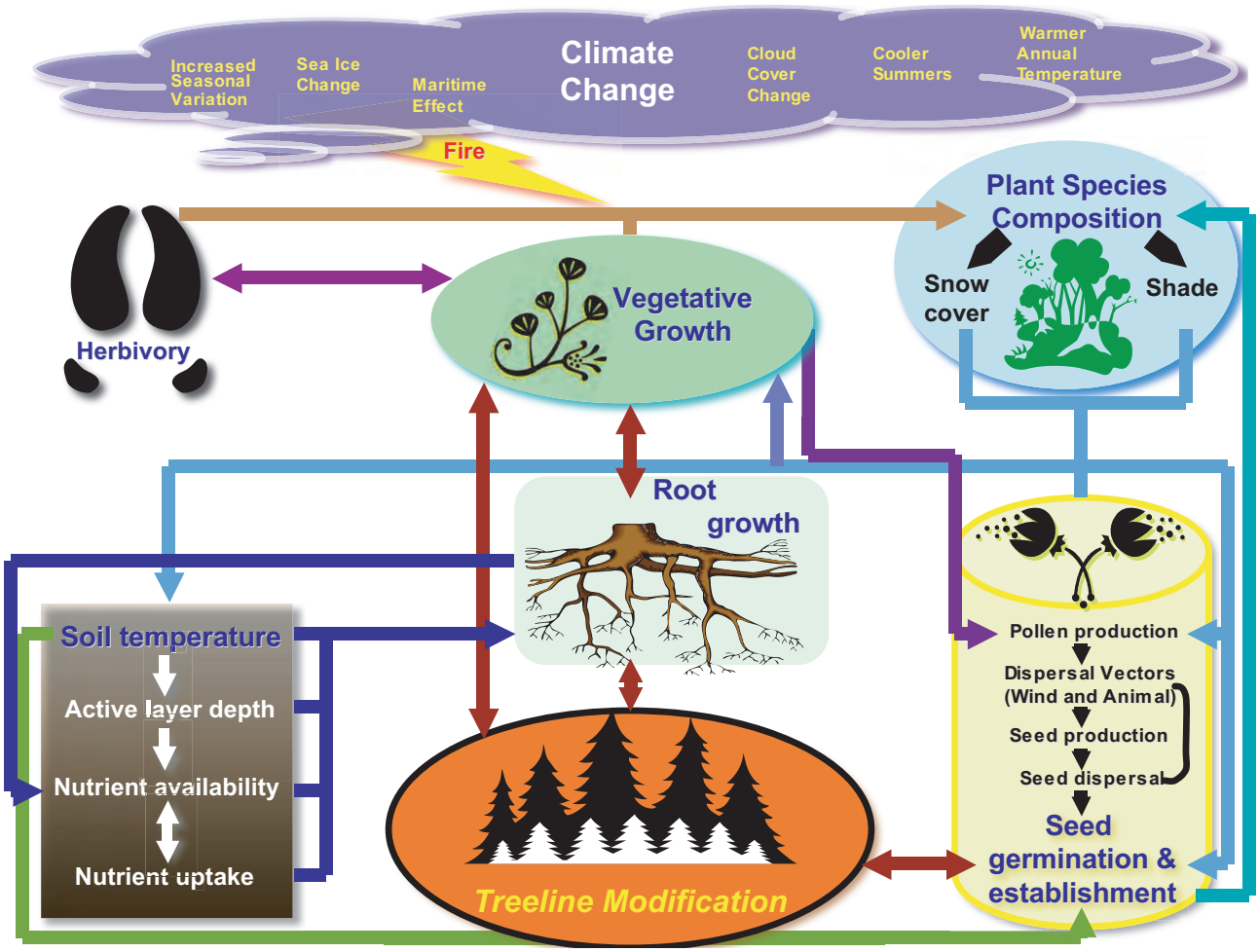


Figure 2.18: Biomechanics and feedback loops of treeline modification in relation to climate change

comes only somewhat less true in the case of species such as shrub birch (*Betula glandulosa* and related forms) or the various willows that comprise the overstory of riparian shrub communities. In the case of less conspicuous species, such as tussock-forming cottongrass (*Eriophorum vaginatum*), only careful, on-the-ground studies may be able to show its presence, absence, advance, or retreat.

Equally important, changes in the distribution of a species such as the above could occur either by migration along a broad front or by the expansion of small, isolated, perhaps relict colonies outside the "normal" range of the species. Under the latter situation, range extensions could be expected to occur much more rapidly in response to changing climate or other environmental changes.

In spite of the complexity noted above, alterations in the distribution of various species and communities can be expected to lead to some of the most powerful concepts and tools with which to monitor the trajectory of overall environmental changes and of the "health" of the environment in general. We have concentrated here, and in the accompanying diagram (Figure 2.18), on plant species and some of the factors and interactions that can be involved in changes in distribution. In some cases, the migration and range extension of certain vertebrates and invertebrates would be dependent on the spread or retreat of vegetation types. This is probably at least partially the case, for example, in the spread of moose into arctic Alaska over the past couple of centuries. In other cases, especially in highly mobile species such as migratory birds, the correlation between range changes and climatic or other environmental change is difficult to address successfully.

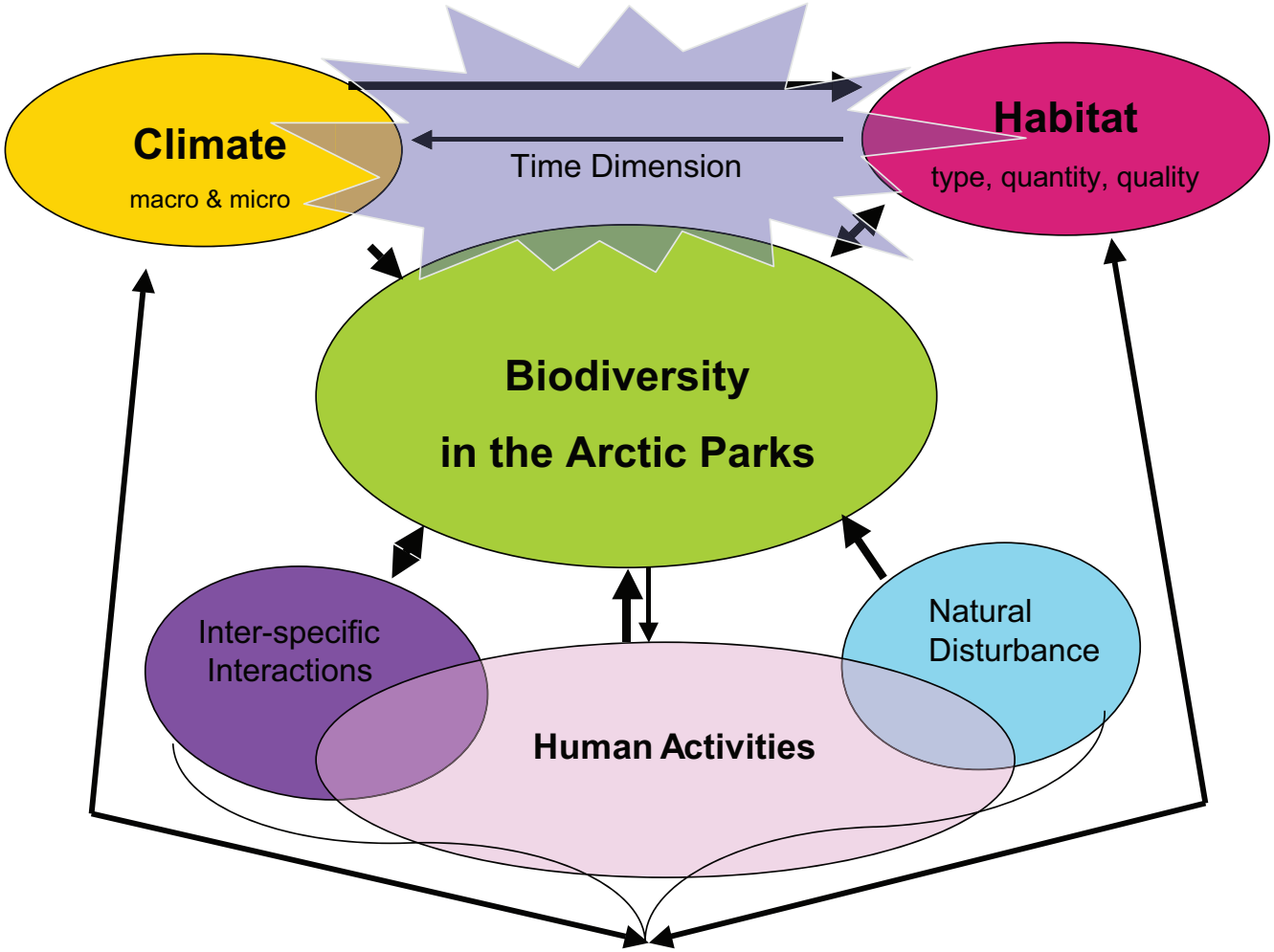


Figure 2.19: Biodiversity in the arctic parklands

2.7.3 Conceptual Framework for Thinking About Biodiversity in the Arctic Network

The National Park System plays a critical role in the preservation of biodiversity. ARCN parklands contain many of the Arctic's unique ecosystems intact, making the parks critically important to species survival. Biodiversity in the Arctic must be considered from a different perspective than in temperate and tropical regions (Figure 2.19). For most groups of organisms, the number of species found in a given area is only a fraction of the number that would occur in a comparable space in lower latitudes. For example, the boreal forest of northwestern Alaska may contain no more than a half-dozen tree species. Of these, one, white spruce (*Picea glauca*), may outnumber all other tree species by a wide margin over enormous areas. Large herbivores may be only two to four species (caribou and moose, with muskox and Dall's sheep in some locations).

Many of the species that do occur in the Arctic are of extraordinarily broad distribution. White spruce dominates the boreal forest from western Alaska to eastern Newfoundland, while both caribou and moose, as well as wolves and brown bear, have completely circumpolar ranges. This is also true for many smaller vertebrates, as well as many of the important species of higher plants, mosses, and lichens.

The observation that many northern species are widespread may lead one to conclude that they will be buffered from the effects of local events and processes that could negatively affect their populations. In fact, the situation is much more complex. While the "fragility" of the arctic environment has probably been overemphasized, there are a number of aspects of arctic ecosystems, at all scales, that lead to a high level of vulnerability.

Arctic ecosystems are unusual in that they often are reconstituted in a major way over relatively short periods of time. For example, an area of tundra that one year has a high population of microtine rodents, which are preyed upon by a array of predators such as snowy owls, jaegers, and arctic foxes, may, only a year later, be almost devoid of small mammals. This, of course, impacts the predators, and they may migrate elsewhere or suspend breeding for that year. Similarly, the nutrient/fertility relationship between small herbivores and plants may be radically altered from year to year, and the numbers of large herbivores such as caribou may fluctuate wildly over periods of only a few years. At various points of these cycles, especially if the population "crashes," relatively minor changes in other aspects of the environment may make the difference between a fairly rapid recovery and an extended decline.

In many cases, the causes of population declines are poorly understood. Spectacular examples are found in marine mammals, such as in the precipitous loss of a major proportion of the populations of sea otters, fur seals, and Steller's sea lions in the southern Bering Sea. Similar declines have been observed in several species of waterfowl, such as spectacled eider and emperor goose.

There are, of course, major changes in the arctic ecosystem from season to season. During the winter, many areas may have a resident bird population of less than a half-dozen species (e.g., rock and willow ptarmigan, gyrfalcon, and raven), while in the summer the number might swell to 50 or more species breeding within an area of a few square kilometers. Both the array of species and the numbers of individuals may vary significantly from year to year, as may breeding success.

It is important to keep in mind that the arctic ecosystem is very young in terms of geologic time. Most of the North American Arctic was under ice within the last 8,000 to 12,000 years. In glaciated areas, the entire biota has been rebuilt by migrants from afar since the end of the last Ice Age. In many cases, it appears that the process is still incomplete. Grizzly bears, for example, have yet to colonize the eastern Canadian Arctic successfully. The biodiversity of large regions of the North American Arctic has yet to stabilize after the retreat of the ice.

It is interesting that ARCN lies within a zone of contact between the recently deglaciated North American Arctic and the much less heavily glaciated, and thus in some senses much more ancient, Asian Arctic. Much of BELA, CAKR, NOAT, and KOVA were not glaciated in the later Pleistocene and were essentially a part of the Asian Arctic, connected by the dry land of the Bering Land Bridge. Thus, these areas both share some of the ancient aspects of arctic Asia and have also served as migratory pathways for the recolonization of the glaciated lands to the east. As a result of this unusual history, the lands within ARCN often have a higher level of diversity of such organisms as vascular plants, small mammals, and insects compared to other parts of the North American Arctic. Not only are there a certain number of endemic species, but there are often isolated populations of rare species and unusual ecological communities and combinations of species (Parker 2006). In addition, Asian species, at least of birds, still seem to be actively colonizing the western Alaskan Arctic. Examples are white wagtail and arctic warbler. Some sea birds, such as black guillemot, are also actively changing their ranges.

While biodiversity issues are complex throughout the entire Arctic, it is safe to say that this is especially true within ARCN. For many species, population and community structure is more variable, and changes appear to be more rapid, than in many other parts of the North. It is important to recognize that many of these local peculiarities are poorly understood and poorly documented at this time. There is no question that many additional examples will come to light as more work is done within

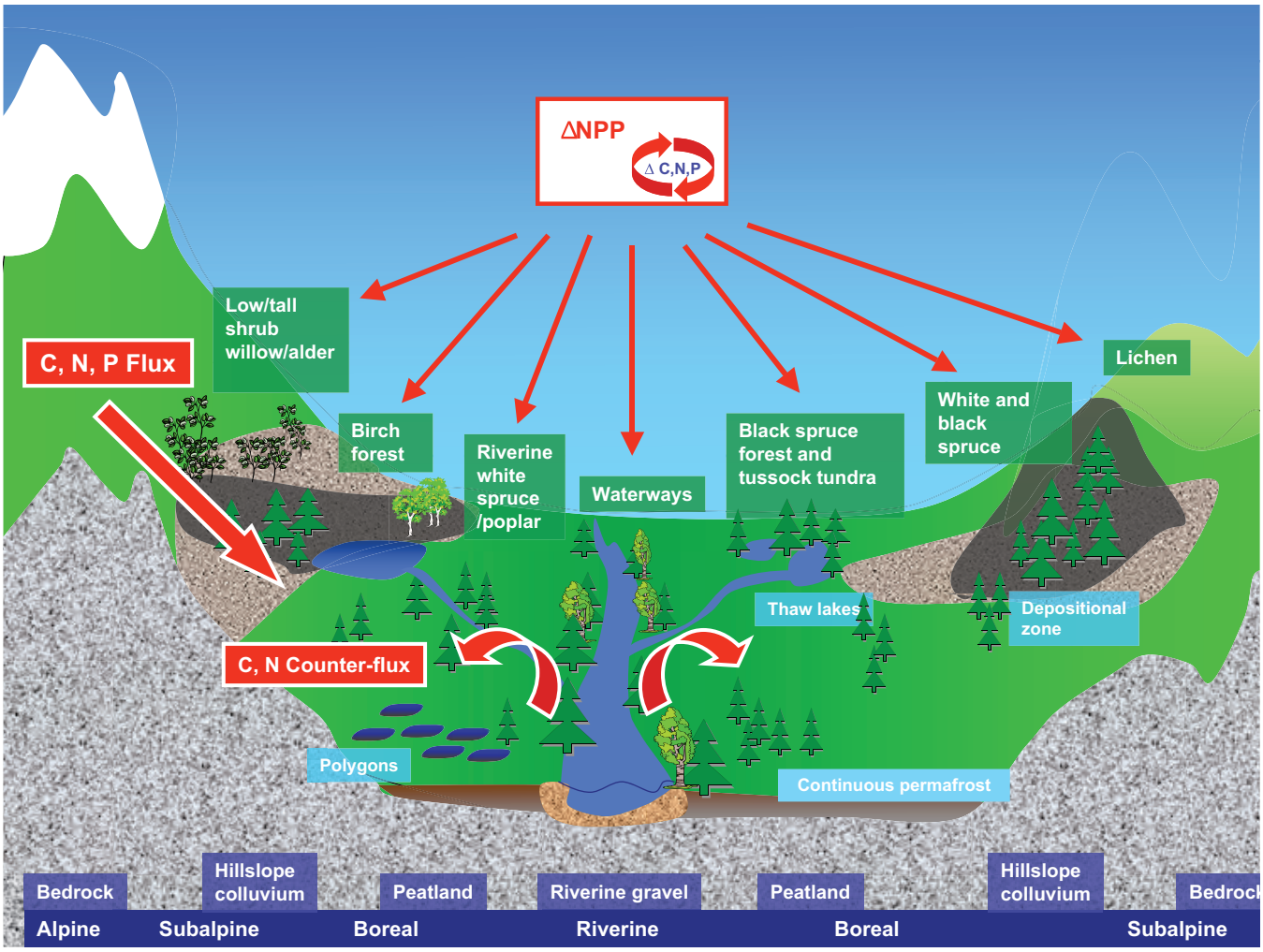


Figure 2.20. Ecosystem-level response to anthropogenic disturbance can be tracked by monitoring shifts in net primary productivity (NPP), cycling of carbon (C), or flux of nitrogen (N) and phosphorus (P).

ARCN. We are still in the early stages of gathering baseline data on the components and nature of the ecosystems represented in ARCN, and this basic enumeration of the biodiversity of the region will continue far into the future.

2.7.4 Changes in Biogeochemistry in the Arctic Network

Ecosystem-level response to human-induced disturbance in the Arctic can be tracked by monitoring shifts in net primary productivity (NPP) and cycling of carbon (C), nitrogen (N), and phosphorus (P). Focusing on the biogeochemistry of the boreal and tundra regions will elucidate the links and feedbacks between biogeochemical cycling, changes in species composition, and landscape-level consequences of these changes (Figure 2.20).

The tundra and boreal biomes represented in the Arctic Network parks contain large reservoirs of C, N, and P. High-latitude terrestrial soils contain from 20–45% of the global pool of soil organic C, and only a small percentage of total soil N and P contained therein is available for plant uptake. These reservoirs have accumulated as a result of slow rates of nutrient cycling in large areas of these biomes, which are dominated by continuous permafrost. The "active" soil layer of these permafrost-dominated ecosystems have characteristically low temperatures and high moisture content. This leads to slow or no decomposition of soil organic matter (SOM) that lies largely below annual thaw depth. Therefore most of the nutrients in these reservoirs are not available for plant uptake. Resultant nitrogen and phosphorus limitation of plant growth in arctic and subarctic regions has been well documented (Chapin et al. 2002, Shaver et al. 2001).

One of the main ecosystem drivers in the Arctic is climate. A substantial body of evidence shows that temperatures are steadily increasing in arctic regions. Ambient temperatures in northwest Alaska have increased since 1950 (Stottlemyer et al. 2001). This may be associated with increased soil active layer depth and permafrost depth, which may in turn be linked to altered soil moisture, soil temperature, SOM decomposition, and soil respiration rates. Expected higher soil temperatures may alter rates of nitrogen (N) mineralization, dissolved organic carbon (DOC), and dissolved organic nitrogen (DON) release and subsequent transport to aquatic systems. This additional input of carbon and nitrogen to freshwater and coastal ecosystems could have an effect on the overall nutrient balance of aquatic ecosystems in ARCN. Tracking the large-scale effects of changing climate on the boreal and tundra biomes will require in-depth investigation of current and future relationships between soil conditions and SOM as well as other element cycles, specifically nitrogen.

Physical changes in the landscape caused by increased temperatures could also have ecosystem-level consequences in ARCN parks. For example, increased temperatures would likely cause increased occurrence of thermokarst: subsidence caused by thawing of ground ice or permafrost. The additional input of C, N, P and trace elements to aquatic systems from thermokarst areas could have far-reaching effects on the biological community. Understanding the relationships between large-scale physical changes to arctic park ecosystems and the coupled chemical and biological processes will be crucial to monitoring ecosystem-level change in ARCN.

Increased ambient temperatures may also directly stimulate primary production to some extent, but it appears to be more likely that increased growth is primarily a factor of higher rates of N mineralization and therefore availability. Changing climate and associated factors have already resulted in increased tree growth and associated advancement of treeline into the tundra biome (Figure 2.18). Ecosystem-scale monitoring is necessary to elucidate such patterns.

2.7.5 *Potential Pathways and Ecosystem-level Consequences of Air Pollutants in Arctic Parklands*

Air toxins, such as mercury and persistent organic pollutants, are produced by a variety of sources. These can be point sources, for example from a power plant, metal smelter, or pool of spilled oil, or much more diffuse nonpoint sources, for example vehicles whose emissions vary in location depending on where the car is being operated. These sources may be close to (e.g., Red Dog Mine) or far away from (e.g., Russia and China) ARCN parklands. The emissions from these sources can be emitted directly into the atmosphere (e.g., from a power plant stack) or introduced into the atmosphere through the volatilization of a compound released into the soil or water (e.g., the volatilization of light hydrocarbons from an oil spill). Once the emissions have been produced, they can be transported to the parks through global and local circulation patterns. Two good examples of this are the transport of Russian pollution into the arctic parks in winter (arctic haze) and the transport of Chinese dust and pollution into the Arctic in spring.

Air toxins can influence the ARCN parklands through a variety of mechanisms (Figure 2.21). The toxins can directly impact geophysical processes or can enter the ecosystem through deposition and then impact biological/biochemical processes. For example, air toxins can change the observed atmospheric geophysical properties by changing the albedo (the reflectivity of the earth's surface and atmosphere to solar radiation) over the parks, changing the frequency and types of clouds occurring in the region, and changing the frequency of precipitation. These effects change the amount of solar

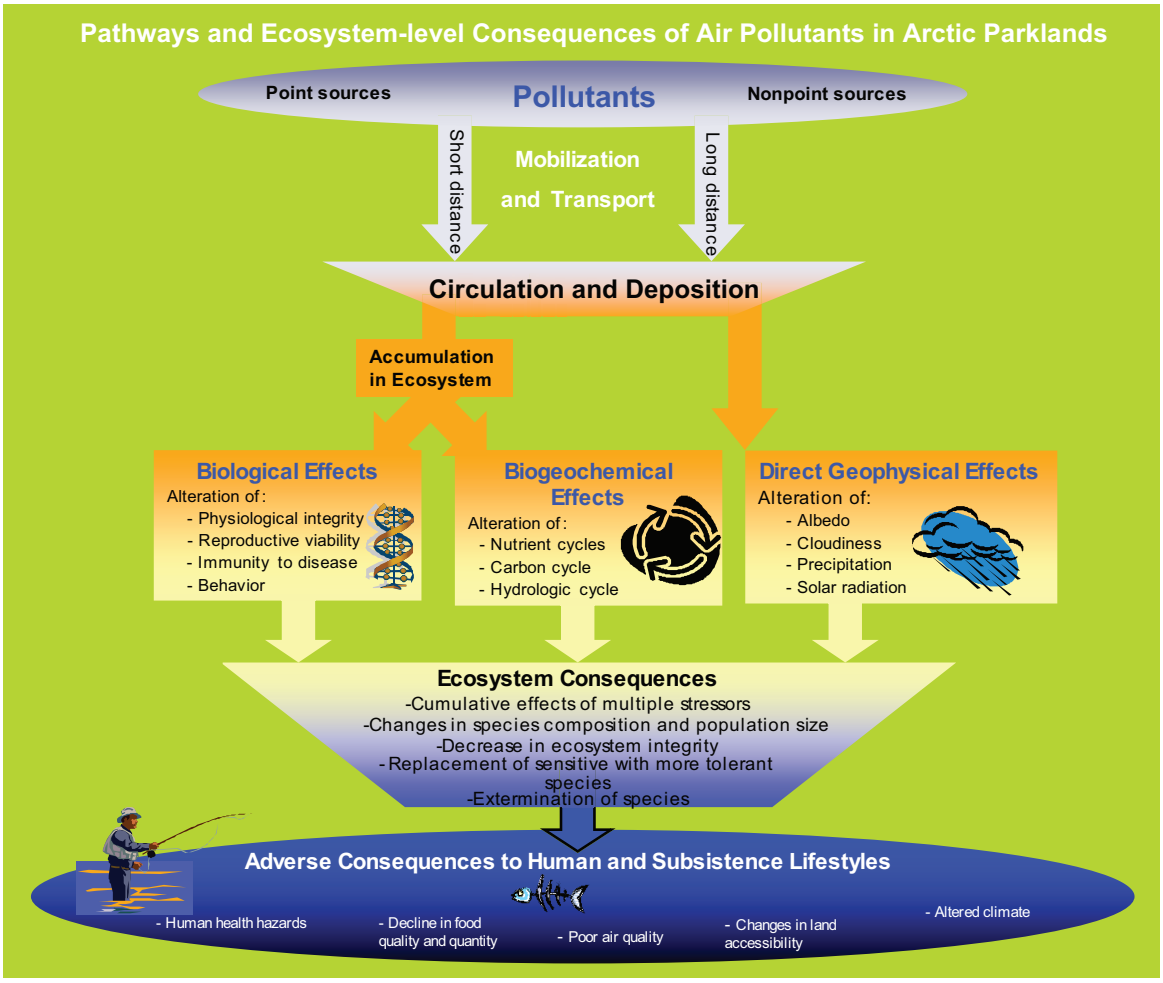


Figure 2.21: Potential pathways and ecosystem-level consequences of air pollutants in arctic parklands

radiation and precipitation reaching the surface. This could lead to an increased growing period (if the cloud amount decreases and more sun reaches the surface) or a decreased growing period (if the precipitation pattern changes to more precipitation during winter and higher snow depths). In addition to these direct geophysical effects, the transported toxins can also be deposited to the parks' ecosystems through dry deposition (settling) or wet deposition (precipitation). As the toxins accumulate in the ecosystems, they can cause a variety of biological responses. Among these responses are the alteration of physiological integrity, reproductive viability, resistance to disease, and behavior. All of these effects can make plants and animals more susceptible to changes in their ecosystems and potentially less viable. The toxins can also have biogeochemical effects, altering nutrient cycles, energy and carbon cycles, and hydrologic cycles. These effects can be cumulative, especially if multiple stressing mechanisms are involved. The overall effects of multiple ecosystem stressors could include changes in species composition and population size (e.g., more moose and fewer caribou), decrease in ecosystem integrity (e.g., making plants less able to adapt to a changing climate), replacement of sensitive with more tolerant species (such as a replacement of tundra with shrubs), or the extirpation of species or communities (e.g., alpine wetland communities).

Humans and their subsistence lifestyles are also directly impacted by these air toxins and their effects. Some of these toxins are human health hazards, and increased exposure to the toxins should lead to increased morbidity. Mercury is a prime example of an air toxin that could lead to adverse health effects in humans living in the Arctic. The air quality in the parks could also deteriorate quality and quantity of food sources. The availability and quality of subsistence foods could deteriorate due to increased stress on terrestrial and aquatic ecosystems, causing changes in habitat, migration patterns of subsistence species, or overall decreased numbers of desired food species. The accessibility of the land may also change if precipitation patterns, melt/thaw periods, etc., change due to alteration of geophysical processes and hydrological cycles. This would impact subsistence lifestyles by decreasing the accessibility of food species. For example, it is much harder to hunt caribou in soggy tundra than on a solid snow surface. Lastly, climate change may be exacerbated by air toxins through increased trapping of heat by greenhouse gases and low-level cloud cover. This could have dramatic effects on the people and animals of the ARCN parklands. The changing climate could lead to changes in ecosystem type, animal viability, land accessibility, etc., that could make a subsistence lifestyle based on the ARCN parks' resources untenable.

2.7.6 A Conceptual Framework for Considering Migratory and Invasive Species in the Arctic Network

Invasive species are those that have changed their distribution and colonized new areas. Current examples within ARCN would be various weedy plants that have established themselves in disturbed areas near villages and along roads. Invasive species can also be native species that have increased their populations and impact on native ecosystems to an important degree. The enormous and destructive rise in bark beetle populations in the spruce forests of southcentral Alaska is a good example of this. Both of these types of situations exist, generally on a small scale, within ARCN. Another common phenomenon, especially in northern environments, is the cyclical rise and fall, often by an order of magnitude or even much more, of populations of native species. While the classic examples of this are various microtine rodents (voles and lemmings) it also occurs in other species, including caribou. There are also migratory species whose breeding location and population status may change radically over time. Several species of Siberian birds (e.g., white wagtail) have colonized western Alaska in recent decades (Badyaev et al. 1996). The known examples of invasive species are mostly conspicuous organisms, but it is probable that invertebrates and certain plants will be found to show similar changes in distribution.

Invasions by "foreign" organisms usually depend on much more than simply the opportunity provided by an unusual (usually anthropogenic) dispersal event. Generally more important are changes in the local environment that allow individuals or propagules from the invasive organisms to establish themselves in areas from which they were previously excluded by ecological conditions. These can be simple changes, such as the disturbance of the soil surface encouraging the growth of ephemeral weeds, or complex alterations in the environments brought about by changing climate. These latter owe much of their complexity to the fact that they are seldom straightforward. The ultimate effect of a climatic change may result from an array of factors: changes in competition or predation as other species are eliminated or favored, changes in precipitation and/or hydrology and permafrost regime that favor certain species, or changes in soil chemistry due to human activities that inhibit otherwise common species and thus provide a habitat with reduced competition for resistant species.

Some "invasions" are actually the reestablishment of species that had previously been reduced or extirpated. Muskoxen in western Alaska are a good example. Others seem to be natural reexpansion, such as the case of grizzly bears on the Seward Peninsula in recent decades. Many of these population reestablishments or expansions are actively encouraged by managers; examples include the efforts to encourage waterfowl such as emperor geese and spectacled eider along the Bering Sea coast.

When viewed in the above context, it should be clear that invasive species, or changes in the distribution and abundance of species, are not only of intrinsic interest but are also likely to be important bellwethers in identifying deeper, more profound, and widespread changes in ecosystems (Figure 2.22). They can be expected to be of great significance in the construction of monitoring programs.

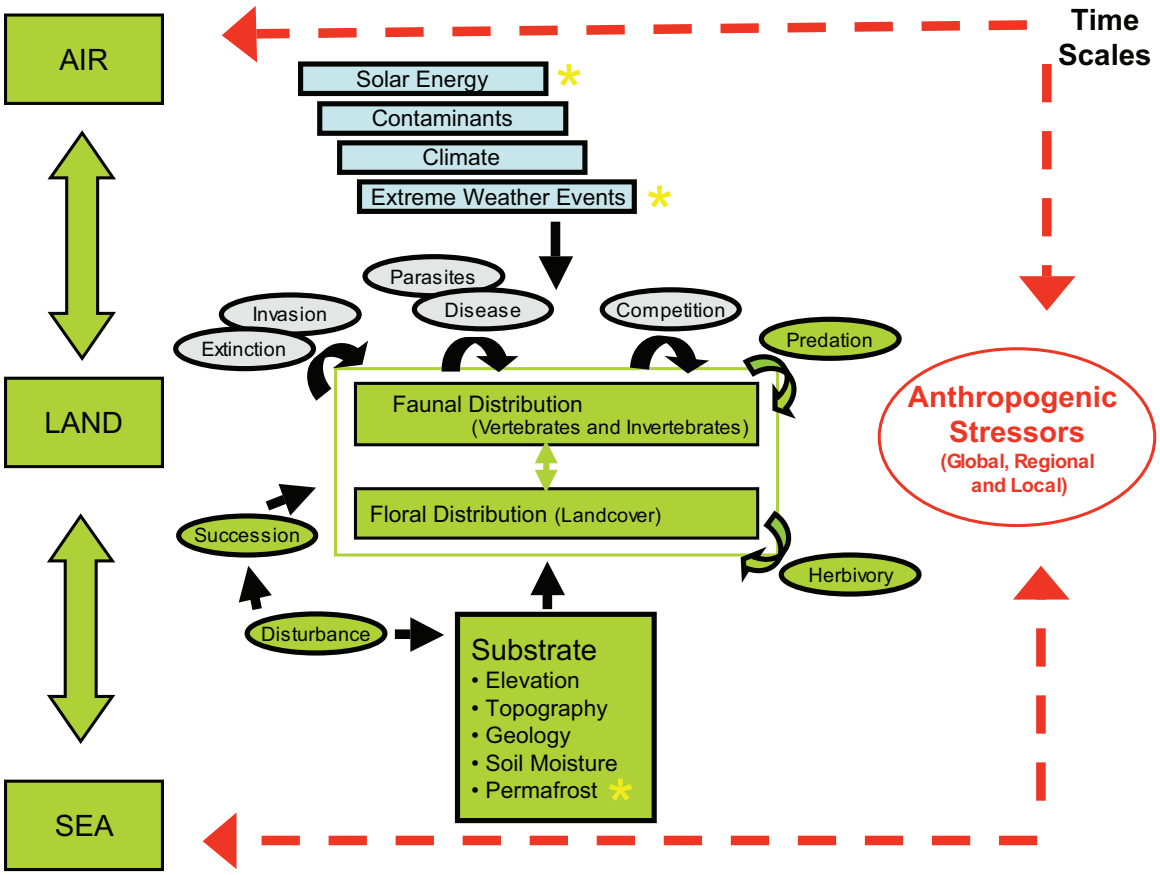


Figure 2.22: A graphic representation of the complex of factors that may be involved in changes in distribution of migratory and invasive organisms over time in ARCN



Figure 2.23: Examples of possible routes and vectors for the dissemination of exotic species within ARCN. Red lines are existing or proposed (RS-2477) roads or trails

2.7.7 Invasive Species Pathways in ARCN

Although environmental factors are likely to be principal determinants in the fate of an invasive species, the importance of dispersal routes and mechanisms should not be overlooked (Figure 2.23). In many cases, of course, a dispersal route also represents an area of environmental alteration. The berms of a gravel roadbed, for example, will normally have very different drainage and soil characteristics from the surrounding unaltered environment. A roadbed may then provide a highway for the spread of weedy species far beyond their normal range. Even a trail that is regularly used by ATVs or snowmobiles may have a similar, although usually less marked, effect.

Even low-impact recreational activities can provide dispersal opportunities for exotic organisms. Camping gear can transport seeds, the floats and hulls of amphibious aircraft can transport propagules of plants from lake to lake, and canoes and kayaks can effectively move plants down a river drainage. Figure 2.23 shows some specific examples of how plants and animals might move about as a result of human activities.

Chapter 3
Vital Signs

"The ecosystem is greater than the sum of its parts."—Eugene Odum (1964)

3.1 Introduction

In this chapter we describe the process used to identify, organize, and prioritize a final set of vital signs for the ARCN. These vital signs are intended to characterize ecosystem condition and signal change across multiple scales of space and time. We explain how the selection and prioritization of vital signs was linked to park resource management and protection issues, conceptual ecosystem models, and the network's monitoring objectives and questions.

The term vital sign is defined in this program as "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" (http://science.nature.nps.gov/im/monitor/).

The Arctic Network has identified 28 vital signs through a multistep process, including scoping sessions, interviews with park superintendents, literature reviews, ecosystem workshops, a vital signs workshop, vital signs selection meetings, and finally, a presentation to the network board of directors. The network plans to implement monitoring or develop a monitoring plan for 19 of these vital signs in the next three to five years. Two vital signs (Sea Ice and Moose) are being monitored by programs other then ARCN. The remaining seven vital signs will be monitored if additional resources become available in the future. Of the vital signs slated for implementation by ARCN, four vital signs relate to air and climate, two relate to geology and soils, three relate to water, one relates to human use, two relate to ecosystem pattern and processes, and seven relate to biological integrity. The network developed this list through a process of meetings and ranking exercises.

3.2 Vital Signs Selection

The process for choosing and prioritizing vital signs, which has been ongoing within the Arctic Network since the fall of 2003, has been a multifaceted effort of scoping and ecosystem workshops, Technical Committee meetings, ranking processes, and park-level meetings. Over the course of this process we have focused the vital signs list and placed it within the conceptual models for the network. Table 3.1 summarizes the major mileposts in the ARCN process for choosing vital signs.

Table 3.1: Timeline for the selection and prioritization of vital signs for the Arctic Network

Date	Event/Milestone	Participants	Products
October–November 2003	Park scoping miniworkshops (2)	Entire park staff in each of the five units	Exhaustive list of stressors and potential vital signs of interest to parks
October 2004	ARCN fully funded and operational	→	
June 2004–August 2005	Freshwater, Coastal and Terrestrial Scoping workshops	Technical Committee + additional experts in the field of arctic ecology	Scoping notebooks, monitoring objectives, conceptual models, development of potential vital signs list and initial list of potential measures
April–July 2005	One-on-one personal interviews with past and present superintendents (6)	Superintendents + ARCN coordinator	Superintendent priorities for the program and key vital signs of interest
September–October 2005	Arctic network staff reorganize vital signs into national framework	ARCN staff	Initial vital signs list and draft measures
25 October 2005	Technical Committee develops criteria for vital signs selection	Technical Committee	Ranking criteria for prioritization of vital signs
December 2005	Initial web-based ranking of vital signs	Technical Committee + invitees to the Land-Air-Water workshop	Web-based ranking of vital signs completed
11–13 January 2006	Land-Air-Water (LAW) workshop, including refinement of vital signs list using several methods	Technical Committee + Superintendents + additional outside experts in the field of Arctic ecology	Vital signs and potential measures further developed
March–April 2006	Series of working group and Technical Committee meetings (4)	Reorganization and prioritization of vital signs	Vital sign description pages with suggested measures completed
23 May 2006	Technical Committee meeting to select vital signs	Selection of vital signs	Recommended vital signs list
June–August 2006	Individual meetings with each park superintendent to discuss vital signs list	Superintendents + ARCN Coordinator	Approved vital signs list
January 2007	State of the Arctic Parks (SOAP) meeting	Park staff and cooperating investigators	Link vital signs and foster collaboration
April 2008	Technical Committee meeting to shorten vital signs list	Technical Committee	Current vital signs list

To initiate discussion of vital signs, the network coordinator held park meetings in Nome, Kotzebue, and Fairbanks to meet with park staff from each of the park units to:

1. present the vital signs program to all interested park staff;
2. learn what monitoring initiatives were currently underway in the parks;
3. discuss potential stressors and possible implications for park resources; and
4. develop an initial list of vital signs that might serve as indicators of change for park resources.

Park-specific lists of potential stressors and an initial list of species, communities, and ecosystems that might be good indicators of change were compiled based on discussion from these meetings.

The next stage of vital signs refinement was a series of scoping workshops to provide a forum for NPS resource managers and scientific experts to discuss ideas for building a statistically sound, ecologically based, management-relevant, and affordable monitoring program for the Arctic Network. Each of the workshops focused on one of the three major ecosystem types in ARCN: freshwater, coastal, and terrestrial ecosystems, which were roughly based on the *State of the Nation's Ecosystems* report (H. John Heinz Center, 2002). Although we realize that this division is somewhat arbitrary, it enabled us to strategically separate ARCN ecosystems into more manageable subunits for the purposes of discussion and stay consistent with other national-level initiatives. One of the main goals of each of the workshops was to identify potential vital signs and possible measures of those vital signs. (See Appendices 1–6 of *Monitoring Ecological Change in the Arctic Parklands: Vital Signs Monitoring Plan for the Arctic Network, Phase 1 Report*, available at <http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm>, for more detail). The combined list of vital signs that emerged from the first three scoping workshops contained 81 vital signs of interest to the parks.

To help ensure that issues identified during the scoping meetings and workshops were issues of importance to park resource management and protection, the ARCN coordinator met with several past and current park superintendents of the five arctic parklands between June and August of 2006. As we examined issues during our interviews, we found that the ARCN parks share similar resource management concerns and monitoring needs. Our interviews revealed that broad issues, for example global climate change and accumulation of globally derived pollutants, ranked high in importance to park management, as did more local issues such as subsistence and visitor use. It was evident from all our scoping processes that there is substantial overlap of resource management concerns among Arctic Network parks.

In the fall of 2005, the ARCN staff structured our monitoring objectives, vital signs, and list of potential measures from the first three workshops into the national framework in preparation for our fourth and final workshop, the Land-Air-Water (LAW) Linkages Scoping Workshop. Redundant vital signs were removed and related indicators were merged under a single vital sign. In addition, the Technical Committee met and developed the ARCN vital sign prioritization criteria (Table 3.2). Vital signs prioritization criteria used by other national programs, including other NPS-Vital Signs Monitoring Networks (http://science.nature.nps.gov/im/monitor/docs/CriteriaExamples.doc), were modified for use by ARCN.

Before the LAW workshop, participants ranked vital signs using a web-based Vital Signs Evaluation Tool (Figure 3.1). Each participant was able to visit the network website, see the list of potential vital signs, and rank the lists. They could also add any comments they felt were needed to accompany their rankings. Once everyone had entered their ranks on the website, average ranks were calculated. These lists represented an attempt at prioritizing the network's vital signs. The comments entered by various members during the ranking process were used to highlight topics for further discussion.

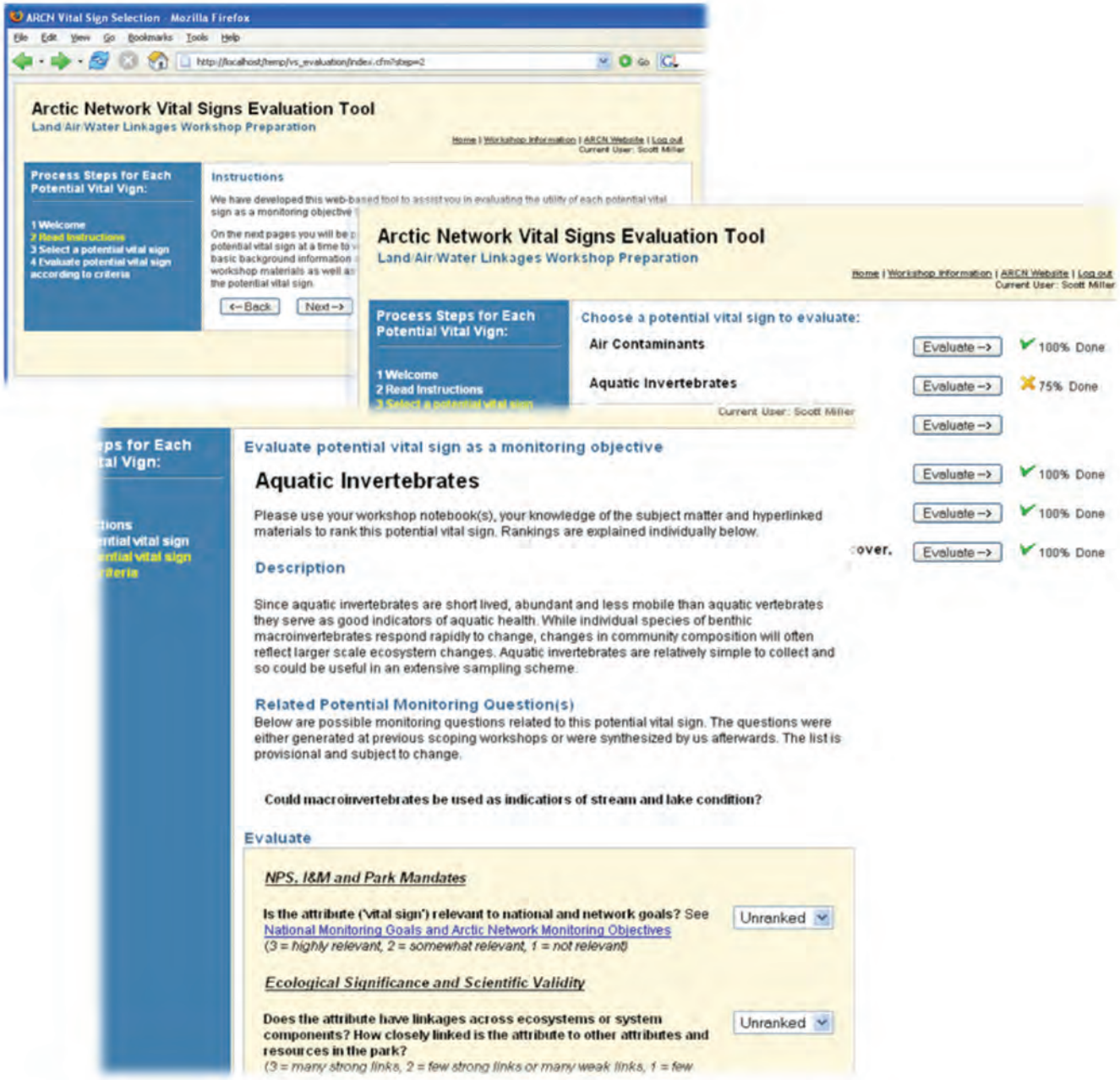


Figure 3.1: Selections from the ARCN web-based vital signs ranking tool that was used to rank vital signs before the Land-Air-Water Linkages (LAW) workshop

This tool allowed much of the personal intellectual work to be done before the workshop. The tool also ensured that each participant had the opportunity to objectively weigh each potential vital sign against our suite of criteria (Table 3.2). The results were tallied, and they provided an efficient starting point for discussion at the workshop.

This web-based ranking process worked well for avoiding "group think" because each member of the committee was asked to conduct their rankings separately. All our prior efforts to generate lists and discuss vital signs were conducted in group settings, so the web-based ranking process was a good opportunity to elucidate individual viewpoints. We were also able to analyze the ranks to assess biases based on each person's area of technical expertise, whether they were a manager or a scientist, and which park they came from.

Table 3.2: Selection criteria that land-air-water (LAW) workshop participants used to rank the draft vital sign list using the web-based program

1. **NPS, I&M and Park Mandates**
   - Is the attribute ("vital sign") relevant to national and network goals?

   [3 = highly relevant, 2 = somewhat relevant, 1 = not relevant]

2. **Ecological Significance and Scientific Validity**
   - Is the attribute ("vital sign") relevant to ecosystem function or structure? How important is the attribute in controlling ecosystem function and/or structure?

     [3 = high relevance AND importance, 2 = high relevance OR importance, 1 = low importance AND low relevance]
   - Does the attribute ("vital sign") have linkages across ecosystems or system components? How closely linked is the attribute to other attributes and resources in the park?

     [3 = many strong links, 2 = few strong links or many weak links, 1 = few weak links]
   - Is the attribute ("vital sign") relevant at multiple spatial, temporal, and hierarchical scales (e.g., population, community, ecosystem, landscape scale)?

     [3 = extremely useful at multiple scales, 2 = somewhat useful at multiple scales, 1 = minimally useful at more than one scale]

3. **Response Variability**
   - Is the attribute ("vital sign") a sensitive indicator of change?

     [3 = extremely useful, 2 = moderately useful, 1 = minimally useful]
   - Will the attribute ("vital sign") detect change within a timeframe useful and appropriate for this monitoring program?

     [3 = highly useful to detect change, 2 = moderately useful to detect change, 1 = minimally useful to detect change]

4. **Park Management Significance**
   - How important is this attribute ("vital sign") for satisfying legal or policy mandates?

     [3 = high importance (required or specifically identified; e.g., in enabling legislation), 2 = moderate importance and potentially supporting legal or policy mandates such as ecological integrity, 1 = low importance (could not help satisfy legal or policy mandates)]
   - How important is the attribute ("vital sign") for managing a resource of high priority for the park?

     [3 = high importance, 2 = moderate importance, 1 = low importance]

As was learned from observing other networks, looking at the variation among responses was as informative to understanding the priorities as looking at the average response. The variation was also helpful for highlighting topics needing further definition and discussion. We learned there was generally good agreement about which vital signs should be at the top of the lists and which should be at the bottom. The vital signs that ended up in the middle of the pack required further discussion to determine where they fit into the priorities. Of particular interest are those vital signs where the distribution of ranks was bimodal, i.e., some members ranked them very high and others ranked very low. Understanding the rationale for the rankings was critical to resolving these differences.

The LAW workshop was held in January 2006. The purpose of the workshop was to focus and prioritize the list of vital signs from earlier workshops and to link terrestrial, aquatic, and air quality vital signs. In order to take a more holistic approach to selecting and prioritizing vital signs, this workshop set out to

1. determine priority monitoring questions and associated vital signs for long-term monitoring in ARCN;
2. discuss potential measures for those priority vital signs in the context of other related vital signs;

3. arrive at an overarching conceptual model that could be used as a framework for developing an integrated monitoring program (Figure 3.2); and
4. begin to discuss possible overarching sample designs for the ARCN monitoring program.

Participants in the LAW workshop included park superintendents, the technical committee, and a subset of the invited experts from the previous three workshops.

A good portion of the first day of the LAW workshop was spent restructuring the vital signs for better integration with related vital signs. Because the vital signs were significantly altered by the end of the first day, the group decided to reprioritize the vital signs at the end of the day using the original ranking criteria (Figure 3.2). Most of the work that took place on day two occurred in smaller breakout groups and involved determining metrics for monitoring the vital signs of particular interest to ARCN. During this workshop, the group was asked to think practically about logistics and access issues in ARCN.

It was clear by the end of this workshop that the Technical Committee needed to meet again to further refine the vital signs list. Part of the need for this refinement was to ensure that we had a sustainable and well-integrated program and to give thought to an overall conceptual framework for the monitoring program.

In spring of 2006 several smaller working groups met to refine vital signs that the Technical Committee considered either too cumbersome or overly broad. Working groups were held to further discuss

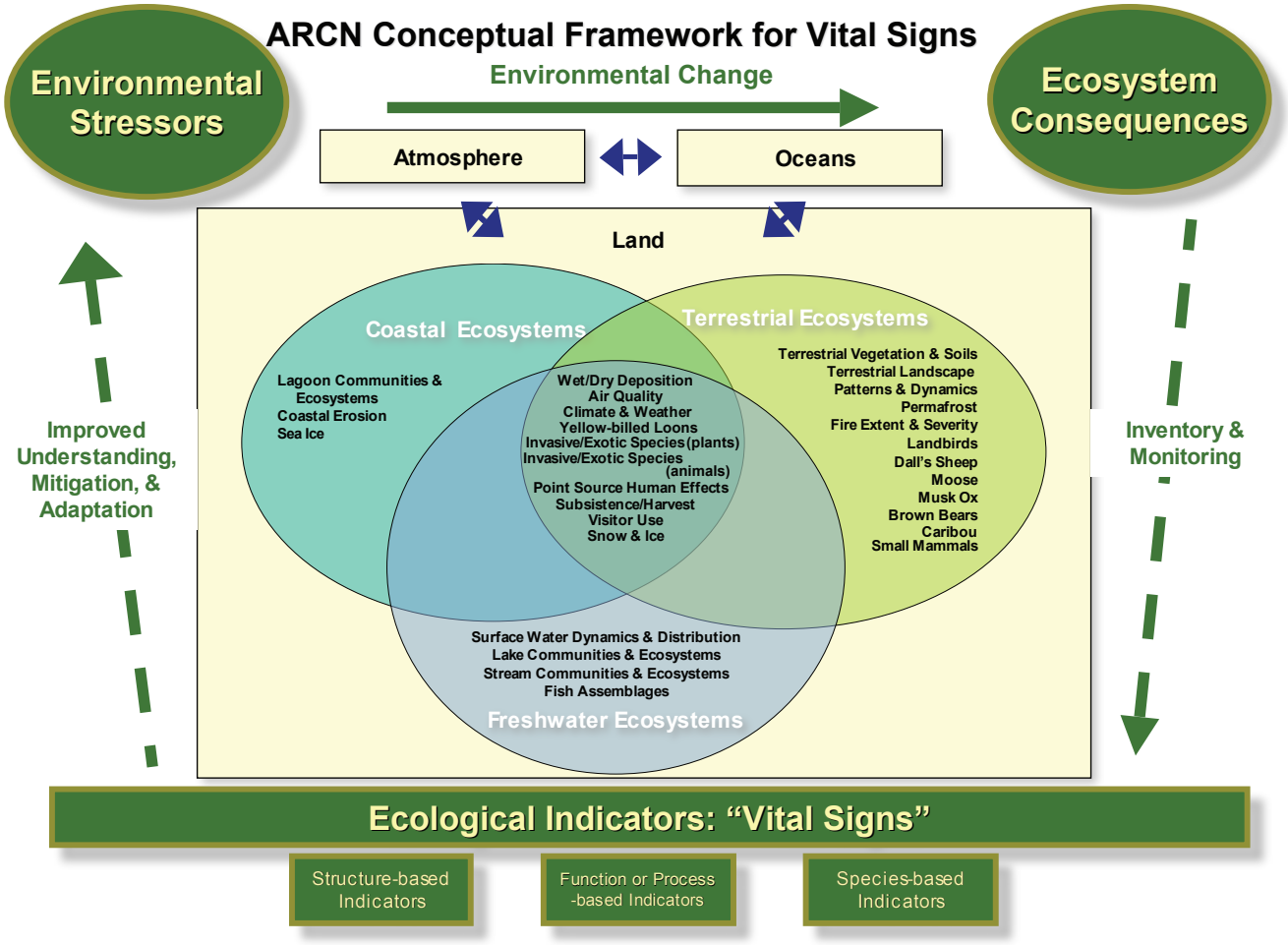


Figure 3.2: Vital signs of the Arctic Network in relation to the holistic model

mammals, birds, terrestrial vegetation, and weather and climate. Results from these working groups were presented during four Technical Committee meetings during the spring of 2006. By the end of April 2006, the refined list from the LAW workshop and working groups consisted of 39 vital signs.

On May 23, 2006, the Technical Committee met to finalize the vital signs list. By the end of the meeting, the ARCN had a "final" list of vital signs, vital sign descriptions, an updated holistic model (Figure 3.2), and the list of vital signs inserted into the national framework (Table 3.3). Prioritization during this final meeting focused on vital signs that are:

- sensitive ecological indicators of change,
- relevant at various spatial and temporal scales,
- important for sound management,
- unique to arctic parks,
- strongly linked with other vital signs, and
- provide leverage for additional resources, either within the NPS or with collaborators.

There are 28 vital signs in this category (Figure 3.2). During this and previous meetings, each of these vital signs was discussed and reaffirmed. Note that water quality parameters are completely integrated with the following three aquatic vital signs: Stream Communities and Ecosystems, Lake Communities and Ecosystems, and Lagoon Communities and Ecosystems (Chapter 1 and Table 3.3). Several vital signs that emerged from the earlier scoping workshops were not recommended by the Technical Committee, either because of redundancy with other vital signs or because they were not strong candidates using the ranking criteria (Table 3.2). Vital signs that did not make the final list were Shrub Communities/Ecosystems, Wetland Communities/Ecosystems, Riparian Communities/Ecosystems, Terrestrial Invertebrates, Forest/Woodland Communities, Wolves, Wolverines, Lynx, Furbearers, Beavers, Marmots, and Arctic Ground Squirrels.

The vital signs lists, framework, overarching conceptual model, and descriptions of each of the vital signs were provided to each member of the Board of Directors for final approval. In addition to individual meetings with each of the members of the board, the board also met as a group to discuss any lingering concerns with the final list of vital signs. All members of the ARCN board of directors expressed satisfaction with the outcome of the vital signs selection and prioritizing process. Questions during this final meeting centered on network staffing and the challenges and costs of monitoring in these most remote parks.

Although the ARCN Technical Committee and Board of Directors has agreed upon a "final" list of vital signs, we do not have resources to monitor all 28 adequately. This was apparent when the Draft Monitoring Plan for the ARCN was submitted to the National Inventory and Monitoring Program for review in December 2007. For this reason, we will defer monitoring seven vital signs until additional resources become available and two vital signs to other entities (Table 3.3). Vital signs that we have chosen to defer include those that are:

1. prioritized toward the bottom of the final list (e.g., Small Mammal Assemblages),
2. being monitored well by another entity (e.g., Sea Ice), and
3. those for which the network lacks expertise or access to expertise (e.g., Visitor Use).

3.3 Vital Signs for the Arctic Network

We present the list of 28 vital signs for the Arctic Network in Table 3.3 with an indication of the relevance of each vital sign to each park and to the network as a whole and the means by which the protocol for each vital sign will be developed. We will implement and develop a monitoring plan for 19 of these vital signs in the next three to five years. Vital signs that we intend to begin monitoring include four vital signs related to air and climate, two related to geology and soils, three related to water, one related to human use, two related to ecosystem pattern and processes, and seven related to biological integrity. Seven remaining vital signs will be monitored if additional resources become available, and two additional vital signs are being monitored by other entities and will be developed to network standards.

Each vital sign is linked to our holistic model, which encompasses our conceptual model for the ecology of our systems as well as our concerns for resource protection (Figure 3.2).

Table 3.3: Arctic Network vital signs and measures under the vitals signs framework, as developed by the National Park Service Vital Signs Monitoring Program. Monitoring currently conducted by the parks and others in the parks is also indicated. Vital signs that have been grayed out will not be implemented until additional staff or funds become available.

Level 1 Category	Level 2 Category	Level 3 Category	ARCN Vital Sign	Measures	BELA	CAKR	GAAR	KOVA	NOAT
Air and Climate	Air Quality	Wet and Dry Deposition	Wet and Dry Deposition	• Concentrations of airborne Pb, Zn, Cd, Cu, Cr, Hg, Al, B, Fe, Ti, Total S, Total N, NO_3^- using the moss *Hylocomium splendens* as a passive sampler • Hg levels in lake trout and sheefish	•	•	•	•	•
		Air Contaminants	Air Contaminants	• Levels of pH, SO_4^{2-}, NO_3^-, NH_4^+, Cl^-, Ca^{2+}, Mg^{2+}, K^+, and Na^+ (NADP*) • Hg • IMPROVE* monitoring network for visibility and fine particles			•		
	Weather and Climate	Weather and Climate	Climate	• Temperature, precipitation, relative humidity, wind speed and direction	•	•	•	•	•
			Snowpack	• Annual deposition	•	•	•	•	•
Geology and Soils	Geo-morphology	Coastal/ Oceanographic Features and Processes	Coastal Erosion	• Accretion, erosion, and bluff retreat of coastline	•	•			
			Sea Ice	• Extent • Presence/Absence	Δ	Δ			
	Soil Quality	Soil Function and Dynamics	Permafrost	• Depth of active layer • Presence/absence and geographical extent of permafrost-related features	•	•	•	•	•
Water	Hydrology	Surface Water Dynamics	Surface Water Dynamics and Distribution	• Surface area and number of lakes • Node frequency, sinuosity, distance between nodes, network patterns, bifurcation rates of streams	†	†	†	†	†
	Water Quality	Water Chemistry	Lagoon Communities and Ecosystems	• Dissolved oxygen, salinity, conductivity, and pH • Surface area • Phytoplankton and zooplankton biomass • Fish species present		•			
			Lake Communities and Ecosystems	• Water chemistry, level, and temperature • Phytoplankton and fish species community composition	•	•	•	•	•
			Stream Communities and Ecosystems	• Water chemistry, level, and temperature • Species composition of macroinvertebrates and diatoms	•		•	•	•

(continued on next page)

Table 3.3 (continued from previous page)

Level 1 Category	Level 2 Category	Level 3 Category	ARCN Vital Sign	Measures	BELA	CAKR	GAAR	KOVA	NOAT
Biological Integrity	Invasive Species	Invasive/Exotic Plants	Invasive/Exotic Species	• Presence/absence	†	†	†	†	†
	Infestations and Diseases	Animal Diseases	Invasive/Exotic Species	• Presence/absence	†	†	†	†	†
	Focal Species or Communities	Fishes	Fish Assemblages	• Presence/absence	†	†	†	†	†
		Birds	Landbirds	• Population trends of common species	•	•	•	•	•
			Yellow-billed Loons	• Population trends • Geographical extent	•	•			
		Mammals	Brown Bears	• Population trends • Geographical extent	•	•	•		•
			Caribou	• Geographical extent • Timing of seasonal movements	•	•	•	•	•
			Dall's sheep	• Population trends • Geographical extent			•		•
			Moose	• Population trends • Geographical extent	Δ		Δ	Δ	Δ
			Muskox	• Sex and age composition	•	•			
			Small Mammal Assemblages	• Density • Geographic extent	†	†	†	†	†
		Terrestrial Complex	Terrestrial Vegetation and Soils	• Plant species cover, diversity, biomass, tall shrub and tree density • Active and organic layer depth, heavy metal concentration • Soil temperature	•	•	•	•	•
Human Use	Point Source Human Effects	Point Source Human Effects	Point Source Human Effects	• Concentrations of heavy metals • Water temperature, pH, conductivity, dissolved O_2, flow, N, P, and chlorophyll *a* in streams, lakes		†	†		†
	Consumptive Use	Consumptive Use	Subsistence/ Harvest	• Fish and wildlife harvest	•	•	•	•	•
	Visitor and Recreation Use	Visitor Use	Visitor Use	• Total numbers and area of use	†	†	†	†	†

Table 3.3 (continued)

Level 1 Category	Level 2 Category	Level 3 Category	ARCN Vital Sign	Measures	BELA	CAKR	GAAR	KOVA	NOAT
Landscapes	Fire and Fuel Dynamics	Fire and Fuel Dynamics	Fire Extent and Severity	• Fire frequency, size, burn severity, and total area affected	•	•	•	•	•
	Landscape Dynamics	Land Cover and Use	Terrestrial Landscape Patterns and Dynamics	• Snow-free dates, date of onset of greenness, date of maximum greenness, date of senescence of greenness • Tree and shrub cover and height	•	•	•	•	•

• Vital sign for which the network will develop protocols and implement monitoring using funding from the vital signs or water quality monitoring program.

Δ Vital signs that are currently being monitored long-term by a network park, another NPS program, or by another federal or state agency. The network will collaborate with these other monitoring efforts where appropriate but will not use vital signs or water quality monitoring program funds.

† Vital sign for which monitoring will likely be done in the future but which cannot currently be implemented due to limited staff and funding.

* See section 4.6.2 for information on National Atmospheric Deposition Program (NADP) and Interagency Monitoring of Protected Visual Environments (IMPROVE).

Chapter 4
Sampling Design

4.1 Introduction

The primary purpose of a sampling design is to ensure the data collected are representative of the target populations(s) and sufficient to draw defensible conclusions about the resource of interest. In this chapter, we discuss how our sample design ensures the scientific merit of our program. We describe how these design principles will be applied in a broad context to the freshwater, coastal, and terrestrial environments of our network. The specific designs detailed in individual protocols follow from these basic themes and incorporate variations as necessary. Our goal is to provide over-arching sampling principles to ensure individual protocols are linked temporally, spatially, ecologically, and statistically (e.g., Ringold et al. 2003, Schreuder et al. 2004).

4.2 Design Considerations and Definitions

Subsequent sections of this chapter describe various sampling plans proposed for parks in ARCN. These sampling plans rely on a few underlying concepts of ecological sampling in space and time. This section describes some of the background concepts behind the sampling designs of the Arctic Network and defines sample unit, panel, rotation design, and membership design.

Our working definition of "monitoring" is the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective (Elzinga et al. 1998). Monitoring is often done by sampling the same sites over time, and these sites may be a subset of the sites sampled for the initial inventory. Monitoring is usually intended to provide unbiased statistical estimates of status and trends in areas ranging in size from park units to specific index sites.

While monitoring might be considered a specific goal, the data from the NPS Inventory and Monitoring Program will undoubtedly be used for many purposes. For example, in case of an ecological insult or planned disturbance at a particular location and time, historic monitoring data would be invaluable to predict ecological variables at that location and time, both in the past and present. As another example, data from several vital signs might be used in a statistical regression model that shows relationships among them; e.g., Maier et al. (2005) used data from local moose abundance surveys by the Alaska Department of Fish and Game (ADF&G) to investigate moose abundance as a function of fire and other landscape metrics in interior Alaska. With the possibility that monitoring data will be used for a wide variety of purposes, it is important that they are collected in ways that are robust to various, and possibly unknown, uses.

Using data collected by monitoring programs, long-term correlations between management actions or natural changes and ecological parameters can occasionally be documented and can provide the most compelling and complete picture of ecosystems and ecosystem changes. Monitoring, as conducted by

the Arctic Network, does not set out to establish statistical cause and effect relationships. However, good sampling design in a monitoring program can document correlations that strengthen the ability to infer such relationships. Because of monitoring's long-term objectives, protocols need to be established that are repeatable in the sense that different people taking the same measurement will likely produce the same value. Successful monitoring programs can produce compelling evidence of ecological status and change because they collect long-term data and their inferences apply to large areas, but these programs are difficult to implement because they require substantial investment in time, commitment, and money.

The monitoring plans for ARCN rely on concepts of finite population sampling. In finite population sampling, the area for which inferences are desired (e.g., a park or ecoregion) is generally viewed as a finite collection of *sample units* (or just *units*). In general, sample units are the smallest entities upon which measurements are taken. The total collection of sample units is called the *population*. In some studies, sample units will be discrete entities such as stream segments, ponds, lakes, etc. In other studies, sample units will be small areas or pixels. In still other studies, sample units will be aerial survey routes or individual animals. *Responses* are defined as measurements taken on the sample units. A *sample* is a subset of units chosen to record a response through counts, observations, or other forms of measurement (Cochran 1977).

As in other NPS monitoring networks, sampling designs of ARCN parks may sometimes rotate sampling efforts through different collections of units over time. We define a *panel* of sample units to be those units that are always all sampled during the same sampling occasion or time period (McDonald 2003). Note that this definition does not preclude a sample unit from being a member of two different panels. In ARCN, however, it will be more typical for sampling units to be members of only one panel.

There are two basic components of a sampling design for monitoring a natural resource: membership design and revisit design.

Membership design specifies the spatial sampling schedule (McDonald 2003). For example, if two panels are to be constructed, the membership design might specify that members of panel 1 be selected at random from the population. For panel 2, the membership design might dictate that the members of panel 1 be placed back into the population and another random sample taken to comprise the units of panel 2. Under this plan, it is possible to select the same unit for membership in both panels. Another membership design might specify a systematic sample of units be drawn and then placement of every other unit into panel 1, starting with the first. Every other unit starting with the second would be placed in panel 2. Under this design, it is not possible to get the same unit in both panels.

A *revisit design* determines when and how often selected units are sampled (or visited) and hence how to temporally allocate sampling efforts (McDonald 2003). For example, members of one panel may be sampled during every sampling occasion and members of another panel every third sampling occasion. Sampling frequency will be dictated both by level of temporal variation in the vital sign metric and by logistical/funding constraints.

4.3 Overview of Sampling Approaches

The Arctic Network is composed of large and remote park areas. This presents a daunting challenge for designing a statistically valid sampling strategy. Access to these parks is expensive and requires a bush plane, helicopter, boat, or snowmachine. Weather conditions can make timing of access uncertain. Large portions of three of the ARCN parks are also legislatively designated wilderness areas, placing additional restrictions on use of motorized vehicles. Consequently, practical considerations, such as

accessibility and cost, will limit design alternatives that can realistically be implemented in these park units. Issues such as fuel costs have substantial impacts on how much monitoring can occur in a given field season. For these reasons, a sample design needs to be flexible enough to allow continued sampling within a range of areas or sites if funding drops to levels too low to support the full program.

Whenever possible we will use a common probabilistic design for monitoring vital signs. By sharing a common design, we will be able to collocate and covisit locations for recording data for a number of vital signs. Nonetheless, an overarching sample design that can be used for all vital signs and metrics is not possible given the different fundamental types of sampling required by each monitoring effort. Individual vital signs chosen by the ARCN Network differ in sampling contexts such as spatial scale and temporal configuration. In some instances we will be acquiring monitoring data from existing programs (both inside and outside the NPS) that employ different sampling designs.

Given finite resources and the size, remoteness, and access issues associated with monitoring in ARCN park units, it is not realistic to collect high-resolution data for all vital signs on a network-wide scale. Therefore, even though our target population may be throughout the network, the actual areas of inference (sampled population) may be much smaller, especially for vital signs requiring on-the-ground sampling. Where network-wide sampling is not feasible, we will incorporate accessibility and prioritization components into our designs. Prioritization criteria will be heavily influenced by park staff. High-priority, easily accessible units or sites will be sampled more frequently than others. This will ensure that these high-priority areas will be monitored even during years of limited resources.

We will use a combination of random and nonrandom sampling designs for those vital signs being developed by ARCN. The random sampling design will primarily be generalized random tessellation stratified sample (GRTS) or systematic sampling with a random start, often with a level or levels of stratification based on environmental attributes (e.g., slope) to increase precision of our trend estimators. Stratification criteria should change little or remain unchanged during the course of the monitoring program (Overton and Stehman 1996). The nonrandom samples will be sites where changes are predicted as most likely to occur, sites that are chosen to represent the range of conditions within the site of interest, or a combination of these two. When possible, randomly chosen sites will supplement nonrandom units to broaden the scale of inference.

In the end, three fundamentally different schemes for collecting measurements in the field were adopted for the ARCN monitoring studies:

- the first scheme (grid-based sampling) constructs a grid of either points or cells to use as sample units and draws a probability sample;
- the second scheme (list-based sampling) constructs a list of sample units and either draws a probability sample or attempts to census all units; and
- the third scheme collects information on areas or at points (index sites) that were hand-picked by lead investigators to yield adequate data on a particular vital sign.

The remainder of this chapter contains one main section for each of the three types of sample schemes with a brief description of which vital signs will be monitored within the framework of that scheme. Proposed sampling designs used for monitoring vital signs are summarized in Table 4.1. No sampling strategy has yet been devised for the nine vital signs that have been deferred (i.e., Sea Ice, Surface Water Dynamics and Distribution, Invasive and Exotic Plants and Animals, Fish Assemblages, Moose, Small Mammal Assemblages, Point Source Human Effects, and Visitor Use).

Table 4.1: Existing and proposed sampling/response designs for monitoring ARCN vital signs. Sampling frequencies are subject to change depending on observed variability and funding/logistical constraints.

Vital Sign	Sampling Design Component		
	Membership	Revisit	Response Design
Wet and Dry Deposition	Fish: Nonrandom (expert judgement) Terrestrial: Nonrandom (expert judgement; systematic with random start once at site)	Every 5–10 years	Ground-based (collocated with vegetation and lake samples)
Air Quality	Nonrandom (expert judgement)	Continuous	Ground-based (station)
Climate	Nonrandom (expert judgement)	Continuous	Ground-based (stations)
Snowpack	Nonrandom (expert judgement)	Continuous	Ground-based (stations; collocated with climate)
Coastal Erosion	Entire coastline	Every 10 years	Aerial photography or high resolution imagery
Permafrost	Systematic	Every 5–10 years	Aerial photography
Lagoon Communities and Ecosystems	Nonrandom (expert judgement)	Semiannual	Ground-based (water quality)
	Nonrandom (expert judgement)	Every 5 years	Ground-based (biological samples)
	Nonrandom (expert judgement)	Every 10 years	Aerial photography
Lake Communities and Ecosystems	GRTS sample	Every 3–5 years	Ground-based
Stream Communities and Ecosystems	Nonrandom (expert judgement)	Every 3–5 years	Watershed
Landbirds	Stratified—systematic with random start	Biennial	Transects along river corridors
Yellow-billed Loons	Targeted (nonrandom) and complete surveys	Every 2–3 years	Aerial survey and contaminant sampling
Brown Bears	Complete survey	Every 3–5 years	Aerial survey, occupancy models
Caribou	Radiocollared caribou	Daily	Coordinates from GPS satellite collars
Dall's Sheep	Complete survey Distance sampling	Every 1–5 years	Aerial survey
Muskox	Targeted (nonrandom) and complete surveys	Every 2 years	Aerial survey
Terrestrial Vegetation and Soils	Nonrandom (expert judgement; systematic with random start once on site)	Every 10 years	Ground-based
	Nonrandom (expert judgement)	Continuous	Ground-based (collocated with climate stations)
	Systematic with random start	Every 10 years	Aerial photography
Subsistence/Harvest	Nonrandom	Annual	Harvest and subsistence reporting
Fire Extent and Severity	Complete survey	Annual	Satellite imagery
	Nonrandom (expert judgement)	Every 5–10 years	Ground-based
Terrestrial Landscape Patterns and Dynamics	Systematic with random start	Every 10 years	Aerial photography, satellite imagery, LIDAR (treeline and shrubline monitoring)
	Complete survey	Annual	Satellite imagery (phenology and growing season)

4.4 Grid-based Sampling

Grid-based sampling will be the primary spatial sampling method for the vital signs of Permafrost and Terrestrial Landscape Patterns and Dynamics. Grid-based sampling may also be used for monitoring coastal erosion. In each of these cases, remotely sensed imagery, either aerial photography, LIDAR or satellite imagery, will be used to gather data. The area of inference possible with these methods is ARCN-wide. A systematically distributed 20 km x 20 km grid will be used to distribute grid points, cells, and transects across the network.

4.4.1 Permafrost

Permafrost-related landscape features can be reliably identified and tallied from high-resolution aerial photography taken at grid points. The area covered and density of permafrost-related features can be photo-interpreted over a specific area centered at each grid point and then extrapolated to quantify the extent of each feature across the landscape. To assure adequate sample size, we will photograph either a smaller grid that is anchored to the initial 20 km grid point or sample within the photograph that is centered at each 20 km grid point.

4.4.2 Terrestrial Landscape Patterns and Dynamics

LIDAR data will be tested for usefulness in measuring the height and density of tree and shrub canopies and their area extent. Aerial photography or high-resolution satellite imagery may also be used to track tree and shrub area and density. Cost will initially constrain sampling to grid points or transects, although area coverage by LIDAR may become feasible in the future.

Long-term landscape scale shifts in phenology and primary productivity may be monitored by using AVHRR (Advanced Very High Resolution Radiometer) and MODIS (Moderate Resolution Imaging Spectroradiometer sensors). Indices that can be used to track phenology and productivity changes over large areas are computed from this imagery and publicly available from U.S. government websites. ARCN is in the process of researching the available products to determine those most useful for phenology change detection. Once images are acquired for ARCN lands, we will organize them into convenient time-series and report on changes significant to ARCN resources.

4.4.3 Coastal Erosion

Coastal erosion will be monitored primarily through remote sensing of the coastline along the BELA and CAKR coasts. Remote sensing methods involve repeated acquisition (approximately every 5–10 years) of orthorectified, high-resolution base imagery and Digital Elevation Models (DEMs). High-resolution imagery (IFSAR radar imagery, Ikonos or QuickBird satellite imagery, or orthorectified aerial photography) is required for the quantification of erosion at rates of typically 0.1–10 m/yr. High-resolution DEMs (from IFSAR or LIDAR) are used to calculate volumetric loss or gain. Standard GIS and remote sensing packages are then used to digitize the base imagery and quantify vector and raster algorithms to show erosion rates, change in erosion rate through time, areas lost and gained, volumes lost and gained, and fluxes.

4.5 List-based Sampling

List-based sampling will be the primary sampling method for monitoring lagoons, lakes, populations of wildlife, and subsistence harvest in ARCN parks. All the lagoons to be sampled under the ARCN vital sign program are in CAKR (n=5). Lakes to be sampled within ARCN will be drawn from a list generated using recent satellite imagery. Each lake was given a unique identifier and classified by size and position. Locations of annual landbird monitoring will be determined by cycling through a list of navigable rivers systems within ARCN. The yellow-billed loon monitoring study will use a list of all lakes >7 hectares within a survey plot for sampling. Brown bears, Dall's sheep, and muskoxen will all be sampled (separately) by rotating through a list of survey areas for each species. The sampling list for caribou includes all GPS-collared caribou.

4.5.1 Lagoon Communities and Ecosystems

Monitoring of all five coastal lagoons in CAKR will occur on semiannual basis, once during ice-covered conditions and once during open water conditions. Continuous data loggers will be deployed into the water column after ice break-up and will be retrieved at the onset of ice formation in the lagoons. Traditional ecological knowledge interviews will be conducted annually during the open water sampling period in cooperation with other agencies and organizations (i.e., Alaska Department of Fish and Game, Maniilaq), during their harvest surveys if lagoon resources are part of the surveys. A second set of monitoring data will be collected every five years and will include fish species richness and abundance, zooplankton biomass, phytoplankton biomass, and nutrients. Every 10 years, aerial photographs gathered for the coastal erosion vital sign will be analyzed. Sediment contaminants and contaminant testing of subsistence fish will also occur on a 10-year basis.

Existing protocols (e.g., U.S. Geological Survey National Water Quality Assessment Program [USGS-NAWQA], Environmental Protection Agency Ecological Monitoring and Assessment Program [EPA-EMAP], U.S. Fish and Wildlife Service [USFWS], Arctic Monitoring and Assessment Programme [AMAP]) will be used to collect natural resource data, but modifications will be made to accommodate for site-specific challenges (e.g. logistics, weather, types of sampling gear, etc.).

Existing protocols (e.g., EPA, ADF&G, Romney et al. 1986, Weller and Romney 1988, D'Andrade 1989, Johnson 1990, and Johnson and Griffith 1998) will be used to collect and analyze subsistence data in cooperation with ADF&G and local Native groups.

4.5.2 Lake Communities and Ecosystems

We will monitor shallow lakes in areas where they are highly concentrated within BELA, KOVA, and NOAT. Lakes in each of the parks will be selected according to a generalized random tessellation stratified sample (GRTS). Twenty to thirty lakes will be selected in each park unit following a power analysis. This spatially balanced sampling design will allow us to extrapolate our findings to these critical regions within BELA, KOVA, and NOAT. Sites will be revisited every three years.

For large lakes, we will use a spatially balanced sampling design, and our population of interest will include lakes that are accessible by float plane (most will have a maximum linear dimension >1.5 km). Lakes will be selected using a GRTS model stratified by physiography and vegetation. Lakes of management concern will be forced into the model. Each year, 10 lakes will be sampled. A revisit design will be selected following a power analysis.

4.5.3 Landbirds

Monitoring of landbirds for relative population levels and bird community composition and distribution in ARCN will be accomplished every two years using modified Alaska Landbird Monitoring Survey (ALMS; Handel and Cady 2004) protocols with limited inference space along riparian corridors as per Guldager (2003, 2005). These surveys are designed for two-person crews to sample 12 transects of 12 point-transects each along major river corridors throughout ARCN. The survey consists of a systematic sampling design with a random start point, using variable circular plot methodology with unlimited distance estimation. Surveys will be conducted during the breeding season (June) as early as river access is possible after spring thaw.

4.5.4 Yellow-billed Loons

Aerial surveys for yellow-billed loons will be conducted in primary breeding yellow-billed loon habitat within ARCN every two to three years. Primary habitat has been determined from previous general waterfowl surveys conducted in the area in 1992–1993 (USFWS, unpublished data). The sample will consist of approximately 30 plots of 12 km square. Plots will be selected for each survey and will be generated around randomly selected points with the constraints that plot centers will be within the survey area and that plots have to be at least 2 km from each other. All lakes >7 hectares will be identified within the plot and assigned a unique number. A lake will be considered within the plot if the centroid of the lake is within the plot boundaries. All identified lakes within the plot will be surveyed. Surveys will be conducted with small fixed-wing aircraft.

4.5.5 Brown Bears

Monitoring of brown bears will be rotated through three survey areas. Occupancy models will be used to estimate the probability of occupancy of sampling units within the larger study area. Occupancy sampling is conducted by visiting a sample of sites within a larger study area and observing individual animals. Sites with no bears present are also recorded. Sampled sites are visited at least twice by independent observers, usually within a time period short enough to restrict the probability of births, deaths, immigration, and emigration in sites during the sampling period. From these data, models are used to estimate the probability of detecting presence given a site is occupied, and detection probability is used to correct raw observations of presence to estimate occupancy probability—the proportion of sites within the larger study area that are occupied (MacKenzie et al. 2006)—thus avoiding bias caused by false absences. Estimates of occupancy are calculated with R statistical programs (R Development Core Team 2006).

Garshelis and McLellan (2006) provide necessary advice and caution on the extension of occupancy to abundance, so we have chosen to estimate abundance with a classical parametric estimator. Brown bear abundance will be estimated with a stratified, simple random sample estimator (Gasaway et al. 1986). The resulting estimate is "corrected" for visibility bias provided by double-sampling (Graham and Bell 1989). Sampling variance for the corrected abundance estimate is calculated according to Goodman (1960). Additional estimators, however, may be more appropriate for these data, especially the estimator developed by Royle and Nichols (2003). An appropriate abundance estimator will be chosen prior to implementation in 2009.

4.5.6 Caribou

Many protocols for monitoring caribou have already been developed by the ADF&G and other groups. An important component of tracking this vital sign by the Arctic Network will be to evaluate the data produced by ADF&G and other natural resource agencies. Collaboration with other natural resources agencies and local users will also be a critical component in making this monitoring effort successful.

ARCN will contribute to the multiagency effort to monitor caribou in the Western Arctic Caribou Herd by contributing GPS radiocollars. The ADF&G has agreed to capture animals for the deployment of the collars. The use of satellite GPS collars will minimize time and money spent on aircraft to radiotrack animals since we will receive caribou location data via the internet daily. The ADF&G is supportive of this effort because the GPS radiocollars will aid in locating groups of caribou for ADF&G photocensus work as well as sex and age composition, recruitment, and calving monitoring. Arctic Network staff will use GPS telemetry data to track the timing and direction of seasonal movements using standard GIS software. We will deploy 15 to 20 collars per year for three to five years. Our goal is to maintain a collared population of 60 animals at the start of each fall. The sample units will be the list of radiocollared caribou. We anticipate sharing the GPS radiocollar data with other natural resource agencies with the expectation that the sharing of radiocollar data will be reciprocal.

4.5.7 Dall's Sheep

In areas of high management concern, aerial direct count surveys of Dall's sheep will be conducted using small, fixed-wing aircraft with one pilot and one observer. These areas will be surveyed as a census every three years. Sightability during aerial surveys may vary considerably from year to year, suggesting the need to use a sightability index when estimating sheep populations from survey data. Udevitz et al. (2006) determined a sightability index for Dall's sheep in the Baird Mountains that will be applied in the Baird Mountains. Similarly, Whitten (1997) evaluated sightability of sheep in the Itkillik Preserve, and we will follow his recommendations on sightability where appropriate.

Sheep surveys will also be conducted ARCN-wide every five years to update the population and distribution estimates for the region. These surveys will be conducted using distance sampling theory (Buckland et al. 2001), with the goal of generating abundance estimates for two target sampling areas:

- GAAR as a whole, and
- delineated sheep habitat in Western Arctic Parklands (WEAR: NOAT, CAKR, KOVA).

Contour transects will be selected randomly throughout each study area to provide an abundance estimate for the entire park/unit. These methods will also provide annual sightability estimates, which have been problematic in the past. We plan to alternate sampling between the two areas so that each is sampled at least every five years.

4.5.8 Muskox

Traditionally, muskoxen censuses in ARCN park units have been done by park resource staff in cooperation with the ADF&G and have focused on winter population censuses. Monitoring of sex and age composition of the herds has happened on a more sporadic basis. ARCN will establish a more consistent effort to monitor the demography of muskoxen in BELA and CAKN. For efficiency, ARCN will

collect data on the sex and age composition of muskoxen immediately following aerial census. Muskoxen locations drawn from the list generated during the census will be sampled.

Sex and age composition are determined using a spotting scope to classify muskoxen. A helicopter is used to ferry observers from one group of animals to the next. It is possible to classify most muskoxen in both park units in two to three days. Initially, composition surveys will be conducted every year.

4.5.9 Subsistence Harvest

The ADF&G, the Federal Subsistence Board, and several Alaska Native organizations in northwestern Alaska have established programs for collecting and maintaining data about resource harvest for subsistence and sport. ARCN will collaborate with these agencies and organizations to help with these programs where possible and to incorporate these data into ARCN data streams.

4.6 Index Sites

Sampling for the vital signs of Wet and Dry Deposition, Air Quality, Climate, Snowpack, Stream Communities and Ecosystems, Terrestrial Vegetation and Soils, and Fire Extent and Severity will occur at index sites. Where possible, vital signs will be collocated at index sites. This focus on index sites is justified due to the high cost of surveys, access, and equipment involved in the measurements. Technically, statistical inference to a larger area, such as a park or a portion of a park, is not possible using data collected in areas or at sites that were not chosen by a probability sample. In some instances, this is acceptable because the spatial fluctuation in measurements across a park is inconsequential for long-term monitoring. In other situations, the value of collocation of two or more vital signs offsets the disadvantages (e.g., Climate and Snowpack). In some cases, a randomized sampling scheme placed at the index site will allow spatially limited inference in the vicinity of the site. In still other situations, it is simply the best we can do with limited resources. Statistical inference from index sites can suggest similar relationships in a wider area and may still provide evidence that changes are occurring.

4.6.1 Wet and Dry Deposition

Baseline levels of heavy metals, sulfur (S), nitrogen (N), and synthetic organic chemicals (SOC) will be established in ARCN using samples from the common moss *Hylocomium splendens*, fish, and lake cores. Sample sites will be collocated with the aquatic vital signs and the Terrestrial Vegetation and Soils vital sign, which will allow for determination of baseline values in abiotic components. It is expected that these measures will occur on a decadal basis.

ARCN will use a well-established method for monitoring moss-derived contaminant concentrations for point source contamination (i.e., Red Dog Mine mine) that was used previously in ARCN (Hasselbach et al. 2004). Methods used and reported on in the Western Airborne Contaminant Assessment Program (2008) will be used and adapted to ARCN needs for fish and lake cores.

4.6.2 Air Quality

ARCN will monitor air quality using the protocols and standard operating procedures established by nationwide air quality monitoring networks. These networks include:

- National Atmospheric Deposition Program (NADP),

- Mercury Deposition Network (MDN), and
- Interagency Monitoring of Protected Visual Environments (IMPROVE) network.

All data on air quality will be collected at a single station near the border of GAAR in Bettles, Alaska.

4.6.3 Climate

Climate monitoring will follow the methodology developed by the Western Regional Climate Center (Davey et al. 2007) and the Central Alaska Network (Sousanes and Adema 2004). ARCN will deploy up to 15 new weather stations throughout the ARCN network. Weather stations will be deployed to capture a broad range of climate gradients based on predicted conditions from the Parameter Regression on Independent Slopes Model (PRISM). This model was developed to address the extreme spatial and elevation gradients exhibited by the climate of the western U.S. (Daly et al. 1994, 2002). Other criteria for site selection will be accessibility and wilderness designation.

Climate stations will measure and record air temperature, soil temperature, wind speed and direction, snow depth, relative humidity, solar radiation, and year-round precipitation (rain, snow, and mixed precipitation). Digital data will be archived with the Western Regional Climate Center (http://www.wrcc.dri.edu/).

4.6.4 Snowpack

ARCN will partner with the Natural Resource Conservation Service to expand their network of snow courses, aerial snow markers, and snow telemetry (SNOTEL) sites to the ARCN parks. A comprehensive site evaluation in the summer of 2008 will provide the information necessary to locate potential new sites. Proximity to field offices (Nome, Kotzebue, Bettles, and Wiseman) will be key factors in site selection due to the amount of usable daylight hours for winter field surveys in the ARCN parks. Snow course and aerial snow markers will be located so that a two- to three-hour flight transect can be accomplished from these base locations. Between one and five SNOTEL sites will be installed within the ARCN parks. These stations will have the full complement of meteorological sensors plus a year-round shielded precipitation gauge that will accurately record both snowfall and rainfall. Acoustic snow depth sensors will also be located on each climate station being deployed under the Climate monitoring protocol.

4.6.5 Stream Communities and Ecosystems

Methods developed by the EPA-EMAP will be modified to deal with specific needs of working in remote arctic locations. Six primary watersheds will be monitored on an annual basis. Data collected will be used to determine general status and trends of chemical, physical, and biological characteristics of aquatic resources. If additional resources become available, we will expand sampling to several extensive watersheds that will be sampled less intensively on a rotating basis. Watersheds will be selected to represent extreme ends of physiographic gradients and by collocating with other vital signs, in particular Lake Communities and Ecosystems. Watersheds will be chosen by expert judgment. Ground-based sampling will be conducted in a given watershed every four years. Between ground-based sampling efforts, data loggers will continuously record temperature and discharge.

4.6.6 Terrestrial Vegetation and Soils

The terrestrial monitoring program will use a combination of ground data and remote sensing to provide extensive coverage at a landscape level in the parks. Detailed measurements of community structure will be taken on the plot level at a series of index sites or nodes. Each node will include a number of ground plots in a diverse set of vegetation associations. Ground data will be used to calibrate remote sensing products, and remote sensing will be used to extrapolate plot results to a landscape level, possibly on a network-wide grid. Data from both levels will be analyzed in concert with input from other linked vital signs such as Wet and Dry Deposition, Climate, Lake Ecosystems and Communities, Permafrost, Terrestrial Landscape Patterns, and the mammal and bird vital signs.

Vegetation composition will be quantified through highly repeatable plot-based measurements of plant cover on permanent plots at chosen ARCN nodes. A grid of points to measure organic horizon thickness may also be established. The interval for re-measurement of organic horizon thickness will be longer than other data collected at the plots due to the slow change typical of this feature. Plots will serve as calibration sites for aerial photograph interpretation.

Nodes will be chosen using the following criteria:

- access,
- subsection physiography,
- land cover classes,
- climate zones, and
- distribution of plots within each park unit.

A subset of the nodes will be in selected areas of high management interest. Collocation with watershed and shallow lake monitoring, weather station monitoring, wildlife monitoring, and existing clusters of vegetation composition and cover data (landcover mapping sample sites, nonvascular plant inventory sites) will provide additional calibration data for aerial photograph interpretation

There will be approximately 30 nodes with approximately 24 plots per node. The field season will be mid-July to mid-August, with two or three crews of three people each visiting a total of six nodes per year. Initial sampling will be completed in five years and repeated every 10 years. Existing sample designs developed by the Central Alaska Network and the Southwest Alaska Network will be modified for use by ARCN.

Soil temperature will be monitored by installation of sensors at various depths in the soil at the weather stations established as a part of the Climate vital sign.

4.6.7 Fire Extent and Severity

The basic approach of the Fire Extent and Severity vital sign will be to work cooperatively with the Fire Management Program of the NPS Alaska Region. Data on frequency, extent, and burn severity is currently being collected by the Fire Management Program in ARCN as well as in the Central Alaska Network. We anticipate ARCN's primary role in maintaining the Fire Extent and Severity vital sign is to ensure that this vital sign is integrated with other vital signs in the program, particularly the Terrestrial Vegetation and Soils vital sign, and to focus on fire effects monitoring through the fire effects monitoring plots in ARCN.

Chapter 5
Sampling Protocols

Monitoring protocols identify methods for gathering information on a vital sign, outline a process to collect information, and establish how information will be analyzed and reported. Protocols are detailed study plans that are necessary to ensure that changes detected by monitoring actually are occurring in nature and do not stem from measurement variability introduced when different people or methods are used (Oakley et al. 2003). Protocols are essential for monitoring vital signs through time.

Monitoring protocols must include a narrative providing the rationale for vital sign selection, an overview of the monitoring protocol components, and a history of the development of the protocol. The narrative details protocol sampling objectives, sampling design (including location and time of sample collection), field methods, data analysis and reporting, staffing requirements, training procedures, and operational requirements (Oakley et al. 2003). Specific measurable objectives must be identified in the objective section of the narrative. Narratives also summarize the design phase of a protocol development and any decision-making that is relevant to the protocol. Documenting the history of a protocol during its development of phase helps ensure future refinement of the protocol continues to improve the protocol and is not a mere repetition of previous trials or comparisons (Oakley et al. 2003). Narratives also provide a listing and brief summary of all standard operating procedures (SOPs), which are developed in detail as independent sections in the protocol.

SOPs carefully and thoroughly explain, in a step-by- step manner, how each procedure identified in the protocol narrative will be accomplished. At a minimum, SOPs address pre-sampling training requirements, data to be collected, equipment operations, data collection techniques, data management, data analysis, reporting, and any activities required at the end of a field season (i.e., equipment storage). One SOP identifies when and how revisions to the protocol are undertaken. As stand alone documents, SOPs are easily updated compared to revising an entire monitoring protocol. A revision log for each SOP identifies any changes that are implemented.

Finally, monitoring protocols identify supporting materials critical to the development and implementation of the protocol (Oakley et al. 2003). Supporting materials are any materials developed or acquired during the development phase of a monitoring protocol. Examples of this material may include databases, reports, maps, geospatial information, species lists, species guilds, analysis tools tested, and any decisions resulting from these exploratory analyses. Material not easily formatted for inclusion in the monitoring protocol also can be included in this section.

Protocol development for the ARCN parks has proceeded with a view to ensuring compatibility with other natural resource monitoring efforts in the region and with other Inventory and Monitoring networks within the Alaska region to facilitate information exchange and sharing. The protocol summaries include the vital signs to be monitored, a justification for monitoring, a list of sampling objectives, and a description of the sample frame and revisit schedule for the parks where the protocol will be implemented (Table 5.2). The full protocol development summaries (PDS) are provided in Appendix 15.

Table 5.1: Justifications and measurable objectives for sampling protocols used to monitor vital signs within ARCN parks.

Vital Sign and Protocol	ARCN Park	Justification	Measurable Objective
Wet and Dry Deposition	BELA, CAKR, GAAR, KOVA, NOAT	Wet and dry deposition is of concern for a number of reasons. First, increasing loads of sulfur and nitrogen from Asian coal-burning has the potential to seriously degrade tundra and alpine vegetation and boreal forest epiphytes. These vegetation communities are dominated by nonvascular plant species (i.e., lichens and mosses) that are highly sensitive to these pollutants. Bioaccumulation of heavy metals including mercury and organic toxins is another key concern from the perspectives of food chain health and subsistence hunting. A recent study that included two lakes within the ARCN found that mercury levels in older, piscivorous fish already exceeds EPA guidelines for human health and wildlife in some cases (Western Airborne Contaminant Assessment Program: WACAP 2008).	• Determine annual status and long-term trends in airborne Pb, Zn, Cd, Cu, Cr, Hg, Al, B, Fe, Total S, Total N, nitrate . • Determine annual status and long-term trends in levels of mercury in piscivorous freshwater fish (e.g., Lake Trout, Sheefish) and relate these levels to fish age and lipid content. • Link status and long-term trends in airborne Pb, Zn, Cd, Cu, Cr, Hg, Al, B, Fe, Total S, Total N, nitrate (using Hylocomium splendens tissue sampling) with surveys of lichen community structure conducted by Vegetation vital sign. This permits a linkage between observed pollutant levels and changes in community structure. • Determine annual status and long-term trends in deposition of Pb, Cd, and Zn along the Red Dog Haul Road in CAKR and link deposition levels with changes in sensitive nonvascular plant communities.
Air Quality	BELA, CAKR, GAAR, KOVA, NOAT	Asiatic and global long-range pollutants deliver significant amounts of airborne contaminants each year to the North American Arctic. Much of this pollution comes in the form of Arctic Haze, a combination of sulfate, particulate matter, nitrate, heavy metals, black carbon, and other minor constituents. Other global pollutants include mercury and semi-volatile organic compounds. There are currently no instrumented NPS air quality monitoring stations in arctic Alaska.	• Monitor weekly levels of pH, sulfate, nitrate, ammonium, chloride, calcium, magnesium, potassium, and sodium in precipitation falling at Bettles through participation in the National Atmospheric Deposition Program (NADP). • Monitor weekly mercury concentrations in precipitation through the Mercury Deposition Network. • Monitor the chemical composition and mass of aerosols (coarse and fine particulate matter, and select gasses) that contribute to visibility impairment through the Interagency Monitoring of Protected Visual Environments (IMPROVE) network. • Integrate air quality data from the Bettles site with data from other ARCN Vital Signs to monitor the ecological condition of ARCN parks.
Climate	BELA, CAKR, GAAR, KOVA, NOAT	Climate is widely recognized as a fundamental driver of ecosystem change in the Arctic and thus nearly all ARCN natural resources are affected by it. Most climate models indicate that the rate of climate change in the Arctic will match or exceed that of anywhere on earth over the next 100 years. Changes in climate that have already taken place are decrease in extent and thickness of Arctic sea ice, permafrost thawing, coastal erosion, changes in ice sheets and ice shelves, and altered distribution of species (IPCC 2001).	• Determine long and short term trends in climate by recording weather parameters at sites that capture the primary climate gradients within ARCN. • Provide monthly and annual summaries of climate data including air temperature, precipitation, wind speed and direction, soil temperature, and snow depth and identify any extreme climatic conditions.

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Vital Sign and Protocol	ARCN Park	Justification	Measurable Objective
Snowpack	BELA, CAKR, GAAR, KOVA, NOAT	The predominant feature of climate in high-latitude regions is the presence of a seasonal snowpack. The snowpack is a major influence on hydrology, vegetation, and faunal communities. Snow affects landscape vegetation patterns, permafrost stability, drainage patterns, nutrient cycling, water quality, productivity of plants and animals, the degree and types of disturbance events, the timing of migratory and breeding events of organisms, predator-prey relationships, and the distribution of plants and animals. Duration of snow on the landscape is also a key indicator of regional climate..	• Monitor annual patterns of snowpack extent, depth, and duration within ARCN parks by working with the USDA-Natural Resources Conservation Service (NRCS) to establish seasonal snowpack monitoring snow courses and aerial snow markers within ARCN parks. • Monitor total annual precipitation and daily accumulation patterns with high accuracy by working with the USDA-NRCS to establish recording precipitation gages in each ARCN park as part of the telemetry (SNOTEL) network.
Coastal Erosion	BELA, CAKR	Coastal ecosystems are changing rapidly with arctic warming and other environmental stressors. Coastal and nearshore environments in BELA and CAKR are experiencing dramatic changes, with impacts on a variety of nearshore marine, terrestrial, and freshwater habitats. Coastal erosion directly impacts beach geomorphology and nearshore ecosystems. Bluff erosion causes loss of terrestrial habitat. Changes in sediment erosion and deposition can lead to capture of thaw-lake basins, migration of barrier inlets, flooding or closure of inlets, and other modifications to freshwater habitats. Release of sediment and organic carbon alters nutrient fluxes in nearshore marine and lagoon ecosystems. Protected by sea ice for several months each year, the fragile coastal zone may change rapidly with Arctic warming. Coastal change is one of the most observable and sensitive indicators of environmental change for the Arctic.	• Determine long-term trends and variation of coastline accretion, erosion, and bluff retreat. • Determine long-term trends in area, volume, or mass fluxes at long-term monitoring sites along the coastline. • Detect changes in nearshore vegetation and landcover. • Link coastline monitoring sites and methods with those for the sea ice, permafrost, and lagoons protocols.
Permafrost	BELA, CAKR, GAAR, KOVA, NOAT	Permafrost extent and thickness is largely controlled by air temperature, snow thickness and duration, and vegetative cover – each of these parameters is currently changing due to climate warming and changes in these factors are having cascading impacts on permafrost distribution. The anticipated changes in permafrost will have broad impacts on infrastructure, regional hydrology, soils, biogeochemistry, trace gas emissions, and vegetation patterns and therefore on large-scale ecosystem structure and function.	• Detect permafrost related surface disturbance (e.g., thermokarst, solifluction) and determine long-term trends in degradation rates as expressed in km2/ year. • Identify and map permafrost-related features in ARCN parks and monitor trends in the distribution and abundance of these features. • Determine long-term temperature trends in existing boreholes gathered by researchers near ARCN parks.

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Table 5.1 (continued)

Vital Sign and Protocol	ARCN Park	Justification	Measurable Objective
Lagoon Communities and Ecosystems	CAKR	The total shoreline in the ARCN, including bay and barrier island ecosystems, is approximately 450 km (250 miles). This is the third largest block of coastline that the NPS manages. Cape Krusenstern National Monument, located along this coastline, contains five coastal lagoons. Key reasons for monitoring the coastal lagoons in CAKR include: (1) lagoons provide habitat for subsistence resources, (2) minimal baseline data exist for the lagoons, (3) lagoons are identified in the Alaska Coastal Management Program, (4) lagoon monitoring is identified in the General Management Plan for CAKR as a management objective, (5) increase understanding of shallow, arctic, coastal lagoons and provide information about these under-studied systems, and (6) provide insight into climate change in the Arctic.	• Determine seasonal and long-term trends in dissolved oxygen, salinity, conductivity, and pH on a semiannual basis in the coastal lagoons of CAKR. • Determine long-term trends in water level in each CAKR lagoon. • Determine long-term trends in nutrient concentrations (total nitrogen and total phosphorus), zooplankton biomass, and phytoplankton biomass in CAKR lagoons. • Detect changes in the hydrologic structure (open or closed to oceanic inputs) and surface area of CAKR coastal lagoons. • Identify the resident fish species and determine the contaminant load of key subsistence fish resources, and determine long-term trends in contaminant load for each identified species. • Identify subsistence activities in the lagoons and determine long-term trends in human use patterns.
Lake Communities and Ecosystems	BELA, CAKR, GAAR, KOVA, NOAT	Because lake ecosystems act as integrators of catchment-scale processes, changes in water quality are often indicative of local, regional and global stressors to local environments. In ARCN these stressors may include visitor use, contaminant deposition, increased air temperatures, melting permafrost and glaciers, and alterations in the hydrologic cycle and terrestrial biogeochemistry. Recent studies have documented high rates of change in the formation and disappearance of many high latitude lakes. Water quality (especially temperature, specific conductance, pH, dissolved oxygen, turbidity and nutrients) is important to the survival, growth, and reproduction of aquatic organisms.	• Detect decadal scale changes in water level in shallow lakes. Determine long-term trends in water-level and surface water inputs and outputs of deep lakes. • Determine long-term trends in surface water temperature in shallow lakes. Determine long term trends and seasonal variation in water temperature in deep lakes. • Determine long-term trends in turbidity, light penetration, pH, dissolved oxygen, specific conductivity and nutrients in deep and shallow lakes. • Determine long-term trends in community composition of phytoplankton, and resident fish in deep lakes.
Stream Communities and Ecosystems	BELA, CAKR, GAAR, KOVA, NOAT	There are seven National Wild and Scenic Rivers in ARCN, including the Noatak, Salmon, Kobuk, Alatna, John, Tinayguk and North Fork of the Koyokuk Rivers. The Kobuk and Noatak rivers are the largest rivers in northwest Alaska.. The Noatak River, which originates in GAAR, flows into NOAT, where the river and its surrounding watershed have been designated as an internationally recognized Biosphere Reserve (UNESCO). Potential local impacts on flowing waters in ARCN include consumptive use of stream and river resources, road construction, industrial development, mining, and nonpoint source petrochemical pollution from snowmobiles and motor boats. Potential global stressors on flowing waters in ARCN include wet and dry deposition of contaminants and climate change. These local and global stressors are likely to affect water quantity and quality, and species diversity within these systems.	• Determine long-term trends in water temperature, pH, conductivity, dissolved oxygen, flow/stage/level, total nitrogen, total phosphorous, and chlorophyll a in selected wadable streams and large receiving rivers in ARCN parks. • Determine varaibility and long-term trends in species composition of macroinvertebrate and diatom communities in ARCN streams and rivers.

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Vital Sign and Protocol	ARCN Park	Justification	Measurable Objective
Landbirds	BELA, CAKR, GAAR, KOVA, NOAT	The landbirds assemblage (passerines, near-passerines and galliformes) encompasses a great variety of species that spend the majority of their life in terrestrial environments. Standardized methods for monitoring landbirds are well-established and currently utilized by several networks. Landbirds are an important component of park ecosystems, and their high body temperature, rapid metabolism, and high ecological position in most food webs make them good indicators of the effects of local and regional changes in ecosystems. Changes in landbird ecology and demography have been demonstrated to be indicators of global climate change. Passerine birds comprise more than 50% of the bird species in ARCN.	• Determine biennial long-term trends in density and frequency of occurrence of 6 common passerine species (GCTH, VATH, GCSP, ATSP, SAVS and WCSP) in selected sites across ARCN during the breeding season (June). • Determine biennial long-term trends in landbird species composition and distribution in selected sites across ARCN during the breeding season (June). • Improve understanding of breeding bird-habitat relationships and climatic changes on bird populations by correlating changes of 6 common passerine species (GCTH, VATH, GCSP, ATSP, SAVS and WCSP) with changes in habitat and climate variables.
Yellow-billed Loons	BELA, CAKR	The yellow-billed loon (*Gavia adamsii*) has a global population estimated at 16,650 - 21,000. The breeding range in Alaska is restricted to large lakes on the Arctic Coastal Plain of Alaska north of the Brooks Range, and in western Alaska including BELA and CAKR. Yellow-billed loon distribution and population levels were poorly documented in western Alaska until 2005. In 2005, results from aerial surveys funded by the ARCN and conducted in and around BELA and CAKR generated population estimates for yellow-billed loons and nests. Due to its small population size and restricted distribution, the U. S. Fish and Wildlife Service is currently evaluating a petition to list this species as Threatened or Endangered under the Endangered Species Act.	• Determine biennial or triennial trends in occupancy of yellow-billed loons in selected sites of BELA and CAKR during the breeding season (June). • Determine triennial status and trends in density estimates of yellow-billed loons in selected sites of BELA and CAKR during the breeding season (June). • Monitor the types and levels of common contaminants (e.g., mercury, PCPs) present in yellow-billed loons in selected sites of BELA and CAKR during the breeding season (June).
Brown Bears	BELA, CAKR, GAAR, KOVA, NOAT	Brown bears (*Ursus arctos*) are good indicators of long-term habitat change within park ecosystems because they are a long-lived species, require large quantities of resources from their habitat, and populations have the potential to respond to long-term changes in resources conditions. These animals play important ecological roles as top predators influencing population dynamics of other species including moose and caribou. Brown bears may be harvested by subsistence users throughout the ARCN parks and only in the preserves by sport hunters. Managing brown bear populations presents biological, cultural, and legal challenges for park managers. Baseline ecological data are lacking for brown bear populations in ARCN despite increasing harvest and viewing demands from the public.	• Determine statistically defensible estimates of brown bear populations. • Develop models of brown bear presence and absence. Incorporate human development metrics into occupancy modeling of brown bears. • Determine long-term trends in brown bear abundance in the ARCN.

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Vital Sign and Protocol	ARCN Park	Justification	Measurable Objective
Caribou	BELA, CAKR, GAAR, KOVA, NOAT	At an estimated population size of over 490,000 animals, the Western Arctic Herd (WAH) are a significant ecological force in Northwestern Alaska and are the largest caribou herd in Alaska. The WAH has a substantial cultural impact in that the heritage and traditions of Native Alaskans in approximately 40 subsistence based communities in the region have been shaped by the availability of these caribou. The availability of WAH also affects the economics of this region. The presence and relative abundance of WAH caribou have substantial impacts on the populations of wolves, bears, and wolverines in the area. Caribou are good integrators of regional conditions in northwestern Alaska because of their migratory nature.	• Determine long-term trends in sex and age composition of WAH caribou cooperatively with the Alaska Department of Fish and Game. • Monitor physical condition (i.e., fat : protein of WAH caribou either by recording body weights and measurements (as outlined by CARMA protocol) or by stable isotope analysis cooperatively with the Alaska Department of Fish and Game. • Monitor seasonal caribou distribution and movements using GPS radiocollar locations. • Determine long-term trends in habitat condition by evaluating plant communities and forage availability.
Dall's Sheep	GAAR, KOVA, NOAT	Dall's sheep reach the northernmost extent of their range in the Brooks Range. Dall's sheep occur throughout the alpine areas of the ARCN. Relative to other large mammals in the ARCN, Dall's sheep are relatively stationary. Population parameters and distribution of Dall's sheep may be good indicators of environmental conditions in alpine areas of ARCN. Dall's sheep can be legally hunted in ARCN parks by subsistence users, and sport hunting for sheep is permitted in the preserve portion of Gates of the Arctic and in the Noatak Preserve. ARCN harbors a large percentage of the world's population of Dall's sheep.	• Determine status and long-term trends in Dall's sheep abundance across ARCN where there is available sheep habitat. • Determine status and trends in Dall's sheep sex and age composition at two areas of high management concern in ARCN (Itkillik Preserve in GAAR and the Baird Mountains in NOAT). • Determine long-term trends Dall's sheep diets in the Itkillik Preserve, GAAR and the Baird Mountains, NOAT.
Muskox	BELA, CAKR	Muskoxen are rare worldwide. Within the U.S. National Park system (NPS), muskoxen only occur in the ARCN. Key reasons for monitoring muskoxen are that muskox are: (1) an important subsistence species; (2) may impact reindeer and caribou in the ARCN; (3) as an arctic obligate species, are a good integrator of the condition in arctic park ecosystems.	• Determine long-term trends in muskoxen sex and age composition and how they potentially relate to herd productivity: This monitoring question is currently being addressed cooperatively with the Alaska Department of Fish and Game.
Terrestrial Vegetation and Soils	BELA, CAKR, GAAR, KOVA, NOAT	Arctic ecosystems, particularly vegetation and underlying substrate, are extremely sensitive to external influences such as changes in climate, disturbances, and human impacts. While human activity in Arctic regions may cause localized changes in vegetation and soils, the impact of global climate change may have regional consequences. Several studies have begun to show changes in arctic and subarctic vegetation patterns due to climate change. Vegetation is the primary foundation for wildlife habitat, nutrient availability for other ecosystem processes, and is tightly linked to aquatic ecosystems.	• Determine long-term trends in plant community structure (species cover, diversity, biomass, tall shrub and tree density) at selected focal areas. • Determine long-term trends in soil properties and chemistry (e.g., depth of active layer, soil structure and soil horizon characterization, % rock, moisture class, depth to ground/surface water, soil organic matter thickness, pH and electrical conductivity, soil temperature, C, N, P, K, selected metals) at selected focal areas. • Monitor long-term trends in abiotic soil environmental parameters at selected focal sites.

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Vital Sign and Protocol	ARCN Park	Justification	Measurable Objective
Subsistence/ Harvest	BELA, CAKR, GAAR, KOVA, NOAT	The enabling legislation for ARCN parklands provides for the traditional subsistence use of resources by 21 neighboring communities. Portions of the ARCN parklands are also open to sport hunting. Increasing population within the region and increasing sport hunting pressures in the preserves combine to raise concerns about long-term health of the resources and the necessity to monitor both the pressures and the status of the resources.	• Summarize harvest data from studies and databases maintained by the Alaska Department of Fish and Game, the Federal Subsistence Board, regional and local Native corporations and organizations, and other resource management entities. • Establish outreach venues whereby information about subsistence resources that is gathered by the ARCN is reported back to local residents.
Fire Extent and Severity	BELA, CAKR, GAAR, KOVA, NOAT	Wildland fire is one of the largest natural disturbance processes in the boreal and tundra ecosystems of the Arctic Network. Fire affects all of the parks within ARCN; in the past 50 yrs over 1 million acres have burned in the network. Fire influences not only vegetation succession and distribution, but also wildlife population and distribution, soil parameters (e.g., permafrost and nutrient cycling), hydrology, water quality and air quality. In addition, the natural fire regime (fire frequency, fire extent, and severity) and secondary fire effects are likely to respond to local and global climate changes.	• Work with the NPS Fire Management Program in the Alaska Region to determine annual variation and long term trends in fire frequency (number of fires/year), average fire size, maximum fire size, and total area affected by fire in ARCN parks. • Work with the NPS Fire Management Program in the Alaska Region to determine the trends and variability in burn severity on fires larger than 300 acres in ARCN. • Work with the NPS Fire Management Program in the Alaska Region to determine the effects of fire and burn severity on vegetation species composition (species and % cover), vegetation structure (tree diameters and heights), and ground cover (% cover and depth) of varying vegetation types (long term monitoring).
Terrestrial Landscape Patterns and Dynamics	BELA, CAKR, GAAR, KOVA, NOAT	Landcover classification and mapping is a cost effective method to monitor status and trends in vegetation in ARCN's 19.1 million acres of remote, roadless areas. Changes in plant production in this vast area may impact every component of associated foodwebs, including humans, via changes to the accessibility and quality of subsistence resources. Current and future climatic change is expected to impact vegetation and landcover in ARCN parks. This will have cascading effects on other ecosystem processes, such as permafrost dynamics, nutrient cycling, carbon gain or loss, and primary productivity.	• Determine status and trends in the aerial extent and configuration of land-cover types on ARCN park lands. • Develop landcover maps that can be integrated with other vital signs monitoring programs, specifically the Surface Water Dynamics and Distribution, Permafrost and Thermokarst, Terrestrial Vegetation, Fire Extent and Severity, and various mammal and bird vital signs. • Determine status and trends in NDVI, date of green-up, date of senescence, total days of greenness; beginning and end of snow melt, and date of first total snow cover.

Chapter 6
Data Management

The Inventory and Monitoring Program has committed to a foundation of good data management in order to supply park managers with sound scientific information for decision making. Because the need for effective natural resource information management cuts across National Park Service divisional boundaries, information management strategies must be defined at the highest level possible. In this context, integrated inventory and monitoring of natural resources is multidisciplinary and requires national-level, programmatic data and information management strategies for success. While such a goal is worthwhile, it is not easy without technical support—someone has to keep the hardware spinning and the numbers crunching to funnel information reliably to stakeholders. Data management fulfills this role by providing expertise in the technical aspects of biological science, including relational databases and software development, metadata generation, web development, and geographic information systems (GIS). By expressing up-front support for data management, the Inventory and Monitoring Program is publicly committing to a culture of good data management practices and expressing pride in the program's resulting technical products.

The Arctic Network's main data management goals are to:

- acquire, store, manage, and archive Arctic Network data,
- ensure high data quality,
- document and disseminate data and information, and
- ensure the long-term access to and utility of data.

In addition to the goals described above, certain expectations that are important to the success of our monitoring program pertain to data management:

- Inventory and monitoring data will be held to an extremely high standard of quality.
- Data management will be a collaborative effort benefitting everyone in the network—each stakeholder must commit the time and resources required.
- Data management will work toward establishing and reinforcing a culture of good data management practices.

6.1 Data Management Process and Workflow

Ecological monitoring projects have a defined life cycle (Figure 6.1). Each stage is characterized by a set of activities carried out by staff involved in the project. Primary responsibility for these activities rests with various individuals according to the different phases of a project. Major tasks are shown in Figure 6.1, while the major roles and responsibilities can be seen in Figure 6.2. Operational details of the project life cycle are described more fully in the network data management plan (https://science1.nature.nps.gov/naturebib/biodiversity/2008-12-1/NPS_ARCN_NRR_2008-053_v1.0_200811202.pdf).

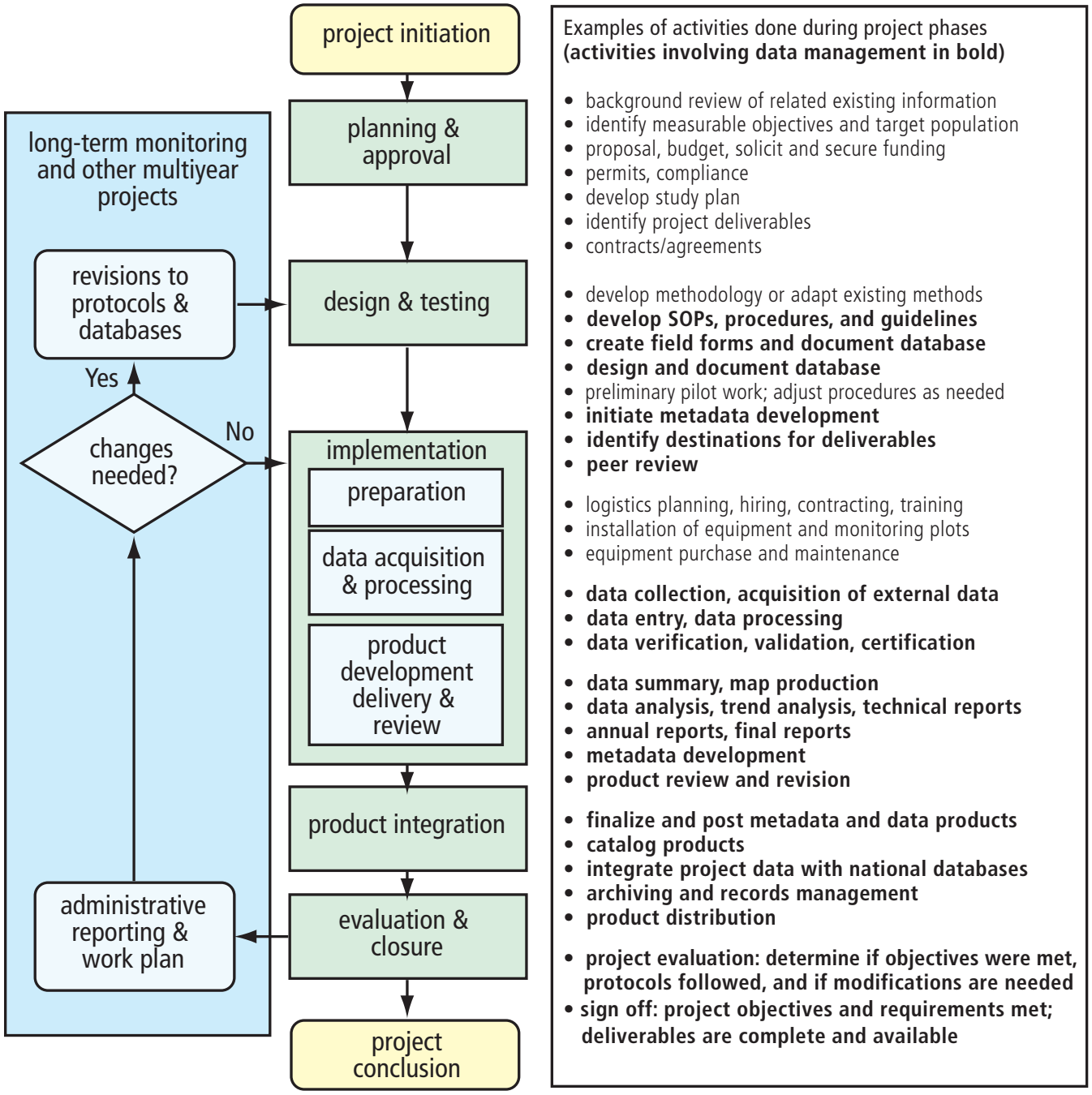


Figure 6.1: Project life cycle

6.2 Data Management Roles and Responsibilities

Data stewardship is the responsibility of all network personnel. There are myriad tasks involved with shepherding a project through its life cycle. At each stage of a project it is imperative that everyone's responsibilities be clearly described and that each individual be aware of their duties. Figure 6.2 shows the major responsibilities involved in project management.

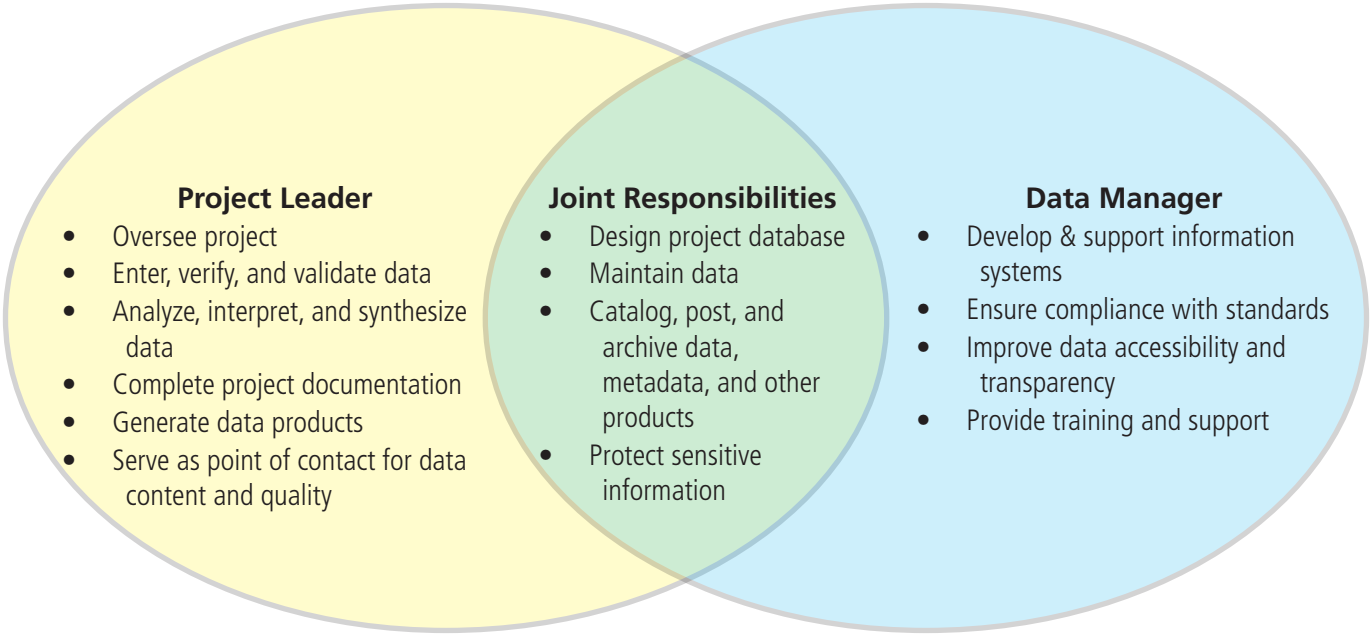


Figure 6.2: Data stewardship major roles and responsibilities

6.3 Data Management Infrastructure and System Architecture

Just as no one would expect a carpenter to build a quality home without a good hammer, one cannot expect to build and maintain a data management system without high quality computing resources. As a network we are fortunate to have a broad array of hardware, software, and support services already in place and available to us through the Fairbanks Administrative Center, the Alaska Regional Office, and the Washington Support Office.

The Arctic Network will employ a highly centralized model of data management. At the heart of the system is an enterprise database that will serve not only monitoring and project data but also project tracking information and a suite of commonly used lookup tables and related information (Figure 6.3). A centralized scheme such as this has numerous advantages over more distributed systems, including simplified backups, granular security schemas, minimized dataset versioning problems, and efficient access to common data resources. Metadata, and in some cases data files, will be uploaded to the NPS Data Store as well as the permanent data stack (X:\ Drive) at the Alaska Regional Office in Anchorage.

In addition to the database server, we will employ a communal file server with structured directories for each project. This file server will store the myriad files generated by projects, including everything from administrative details through draft reports and analyses to working data files. Investigators will be required to use these directories and keep them up to date. The file server will be backed up regularly to an off-site location.

The Arctic Network will also make use of existing infrastructure provided by the Washington Support Office. These services and databases include service-wide inventory and monitoring databases, bibliographies, and FTP sites as well as web and data servers.

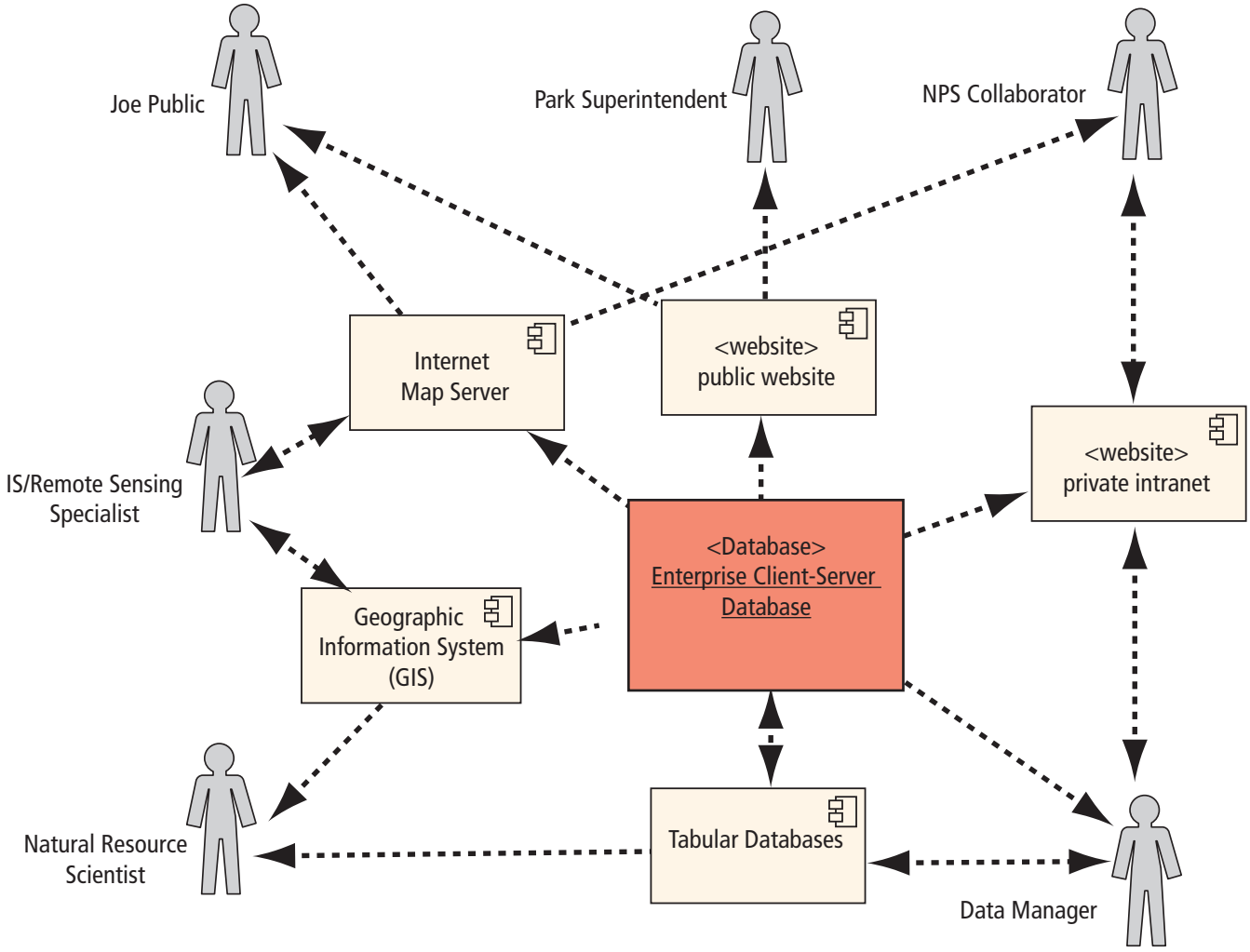


Figure 6.3: An enterprise client-server database will be the heart of the Arctic Network data management system

6.4 Data Acquisition and Processing

Data are dynamic and flow through an organization following a distinct path from acquisition through processing, analysis, reporting, and archival. Protocols for each vital sign dictate how data are acquired, processed, and ultimately reported. Major tasks covered by these protocols include:

- acquiring data (field work, satellite download, etc.),
- data archival (physical and possibly digital material),
- data entry/import,
- quality assurance and control,
- documentation, metadata, etc.,
- analysis and reporting, and
- data validation, documentation, and cataloging.

The types of data handled by the Inventory and Monitoring Program fall into three general categories:

- **Program data**—produced by projects that are either initiated (funded) by the Inventory and Monitoring Program or involve the Inventory and Monitoring Program in another manner (e.g., natural resource inventories and vital signs monitoring projects);
- **Nonprogram legacy/existing data**—produced by National Park Service entities without the involvement of the Inventory and Monitoring Program (e.g., park or regional projects); and
- **Nonprogram external data**—produced by agencies or institutions other than the National Park Service (e.g., weather and water quality data).

Most data acquired by the network will be collected as field data (inventories and monitoring studies) or obtained through data mining initiatives (legacy/existing data). Methods of field data collection, such as paper field data forms, field computers, automated data loggers, and GPS units will be specified in individual monitoring protocols and study plans. Field crew members will closely follow the established standard operating procedures in the project protocol. Data acquired by nonprogram sources, such as data downloaded from other agencies, will be held to the same data quality requirements as program data with details specified in individual monitoring protocols.

6.5 Quality Assurance and Quality Control

Scientific analyses and conclusions are only as good as the data from which they are derived. Our ability to detect trends or patterns in ecosystem processes is maximized by using data of documented quality that minimize error and bias. Data of inconsistent or poor quality can result in loss of sensitivity and incorrect interpretations and conclusions. The Arctic Network monitoring program will bring together analyses from an array of widely varying projects aimed at detecting changes in the environment over time. The inherent complexity in this endeavor demands stringent and consistent quality assurance and control. The most effective mechanism for ensuring that a project produces data of the right type, quality, and quantity is to provide procedures and guidelines to assist the researcher in accurate data collection, entry, and validation. As part of data management operations, the Arctic Network will develop a comprehensive set of standard operating procedures and tools for quality assurance and quality control (QA/QC) in field procedures, data entry/validation/verification, and data use.

Data quality assurance and control is a process that expands on the project life cycle described earlier in this document. Figure 6.4 shows the general course of Arctic Network data and associated QA/QC procedures. Quality control with regard to data analysis is specific to each project and addressed in appropriate standard operating procedures. Each step in the cycle shepherds the data through collection, verification, documentation, and archival.

Each vital sign protocol will include standard operating procedures that address core data management practices with quality control in mind. These may include:

- field crew training (addressing both data collection and entry),
- standardized data sheets,
- use of handheld computers,
- equipment maintenance and calibration,
- procedures for handling data (including specimens) in the field, and
- data backup, entry, verification, and validation.

The National Park Service requires QA/QC review prior to communicating and disseminating data and information. Only data and information that adhere to National Park Service quality standards may be released. Documentation of the QA/QC standards that were used in producing the information and that substantiate the quality of the information must be formally certified and distributed with related data and information.

6.6 Data Documentation

Documenting data sets, data sources, and methodology by which the data were acquired establishes the basis for interpreting and appropriately using data. At a minimum, all data managed by the Arctic Network will require the following elements of documentation:

- project documentation,
- formal metadata compliant with Federal Geographic Data Committee (FGDC) standards, and
- data dictionaries and entity/attribute/relationship diagrams for all tabular databases.

Data documentation will be available and searchable in conjunction with related data and reports via the Arctic Network website as well as with the NPS Data Store. The Arctic Network data management plan will provide details on the mechanics of handling metadata.

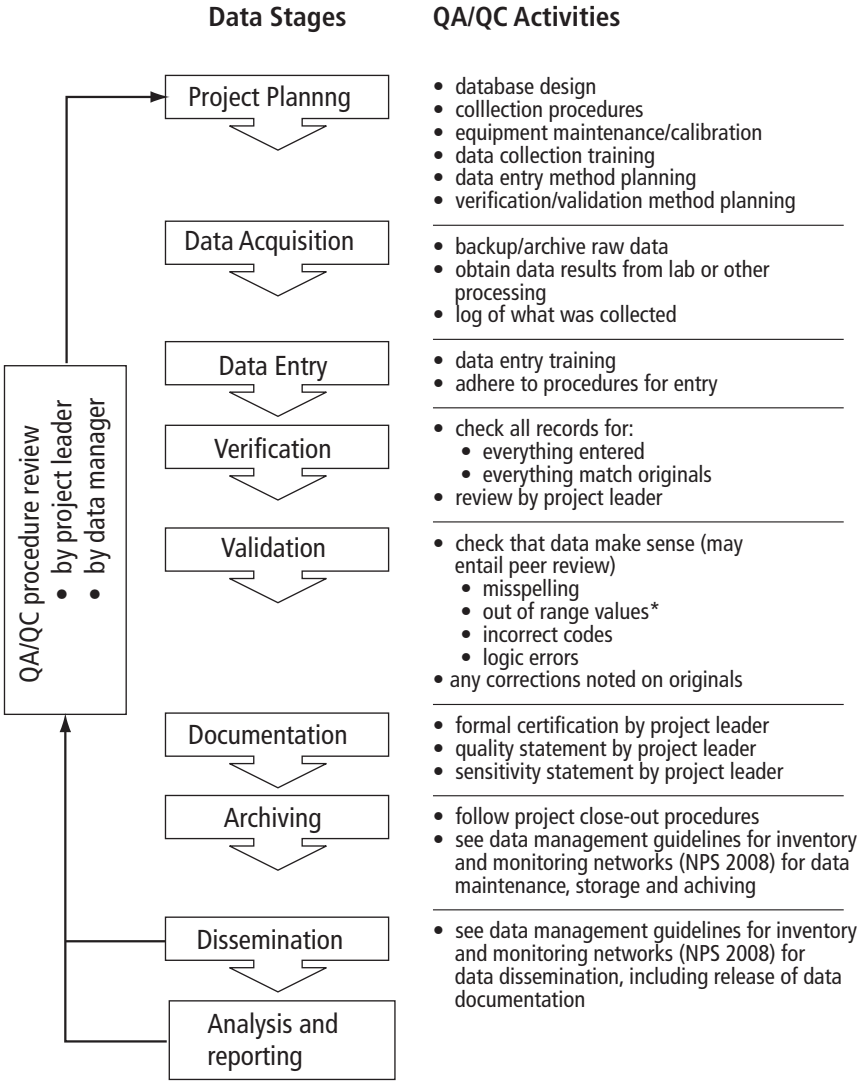


Figure 6.4: General course of data and associated QA/QC procedures. Quality control with regard to data analysis is specific to each project and addressed in appropriate standard operating procedures.

6.7 Data Analysis and Reporting

Generating meaningful results from data summary and analysis is a cornerstone of the Inventory and Monitoring Program. The associated data management role is to provide valid data in formats that support the statistical design of our monitoring program as well as ad hoc querying, analysis, and reporting of data. While data analysis is generally the purview of project leaders and biometricians, data managers fill an integral role in providing required data in formats that easily integrate with statistical and analytical software.

Each Arctic Network vital sign is required to have a series of standard operating procedures (Oakley et al. 2003). A subset of each vital sign's standard operating procedures defines all aspects of data analysis and reporting, including sections on generating data summaries and statistical analyses, recommended reporting schedules, report formats with examples of summary tables and figures, and methods for long-term trend analysis. The data manager will work closely with the network biometrician in the development of these standard operating procedures.

Reporting is critical to the long-term success of the Arctic Network. Results must be credible and delivered in a timely fashion to the appropriate audiences in a manner that is understandable to them. It is especially critical that results are delivered to park managers in an appropriate fashion. Data generated from the Inventory and Monitoring Program are intended to help with management decisions. In addition, through good data management and reporting practices, institutional knowledge obtained and organized by the Inventory and Monitoring Program can be captured and preserved. The Arctic Network strategy for data analysis and reporting also rests upon providing sufficient funding for these activities so that they occur promptly.

6.8 Data Dissemination

Data management within the Arctic Network Inventory and Monitoring Program aims to ensure that:

- data are easily discoverable and obtainable,
- only data that have been subjected to full quality control are released,
- distributed data are accompanied by complete metadata that clearly establishes the data as a product of the inventory and monitoring program,
- sensitive data are identified and protected from unauthorized access and inappropriate use, and
- a complete record of data distribution/dissemination is maintained.

Access to Arctic Network data products will be facilitated via a variety of means that allow users to browse, search, and acquire network data and supporting documents. These means include but are not limited to:

- Arctic Network public web site (http://www.nature.nps.gov/im/units/arcn/)
- NPS Data Store. Distribution instructions for each data set will be provided in the respective metadata. The NPS Data Store is available at http://science.nature.nps.gov/nrdata/ and is also accessible by the National Spatial Data Infrastructure, Geospatial One Stop web site (http://gos2.geodata.gov)
- Service-wide databases, such as NPSTORET, NPSpecies, and NatureBIB
- Regional, Network, or park data servers protected with read-only access
- External repositories as required
- Magnetic or optical media

In general, data will be available upon completion of analysis and reporting. Data for which analysis and reporting has not been completed but are otherwise certified (verified and validated) will be released no later than one year after certification.

6.9 Data Maintenance, Storage, and Archiving

Data are complex and highly valuable commodities that must be organized, protected, and maintained to preserve their usefulness through time. Arctic Network data maintenance, storage, and archiving procedures aim to ensure that data and related documents and materials are

- kept up to date with regard to content and format such that the data are easily accessed and their heritage and quality easily learned;
- physically secure against environmental hazards, catastrophe, and human malice; and
- archived in a manner that expedites recovery if needed.

Most data (monitoring data in particular) will reside in a management system comprised of file and web servers and an enterprise database. The benefits to this arrangement are numerous and include:

- secure, high-volume storage space;
- concurrency;
- multiple-user environment;
- availability of centralized lookup tables and communal information; and
- near-universal access for National Park Service personnel.

Ongoing spatial datasets will reside in our enterprise database with snapshots archived with metadata on the NPS Data Store and in the GIS permanent data stack at the Alaska Regional Office. Static datasets will be processed and archived with the NPS Data Store.

The water quality component of the Natural Resource Challenge requires that networks archive all water quality data collected as part of the monitoring program in a STORET (STORage and RETrieval) database maintained by the NPS Water Resources Division. ARCN will consolidate and contribute available water quality data collected in the arctic park units. Associated with this database are water quality standards assessment tools that allow comparisons of historical and current data with applicable state standards. ARCN will maintain this database and integrate new data collected so it can serve as an ongoing tool for the network's long-term water quality monitoring and analysis needs.

Chapter 7
Data Analysis and Reporting

In this chapter we describe how data collected as part of the Arctic Network Inventory and Monitoring Program will be analyzed, outline how the information from this effort will be disseminated, and provide a timeline for reporting findings. We anticipate that a variety of audiences will be interested in the findings of this program. The principal audience will be park managers interested in meeting park goals and legal mandates. Other audiences may include environmental educators interested in natural history and scientists looking for long-term data sets to enrich their own research.

7.1 Data Analysis

For the purposes of this program, we define data analysis as the process by which observations of natural resources are converted into meaningful information (MacCluskie et al. 2005). This is a broad definition of data analysis that includes a range of activities, such as applying statistical tests and models, interpreting remotely sensed imagery, and comparing historical and contemporary photos. We also include in this definition of data analysis the processes of data exploration, quality control, and mining existing data for relevant information.

Efficient data analysis can be achieved by careful planning. Aspects of the planning process include setting clear and measurable goals and designing effective sampling strategies to meet these goals. The sampling design dictates the statistical approach to the data. One of the challenges of building a long-term monitoring program, however, is that data from this program are likely to be used for a variety of purposes, and many of those purposes cannot be anticipated by the program. Long-term data sets provide a wealth of information about the natural environment that cannot be observed in the short term. However, long-term data sets are a rarity, particularly in the Arctic. We therefore hope and intend that our data will be used to meet a variety of diverse objectives. In this chapter, we present some general considerations of data analysis and outline the general analysis strategy of the Arctic Network.

7.1.1 Analysis of Monitoring Data: General Considerations

Ecology can be viewed basically as the study of the distribution and abundance of plants and animals and their interaction with the environment on levels from cellular to ecosystem (Krebs 1985). Variables that may be useful in learning about a vital sign and explaining its distribution and abundance include ecological community measures (e.g., species richness and community composition/associations), occupancy in time and space, and rates and direction of change (e.g., vital rates for plants and animals; MacKenzie et al. 2006). The status and change of physical systems (e.g., climate, terrestrial landscape dynamics) often strongly influences biological change.

The network will guide the development of standard operating procedures (SOPs) for the data analysis for the ARCN vital signs program by using straightforward sampling designs for as many vital signs as possible. In addition, ARCN is working closely with statisticians in developing and implementing change detection analyses.

Many of the difficulties typically encountered in analysis of monitoring data can be avoided by proper planning. Appropriate analysis of monitoring data is directly linked to the monitoring objectives, the spatial and temporal aspects of the sampling design used, and management uses of the data. Analysis methods need to be considered when the objectives are identified and the sampling design is selected, rather than after the data are collected. Failure to adequately consider analysis methods during monitoring program development could result in use of sampling designs that are either inadequate or too complex to meet the monitoring objectives. The purpose of this portion of the ARCN monitoring plan, and of the specific SOPs on data analysis for each ARCN vital sign, is to ensure that the sampling designs and analysis methods we plan to use will allow us to meet our monitoring objectives.

The first step in data analysis is data management (Chapter 6). Data management is critical for overall quality control. The structure of a database influences how information is entered, extracted, and summarized. Missing, unusual, and inappropriate classification of data is first identified during the data entry stage. It is important that data processing occur in a timely fashion, because problems related to data collection, acquisition, and entry are best dealt with early in the process (Reid 2001). The relationship of a measured variable to other variables is also specified in database design, which allows specific queries to take place. Queries of the data then lead to the second step, summarization of the data.

Timeliness is also an important issue in data summarization (Mulder et al. 1999). Data summarization typically involves a measure of central tendency (e.g., mean, median, and proportions) and dispersion (e.g., range, standard deviation, coefficient of variation, and kurtosis; Zar 1999). Summarization also includes some indication of the sample size and the size or scale of the sampling population from which measurements are being taken. Important aspects of data summarization include tables, charts, graphs, maps, and interpretive text. The Arctic Network lead personnel for a particular vital sign (Table 7.1) will be responsible for seeing that summary analyses are reported for a vital sign on a regularly scheduled basis. There are several benefits to preparing data summaries. Regular summaries can demonstrate problems with sample design or data collection and are often the first indication of changing status of a vital sign (e.g., a sudden change in value). Routines for summarization will be prepared and included in the standard operating procedures for each vital sign. Standardized routines will also help the Arctic Network report on vital signs efficiently.

Following data summarization, the third step in analysis will be a more thorough investigation of status and trends of vital signs. Because the Arctic Network is a monitoring program, we ultimately are interested in identifying changes, trends, and temporal and spatial patterns. These measures may best be evaluated through modeling (Chapter 4). Examples of statistical models for examining trends in ecological data include regression, time-series, trend estimation, and kriging. Models can also be used to elucidate relationships between ecological variables. Although we anticipate integration across all vital signs, models such as analysis of covariance (ANCOVA), multiple linear regression, and multivariate community analysis (e.g., ordination) may apply when we are interested in questions regarding species habitat relationships and community structure. In a few instances, we are interested in whether the status of a particular indicator meets a certain criterion (e.g., threshold level for a management action). Traditional hypothesis tests may be used in these situations, including *T*-tests and Chi-square goodness of fit. We anticipate the analytical methods used by the Arctic Network will change with time as datasets grow, environmental changes occur, and new statistical tools are developed.

Table 7.1: Summary of data analysis approach, timing of analysis, and ARCN lead for vital signs of the Arctic Network monitoring program.

ARCN Vital Sign	Data Analysis Approach	How Often	Who is Responsible for Data Analysis*
Wet and Dry Deposition	Kriging Mixed linear models	Decadal	WEAR plant ecologist (Peter Neitlich)
Air Quality	Time series analysis	Annual	NPS National Air Quality Monitoring Program
Climate	Summary statistics	Annual	NOAA National Weather Service, Western Regional Climate Center under terms managed by ARCN physical scientist (Pam Sousanes)
Snowpack	Mixed linear models	Annual	USDA Natural Resource Conservation Service (Rick McClure), under terms of agreement managed by ARCN physical scientist (Pam Sousanes)
Coastal Erosion	Summary statistics Map Mixed linear models	TBD	Colorado University (Bill Manley), under terms of agreement managed by ARCN coordinator (Jim Lawler)
Permafrost	Map Summary statistics Mixed linear models	Decadal	ARCN terrestrial ecologist (Dave Swanson)
Lagoon Communities and Ecosystems	Summary statistics Mixed linear models Multivariate (e.g., community) analysis	Annual	GAAR aquatic ecologist (Amy Larsen)
Lake Communities and Ecosystems	Summary statistics Mixed linear models Multivariate (e.g., community) analysis	Annual	GAAR aquatic ecologist (Amy Larsen) ARCN aquatic ecologist (Greta Burkart)
Stream Communities and Ecosystems	Summary statistics Mixed linear models Multivariate (e.g., community) analysis	Annual	ARCN aquatic ecologist (Greta Burkart)
Landbirds	Distance estimation to address detection bias Mixed linear models	Annual	GAAR wildlife biologist (Melanie Flamme)
Yellow-billed Loons	Strip/plot survey analysis Summary statistics Mixed linear models	Every 3 years	GAAR wildlife biologist (Melanie Flamme)
Brown Bears	Occupancy modeling Mixed linear models	Annual	WEAR wildlife biologist (Brad Shults)
Caribou	Maps Time series analysis	Annual	GAAR wildlife biologist (Kyle Joly)
Dall's Sheep	Distance estimation to address detection bias Mixed linear models	Annual	ARCN ecologist (Kumi Rattenbury)
Muskox	Summary statistics Mixed linear models	Annual	WEAR wildlife biologist (Brad Shults)
Terrestrial Vegetation and Soils	Summary statistics Mixed linear models Multivariate (e.g., community) analysis	Annual	ARCN terrestrial ecologist (Dave Swanson)
Subsistence/Harvest	Summary statistics Mixed linear models	Annual	ARCN ecologist (Kumi Rattenbury)
Fire Extent and Severity	Map Summary statistics Mixed linear models	Annual	Alaska Regional Office fire ecologist (Jennifer Allen)
Terrestrial Landscape Patterns and Dynamics	Map Summary statistics Mixed linear models	Decadal	ARCN terrestrial ecologist (Dave Swanson)

* The data manager will be involved in data analysis for all vital signs in the Arctic Network because database design is integral to the input, summarization, and presentation of data.

A fourth step in data analysis is also possible, depending on the goals of park managers. Models can be used to forecast future conditions and interpolate across space. If the principal audience of monitoring data is park managers, this final role of data analysis is a logical step. Of special note in this regard are Bayesian Belief Networks (BBNs). BBNs are graphical models that depict relationships among variables using empirical data and expert opinion to reach a probabilistic outcome (Marcot et al. 2001). BBNs offer a transparent framework to link monitoring data to management decisions (Bennet et al. 2006).

ARCN's initial approach to data analysis is presented in Table 7.1. A variety of analytical software programs are available for data analysis. Depending on who is performing the analyses and the specifics of the analysis, analyses will be performed with JMP, SPSS, SAS, R, or PC-ORD. The R software is particularly appealing because customized R functions can be written to perform data analysis, generate graphical displays, and automate repetitive data summaries and reports. R is open-source software available at no cost. R routines can be run on a local machine or delivered over the web (Debevec and Rexstad 2004). The Arctic Network is currently developing R routines for GRTS sampling of shallow lakes, occupancy modeling for brown bears, and population estimation for Dall's sheep. We intend to continue to develop routines for data analysis and summarization.

7.2 Reporting: General Considerations

The principal audience for data gathered through the Arctic Network Inventory and Monitoring Program is the park superintendents, resource management chiefs, and other park management personnel. Results from this program are intended to guide decision-making in the management of the ARCN parks. Because data gathered under this program have resource management implications, results are also of great interest to other local, state, and federal natural resource managers and users.

Parks also have an obligation to educate the public about resources in their national parks. Data from the Arctic Network can provide the American public with insights into the arctic environment and changes occurring in this environment. The basic information on status and trend of the natural environment provided by the network is also extremely useful for scientists working on detailed research questions. For residents engaged in subsistence activities in the region, data gathered by the Arctic Network may have very personal implications for harvest opportunities, food safety, and health.

Although the form of reporting to different audiences may vary, there are a few general considerations, including timeliness and accessibility. Park managers cannot always anticipate their information needs, and often the timescale for providing critical information is short. Management action to protect natural resources is most effective if implemented early. Similarly, subsistence users of park areas would prefer to know about changes in status of natural resources as soon as possible, because this information may affect their ability to pursue particular subsistence activities.

Data must be accessible to be useful. Given the different audiences that will be using this data, the Arctic Network must report data in a variety of formats to meet different audiences' needs. Outlets that the Arctic Network will use to report findings include:

- informal verbal communication with superintendents and NPS staff,
- informal verbal communication with staff from other natural resource agencies,
- staff meetings,
- public presentations (talks and posters),

- newsletters,
- reports (annual reports, project-specific reports, analysis and synthesis reports, state of the park reports),
- journal articles,
- ARCN website (including publications, data, and interactive maps),
- podcasts, and
- public radio.

Monitoring reports can be quite lengthy and difficult to digest. In general, park managers and others do not have the time to read about the intricacies of how information was gathered. Therefore, the Arctic Network will emphasize reporting results in short, easy-to-process formats at regular intervals. The combined impact of shorter and more frequent reports will likely be greater than that of a detailed project report.

Detailed reports will, however, be important to the longevity of the Arctic Network. Only through detailed reports can others evaluate the quality of our work. Detailed reports are therefore important for maintaining the credibility of the program. Detailed reports also serve an archival purpose. This is especially important in a monitoring program. Information included in detailed reports is accessible for analysis by Arctic Network staff as well as scientists from outside the agency.

7.2.1 Initial Reporting Approaches

The list of reports to be produced by the Arctic Network follows national guidelines and meets network reporting goals (Table 7.2). The Annual Administrative Report and Workplan provides a means to track the accountability of the program. Results that may help with day-to-day management decisions in the parks and that maintain interest in the monitoring program will be presented in annual technical reports. Concise information that may be of interest to a larger audience will be presented in a newsletter and on the Arctic Network website. Findings from the program will also be presented at public talks, professional meetings, and on public radio. The network will also conduct periodic program and protocol reviews.

A final reporting goal for the Arctic Network is to integrate the findings from the monitoring of various vital signs into a synthesis of the State of the Parks. This report will provide an explicit opportunity to examine the status and relationship of various vital signs. An Analysis and Synthesis Report produced every three to five years will build on the State of the Parks by looking at the interplay of vital signs over time. The first State of the Arctic Parks report will be produced in March 2010, following the first full year of program implementation.

Table 7.2: Reports that will be produced by the Arctic Network Vital Signs Monitoring Program

Type of Report	Purpose	Target Audience	Frequency	Peer Review Process
Annual Administrative Report and Workplan	Account for funds expended and work accomplished during the last fiscal year Outline planned work and expenditures for the next fiscal year	Network staff, Technical Committee, superintendents, regional coordinators, servicewide program managers; admin. report used for annual report to Congress	Annual	Regional Office Servicewide program manager
Annual reports for each protocol or project	Inform Technical Committee and park staff of findings Document and archive of data from the previous year Provide quality control	Park resource managers, network staff	Annual	Network level
Annual report on "State of the Park" for the ARCN Vital Signs Program	Highlight interesting monitoring findings Identify interesting trends Evaluate status of vital signs	Superintendents, park resource managers, network staff, external scientists, public	Annual	Network level
Analysis and synthesis reports: trends	Identify trends of concern Evaluate direction of program Provide information to park managers	Superintendents, park resource managers, network staff, external scientists	3–5 Years	Network level
Program and protocol review reports	Formally review operations and results Review administration of the network	Superintendents, park resource managers, network staff, monitoring program managers, external scientists	5 years	Regional or national
Scientific posters and peer-reviewed literature	Provide peer review of program and projects Provide feedback on study design, results, and interpretation Present collaborative opportunities	Park resource managers, network staff, external scientists	Varies	Professional peers/editors
Symposia, conferences and workshops	Provide peer review of program and projects Provide feedback on study design, results, and interpretation Present collaborative opportunities	Park resource managers, park staff, network staff, external scientists	Varies	Professional peers/editors
ARCN contribution to the National State of the Parks Report	Report condition of park resources at a national level Highlight activities and interesting findings of the ARCN network	Congress, Budget Office, monitoring program managers, public	Annual	National level

Chapter 8

Administration and Implementation of the Monitoring Program

In this chapter, we describe the administration of the Arctic Network and our plan for implementing the monitoring program. Key components of the administrative process are the Board of Directors, Technical Committee, and the Arctic Network staff. In this chapter we describe the makeup of these groups and the process by which decisions are made. We also describe how the network will integrate with other park operations, staff, and collaborators from outside of the NPS. Finally, in this chapter we discuss the periodic review process for this program.

8.1 ARCN Board of Directors and Technical Committee and Their Roles in Developing and Implementing the Monitoring Program

Oversight of the Arctic Network monitoring program is provided by a Board of Directors. The Arctic Network Board of Directors is composed of the superintendent from each park, the Alaska Region Inventory and Monitoring coordinator, and the Arctic Network coordinator (Table 8.1). One of the superintendents serves as the chairman of the board, and this responsibility is rotated among the superintendents every two to three years. Decisions of the board are made by consensus among the three superintendents with the other members serving as advisors to the superintendents.

Table 8.1: Composition of the ARCN Board of Directors, 2008

Title	Current Member	Voting	Advisor
Superintendent, BELA	Nancy Swanton	X	
Superintendent, GAAR	Greg Dudgeon	X	
Superintendent, WEAR	George Helfrich	X	
Regional I&M coordinator	Sara Wesser	X	
Network coordinator	Jim Lawler		X

The Board of Directors ensures that the monitoring program remains relevant to the mandates, needs, and goals of the individual park units. The Board of Directors also ensures the integrity of the monitoring program by overseeing its efficient operation within existing park programs. The board protects the unique mandates, functions, and capabilities of the monitoring program. Finally, the Board of Directors uses the results of Arctic Network's long-term monitoring program to improve and enhance the management of park resources.

Programmatic direction for ARCN is guided by input from a committee of technical experts. The Technical Committee is composed of the chief of cultural and natural resources for GAAR and

resource staff with subject area expertise from GAAR and WEAR (Table 8.2). The network coordinator serves as the chairperson for the Technical Committee. ARCN staff participate in Technical Committee meetings but are not voting members.

Table 8.2: Composition of the ARCN Technical Committee, 2008

Title	Name	Park
ARCN coordinator, chair	Jim Lawler	ARCN
fire ecologist	Jennifer Allen	Alaska Region
North and West Alaska Cooperative Ecosystem Studies Unit, coordinator	Lois Dalle-Molle	Alaska Region
chief of cultural and natural resources	Tom Liebscher	GAAR
aquatic ecologist	Amy Larsen	GAAR
anthropologist	Ken Adkisson	WEAR
plant ecologist	Peter Neitlich	WEAR
wildlife biologist	Brad Shults	WEAR

The Technical Committee is a decision-making body that provides guidance for development and implementation of the detailed workings of the monitoring program. Individuals on the Technical Committee are familiar with the resources in the ARCN parks and with strategies for monitoring these resources. The Technical Committee works with the network coordinator on establishing recommendations for all aspects of the program, and these recommendations are presented to the Board of Directors for approval. The Technical Committee serves as liaisons between the ARCN and other park staff. Much of the work of performing or overseeing specific monitoring efforts is done by the Technical Committee. To address particularly complex topics, the Technical Committee uses work groups composed of selected Technical Committee members and ARCN staff to develop materials, background information, and recommendations for consideration by the full committee.

The link between the Board of Directors and the Technical Committee is provided by the network coordinator. it is the network coordinator's job to ensure that park priorities for monitoring identified by the Board of Directors are communicated to the Technical Committee. Conversely, the network coordinator communicates the expert opinions of the Technical Committee regarding the options for monitoring specific vital signs to the Board of Directors. The network coordinator ensures information flows between the Board of Directors and the Technical Committee by meeting regularly with each group. Meetings with the Board of Directors typically occur twice a year and coincide with the preparation of the Annual Administrative Report and Work Plan (see Table 7.2 and section 8.6) and deadlines associated with the phase reporting process of the national monitoring program. Technical Committee meetings are held every few months. Over the past four years, the ARCN Technical Committee has met four to six times per year with teleconferences occurring more frequently.

8.2 Staffing Plan

Although the natural resources staffs of the five ARCN parks are relatively small and already have full workloads, it is important to have existing park staff engaged in implementing the monitoring plan. These staff members have substantial experience working in the ARCN park units as well as demonstrated areas of expertise. They also ensure that the monitoring program stays relevant to the parks. Park management's willingness to allow park staff to participate in the monitoring program demonstrate managers' commitment to the monitoring program. Park staff, therefore, are the foundation of

Table 8.3: Roles of network and park staff in the Arctic Network FY 2008–2012

Position	GS level	Type	Pay Periods to Network/Year	Duty Station	Role in Vital Signs Program
Network coordinator	12	Permanent	26	Fairbanks, AK	Coordinates and administers all aspects of the monitoring program. Advises the Board of Directors on administering the ARCN program and maintaining accountability. Serves as the chair of the Technical Committee to formulate direction and administration of the program. Supervises ARCN staff. Serves as project lead for monitoring projects.
Data manager	11, CI	Permanent	26	Fairbanks, AK	Responsible for data management in ARCN, including tracking projects and data flow from collection to reporting and archiving. Provides tools for dissemination of program information such as architecture for web sites. Works with Principal Investigators to design appropriate databases for data collection and for integration of data.
Assistant data manager*	11/9, CI	Term	26	Fairbanks, AK	Assists the data manager in all aspects of data management for ARCN. Develops specific databases and applications for use by ARCN.
Aquatic ecologist	11	Term	26	Fairbanks, AK	Serves as project lead for freshwater monitoring in ARCN. Responsible for developing monitoring protocols and standard operating procedures for aquatic vital signs in the ARCN.
Terrestrial ecologist	12	Permanent	26	Fairbanks, AK	Serves as project lead for terrestrial monitoring in ARCN with a focus on vegetation and soils. Responsible for study design, data collection, analysis, and reporting of results for projects dealing with terrestrial vegetation and soil.
Landscape ecologist*	12	Term	26	Fairbanks, AK	Serves as project lead for landscape-level monitoring in ARCN with a focus on remote sensing and GIS. Responsible for study design, data collection, analysis, and reporting of results for projects dealing with landscape-level ecological processes and patterns.
Physical scientist	11	Permanent	12	Fairbanks, AK	Serves as project lead for physical environment monitoring in ARCN with a focus on weather and climate. Responsible for study design, data collection, analysis, and reporting of results for projects dealing with physical environment monitoring. This position is shared with the Central Alaska Network.

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Position	GS level	Type	Pay Periods to Network/Year	Duty Station	Role in Vital Signs Program
Ecologist	9	Term	26	Fairbanks, AK	Serves as project lead for Dall's sheep monitoring and contact for other ecological monitoring projects in ARCN. Responsible for developing an ARCN outreach program. Responsible for study design, data collection, analysis, and reporting of results.
Administrative assistant	6	Permanent	26	Fairbanks, AK	Serves as liaison with park administrative staff. Files and organizes paperwork for network coordinator. Enters budget information into financial database. Enters information into project tracking databases. Organizes logistics for meetings.
Biological technician	6	Term	26	Fairbanks, AK	Assists network coordinator and project leaders with expediting field work and data collection. Enters and summarizes data. Acts as contact for network cooperators for field logistics and permitting.
Biological technician (3 positions)*	5	Seasonal	8	Fairbanks / Kotzebue/ Nome, AK	Assists network coordinator and project leaders with expediting field work and data collection. Enters and summarizes data.
Alaska Regional Office Staff Working on ARCN Monitoring Program but Paid from ARO Funds					
Fire ecologist	11	Permanent	4	Fairbanks, AK	Serves as project lead on fire extent and severity, terrestrial landscape patterns and dynamics, and terrestrial vegetation and soils protocols. Responsible for study design, data collection, analysis, and reporting of results. Serves on the Technical Committee.
Gates of the Arctic Staff Working on ARCN Monitoring Program but Paid from Park-base Funds					
Aquatic ecologist	11	Permanent	10	Fairbanks, AK	Serves as project lead for aquatics in all ARCN parks as well as parks in the Central Alaska Network. Responsible for study design, data collection, analysis, and reporting of results for projects dealing with aquatic monitoring. Serves on the Technical Committee.
Western Arctic Parklands Staff Working on ARCN Monitoring Program but Paid from Park-base Funds					
Wildlife biologist	12	Permanent	8	Fairbanks, AK	Serves as project lead for wildlife projects in ARCN parks. Responsible for study design, data collection, analysis, and reporting of results for projects dealing with aquatic monitoring. Serves on the Technical Committee.
Plant ecologist	11	Permanent	10	Twisp, WA	Serves as project lead for plant, nonvascular plants, landscape, and contaminant protocols in ARCN parks. Responsible for study design, data collection, analysis, and reporting of results. Serves on the Technical Committee.

* New position not existing in FY 2008.

the monitoring program. In addition, implementation of the monitoring program will require expertise not currently represented in the program. The challenge is to develop a broad range of technical expertise that will complement existing expertise without overcommitting the ARCN budget. We plan to accomplish this through sharing resources and staff with other ARCN parks and through a small number of cooperative agreements and contracts with universities, federal and state agencies, and other collaborators.

Vital signs monitoring and related projects are the heart of the program. Staff, whether network or park, can be involved in the vital sign monitoring at four levels:

- **Advisor:** staff that provides input to the ARCN program. The broad vision and direction of the Network is provided by the ARCN Board of Directors. Detailed ideas and strategies for achieving this broad vision are provided primarily by the Technical Committee. The guidance provided by the Technical Committee is crafted with input from regional and subject matter experts.
- **Technical/Assistant:** a staff member providing technical support for conducting a project. Assistance may be at a technical level, such as identifying plants during a field effort, or may be broader, such as planning flight logistics.
- **Project Lead:** the staff member responsible for shepherding a project. This position typically exists when the network is working with a cooperator because no park staff have the expertise to be the principal investigator. Responsibilities of the project lead may range from providing logistics to dealing with compliance issues. The project lead ensures that the project addresses monitoring objectives, meets deadlines, and delivers established products.
- **Principal Investigator:** the individual designated to take overall responsibility within the network context for the design, conduct, and reporting of the monitoring effort on a vital sign. He or she works with the Network Coordinator and Technical Committee to provide long-range guidance for data collection. They oversee collation, summarization, and analysis of the monitoring data.

To broaden the existing expertise within the ARCN program, the network will hire two full-time term employees and three summer seasonal employees (Table 8.3). The two full-time hires will fulfill many of the outstanding technical needs of the network. These positions will be:

1. an assistant to the network data manager for development of databases; and
2. a landscape ecologist to develop the remote sensing capabilities of the network.

The three seasonal positions will be summer biological technicians who will help throughout the monitoring program.

8.3 Integration of Program with Park Operations

As an NPS program, it is essential that the monitoring program integrate with existing park programs and divisions. Integration of the network with existing park infrastructure occurs at many levels, including personnel, facilities, job tasks, and administration. Integration and sharing of resources provides efficiencies that allow us to extend the capabilities of the monitoring program and, in some cases, to leverage additional support for the program.

As previously discussed, the network relies on park scientists and natural resource specialists to act as project leads and principal investigators for monitoring projects. Existing park staff members are most familiar with ongoing natural resource projects and legacy data sets for their park area. Rather than educating new individuals, it is more efficient to rely on existing experts who are known in their

parks and regions; this facilitates cooperation and collaboration with other agencies and ecological professionals. As a new program, ARCN needs the support of the parks it represents to succeed. Park employees from all job fields need to recognize the value of the monitoring program, and this is best achieved by ensuring that we are working together as a team to accomplish the goals of the park and the monitoring program.

Due to the remoteness of the ARCN parks, field efforts rely on the existing infrastructure and facilities that have been established to administer these areas. Access to ARCN parks may be by aircraft, boat, or snowmachine. Logistics are often complex. Conducting work in these parks generally requires multiple nights in the field. In all cases, cooperation with the staff members who maintain the facilities and equipment within the parks is critical.

Further integration and cooperation with park operations are achieved when the network can combine missions with those of other park staff. For example, the safety and efficiency of ARCN field efforts are often enhanced by cooperation with the ranger staff. Monitoring products and results are ideal material for park interpretive programs, while the monitoring program benefits through public support garnered through education.

Integration is also important in the administration of the network. The ARCN budget is administered through the NPS Fairbanks Administrative Center. This removes a large administrative burden from the network. In addition, this arrangement helps emphasize the integrated nature of the network program in day-to-day park operations.

8.4 Field Efforts to be Conducted by the ARCN

ARCN field work will be conducted primarily by existing park natural resource staff and ARCN staff (Table 8.4). Park and network staff are aware of the goals and the missions of the monitoring program and NPS in general. Using "in-house" experts avoids the overhead costs typically associated with using experts from other entities. In addition, outside entities may have objectives that compete with those of the monitoring program. In some cases, however, it will be advantageous to use experts outside of the NPS (Table 8.4). Use of outside experts can broaden the expertise of the network. Cooperative agreements with outside experts may be particularly useful in situations in which a vital sign is monitored with long intervals between efforts. Outside experts may also be used in situations that require a relatively short period of intense effort, such as pilot studies used to investigate methodology. The division of labor between network and park staff with outside cooperators will continue to evolve as the program matures.

8.5 Partnerships

Partnerships have played a large role in ARCN, and we anticipate that they will continue to be important into the future. Partnerships were established to complete inventories within the network and to initiate the monitoring process as ARCN started the process of hiring new employees. The establishment of a long-term monitoring program in the Arctic is an exciting prospect for many scientists interested in the region, and there is great anticipation regarding the utility of the data streams this program will provide. Currently ARCN has a number of partnerships (Table 8.5).

Table 8.4: Vital signs implemented by the Arctic Network under the Vital Signs Framework as developed for the National Park Service Vital Signs Monitoring Program. Vital signs that have been grayed out will only be implemented if additional resources become available.

National Vital Signs Framework Level 1	National Vital Signs Framework Level 2	Vital Sign Name	Field Efforts Solely by Networks	Field Efforts by Network and Cooperators	Field Efforts Only by Cooperators
Air and Climate	Air Quality	Wet and Dry Deposition		X	
		Air Contaminants		X	
	Weather and Climate	Climate	X		
		Snow	X		
Geology and Soils	Geomorphology	Coastal Erosion			X
		Sea Ice*			X
	Soil Function and Dynamics	Permafrost		X	
	Hydrology	Surface Water Dynamics and Distribution*	X		
	Water Quality	Lagoon Communities and Ecosystems		X	
		Lake Communities and Ecosystems	X		
		Stream Communities and Ecosystems	X		
Biological Integrity	Invasive/Exotic Plants	Invasive/Exotic Species*		X	
	Animal Diseases	Invasive/Exotic Species *		X	
	Focal Species or Communities	Fish Assemblages		X	
		Landbirds	X		
		Yellow-billed Loons		X	
		Brown Bears		X	
		Caribou		X	
		Dall's Sheep		X	
		Moose*		X	
		Muskox		X	
		Small Mammal Assemblages*	X		
		Terrestrial Vegetation and Soils		X	
Human Use	Point-Source Human Effects	Point Source Human Effects*		X	
	Consumptive Use	Subsistence/Harvest		X	
	Visitor and Recreation Use	Visitor Use*		X	
Landscapes	Fire and Fuel Dynamics	Fire Extent and Severity		X	
	Landscape Dynamics	Terrestrial Landscape Patterns and Dynamics		X	

* Vital sign will only be implemented if additional resources become available.

Table 8.5: Examples of current partnerships and proposed partnerships for the Arctic Network monitoring program

Partner	Type of Agreement	Nature of Partnership
Alaska Department of Fish and Game	Cooperative	Co-principal investigators and protocol development for brown bear, caribou, Dall's sheep, moose and muskoxen
Alaska Biological Research, Inc. (ABR)	Cooperative	Principal investigator and protocol development for ecological land surveys for development of land cover maps for the Network
Biological Resources Division, USGS	Cooperative	Principal investigator for yellow-billed loon survey
U.S. Fish and Wildlife Service	Cooperative	Principal investigator and protocol development for aerial loon and waterfowl surveys Protocol development for caribou and muskoxen vital signs
University of Alaska Fairbanks	Cooperative	Development of protocols for climate and weather, snow and ice, and permafrost vital signs Development of methodology for brown bear aerial survey Development of methodology for measuring tree line advance and shrub expansion
University of Colorado		Principal investigator for monitoring coastal erosion
University of Vermont		Protocol development for aquatic and permafrost vital signs
Western Regional Climate Center, Desert Research Institute*	Cooperative	Archive and deliver climate data via the world wide web Develop analysis tools for network climate data via the world wide web

* Partnership expected following the deployment of network weather stations.

Table 8.6: Review process for the Arctic Network monitoring program

Review	Timing	Who is Involved	Intent of Review
Annual Administrative Report and Work Plan	Annual	Technical Committee and Board of Directors	Provide accountability annually. Provide a forum to summarize results from the past year.
Science Symposium/ Investigators' Report to the Technical Committee	Biannual	All investigators who collect data for ARCN Invited experts Technical Committee and Board of Directors	Present results and status of work in ARCN. Provide an opportunity to develop collaboration across the network. Evaluate the success of meeting goals of the program. Evaluate day-to-day operation of the program.
Five-year Program Review	Every 5 years	All investigators who collect data for ARCN Invited experts Representatives of the Technical Committee and Board of Directors	Provide synthesis of the program. Evaluate direction of the program and redirect if necessary. Evaluate performance of the program.

8.6 Review Process for the Program

Periodic review of the network's program provides the opportunity to adjust Network resources to better meet the objectives of the Vital Sign's Monitoring Program. Three levels of review will be used to keep the ARCN on track (Table 8.6). On an annual basis, the Annual Administrative Report and Work Plan (AARWP) provides the opportunity for input. Every two years, the network will hold a symposium to review the program more fully. Every five years, an in-depth review of the overall program will occur.

The Annual Administrative Report and Work Plan focuses attention on individual projects. Every year it provides the Board of Directors and the Technical Committee the opportunity to evaluate the merits of individual projects. The structure of this report is conducive to tracking allocation of resources, and reviewers are encouraged to evaluate the value and importance of projects and identify weaknesses in the Network's program.

A science symposium will be held every two years, with investigators' reports to the Technical Committee. This will provide the opportunity to discuss the program with other scientists involved with ARCN in more detail. The symposium/investigators' report to the Technical Committee will be a two-day meeting, during which all investigators conducting work with the network will present their findings. At the end of the presentations, the Technical Committee will meet and discuss the overall results and products from the ARCN program. The format associated with symposia is conducive to brainstorming, and the collective thought of a number of engaged network staff and collaborators will allow improved integration and realignment of the network.

The third level of review is the five-year formal review. This review is aimed specifically at ensuring the quality of the network's program and making recommendations for improvement. Decisions will be made regarding the relevance of data streams and the network's effectiveness in addressing objectives. The administration and operation of the program will be evaluated, and recommendations for improvement will be made.

In addition to the cyclical periodic reviews, there will be a start-up review, which will occur once the Arctic Network monitoring plan is accepted as final. This one-time review will happen in the months before the three-year anniversary of the monitoring plan being approved and implemented.

Chapter 9
Schedule

This chapter describes the Arctic Network's plan for implementing the Vital Signs Monitoring Program during the next four years (FY 2009–2012). The transition from defining the program to implementing a functional monitoring program requires planning to ensure that financial and staffing resources are not overcommitted. The Arctic Network's strategy for sustainability is to stagger the timing of implementation of the network's identified vital signs (Table 9.1).

There are some tasks associated with all vital signs identified by the Arctic Network that need to be addressed before monitoring occurs. In all cases, a thorough investigation of existing methodologies and datasets associated with the vital sign needs to be made. Explicit decisions regarding spatial and temporal extent of monitoring need to be made; pilot studies may be necessary to inform these decisions. Following completion of these tasks, protocols and standard operating procedures have to be written, and explicit decisions need to be made regarding data management and mechanisms for future review of the monitoring effort's effectiveness. Both the progress on completion of these tasks and the availability of existing information vary and are reflected in our schedule for implementing the monitoring of specific vital signs (Table 9.1).

Many of the vital signs chosen by the Arctic Network are also of interest to other natural resource agencies and partners; several tasks detailed in Table 9.1 reflect the need for the Arctic Network to coordinate with a range of partners in collectively developing monitoring protocols. Although coordination can add complexity during scheduling and implementation of monitoring plans, it is an important component of the program. Only through effective cooperation will we be able integrate historical and existing programs into the Arctic Network monitoring program. This integration is important for efficient and effective operation. Integration and support from cooperators will be necessary for the long-term success of the program.

Vital signs monitoring will be performed on various schedules (Table 9.2). In many instances, sampling is restricted to specific seasons. Sampling within a designated time period can minimize between-year variability. In addition, the frequency of monitoring is often governed by the scale of resolution being monitored and the rate of change expected. For example, a vital sign such as coastal erosion can be measured using remotely sensed imagery at a coarse scale, and an appropriate frequency for monitoring may be once every ten years. In contrast, a metric such as brown bears may require a concentrated effort annually (Table 9.2). These differences in timing and sampling frequency need to be recognized to ensure the availability of resources to sustain the monitoring program.

As we progress through FY 2009, the network will continually be reviewing the implementation schedule and the success of the program. This informal evaluation will take place on a vital sign by vital sign basis, but we will also be considering the overall performance of the program. Results of these observations will help us adjust the 2009 plans as necessary to meet our program objectives effectively.

Table 9.1: Tasks to be completed for protocol development or for acquiring existing data for the ARCN Vital Signs Monitoring Program.

Target Year for Protocol Completion	Vital Sign	Issues and Tasks to be Addressed Before Full Monitoring will be Implemented
FY 2009	Air Quality	Draft protocols and SOPs will be peer-reviewed and finalized. Formats for data summarization will be evaluated. Databases will be developed.
	Coastal Erosion	Draft protocols and SOPs will be peer-reviewed and finalized. Work will focus on database development.
	Lagoon Communities and Ecosystems	Draft protocols need to be reviewed. Frequency of monitoring needs to be finalized. Databases need to be developed, and final protocols need to be written.
	Lake Communities and Ecosystems	Sampling interval based on natural variability needs to be determined. A subset of large lakes for routine sampling will be selected. Work will focus on database development. Protocols and SOPs will be drafted and peer-reviewed.
	Stream Communities and Ecosystems	A subset of streams and rivers for routine sampling needs to be selected. Sampling interval based on natural variability needs to be determined. Work will focus on database development and writing the protocol to NPS specification.
	Brown bears	Peer review of methodologies and techniques will be completed. Work will focus on database development. Draft protocols and SOPs will be peer-reviewed and finalized.
FY 2010	Climate	Scoping of weather station sites needs to be completed. Legal compliance regarding placement of weather stations on park-administered lands needs to be completed. Databases need to be developed, and final protocols need to be written.
	Snowpack	The Snowpack vital sign will be developed in concert with the Climate vital sign. Tasks to be completed will progress on the same schedule as the Climate vital sign.
	Permafrost	During FY 2009 collaborators will submit a final report regarding thermokarst monitoring. Protocols and SOPs will be finalized by FY 2010. Databases need to be developed.
	Caribou	Emphasis area of monitoring effort between NPS and cooperators needs to be finalized. Data sharing mechanisms between NPS and partners need to be finalized. Databases need to be developed. Draft protocols and SOPs will be peer-reviewed and finalized.
	Terrestrial Vegetation and Soils	ARCN will evaluate the results from a multiyear cooperative agreement. A cost and methods comparison for various remote sensing platforms will be conducted. Remote sensing options need to be compared to ground-based measures. Databases need to be developed, and final protocols need to be written.
	Fire Extent and Severity	Need to finalize integration plan between FirePro and ARCN data streams. Site selection of the fire plots and historic plots needs to be assessed statistically. Databases need to be developed, and final protocols need to be written.

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Target Year for Protocol Completion	Vital Sign	Issues and Tasks to be Addressed Before Full Monitoring will be Implemented
FY 2011	Wet and Dry Deposition	Pilot work on sampling methodology needs to be completed. Mercury methylation risk map needs to be completed. Protocols need to be written, reviewed, and finalized. Databases need to be developed.
	Landbirds	Draft protocols and SOPs need to be developed and reviewed. Sample design will require one year of field testing. Databases need to be developed, and final protocols will be finalized.
	Dall's sheep	Methodology for distance sampling of Dall's sheep and microhistological work needs to be tested. Databases need to be developed. Protocols and SOPs need to be drafted, reviewed, and finalized.
	Muskox	Rotation schedule of monitoring effort needs to be determined. Data sharing mechanisms between NPS and partners need to be finalized. Databases need to be developed, and final protocols need to be written.
	Terrestrial Landscape Patterns and Dynamics	Remote sensing platforms for monitoring need to be evaluated. Imagery will be purchased for a subset of index sites. Soil temperature monitoring will be deployed with climate stations. Databases need to be developed, and final protocols need to be written.
FY 2012	Yellow-billed Loons	Protocols and SOPs need to be drafted, reviewed, and finalized. Protocols for on-the ground work need to be tested before full implementation. Databases need to be developed.
	Subsistence/ Harvest	Harvest records are maintained by the Alaska Department of Fish and Game and some of the village corporations in northern and northwestern Alaska. Work will focus on acquiring this data and incorporating it into ARCN data streams. A full protocol needs to be written.

Table 9.2: Sampling interval, observation method (ground-based or remote sensing), and annual timing of sampling for the vital signs to be monitored by ARCN in 2009–2012

Vital Sign to be Sampled	Sampling Interval (Observation Method)	January	February	March	April	May	June	July	August	September	October	November	December
Wet and Dry Deposition	Decadal (ground-based)							X	X				
Air Quality	Weekly	X	X	X	X	X	X	X	X	X	X	X	X
Climate	Continuous	X	X	X	X	X	X	X	X	X	X	X	X
Snowpack	Continuous	X	X	X	X	X	X	X	X	X	X	X	X
Coastal Erosion	Decadal (remote sensing)						X	X	X				
Permafrost	Decadal (remote sensing)						X	X	X				
Lagoon Communities and Ecosystems	Twice annually (ground-based)		X	X	X		X	X	X				
Lake Communities and Ecosystems	Annual (ground-based)						X	X	X				
	Every 5 years (remote sensing)					X	X	X	X	X			
Stream Communities and Ecosystems	Annual (ground-based)						X	X	X				
	Every 5 years (remote sensing)					X	X	X	X	X			
Yellow-billed Loons	Every 2 years (ground-based)							X	X				
Landbirds	Every 2 years (ground-based)						X	X					
Brown Bears	Annual					X							
Caribou	Continuous	X	X	X	X	X	X	X	X	X	X	X	X
Dall's Sheep	Annual							X					
Muskox	Annual								X				
Terrestrial Vegetation and Soils	Annual (ground-based)							X	X				
	Annual (remote sensing)					X	X	X	X	X			
Subsistence/ Harvest	Annual	X	X	X									X
Fire Extent and Severity	Annual (ground-based)							X	X				
Terrestrial Landscape Patterns and Dynamics	Twice annually, annually, or decadal, depending on metric (remote sensing)					X	X	X	X	X			

Chapter 10
Budget

We anticipate the monitoring plan for the Arctic Network will be reviewed and approved by the end of 2008. In this chapter we present the Arctic Network's budget for the first year of implementation of this monitoring plan, FY 2009. We present this budget with the same expense categories networks use to prepare the Annual Administrative Report and Work Plans submitted to Congress.

In developing the ARCN Vitals Signs Monitoring Program, one of our objectives has been to complement but not duplicate or replace existing programs within the ARCN parks and in northern Alaska in general. It is important to be cognizant of these other data streams and to capture information pertinent to the Arctic Network parks. The ARCN has identified 19 vital signs that will be monitored during the first five years of implementation. Vital signs for which there is no current monitoring and for which ARCN has staff expertise will receive full financial support from ARCN. Vital signs that are currently being monitored by the parks or other agencies will receive partial or no financial support from ARCN but will be mined for data relevant to the ARCN monitoring program (Table 10.1). This graded approach to funding is beneficial for more than just financial reasons. We anticipate that much of the work in ARCN will be performed by existing park personnel. As discussed in chapter 8, the integration of projects, funds, and personnel will promote consistency and longevity in our program.

Funding for the Arctic Network comes from the National Park Service Natural Resource Challenge Program. Funds are transferred annually from the Washington Office, through the Alaska Regional Office, to the Fairbanks Administrative Unit. In FY 2008, the network received $145,100 from the NPS Water Resources Division and $1,559,680 from the Servicewide Inventory and Monitoring Vital Signs Program. Budget figures are reported once a year in a standard format in the Annual Administrative Report and Work Plans submitted to Congress (Table 10.2).

In FY 2009, approximately 43% ($735,000) of the network budget will be committed to personnel. This expenditure includes permanent staff, term staff, and seasonal help for data collection. Approximately 15% ($250,000) of the FY 2009 budget will support protocol development, testing, and reporting through cooperative agreements and contracts. Annual operations and equipment will comprise 33% ($668,000) of the budget. For the model of a centralized staff to be successful, 3% ($49,000) of the budget will be spent on travel funds. Travel funds will be used to maintain close communication between network and park staff, the Board of Directors, and the Technical Committee. Travel funds are also needed to participate in regional and national inventory and monitoring meetings and workshops.

We are cognizant that conducting the field work to collect data on our vital signs is dependent on some things over which we have no control. For example, aerial Dall's sheep surveys require good visibility and light winds. If these conditions do not exist, surveys are not conducted. A situation such as this could result in a significant and unforeseen monetary windfalls. Conversely, long-term commitment from other NPS programs and natural resources agencies cannot be guaranteed, which may result in a budget shortfall in a given year. To handle this situation, each year during the formulation of the work

plan, the network will determine a back-up plan for how rotational work could be shifted or funds allocated to accomplish work on a different vital sign. This will be a relatively time-consuming process during the early years of the program until we establish a set of workable contingency plans.

Guidelines for developing a monitoring program suggest that approximately 30% of the budget should be allocated to information/data management so that information is not lost, results are communicated, and adequate reporting takes place. In Table 10.2 we provide the approximate percent of time that each network position will devote to information/data management in FY 2009. We will also provide the estimated portion of the budget that will be allocated to individual vital signs for information/data management during FY 2009. We anticipate that more of the budget will go toward information/data management as more vital signs transition from a development stage to a full implementation stage and as data begins to accumulate.

Table 10.1: Network contributions to staff and funding with respect to vital signs monitoring in ARCN. Greater amounts of network funding will be directed to monitoring projects that parks or other natural resource agencies have not had financial or staff resources to initiate or sustain.

ARCN Vital Sign	ARCN Funding Contribution (%)	Description of Contribution
Wet and Dry Deposition	75–100%	• ARCN will provide funds for field work, equipment, laboratory analysis, data management, and reporting. • Parks will contribute staff ecologist as project principal investigator. • Work will be accomplished with university and Environmental Protection Agency (EPA) researchers.
Air Quality	0–25%	• ARCN will provide two technicians working approximately 3 hours/week. • Parks will maintain Air Quality structure. • NPS Air Resource Division will function as the principal investigator and will provide equipment, sample analysis, and data summaries.
Climate	75–100%	• ARCN will provide the principal investigator and funds for field work, equipment, and reporting. • Parks will contribute some logistics. • Work will be accomplished through cooperation with the Natural Resource Conservation Service, Western Regional Climate Center, and the National Weather Service.
Snowpack	75–100%	• ARCN will provide the principal investigator and funds for field work, equipment, and reporting. • Parks will contribute some logistics. • Work will be accomplished through cooperation with the Natural Resource Conservation Service and the Western Regional Climate Center.
Coastal Erosion	50–75%	• ARCN will provide funding for cooperative agreement, data management, and reporting. • Parks will contribute some staff support for public outreach. • Work will be accomplished through a cooperative agreement with Dr. William Manley, University of Colorado.
Permafrost	75–100%	• ARCN will provide the principal investigator and funds for field work, remotely sensed imagery, equipment, data management, and reporting. • Parks will contribute some logistics. • Some work may be accomplished through cooperation with Torre Jorgenson of Alaska Biological Research, Inc.

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ARCN Vital Sign	ARCN Funding Contribution (%)	Description of Contribution
Lagoon Communities and Ecosystems	50–75%	• ARCN will provide funds for field work, remotely sensed imagery, equipment, data management, and reporting. • Parks will contribute some logistics. • Work may be accomplished through cooperation with the Kotzebue IRA Council and East Carolina University.
Lake Communities and Ecosystems	75–100%	• ARCN will provide the principal investigators and funds for field work, equipment, data management and reporting. • Parks will contribute some logistics. • Some work may be accomplished through cooperation with Dr. Chris Luecke of Utah State University and others.
Stream Communities and Ecosystems	75–100%	• ARCN will provide the principal investigator and funds for field work, equipment, data management, and reporting. • Parks will contribute some logistics. • Some work may be accomplished through cooperation with Dr. Chris Luecke, Utah State University.
Landbirds	75–100%	• ARCN will provide the funds for field work, equipment, data management, and reporting. • Parks will contribute the principal investigators and some logistics. • Some work may be accomplished through cooperation with the Alaska Bird Observatory.
Yellow-billed Loons	50–75%	• ARCN will provide the funds for field work, equipment, flight time, data management, and reporting. • Parks will contribute some logistics. • Work may be accomplished through cooperation with the U.S. Fish and Wildlife Service and the U.S. Geological Survey.
Brown Bears	50–75%	• ARCN will provide the funds for field work, equipment, flight time, data management, and reporting. • Parks will contribute the principal investigator, aircraft, and some logistics. • Work may be accomplished through cooperation with the Alaska Department of Fish and Game and the U.S. Fish and Wildlife Service.
Caribou	25–50%	• ARCN will provide the funds for radiocollars, data acquisition (from radiocollars), and some data management and reporting. • Parks will contribute the principal investigators and some logistics. • Work will be accomplished through cooperation with the Alaska Department of Fish and Game, U.S. Fish and Wildlife Service, and the Bureau of Land Management.
Dall's Sheep	50–75%	• ARCN will provide the principal investigator and funds for field work, equipment, data management, and reporting. • Parks will contribute aircraft, pilots, and some logistics. • Work will be accomplished through cooperation with the Alaska Department of Fish and Game.
Muskox	0–25%	• ARCN will provide funds for field work, equipment, data management, and reporting. • Parks will contribute the principal investigator, aircraft, pilots, and some logistics. • Work will be accomplished through cooperation with the Alaska Department of Fish and Game and the U.S. Fish and Wildlife Service.

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Table 10.1 (continued)

ARCN Vital Sign	ARCN Funding Contribution (%)	Description of Contribution
Terrestrial Vegetation and Soils	75–100%	• ARCN will provide the principal investigator and funds for field work, equipment, data management, and reporting. • Parks will contribute some logistics. • Work may be accomplished through cooperative agreements with university and other researchers.
Subsistence/ Harvest	0–25%	• ARCN will provide funds for field work, data management, and reporting. • Parks will contribute some logistics. • Work will be accomplished through cooperation with the Alaska Department of Fish and Game and local village and Native associations.
Fire Extent and Severity	0–25%	• ARCN will provide funds for some field work, data management, and reporting. • Parks will contribute some logistics. • Work will be accomplished through cooperation with the Alaska Regional Fire Management Program. The Fire Management Program will provide the principal investigator, staff for field work, and the majority of the funding for field work.
Terrestrial Landscape Patterns and Dynamics	75–100%	• ARCN will provide the principal investigator and funds for field work, equipment, data management, and reporting. • Parks will contribute some logistics. • Work may be accomplished through cooperative agreements with university and other researchers.

Table 10.2: Anticipated income and expenditures for FY 2009 (based on FY 2008 levels), Arctic Network

ARCN Vital Signs Monitoring Budget, 2009			
Income			
Vital Signs Monitoring		$1,559,680	
Water Resources Division		$145,100	
	Total	$1,704,780	
Expenditures			
Personnel	**GS Level (Pay period/year)**	**Salary**	**Information Management***
Network Coordinator	12 (26)	$98,000	$32,000 (30%)
Data Manager	11 (26)	$92,000	$92,000 (100%)
Physical Scientist (45%)	12 (13)	$47,000	$16,000 (30%)
Landscape Ecologist	12 (13)	$48,000	$16,000 (30%)
Terrestrial Ecologist	12 (26)	$96,000	$32,000 (30%)
Aquatic Ecologist (term)	11 (26)	$82,000	$27,000 (30%)
Data Management Assistant (term)	11 (26)	$70,000	$70,000 (100%)
Biotechnician (student—term)	5 (26)	$46,000	$15,000 (30%)
Ecologist	9 (26)	$70,000	$23,000 (30%)
Budget Analyst	11 (2)	$6,000	–
Administrative Assistant	6 (26)	$50,000	–

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Table 10.2 (continued)

ARCN Vital Signs Monitoring Budget, 2009			
Biotechnician (seasonal)	7 (8)	$15,000	$5,000 (30%)
Biotechnician (seasonal)	7 (8)	$15,000	$5,000 (30%)
Subtotal		$735,000	$333,000
Cooperative Agreements/Contracts			
Alaska Park Science Symposium Materials Development		$20,000	$20,000 (100%)
Wet and Dry Deposition Protocol Development		$115,000	11,500 (10%)
Permafrost Protocol Development		$15,000	$1,500 (10%)
Lagoon Protocol Development/ Implementation		$30,000	$10,000 (30%)
Yellow-billed Loon Protocol Development		$30,000	$10,000 (30%)
Coastal Erosion Workshop/Education Outreach		$20,000	$20,000 (100%)
Development of Network-wide Sampling Strategies		$20,000	$20,000 (100%)
Subtotal		$250,000	$93,000
Operations/Equipment			
Activate Air Quality Station		$15,000	$750 (5%)
Activate Weather Stations/Purchase Equipment		$123,000	$37,000 (30%)
Lake Communities and Ecosystems Protocol Development		$100,000	$5,000 (5%)
Stream Communities and Ecosystems Protocol Development		$40,000	$2,000 (5%)
Brown Bear Monitoring		$60,000	$6,000 (10%)
Caribou Protocol Development		$125,000	$12,500 (10%)
Dall's Sheep Monitoring		$50,000	$5,000 (10%)
Muskox Monitoring		$15,000	$1,500 (10%)
Terrestrial Vegetation and Soils Protocol Development		$125,000	$6,250 (5%)
Extract Historical Vegetation Data into Electronic Database		$15,000	$15,000 (100%)
Subtotal		$668,000	$90,900
Travel/Training		$49,000	
Other Miscellaneous		$2,780	
Grand Total		$1,704,780	$516,900 (30%)

* Amount of expenditure going toward information management.

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Glossary of Terms

Adaptive Management: A systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form—"active" adaptive management—employs management programs that are designed to compare selected policies or practices experimentally by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed (http://science.nature.nps.gov/im/monitor/glossary.cfm).

ANILCA: The Alaska National Interest Lands Conservation Act of 1990 (Public Law 96-487), which provided for the designation and conservation of certain public lands in Alaska, including the designation of units of the National Park Service, National Wild and Scenic Rivers, and National Wilderness Preservation System (http://www.r7.fws.gov/asm/anilca/toc.html).

Anthropogenic: Effects caused by or attributed to humans. As used here they are human-influenced factors that cause stress in natural systems.

Attribute: Any living or nonliving feature or process of the environment that can be measured or estimated and that provides insights into the state of the ecosystem.

Biodiversity: Short for "biological diversity" and is typically used to refer to the variety of life forms found on earth. Biodiversity can be used to describe the number of taxa found in a specific geographic area by levels of the taxonomic hierarchy (e.g., number of phyla represented, number of bird species, number of chironomid genera, etc.). Various metrics have been developed to describe biodiversity, including species richness, Shannon-Wiener Diversity Index, etc.

Conceptual ecosystem models: Purposeful representations of ecosystem components and processes that provide a mental picture of how an ecosystem works to communicate that explanation to others (Starfield et al. 1994).

Conceptual "stressor" models: Visual representation of known stressors that may cause changes in park resources.

Drivers: Major external driving forces, such as climate change, regional land-use change, or air pollution, that have large-scale influences on natural systems. Drivers can be natural forces or anthropogenic. These may be related to global or regional changes in climate, nutrient inputs, or human pressures.

Ecological integrity: A concept that expresses the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and capable of self-renewal. Ecological integrity implies the presence of appropriate species, populations, and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes.

Ecosystem: "A spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries" (Likens 1992).

Ecosystem attributes (vital signs): Component or process of an ecosystem used to describe the long-term "health" of an ecosystem.

Ecosystem components: Part(s) of an ecosystem (e.g., nitrogen, eelgrass, insect, seal, water).

Ecosystem function: All physical and chemical properties of an ecosystem that relate to its form and organization, excluding the action or use of the structure that is more critically termed its role (e.g., dispersal mechanism, ecosystem stability).

Ecosystem management: The process of land-use decision-making and land-management practice that takes into account the full suite of organisms and processes that characterize and comprise the ecosystem. It is based on the best understanding currently available of how the ecosystem works. Ecosystem management includes a primary goal to sustain ecosystem structure and function, a recognition that ecosystems are spatially and temporally dynamic, and acceptance of the dictum that ecosystem function depends on ecosystem structure and diversity. The whole-system focus of ecosystem management implies coordinated land-use decisions.

Ecosystem process: A series of ecosystem actions or changes bringing about a result (e.g., decomposition, photosynthesis).

Ecotone: The boundary or transitional zone between adjacent communities or biomes (e.g., riparian zone).

Focal resources: Park resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity. Focal resources might include ecological processes, such as deposition rates of nitrates and sulfates in certain parks, or they may be a species that is harvested, endemic, alien, or has protected status.

Index sites: As used by the Arctic Network, refers to how sampling locations for selected protocols, including climate, snowpack, terrestrial vegetation and soils, and air quality were selected. For these vital signs, probability sampling designs were not possible due to cost, and measurement locations were established using professional judgement.

Indicators: A subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003). Indicators are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system.

Inventory: An extensive point-in-time effort to determine location or condition of a resource, including the presence, class, distribution, and status of plants, animals, and abiotic components such as water, soils, landforms, and climate.

Measures: The specific feature(s) used to quantify an indicator, as specified in a sampling protocol.

Monitoring: The collection and analysis of repeated observations or measurements over time to evaluate changes in condition and progress toward meeting a management objective (Elzinga et al. 1998). Detection of a change or trend may trigger a management action or it may generate a new line of inquiry. Monitoring is often done by sampling the same sites over time, and these sites may be a subset of the sites sampled for the initial inventory.

Protocol: As defined for this program, detailed study plans that provide a rationale for monitoring a vital sign and instructions for carrying out the monitoring. Protocols consist of a narrative, standard operating procedures, and supplementary materials (Oakley et al. 2003).

Research: The objective of understanding ecological processes and, in some cases, determining the cause of changes observed by monitoring.

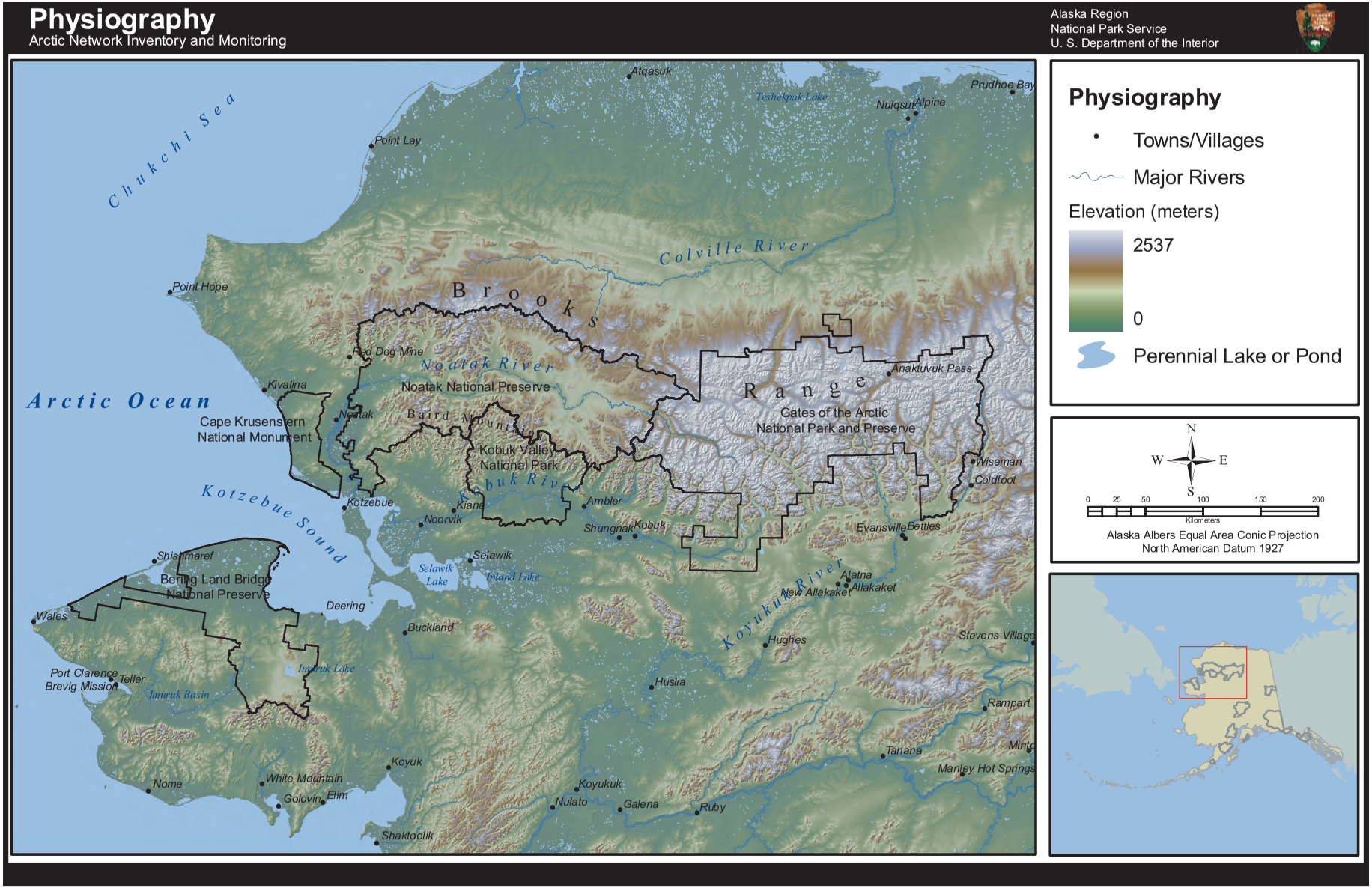
Status: Status as used by this program refers to the condition of a resource or vital sign at a given point in time.

Stressors: Physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive (or deficient) level (Barrett et al. 1976:192). Stressors cause significant changes in the ecological components, patterns, and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution.

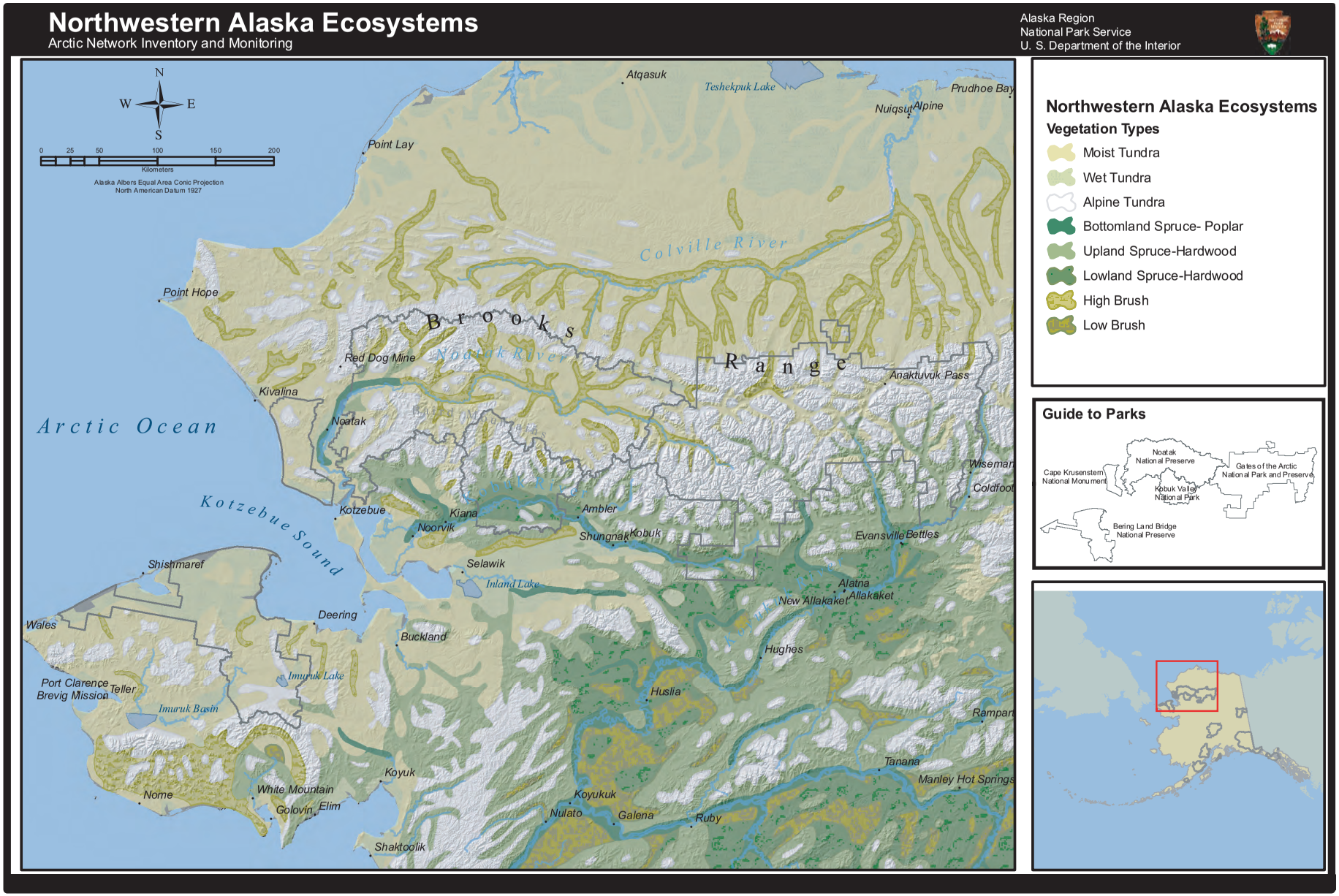
Trend: Refers to directional change measured in resources by monitoring their condition over time. Trends can be measured by examining individual change (change experienced by individual sample units) or by examining net change (change in mean response of all sample units).

Vital signs: As used by the National Park Service, 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. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes).

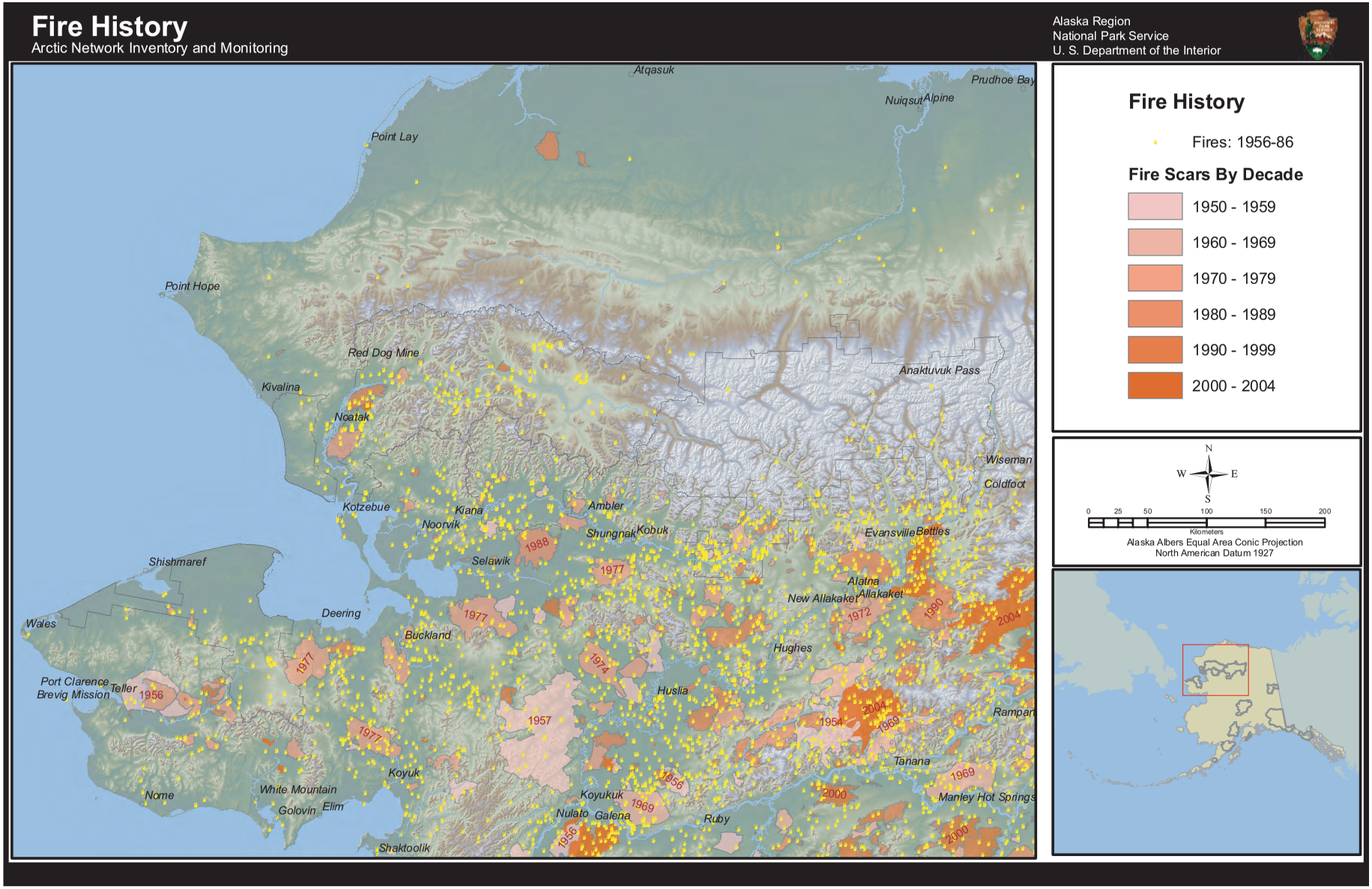
Network Maps



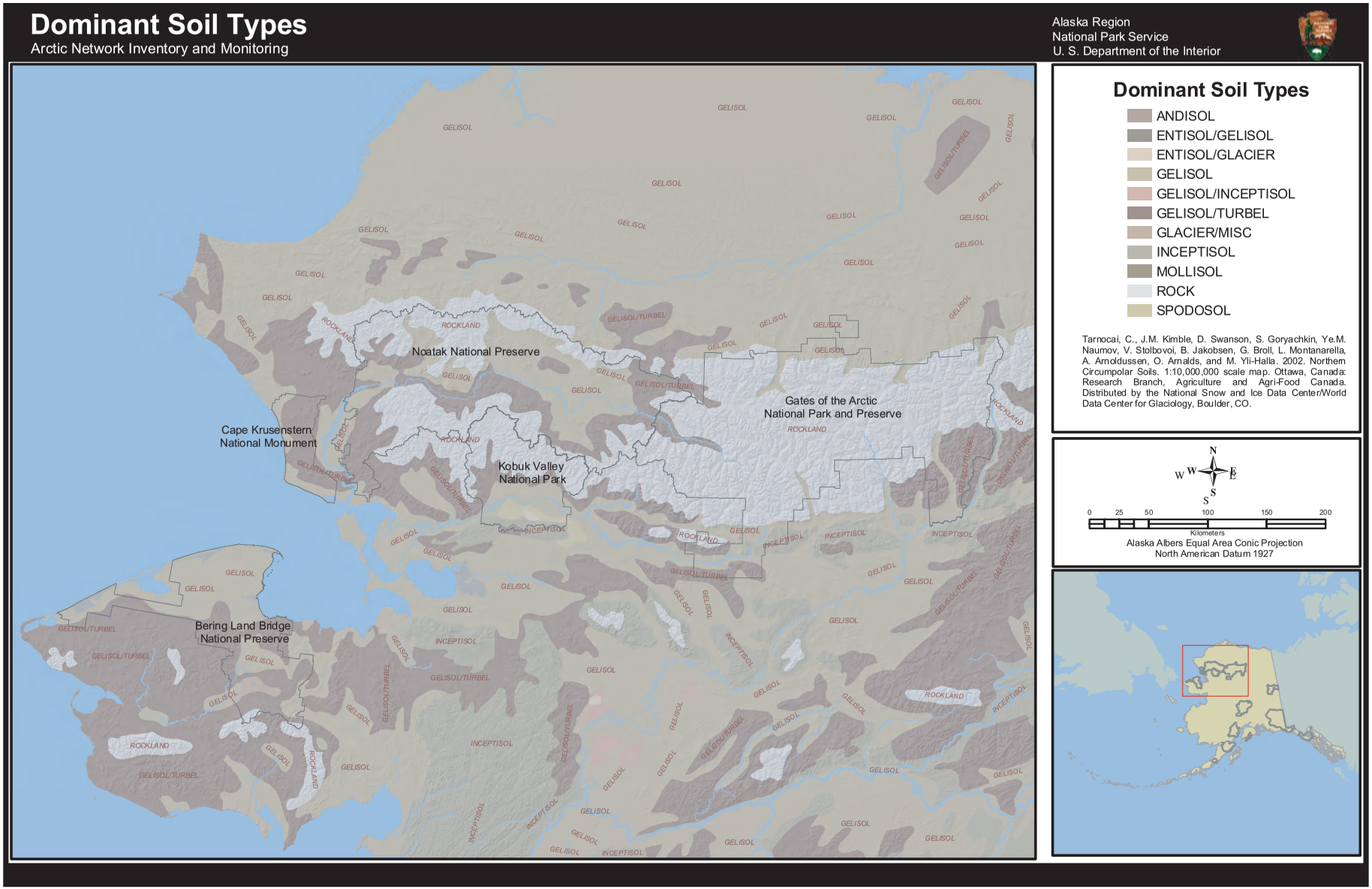
Map 1: *Physiography of ARCN. Digital elevation model 90 m grid for Alaska, from best available data. In some areas of missing data, a 300 m and 60 m DEM were used to patch in.*



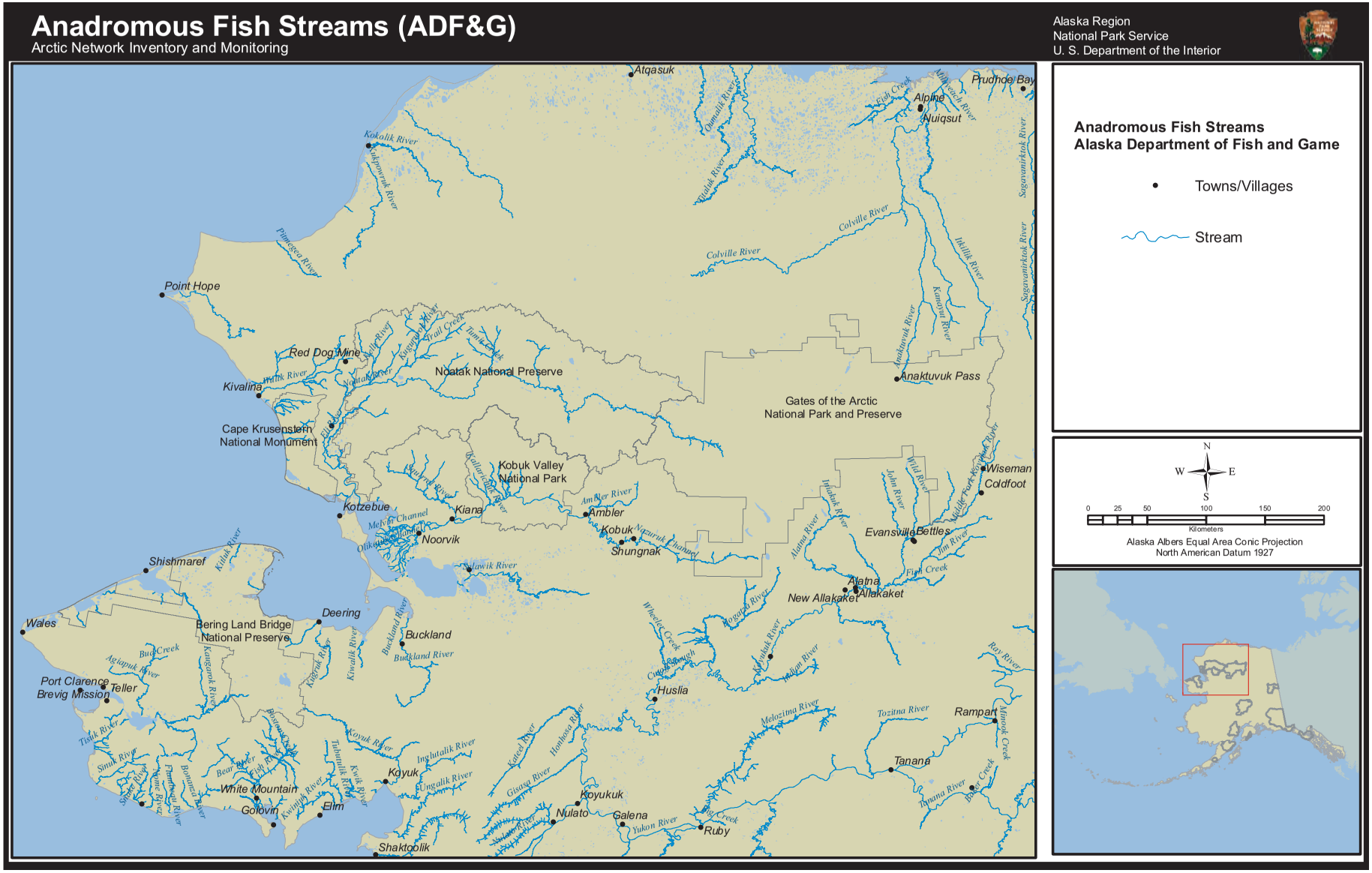
Map 2: *The 1973 map of "Major Ecosystems of Alaska" shows the distribution of nine classes of ecosystems within a single hierarchic level. Scale of coverage is 1:250:000. The focus of the ecosystems map is on the regional distribution of vegetation community type and structure. Information relating to other landscape characteristics, such as topography, hydrology, and climate, is considered only so far as it influences ecosystem type. (NPS Alaska Region Support Office.)*



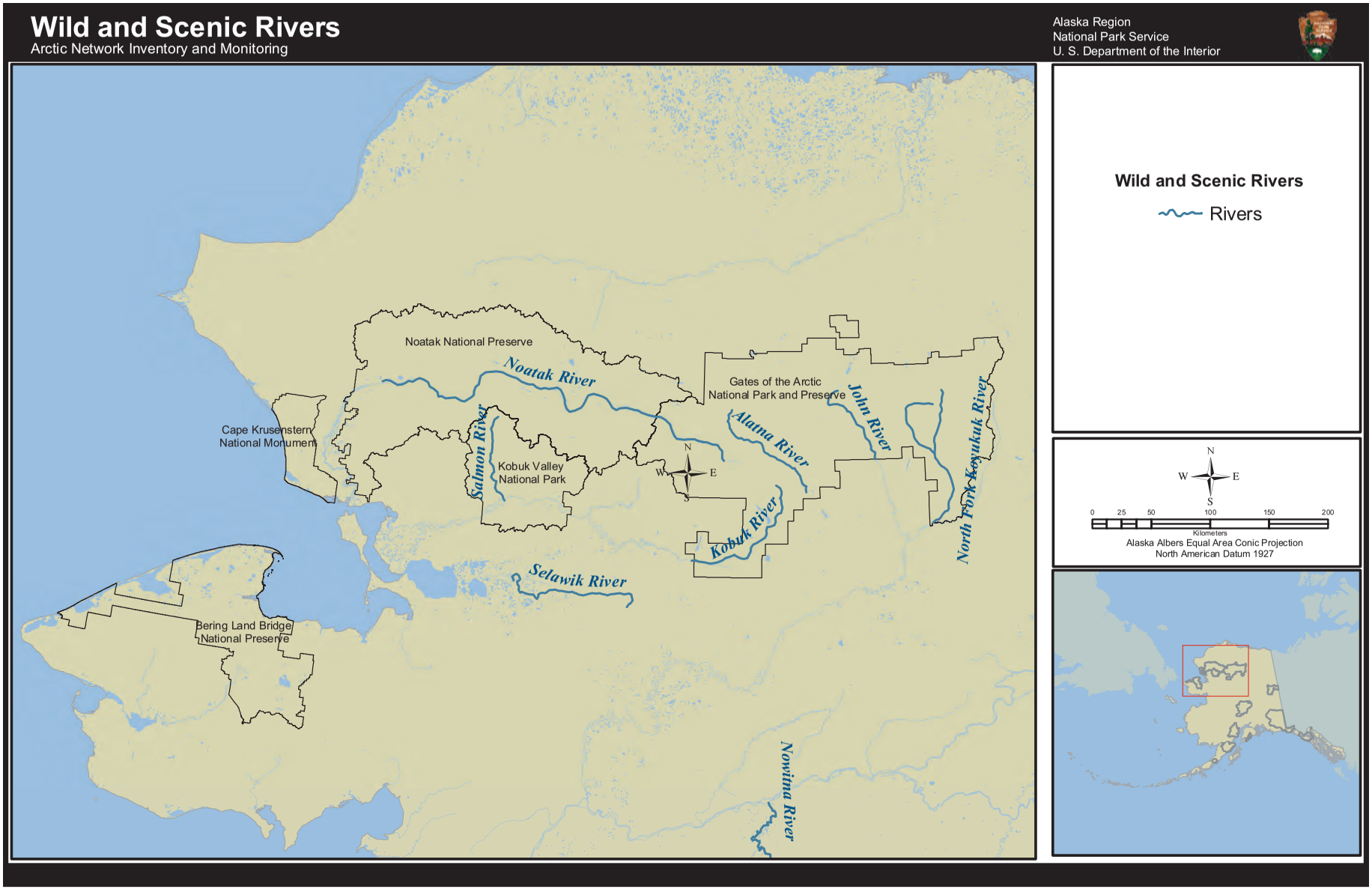
Map 3: *Fire history of northwest Alaska. Point data shows historic fire ignitions, 1950 to 2004. Area polygons represent historical wildland fire perimeters of fires greater than 1,000 acres between 1950 and 1987, inclusive, and fires greater than 100 acres between 1988 and 2002, inclusive. Data were compiled from BLM Alaska Fire Service, State of Alaska Department of Forestry and National Park Service records. (NPS Alaska Regional Office, BLM Alaska Fire Service, Environmental Resource Institute of Michigan.)*



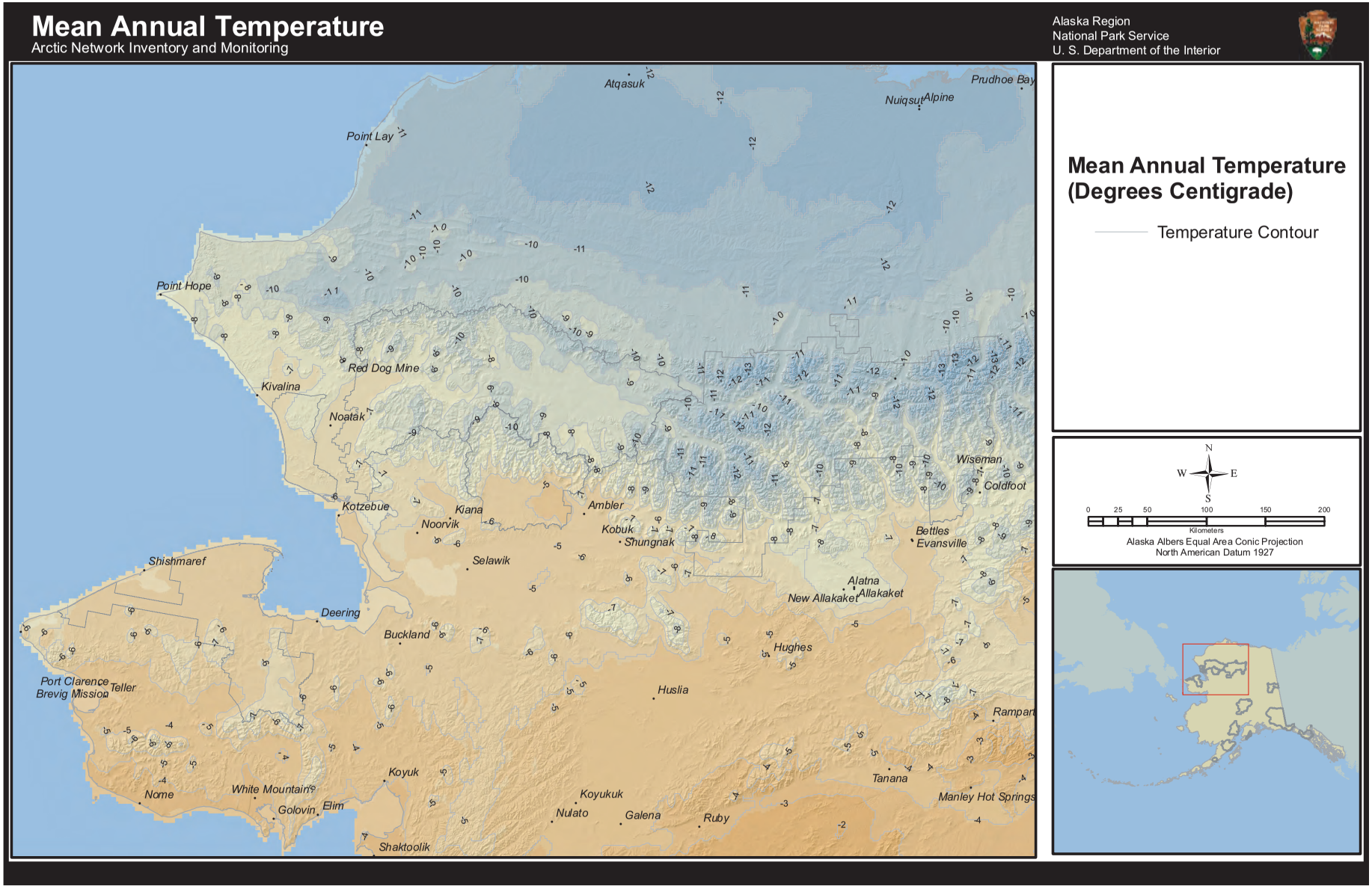
Map 4: *Map of northwestern Alaskan dominant soil characteristics. The map was created using the Northern and Mid Latitude Soil Database. The map shows the dominant soil of each spatial polygon unless the polygon is over 90 percent rock or ice. Soils include turbels, orthels, histels, mollisols, vertisols, aridsols, andisols, entisols, spodosols, incpetisols (and hapludolls), alfisols (cryalf and udalf), natric great groups, aqu-suborders, glaciers, and rocklands.*



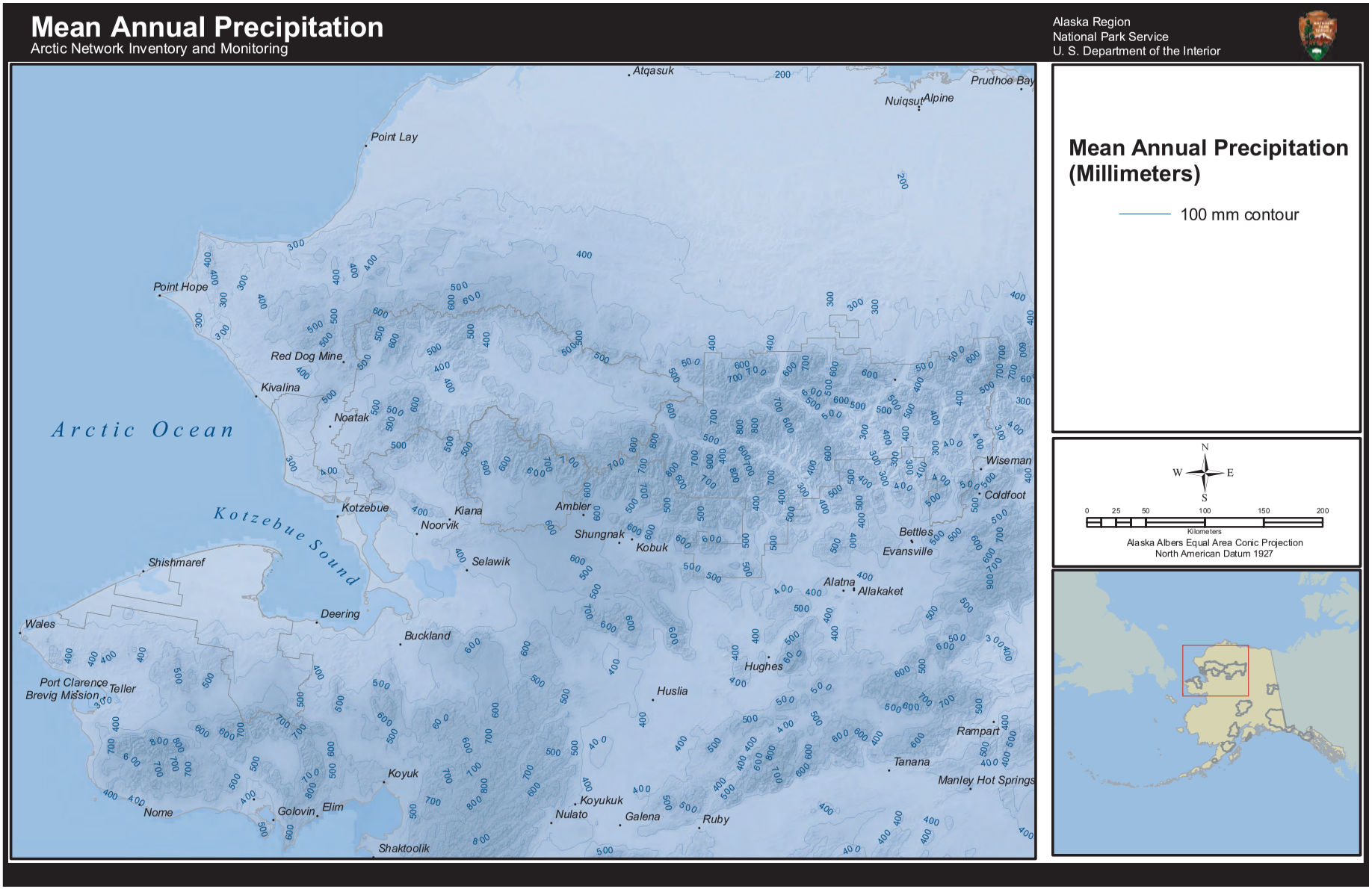
Map 5: *Anadromous fish streams. The Alaska Department of Fish and Game's (ADF&G) Anadromous Streams data is derived from the ADF&G's "Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes" and the "Atlas to the Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes." The map depicts the known anadromous fish bearing streams within Alaska (from the mouth to the known upper extent of species usage). It incorporates data from a variety of sources, including USGS Digital Line Graph (DLG) and National Hydrography Dataset (NHD) hydrography data; Alaska Department of Natural Resources hydrography layer; and ADF&G data for the atlas and catalog. Data for the shapefiles are current as of January 15, 2005.*



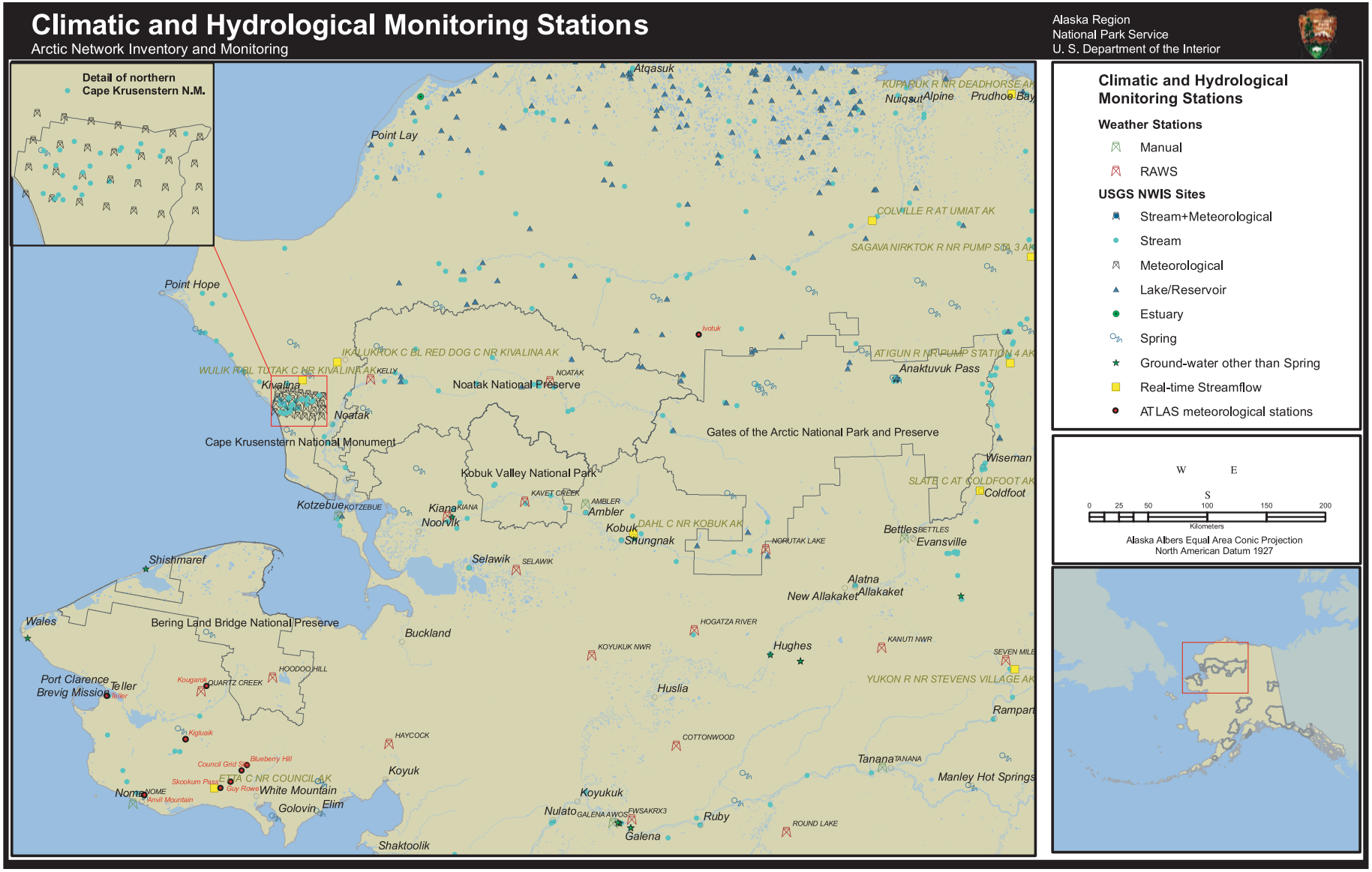
Map 6: *Wild and scenic rivers in ARCN.*



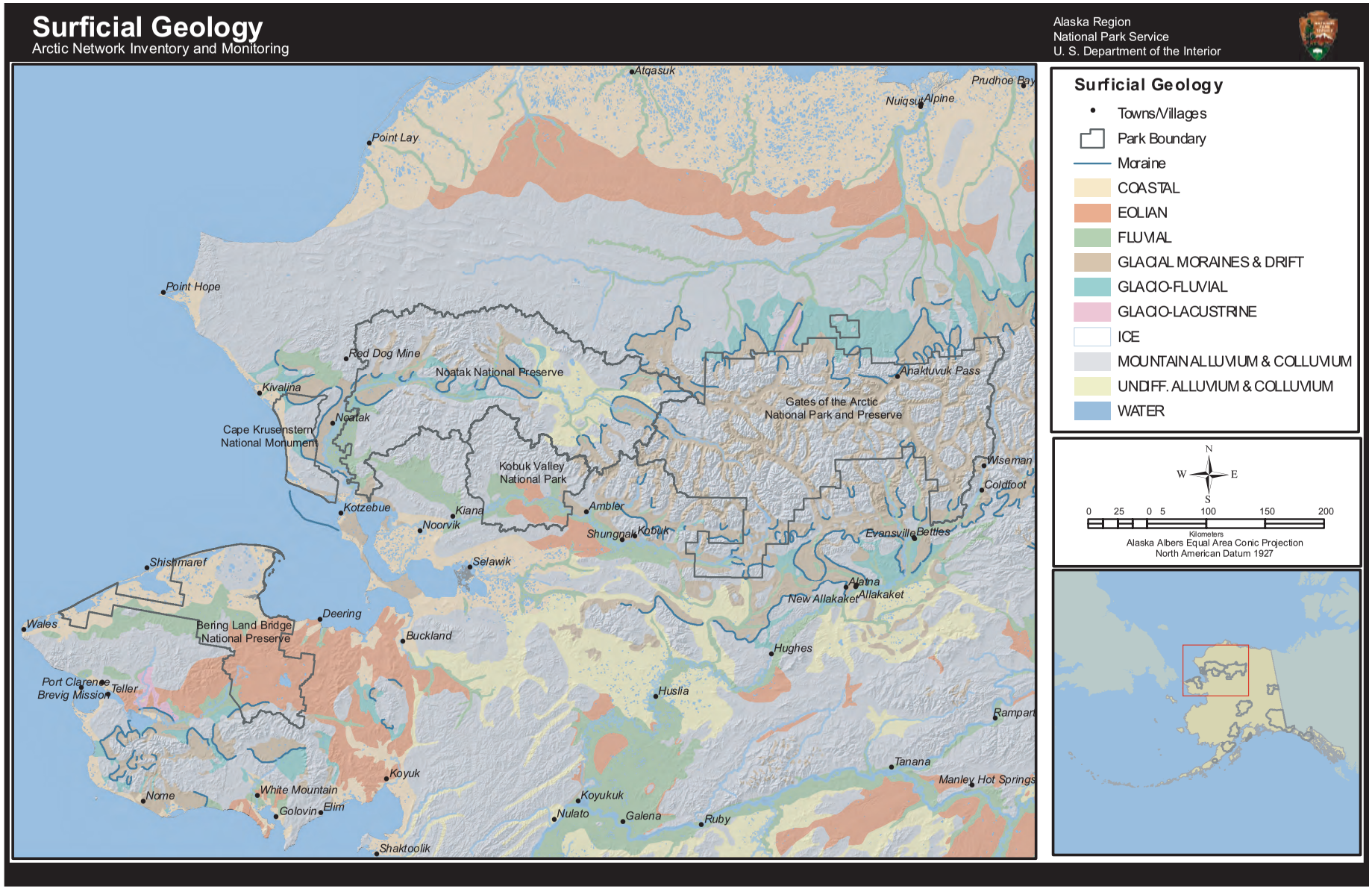
Map 7: *This map contains spatially gridded average monthly and annual mean temperature for the climatological period 1961–1990 for Alaska. Distribution of the point measurements to a spatial grid was accomplished using the PRISM model, developed by Christopher Daly of SCAS/OSU.*



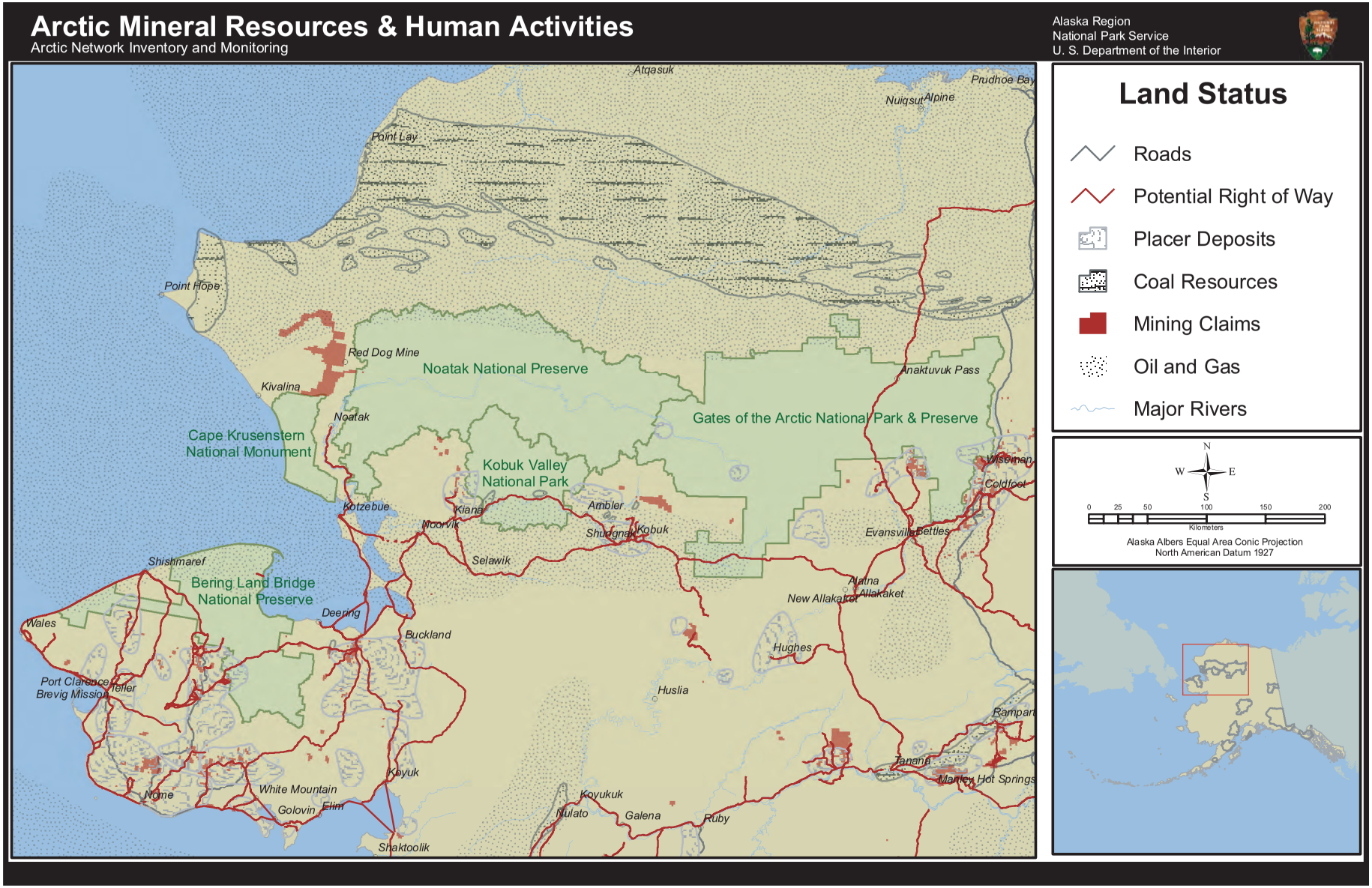
Map 8: *This map contains spatially gridded average monthly and annual precipitation for the climatological period 1961–1990 for Alaska. Distribution of the point measurements to a spatial grid was accomplished using the PRISM model, developed by Christopher Daly of SCAS/OSU.*



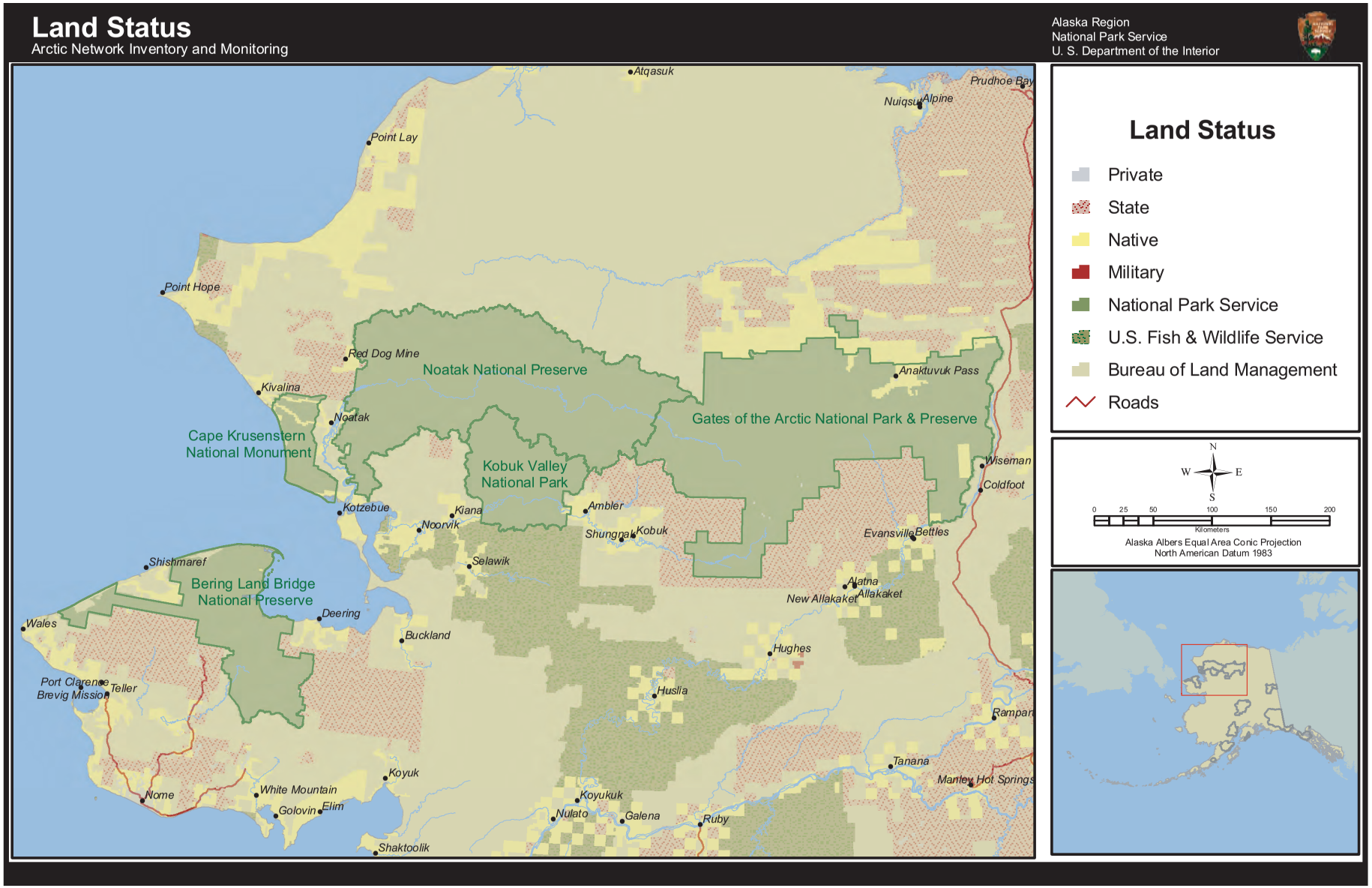
Map 9: *Remote automated weather stations (RAWS) and manual weather stations throughout Alaska. USGD data obtained from the NWIS database. Most sites consist of one-time water quality sampling events. Stream discharge is not measureed within any arctic park, but there is real-time data collected downstream of the parks at five locations. Arctic Transitions in the Land-Atmosphere System (ATLAS) meteorological stations on the Seward Peninsula from University of Alaska Fairbanks Water and Environmental Research Center website.*



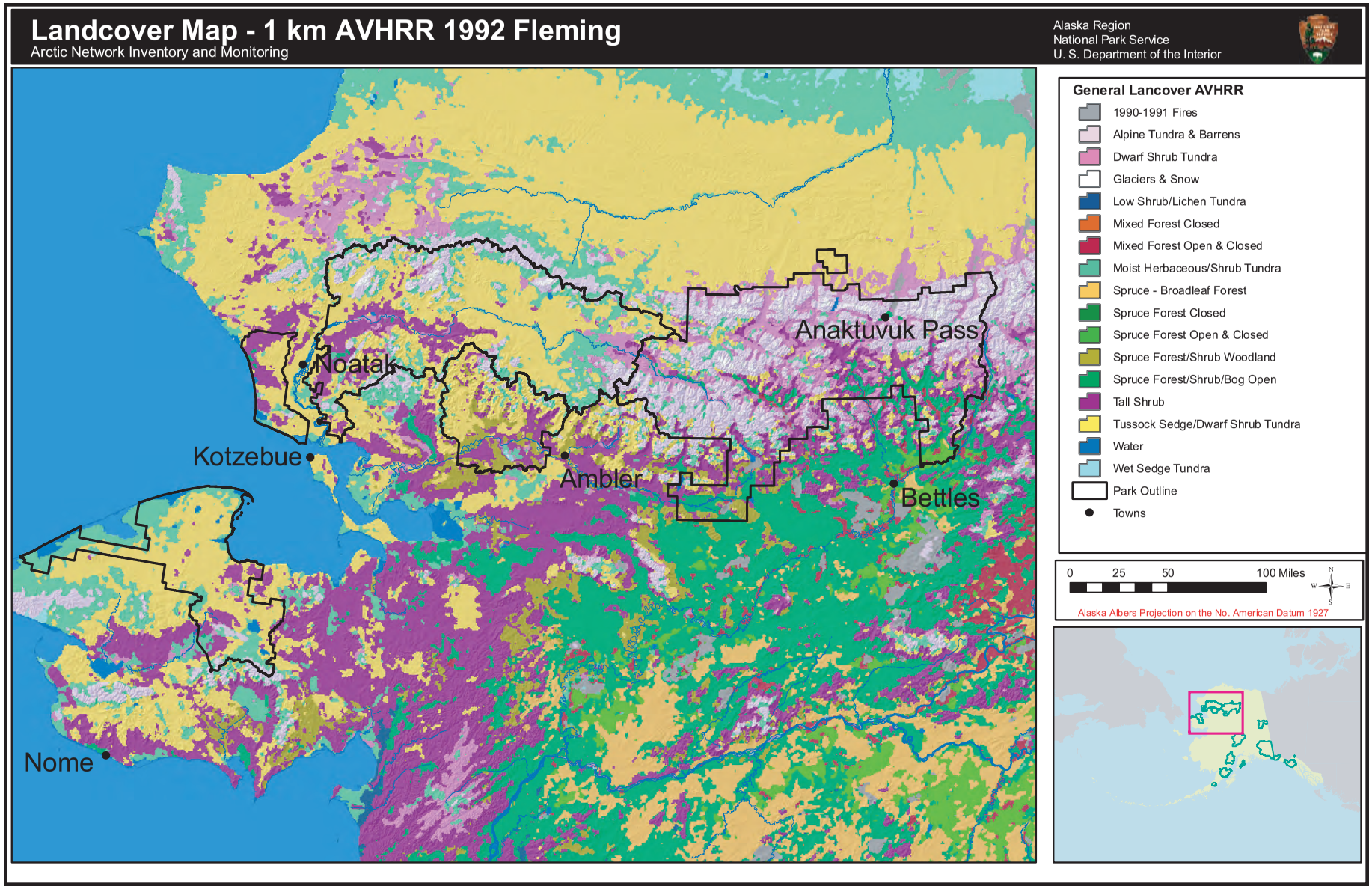
Map 10: *Surficial geology. Data from digital version of two USGS maps titled Miscellaneous Geologic Investigations (West) I-357 and Miscellaneous Geologic Investigations (East) I-357 in association with the work of Karlstrom et al. 1964.*



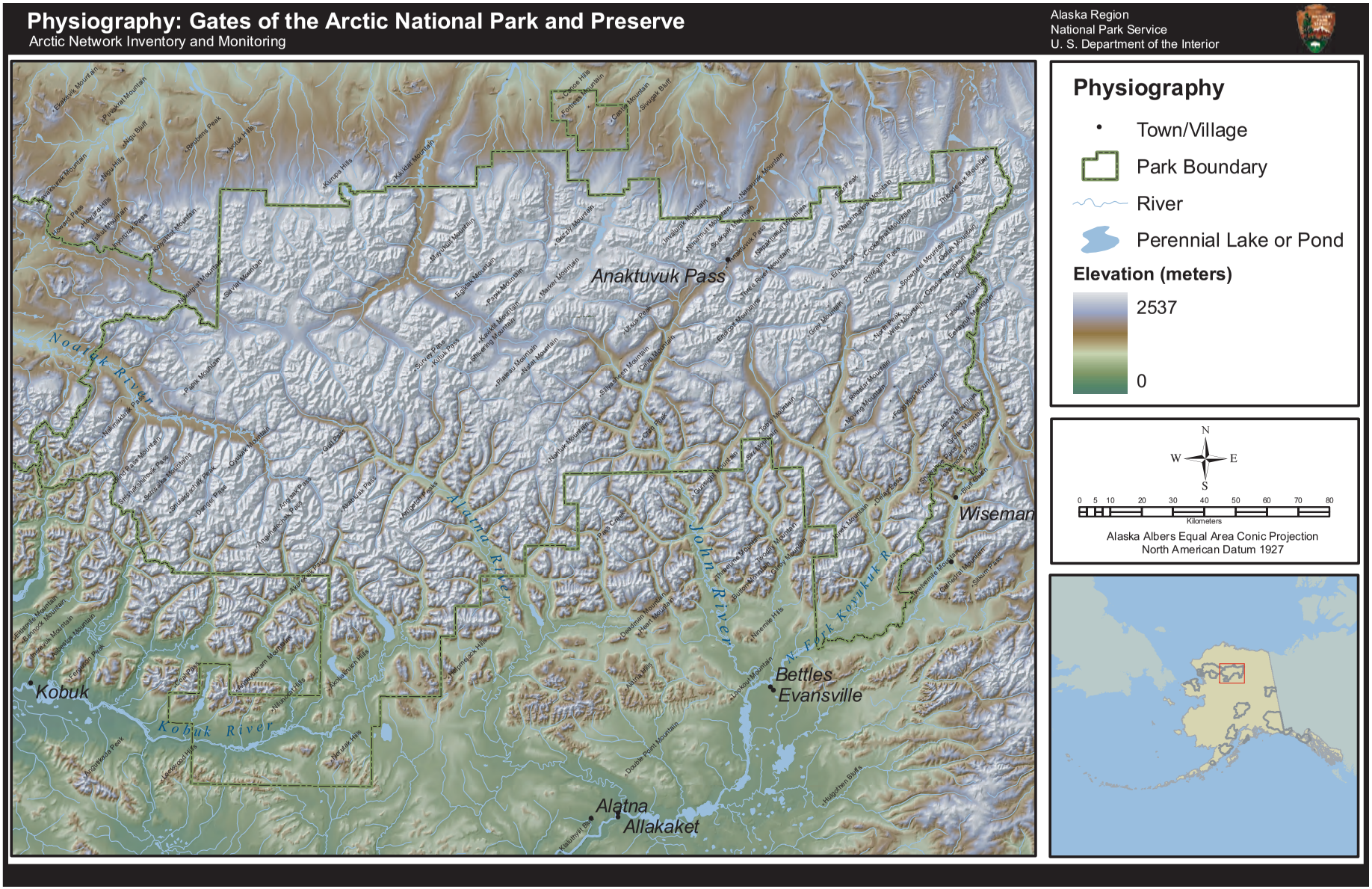
Map 11: *Arctic mineral resources, mining claims, and oil and gas basins. Current BLM case type, case status, and land status information was used to classify data extracted from federal land records stored in the Alaska Land Information System (ALIS). Data also from the Alaska Department of Natural Resources, Land Records Information and Division of Geological and Geophysical Surveys. Potential rights-of-way (ROW) established under the federal Revised Statute 2477 from Department of Natural Resources Land Administration System (LAS).*



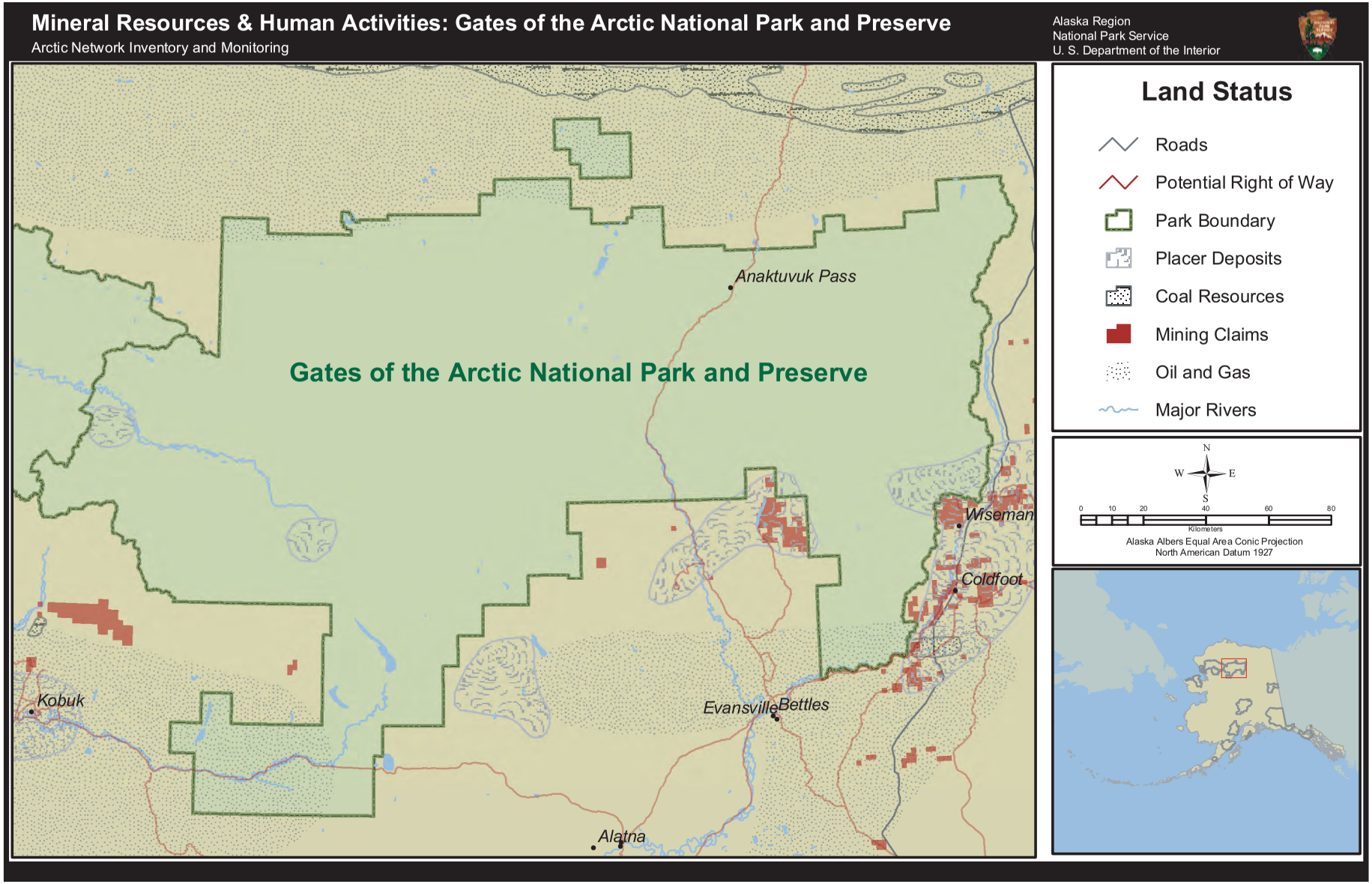
Map 12: *Land ownership at the section level for the state of Alaska. Land ownership and status records used to create this map were extracted from two major sources: Bureau of Land Management (BLM) Alaska Land Information System (ALIS) on January 5, 2004; and the State of Alaska Department of Natural Resources (ADNR) Land Administration System (LAS) on April 16, 2004.*



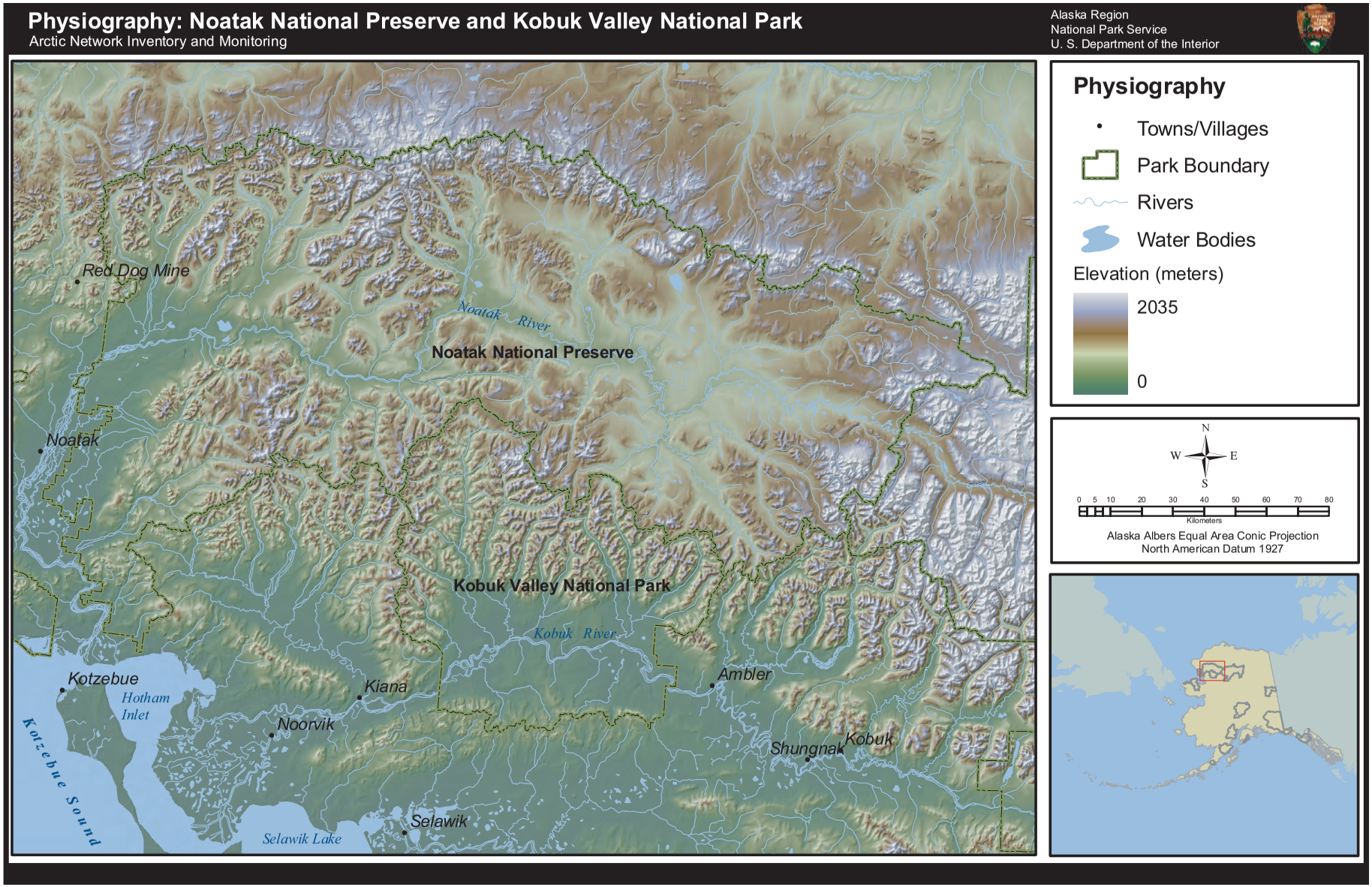
Map 13: *Landcover vegetation map of Alaska developed by Michael Fleming of the USGS using AVHRR and NDVI data collected during the 1991 growing season. The original map has 23 classes; some of these classes have been collapsed or renamed for the purpose of display. Scale of the map is 1-km grid size. The GIS coverage for this map is available at <http://agdc.usgs.gov/data/projects/fhm/#G>.*



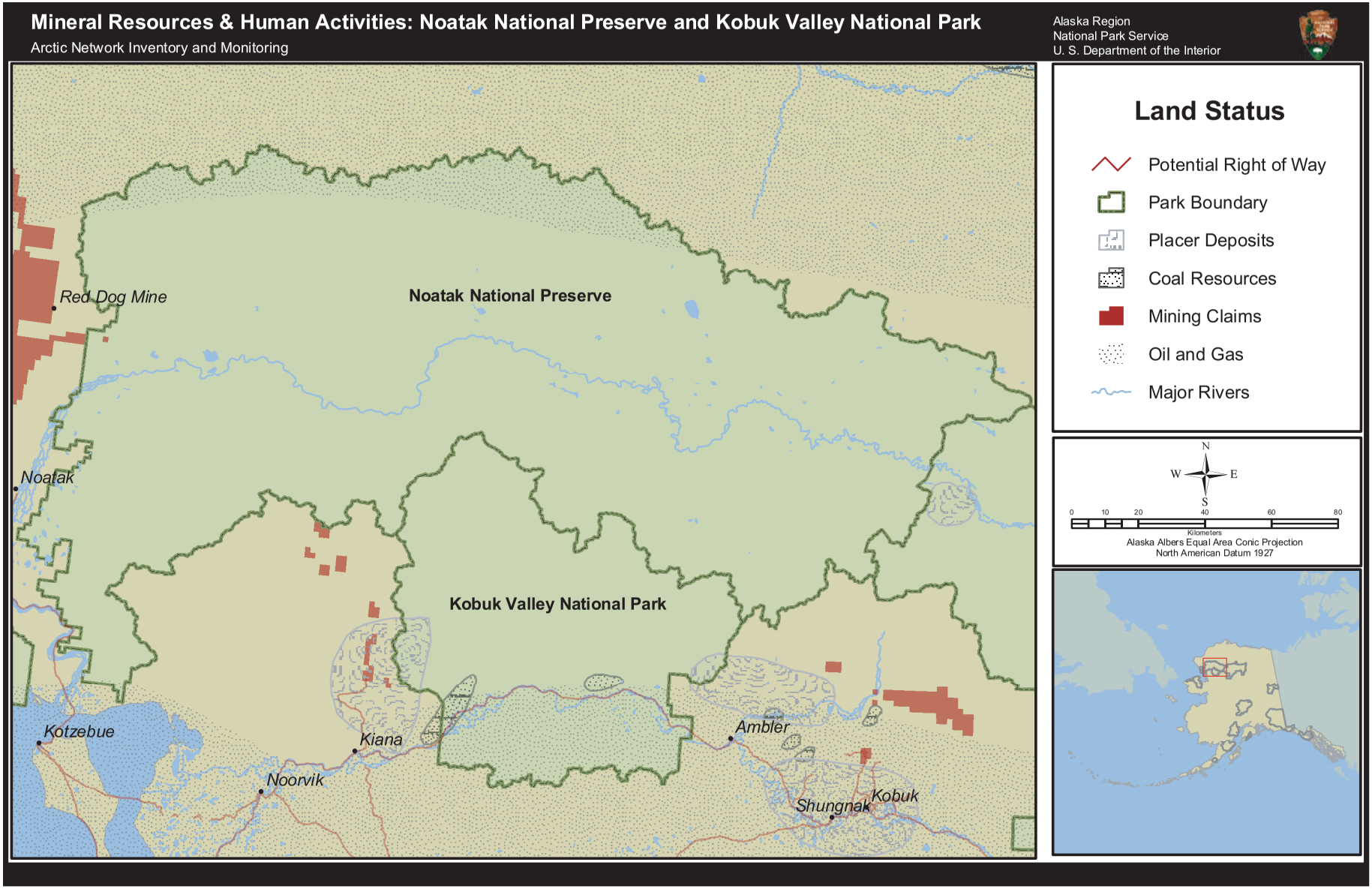
Map 14: *Physiography of Gates of the Arctic National Park and Preserve. Digital elevation model 90 m grid for Alaska, from best available data. In some areas of missing data, a 300 m and 60 m DEM were used to patch in.*



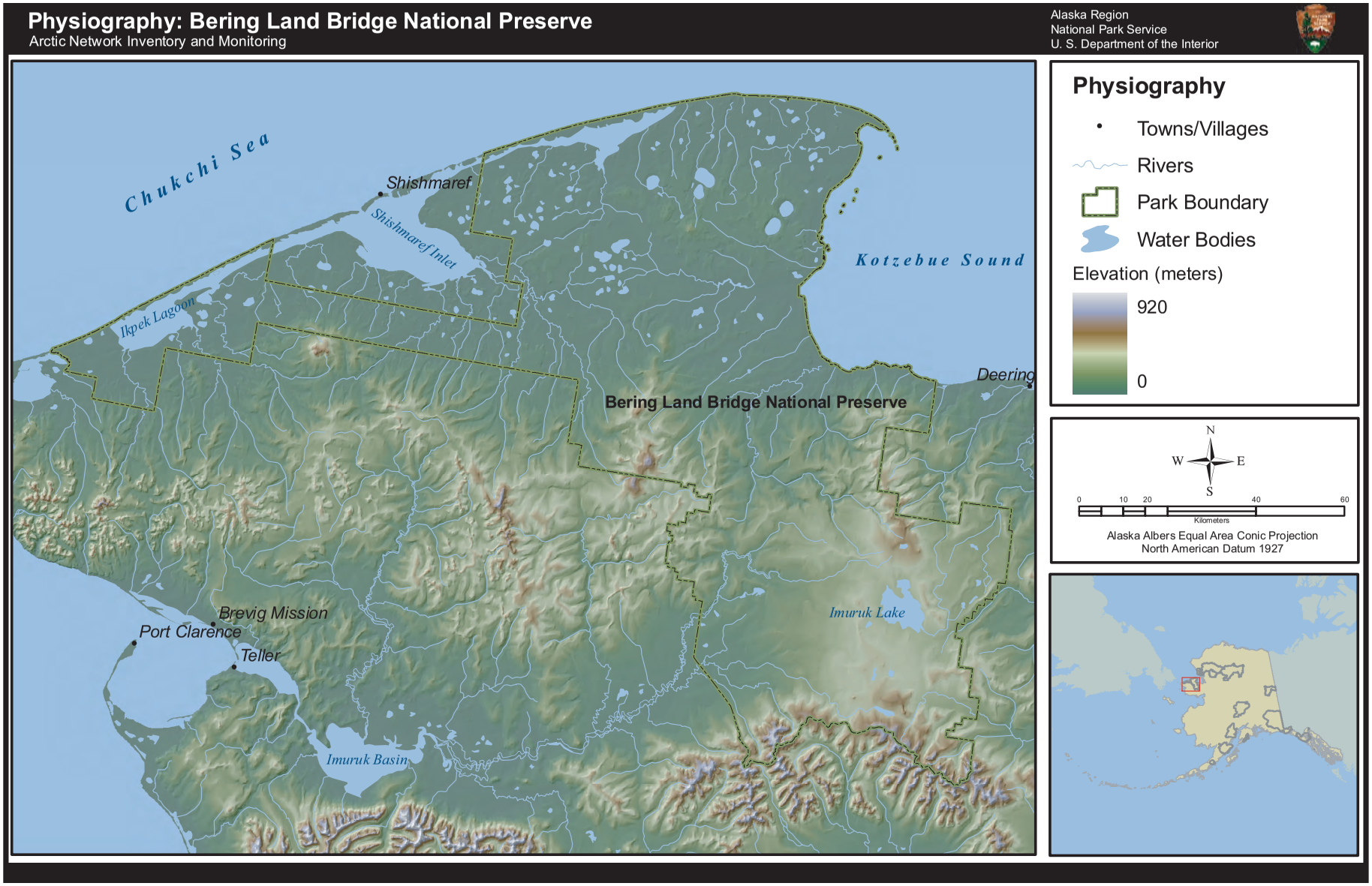
Map 15: *Mineral resources, mining claims, and oil and gas basins in Gates of the Arctic National Park and Preserve. Current BLM case type, case status, and land status information was used to classify data extracted from federal land records stored in the Alaska Land Information System (ALIS). Data also from the Alaska Department of Natural Resources, Land Records Information and Division of Geological and Geophysical Surveys. Potential rights-of-way (ROW) established under the federal Revised Statute 2477 from Department of Natural Resources Land Administration System (LAS).*



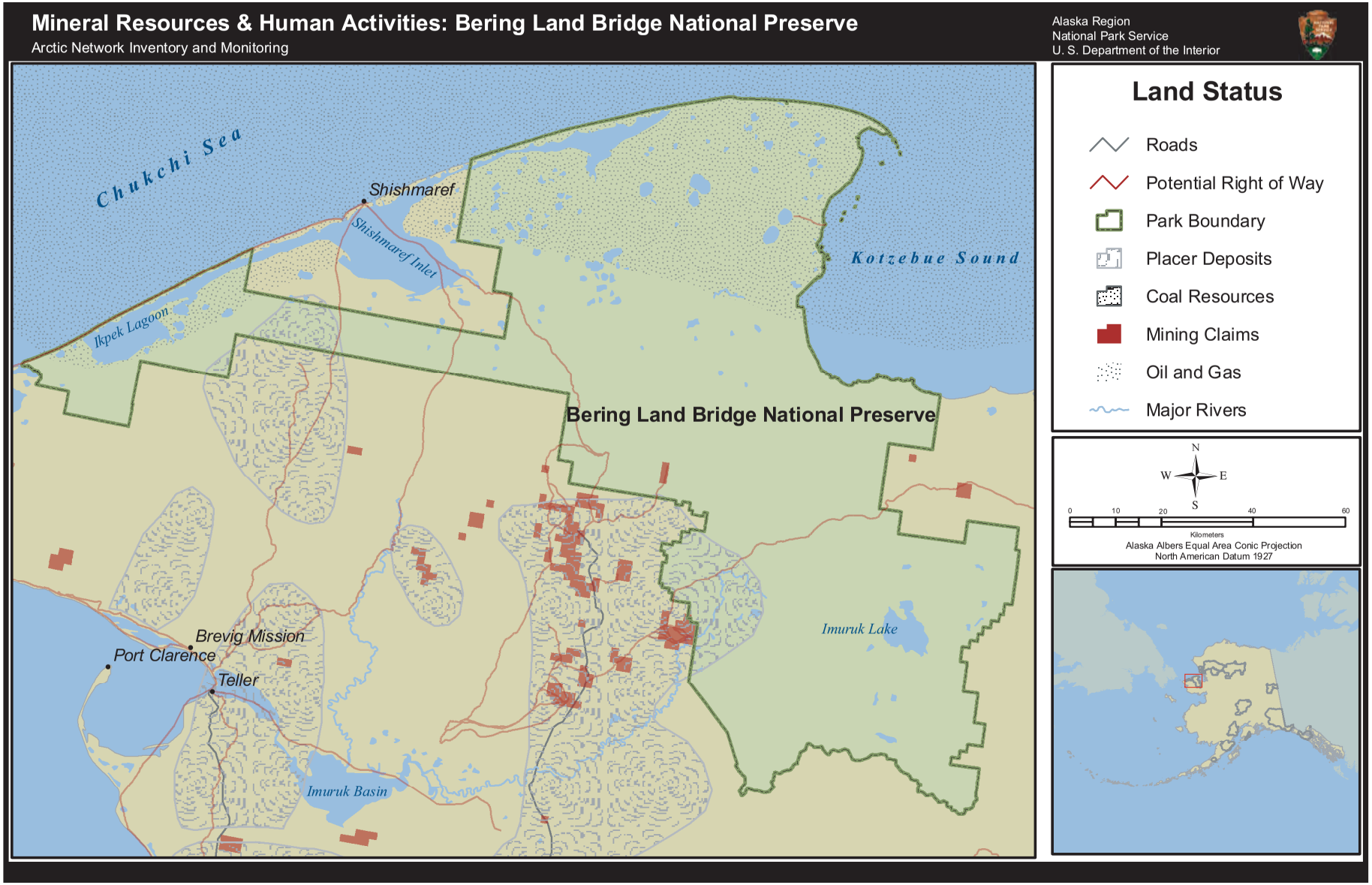
Map 16: *Physiography of Noatak National Preserve and Kobuk Valley National Park. Digital elevation model 90 m grid for Alaska, from best available data. In some areas of missing data, a 300 m and 60 m DEM were used to patch in.*



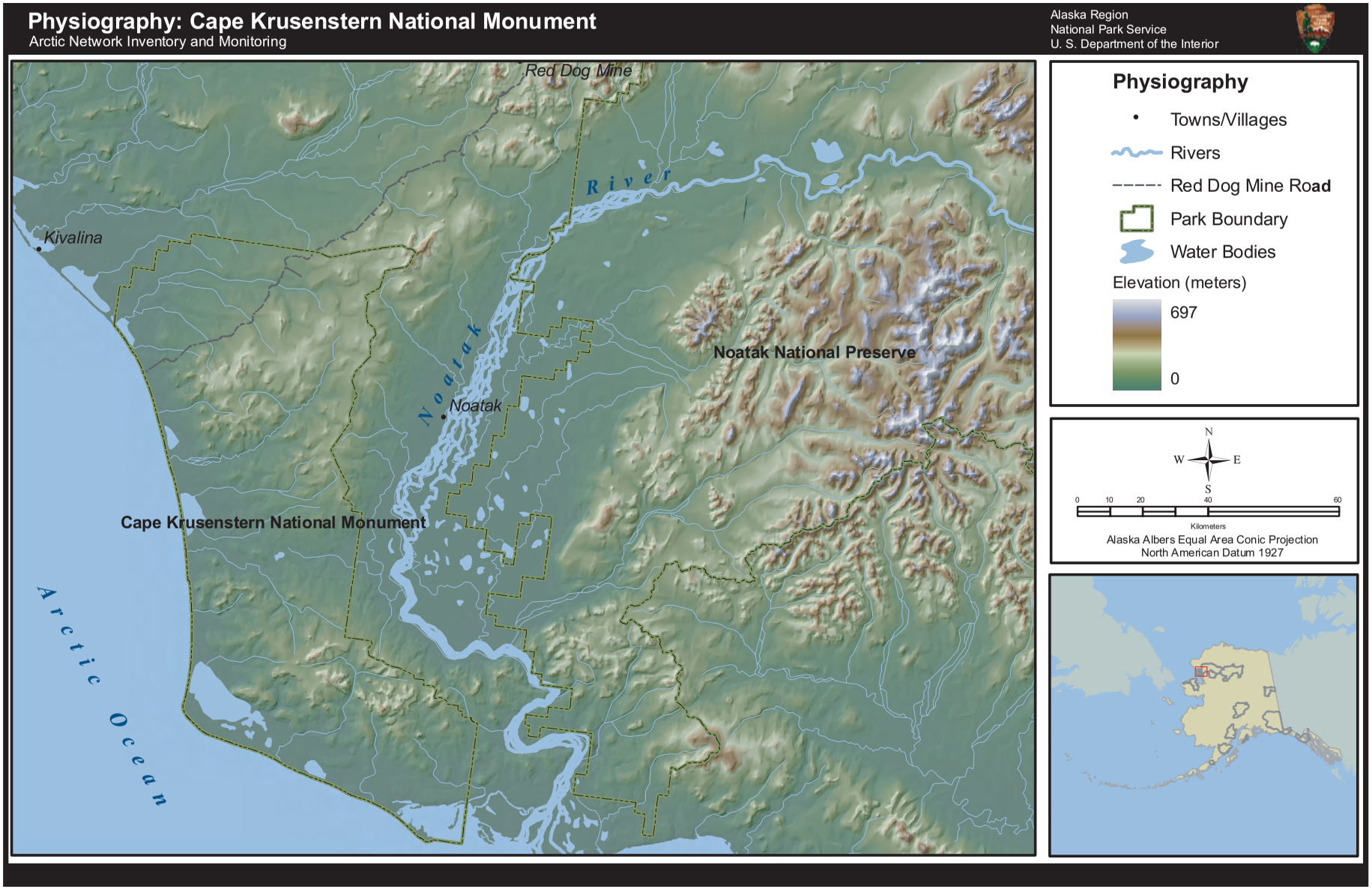
Map 17: *Mineral resources, mining claims, and oil and gas basins in Noatak National Preserve and Kobuk Valley National Park. Current BLM case type, case status, and land status information was used to classify data extracted from federal land records stored in the Alaska Land Information System (ALIS). Data also from the Alaska Department of Natural Resources, Land Records Information and Division of Geological and Geophysical Surveys. Potential rights-of-way (ROW) established under the federal Revised Statute 2477 from Department of Natural Resources Land Administration System (LAS).*



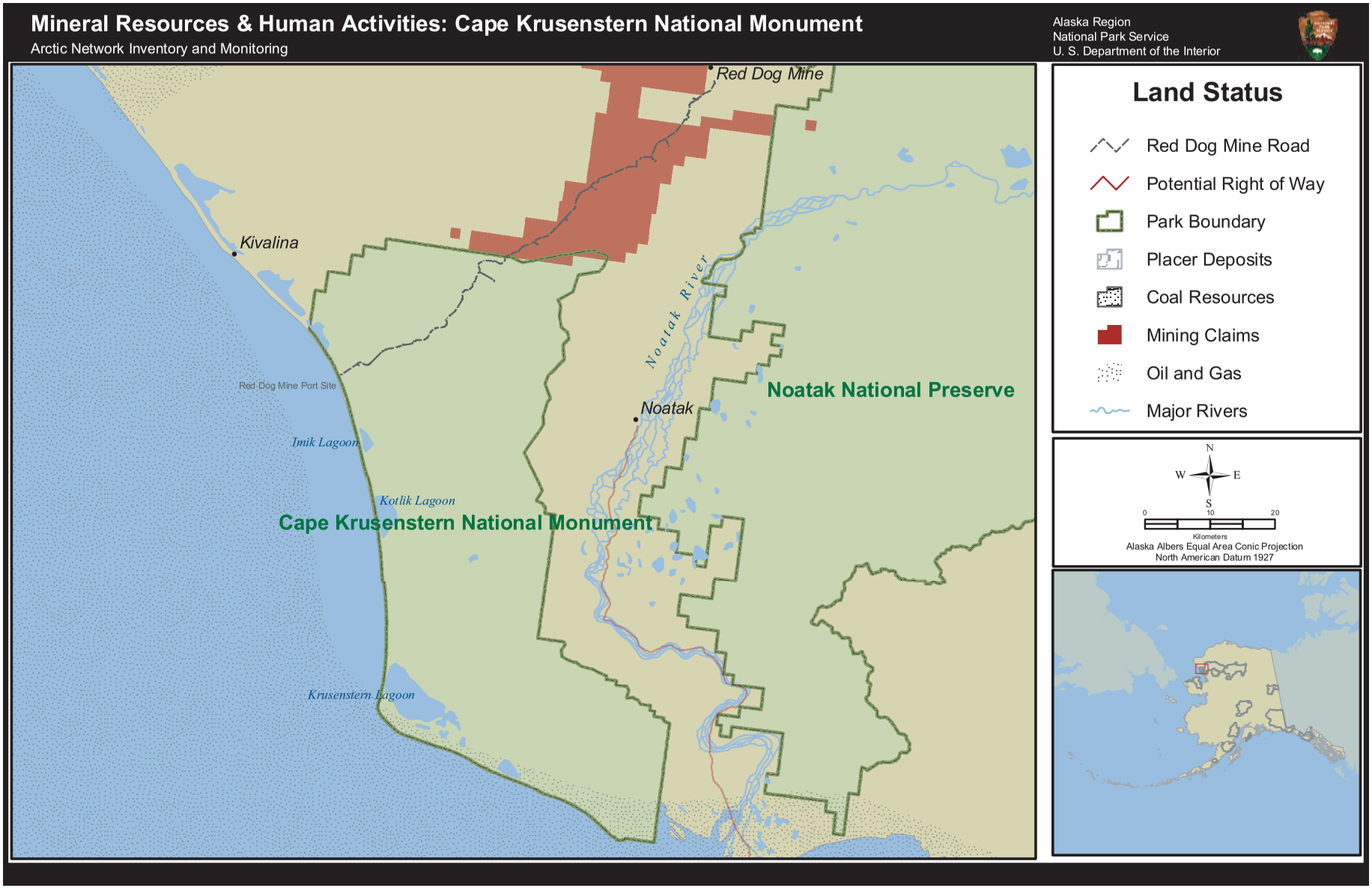
Map 18: *Physiography of Bering Land Bridge National Preserve. Digital elevation model 90 m grid for Alaska, from best available data. In some areas of missing data, a 300 m and 60 m DEM were used to patch in.*



Map 19: *Mineral resources, mining claims, and oil and gas basins in Bering Land Bridge National Preserve. Current BLM case type, case status, and land status information was used to classify data extracted from federal land records stored in the Alaska Land Information System (ALIS). Data also from the Alaska Department of Natural Resources, Land Records Information and Division of Geological and Geophysical Surveys. Potential rights-of-way (ROW) established under the federal Revised Statute 2477 from Department of Natural Resources Land Administration System (LAS).*



Map 20: *Physiography of Cape Krusenstern National Monument. Digital elevation model 90 m grid for Alaska, from best available data. In some areas of missing data, a 300 m and 60 m DEM were used to patch in.*



Map 21: *Mineral resources, mining claims, and oil and gas basins in Cape Krusenstern National Monument. Current BLM case type, case status, and land status information was used to classify data extracted from federal land records stored in the Alaska Land Information System (ALIS). Data also from the Alaska Department of Natural Resources, Land Records Information and Division of Geological and Geophysical Surveys. Potential rights-of-way (ROW) established under the federal Revised Statute 2477 from Department of Natural Resources Land Administration System (LAS).*

Appendix 1

Summary of Legislation, National Park Service Policy, and Guidance Relevant to Development and Implementation of Natural Resources Monitoring in National Parks

Taken from National Park Service Inventory and Monitoring website: http://science.nature.nps.gov/im/monitor/LawsPolicy.htm

Public Laws	Significance to Inventory and Monitoring
National Park Service Organic Act (16 USC 1 et seq. [1988], Aug. 25, 1916).	The 1916 National Park Service Organic Act is the core of park service authority and the definitive statement of the purposes of the parks and of the National Park Service mission. The act establishes the purpose of national parks: "To conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."
General Authorities Act of 1970 (16 USC 1a-1–1a-8 [1988], 84 Stat. 825, Pub. L. 91-383)	The General Authorities Act amends the Organic Act to unite individual parks into the "National Park System." The act states that areas of the National Park System, "though distinct in character, are united through their inter-related purposes and resources into one national park system as cumulative expressions of a single national heritage; that individually and collectively, these areas derive increased national dignity and recognition of their superb environmental quality through their inclusion jointly with each other in one national park system preserved and managed for the benefit and inspiration of all the people of the United States."
Redwood National Park Act (16 USC 79a-79q [1988], 82 Stat. 931, Pub. L. 90-545)	This act includes both park-specific and system-wide provisions. This act reasserts system-wide protection standards for the National Park System. This act qualifies the provision that park protection and management "shall not be exercised in derogation of the values and purposes for which these areas have been established" by adding "except as may have been or shall be directed and specifically provided for by Congress." Thus, specific provisions in a park's enabling legislation allow park managers to permit activities such as hunting and grazing.
National Environmental Policy Act of 1969 (42 USC 4321-4370)	The purposes of NEPA include encouraging "harmony between [humans] and their environment and promote efforts which will prevent or eliminate damage to the environment . . . and stimulate the health and welfare of [humanity]." NEPA requires a systematic analysis of major federal actions that includes a consideration of all reasonable alternatives as well as an analysis of short-term and long-term, irretrievable, irreversible, and unavoidable impacts. Within NEPA the environment includes natural, historical, cultural, and human dimensions. Within the NPS emphasis is on minimizing negative impacts and preventing "impairment" of park resources as described and interpreted in the NPS Organic Act. The results of evaluations conducted under NEPA are presented to the public, federal agencies, and public officials in document format (e.g., environmental assessments and environmental impact statements) for consideration before taking official action or making official decisions.

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Public Laws	Significance to Inventory and Monitoring
Clean Water Act (33 USC 1251-1376)	The Clean Water Act, passed in 1972 as amendments to the Federal Water Pollution Control Act, and significantly amended in 1977 and 1987, was designed to restore and maintain the integrity of the nation's water. It furthers the objectives of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters and of eliminating the discharge of pollutants into navigable waters by 1985. Establishes effluent limitation for new and existing industrial discharge into U.S. waters. Authorizes states to substitute their own water quality management plans developed under S208 of the act for federal controls. Provides an enforcement procedure for water pollution abatement. Requires conformance to permits required under S404 for actions that may result in discharge of dredged or fill material into a tributary to, wetland, or associated water source for a navigable river.
Clean Air Act (42 USC 7401-7671q, as amended in 1990)	Establishes a nationwide program for the prevention and control of air pollution and establishes National Ambient Air Quality Standards. Under the Prevention of Significant Deterioration provisions, the act requires federal officials responsible for the management of Class I Areas (national parks and wilderness areas) to protect the air quality related values of each area and to consult with permitting authorities regarding possible adverse impacts from new or modified emitting facilities. The act establishes specific programs that provide special protection for air resources and air quality related values associated with NPS units. The EPA has been charged with implementing this act.
Endangered Species Act of 1973, as amended (ESA) (16 USC 1531-1544)	The purposes of the ESA include providing "a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved." According to the ESA, "all federal departments and agencies shall seek to conserve endangered species and threatened species" and "[e]ach federal agency shall . . . insure that any action authorized, funded, or carried out by such agency . . . is not likely to jeopardize the continued existence of any endangered species or threatened species." The U.S. Fish and Wildlife Service (USFWS) (nonmarine species) and the National Marine Fisheries Service (NMFS) (marine species, including anadromous fish and marine mammals) administers the ESA. The effects of any agency action that may affect endangered, threatened, or proposed species must be evaluated in consultation with either the USFWS or NMFS, as appropriate.
Environmental Quality Improvement Act of 1970 (42 U.S.C. 56 § 4371)	Directs all federal agencies whose activities may affect the environment to implement policies established under existing law to protect the environment.
Coastal Zone Management Act of 1972 (16 U.S.C. 33 § 1452)	"Congress finds and declares that it is the national policy—to preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone for this and succeeding generations."
Marine Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C. 32 § 1431)	Recognizes that the United States has historically protected "special areas of its public domain, but (that) these efforts have been directed almost exclusively to land areas above the high-water mark." For this reason Congress elected to recognize and protect "certain areas of the marine environment possess[ing] conservation, recreational, ecological, historical, scientific, educational, cultural, archeological, or esthetic qualities which give them special national, and in some cases international, significance." Specifically this law intends to "improve the conservation, understanding, management, and wise and sustainable use of marine resources; [to] enhance public awareness, understanding, and appreciation of the marine environment; and [to] maintain for future generations the habitat, and ecological services, of the natural assemblage of living resources that inhabit these areas."

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Public Laws	Significance to Inventory and Monitoring
National Historic Preservation Act of 1966, as amended (16 USC 470 et seq.)	Congressional policy set forth in NHPA includes preserving "the historical and cultural foundations of the Nation" and preserving irreplaceable examples important to our national heritage to maintain "cultural, educational, aesthetic, inspirational, economic, and energy benefits." NHPA also established the National Register of Historic Places, composed of "districts, sites, buildings, structures, and objects significant in American history, architecture, archeology, engineering, and culture." NHPA requires federal agencies to take into account the effects of their actions on properties eligible for or included in the National Register of Historic Places and to coordinate such actions with the state historic preservation offices (SHPO).
Wilderness Act of 1964 (16 USC 1131 et seq.)	Establishes the National Wilderness Preservation System. In this act, wilderness is defined by its lack of noticeable human modification or presence; it is a place where the landscape is affected primarily by the forces of nature and where humans are visitors who do not remain. Wilderness areas are designated by Congress and are composed of existing federal lands that have retained a wilderness character and meet the criteria found in the act. Federal officials are required to manage wilderness areas to retain their wilderness character and must consider the effect upon wilderness attributes from management activities on adjacent lands.
Forest and Rangeland Renewable Resources Planning Act of 1974 (16 U.S.C. 36 § 1642)	Mandates that the secretary of agriculture inventory and monitor renewable natural resources in national forests, and has been cited as congressional authorization for the inventory and monitoring of natural resources on all federal lands. While this is not specifically directed in the act, it is perhaps indicative of a national will to account for and manage the nation's natural heritage in a manner that sustains these resources in perpetuity.
Surface Mining Control and Reclamation Act	The Surface Mining Control and Reclamation Act was enacted in 1977. It establishes a nationwide program to protect the environment from adverse effects of surface coal mining operations, establishes minimum national standards for regulating surface coal mining, assists states in developing and implementing regulatory programs, and promotes reclamation of previously mined areas with inadequate reclamation. Under the act, the secretary of the interior is directed to regulate the conduct of surface coal mining throughout the United States for both federally and nonfederally owned rights. The act establishes the Abandoned Mine Reclamation Fund, which is for the reclamation of land and water affected by coal mining. Eligibility for reclamation under this program requires that the land or water had been mined for coal, or affected by coal mining, and had been inadequately reclaimed prior to the enactment of this act in 1977. Both public and private lands are eligible for funding. Sections 522(e)(1) and 533(e)(3) of the act specifically prohibit surface mining within the National Park System, National Wildlife Refuge System, National System of Trails, National Wilderness Preservation System, or Wild and Scenic Rivers System. The act also prohibits surface mining that adversely impacts any publicly-owned park or place included in the National Register of Historic Sites. These prohibitions are subject to valid existing rights at the time of the act, the exact definition of which remains the subject of administrative and legal action.
Geothermal Steam Act 1988	This act specifically calls for a monitoring program for certain parks with thermal resources: 1. The secretary shall maintain a monitoring program for significant thermal features within units of the National Park System.

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Public Laws	Significance to Inventory and Monitoring
	2. As part of the monitoring program required by paragraph (1), the secretary shall establish a research program to collect and assess data on the geothermal resources within units of the National Park System with significant thermal features. Such program shall be carried out by the National Park Service in cooperation with the U.S. Geological Survey and shall begin with the collection and assessment of data for significant thermal features near current or proposed geothermal development and shall also include such features near areas of potential geothermal development.
Federal Advisory Committee Act	Creates a formal process for federal agencies to seek advice and assistance from citizens. Any council, panel, conference, task force, or similar group used by federal officials to obtain consensus advice or recommendations on issues or policies falls under the purview of FACA.
National Parks Omnibus Management Act, 1998 (P.L. 105-391)	Requires the secretary of the interior to continually improve NPS' ability to provide state-of-the-art management, protection, and interpretation of and research on NPS resources. Secretary shall assure the full and proper utilization of the results of scientific study for park management decisions. In each case where an NPS action may cause a significant adverse effect on a park resource, the administrative record shall reflect the manner in which unit resource studies have been considered. The trend in NPS resource conditions shall be a significant factor in superintendents' annual performance evaluations. Section 5939 states that the purpose of this legislation is to: 1. more effectively achieve the mission of the National Park Service; 2. enhance management and protection of national park resources by providing clear authority and direction for the conduct of scientific study in the National Park System and to use the information gathered for management purposes; 3. ensure appropriate documentation of resource conditions in the National Park System; 4. encourage others to use the National Park System for study to the benefit of park management as well as broader scientific value, and 5. encourage the publication and dissemination of information derived from studies in the National Park System.
Government Performance and Results Act (GPRA)	Requires the NPS to set goals (strategic and annual performance plans) and report results (annual performance reports). The NPS Strategic Plan contains four GPRA goal categories: park resources, park visitors, external partnership programs, and organizational effectiveness. In 1997, the NPS published its first GPRA-style strategic plan, focused on measurable outcomes or quantifiable results.
EXECUTIVE ORDERS	
Off-Road Vehicle Use (Executive Orders 11644 and 11989)	Executive Order 11644, enacted February 8, 1972, and amended by Executive Order 11989 on May 24, 1977, regulates off-road vehicle use. If the enabling legislation allows the use of off-road vehicles, NPS is required to designate specific areas for off-road vehicle use. These areas must be "located to minimize damage to soil, watershed, vegetation, or other resources" (Section (3)(a)(1)). If it is determined that such use is adverse to resources, the NPS is to immediately close such areas or trails until the impacts have been corrected.
Floodplain Management (Executive Order 11988)	Executive Order 11988 was enacted May 24, 1977. It requires all federal agencies to "reduce the risk of flood loss, . . . minimize the impacts of floods on human safety, health and welfare, and . . . restore and preserve the natural and beneficial values served by flood plains." To the extent possible, park facilities, such as campgrounds and rest areas, should be located outside floodplain areas. Executive Order 11988 is implemented in the National Park Service through the Floodplain Management Guidelines (National Park Service, 1993b). It is the policy of the National Park Service to:

(continued on next page)

Public Laws	Significance to Inventory and Monitoring
	1. restore and preserve natural floodplain values; 2. to the extent possible, avoid environmental impacts to the floodplain by discouraging floodplain development; 3. minimize the risks to life and property when structures and facilities must be located on a floodplain; and 4. encourage nonstructural over structural methods of flood hazard mitigation.
Protection of Wetlands (Executive Order 11990)	Executive Order 11990 was enacted May 24, 1977. It requires all federal agencies to "minimize the destruction, loss, or degradation of wetlands, and preserve and enhance the natural and beneficial values of wetlands". Unless no practical alternative exists, federal agencies must avoid any activities that have the potential to adversely affect wetland ecosystem integrity. NPS guidance pertaining to this Executive Order is stated in Floodplain and Wetland Protection Guidelines (National Park Service, 1980).
Invasive Species (Executive Order 13112)	This executive order was signed into law on February 3, 1999, to prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause. Among other things, this executive order established the National Invasive Species Council and required the preparation of a National Invasive Species Management Plan to recommend specific, performance-oriented goals and objectives and specific measures of success for federal agency efforts concerning invasive species.
NPS POLICIES AND GUIDANCE	
NPS Management Policies—2001 (NPS Directives System)	This is the basic NPS servicewide policy document. It is the highest of three levels of guidance documents in the NPS Directives System. The Directives System is designed to provide NPS management and staff with clear and continuously updated information on NPS policy and required and/or recommended actions, as well as any other information that will help them manage parks and programs effectively.
NPS Directors Orders	Second level of NPS Directives System. Directors Orders serve as a vehicle to clarify or supplement management policies to meet the needs of NPS managers. Relevant Directors Orders: DO-2.1 Resource Management Planning DO-12 Environmental Impact Assessment DO-14 Resource Damage Assessment & Restoration DO-24 Museum Collections Management DO-41 Wilderness Preservation & Management DO-47 Sound Preservation & Noise Management DO-77 Natural Resource Protection
NPS Handbooks and Reference Manuals	This is the third tier in the NPS Directives System. These documents are issued by associate directors. These documents provide NPS field employees with a compilation of legal references, operating policies, standards, procedures, general information, recommendations, and examples to assist them in carrying out management policies and directors orders. Level 3 documents may not impose any new servicewide requirements, unless the director has specifically authorized them to do so. Relevant handbooks and reference manuals: NPS-75 Natural Resources Inventory & Monitoring NPS-77 Natural Resources Management Guidelines NPS Guide to Federal Advisory Committee Act Website: Monitoring Natural Resources in our National Parks (http://science.nature.nps.gov/im/monitor)

Appendix 2
Definition of Natural Resource Inventories, Monitoring, and Research

Natural resource inventories, monitoring, and research are closely related activities needed for effective science-based management of park resources, and the terms are sometimes confused. A natural resource inventory is an extensive point-in-time effort to determine location or condition of a resource, including the presence, class, distribution, and status of plants, animals, and abiotic components such as water, soils, landforms, and climate. Inventories contribute to a statement of park resources, which is best described in relation to a standard condition such as the natural or unimpaired state. Inventories may involve both the compilation of existing information and the acquisition of new information. They may be relative to either a particular point in space (synoptic) or time (temporal).

Monitoring differs from inventory in adding the dimension of time, and the general purpose of monitoring is to detect changes or trends in a resource. Elzinga et al. (1998) defined monitoring as "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective." Natural resource monitoring is conducted primarily for two purposes:

1. to detect significant changes in resource abundance, condition, population structure, or ecological processes, or
2. to evaluate the effects of some management action on population or community dynamics or ecological processes.

Detection of a change or trend may trigger a management action, or it may generate a new line of inquiry. Monitoring is often done by sampling the same sites over time, and these sites may be a subset of the sites sampled for the initial inventory. Cause and effect relationships usually cannot be demonstrated with monitoring data, but monitoring data might suggest a cause and effect relationship that can then be investigated with a research study. The key points in the definition of monitoring are that:

1. the same methods are used to take measurements over time,
2. monitoring is done for a specific purpose, usually to determine progress towards a management objective, and
3. some action will be taken based on the results, even if the action is to maintain the current management.

Research is generally defined as the systematic collection of data that produces new knowledge or relationships and usually involves an experimental approach, in which a hypothesis concerning the probable cause of an observation is tested in situations with and without the specified cause. Research has the objective of understanding ecological processes and in some cases determining the cause of changes observed by monitoring, which is needed for determining the appropriate management response to threats. In general, monitoring is the tool used to identify whether or not a change occurred, and research is the tool to determine what caused the change. While it is often hoped that ecological monitoring can help to explain complex relationships in ecological systems, such understanding often requires a more focused research investment. The design of sampling protocols for various types of park resources at different locations and spatial scales requires a research effort and is incorporated into the NPS approach for planning and designing long-term monitoring of park resources.

Appendix 3
Framework for National Park Service Inventory and Monitoring

The National Park Service strategy to institutionalize inventory and monitoring throughout the agency consists of a framework having three major components:

1. completion of 12 basic resource inventories upon which monitoring efforts can be based;
2. a network of 11 experimental or "prototype" long-term ecological monitoring (LTEM) programs begun in 1992 to evaluate alternative monitoring designs and strategies; and
3. implementation of operational monitoring of critical parameters (i.e., "vital signs") in approximately 270 parks with significant natural resources that have been grouped into 32 vital sign networks linked by geography and shared natural resource characteristics.

Natural Resource Core Inventories

All natural resource parks must possess at least a minimal complement of resource inventory information in order to be able to deal effectively with park planning, management, and protection of natural resources. The minimal inventory information required by all parks has been defined in terms of 12 data sets that include a variety of biotic and abiotic ecosystem components. The 12 data sets are as follows:

- natural resource bibliography,
- base cartographic data,
- geology map,
- soils map,
- weather data,
- air quality,
- location of air quality monitoring stations,
- water body location and classification,
- water quality data,
- vegetation map,
- documented species list of vertebrates and vascular plants, and
- species distribution and status of vertebrates and vascular plants.

Prototype Monitoring Programs

The prototype LTEM programs were established in the early 1990s primarily in an attempt to learn how to design scientifically credible and cost-effective monitoring programs in ecological settings of major importance to a number of NPS units. Much of the design, development, and testing of monitoring protocols is conducted in prototype parks in cooperation with scientists from the U.S. Geological Survey. Because of higher funding and staffing levels, as well as USGS involvement and funding in program design and protocol development, the prototypes are expected to serve as "centers of

excellence" that will be able to do more extensive and in-depth monitoring and continue research and development work to benefit other parks. Prototype LTEM programs possess a wealth of experience and expertise related to the development and implementation of ecological monitoring that can greatly benefit other parks throughout the NPS. The prototype programs provide mentoring assistance to other parks undertaking long-term ecological monitoring and provide technical assistance to staff from other parks on a wide variety of technical issues related to monitoring, including conceptual design, database management, data integration and analysis, and reporting of monitoring findings.

Vital Signs Networks

In FY 2000, as part of the Natural Resource Challenge, the NPS implemented a new strategy for natural resource monitoring in parks with significant natural resources, whereby 270 parks with significant natural resources (including all of the prototype parks) were organized into 32 networks linked by geography and shared natural resource characteristics. The network approach will facilitate collaboration, information sharing, and economies of scale in natural resource monitoring and will provide parks with a minimum infrastructure for initiating natural resource monitoring that can be built upon in the future. As part of a new framework for inventory and monitoring, prototype LTEM programs are nested within a network structure and provide expertise and support to other parks in their network as well as providing protocols and expertise to parks throughout the NPS. The level of funding available through the Natural Resource Challenge will not allow comprehensive monitoring in all parks but will provide a minimum infrastructure for initiating natural resource monitoring in all parks that can be built upon in the future.

To implement the program, parks in each of the 32 networks share funding and staffing provided by the Servicewide Inventory and Monitoring Program and other divisions of the Natural Resources Program Center, supplemented by funding and staffing from other sources (e.g., base-funded positions, partnerships). Each of the 32 park networks is guided by a board of directors (usually comprised of park superintendents and the regional and network coordinators) who specify desired outcomes, evaluate performance for the monitoring program, and promote accountability. The working relationships and descriptions of the procedures the board uses to make decisions are codified in the form of a network charter signed by each of the park superintendents. An example of how the parks in each network might work together is contained in the following vision statement for the North Coast and Cascades Network:

- In response to the Natural Resources Challenge, the seven National Park Service units in the North Coast and Cascades Network work collaboratively to design and implement a Network Monitoring Program to focus collective efforts on inventory, monitoring, and research on natural ecosystems. This will result in a comprehensive body of knowledge that provides timely and relevant, scientifically credible information to park managers and the public.
- Through these efforts we will be better able to understand, and explain to others, the status and trends in key components and indicators of park ecosystems, and how they have and will respond over time to natural and human-induced changes both from within and outside of park boundaries.
- This comprehensive, integrated long-term ecological monitoring program provides for better protection, restoration, and maintenance of the natural ecosystems under NPS management.
- The Network Monitoring Program collaborates with complementary monitoring efforts of all levels of government, in order to achieve the greatest level of protection to natural resources and to contribute a body of knowledge to address broader, regional natural resource issues.

Appendix 4
Overview of ARCN Program Development, June 2003 to August 2008

The Arctic Network received initial funding from the Servicewide Inventory and Monitoring Program to conduct biological inventories in FY2001. In FY2003 ARCN received initial funding for vital signs monitoring. A network coordinator was hired in June 2003 to begin designing the monitoring program. In FY2003 the Board of Directors and Technical Committees were formed, and each adopted charters. Also in FY2003 ARCN held park scoping workshops and informally interviewed staff in each of the five parks. In FY2004 ARCN received funds to continue inventories of vascular plants and vertebrates and startup funds for initiating the water quality and vital signs monitoring programs. In FY2004 the network data manager was hired, and two of the four scoping workshops were held: Freshwater Ecosystems (June 2004) and Coastal Influenced Ecosystems (November 2004). In FY2005 the network received full funding for vital signs and water quality monitoring. The remaining two scoping workshops were held in April 2005 (Terrestrial Ecosystems) and January 2006 (Land-Air-Water Linkages). In September 2006 vital signs were selected (Phase 2 report). The first draft of the monitoring plan (Phase 3 report) was completed in January 2009. The final monitoring plan will be complete in December 2008.

Network Structure and Function

In order for this program to be accessible and useful to park managers, each network was advised to establish a board of directors and technical committee to help plan and implement the monitoring program. The ARCN Board of Directors consists of three superintendents representing the ARCN park units, the Alaska Region I&M coordinator, and the ARCN I&M coordinator. The ten-member Technical Committee consists of the chiefs of resource management from each park unit, two natural resource scientists from each park unit, a regional fire ecologist, an aquatic ecologist with the Water Resources Division, the ARCN I&M coordinator (chair), and the Alaska Cooperative Ecosystem Studies Unit (CESU) coordinator. The Technical Committee meets several times a year to discuss progress and performance of the program and staffing and budget projections. The coordinator also meets with a variety of working groups and individual principal investigators to discuss specific aspects of the program on a regular basis. These smaller working groups are composed of members of the Technical Committee and park staff. These smaller working groups advise the Technical Committee on specific aspects of network functions. Consultation with scientific experts and peer review has been crucial in the development of this program.

ARCN is following the basic approach to designing a monitoring program laid out in the national framework. The process involves five key steps:

1. Define the purpose and scope of the monitoring program.
2. Compile and summarize existing data and understanding of park ecosystems.
3. Develop conceptual models of relevant ecosystem components.
4. Select indicators and specific monitoring objectives for each.
5. Determine the appropriate sampling design and sampling protocols.

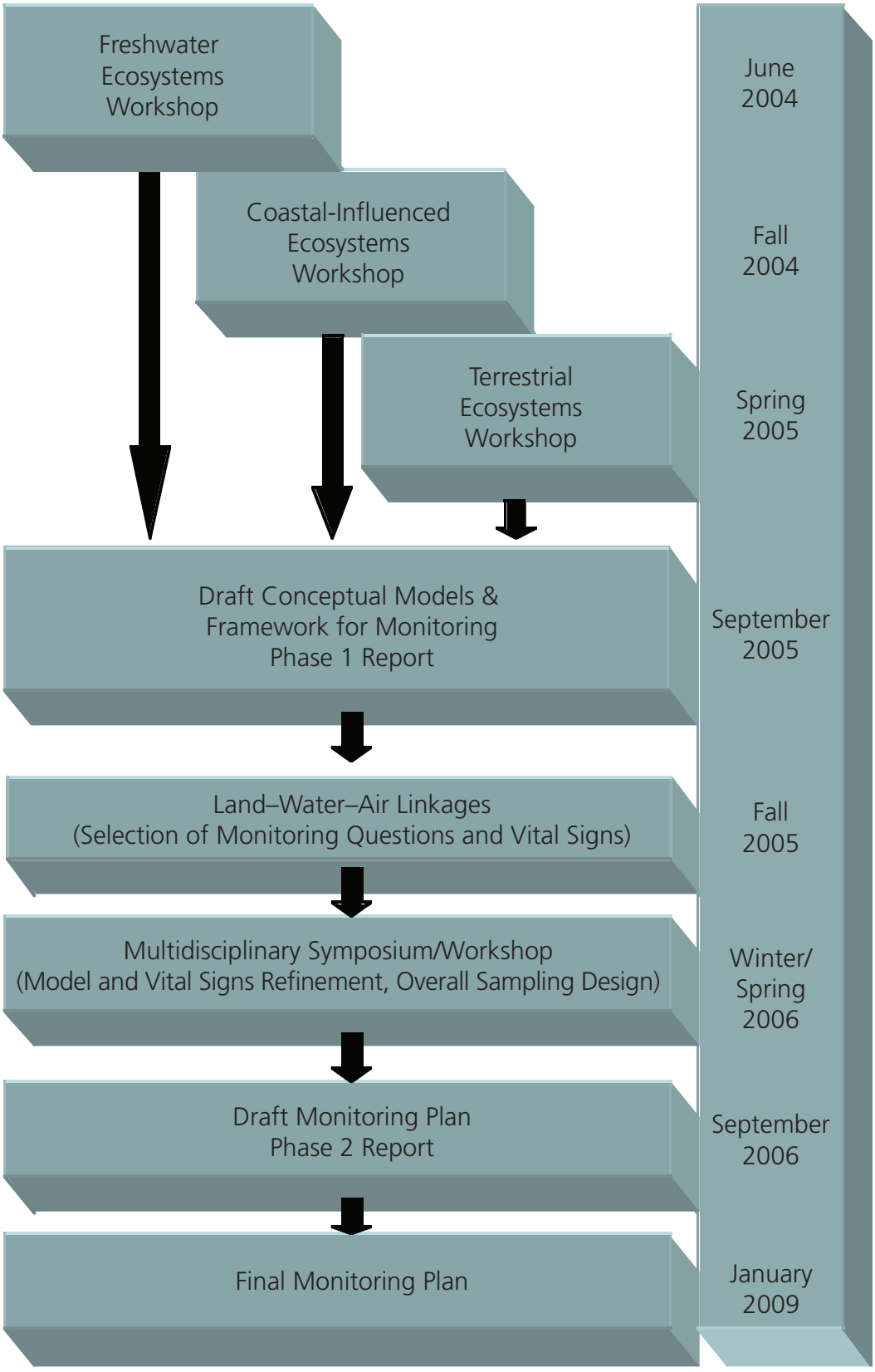


Figure A4.1: Timeline for ARCN monitoring plan development.

These five steps are incorporated into a three-phase planning process that has been established for the NPS monitoring program (Figure 1.6):

- Phase 1 involves defining goals and objectives; beginning the process of identifying, evaluating, and synthesizing existing data; developing draft conceptual models; and determining preliminary monitoring questions.
- Phase 2 involves refining the conceptual ecosystem models and selecting "vital signs" that will be used as indicators to detect change.
- Phase 3 involves determining the overall sample design for monitoring, developing protocols for monitoring, and producing a data management plan for the network.

Ecosystem Monitoring Scoping Workshops

The Arctic Network held a series of scoping workshops to provide a forum for NPS resource managers and scientists to discuss ideas for building a statistically sound, ecologically based, management-relevant, and affordable monitoring program for ARCN. In three of these workshops, we delineated the landscape into freshwater, coastal-influenced, and terrestrial ecosystems. Although we realize this division is somewhat arbitrary, it enabled us to strategically separate ARCN ecosystems into more manageable subunits for the purposes of discussion. A fourth workshop, land-air-water linkages (LAW), enabled participants to take a larger, landscape-scale approach to thinking about monitoring in ARCN.

The workshops were built around a series of small working group sessions in which invited experts focused on particular ecological subjects. The overall objectives of the meetings were to:

1. create and refine conceptual models,
2. develop a comprehensive list of potential monitoring questions,
3. identify potential ecosystem attributes of interest ("vital signs"), and
4. determine possible measures for those vital signs.

See Phase 1 Workshop Appendices 1–6 at <http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm> for more detail.

To facilitate better discussion during the workshops, the ARCN staff assembled extensive background materials for each of the parks. This background material was put into a scoping notebook and given to each of the participants well in advance of the meeting (see Phase 1 Appendices 1 and 3, available at <http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm>). Included in the notebook were worksheets that helped the participants prepare for the workshop.

Each of the first three workshops followed a formula in which the first afternoon and following morning were spent in a large group, gaining background information on the specific ecosystem components (e.g., birds, soils, vegetation), the drivers and stressors that impact them (e.g., climate, fire, visitor impacts, adjacent North Slope development), and possible ecosystem responses. During the second day, the group divided into smaller working groups of six to twelve, which were given the task of commenting on, revising, or replacing existing models as needed for thoroughness, accuracy, descriptive quality, etc. These new and revised models were presented to and further refined by the larger group. The second task on day two was to break up into small groups and, with the ecosystem models in mind, work toward developing monitoring questions and proposing preliminary vital signs. Each group then shared its results with the larger group. After reviewing our progress with the whole group,

we reconvened in a second working group session. Having heard other groups' proposed monitoring questions, we identified each group's highest priority questions.

By the end of the third day, we had a focused set of potential monitoring questions in a database. In addition, we had expert opinions on which questions were the most compelling for ARCN and how we might go about answering them. We also compiled a list of potential partners that might be willing to collaborate and share costs.

Products from each of the workshops were compiled into a workshop summary report (see Phase 1 Appendices 2, 4, and 6, available at <http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm>).

The summary report included conceptual models that were created based on input gleaned from the scoping workshops, potential monitoring questions, possible ecosystem components or attributes of interest, and discussion notes. These summary reports were placed on the ARCN web site for further comment and review by all workshop attendees and technical committee members.

Our fourth and final workshop, Land-Air-Water Linkages (LAW), was held in January 2006. The ARCN Board of Directors, ARCN Technical Committee, ARCN staff, and a subset of outside experts from the first three workshops were invited to attend the LAW workshop. The purpose of the workshop was to reorganize and prioritize vital signs from earlier workshops and link terrestrial, aquatic, and air quality vital signs. Although ARCN's monitoring plan will not focus directly on large-scale monitoring of atmospheric or oceanic systems, we recognize the important influences these systems exert on ARCN's terrestrial, coastal influenced, and freshwater ecosystems.

Although it cannot be considered a workshop, ARCN also held a State of the Arctic Parks meeting in January of 2007. Presenters at this meeting included the majority of the principal investigators who had been working on Inventory and Monitoring projects for ARCN since 2003. This meeting provided a forum for ARCN and cooperators to discuss study design and collaboration across vital signs. Observations and discussing from this meeting provided a synthesis for developing protocols for vital signs.

Appendix 5

Freshwater Resources of ARCN Parks

The ARCN parks have an extensive and diverse array of freshwater ecosystems that are relatively undisturbed by human activity. Key features of the landscape are the large freshwater lakes, seemingly endless miles of river networks, large expanses of wetlands, and unique isolated spring systems. There are seven wild and scenic rivers in the ARCN, including the Noatak, Salmon, Kobuk, Alatna, John, Tinayguk, and North Fork of the Koyukuk. All of the rivers of the ARCN are free-flowing and run clear most of the year. There are a few glacial streams that originate in the Brooks Range and several spring-fed streams, including tributaries of the Reed River, Kugrak River, and Alatna River, although to date few studies have been conducted on them.

Much of the land within the ARCN is drained by streams that flow from the uplands into lowland areas, then empty into the Chukchi Sea or coastal lagoons. These lagoons have been a primary fishing area for local Native people for the past 9,000 years. During the ice-free season, some of these streams and associated coastal lagoons provide important habitat for anadromous and freshwater fish populations, birds, and terrestrial mammals.

There are many lakes in the ARCN. Many of the large, deep lakes such as Chandler, Selby, Feniak, and Matcharak are renowned for their fisheries resources. These sites are used by both subsistence and sport fishers. One of the largest, Walker Lake, was designated a national natural landmark in April 1968. Thousands of shallow lakes and wetlands are distributed throughout the parks. These ecosystems have diverse geologic origin, including countless thaw ponds, kettle lakes, maars, and oxbows that provide important rearing areas for fish, macroinvertebrates, and waterfowl.

There is little information on ground water in these parks, although some larger geothermal systems have been studied (e.g., Serpentine Hot Springs).

Freshwater Resources of the Bering Land Bridge National Preserve

Further study and classification of the freshwater resources within Bering Land Bridge National Preserve is needed. Two of the largest ecologically significant landscape features in BELA are Ikpek and Cowpack lagoons. These lagoons and the drainages that surround them are part of an important migratory shorebird and waterfowl resting and feeding area. The rivers and lagoons along this stretch of coast provide the only extensive system of barrier islands and sheltered water between the Arctic Ocean and the Yukon River delta. Consequently, migrating shorebirds and waterfowl use it extensively.

Extensive surface water is present in the northern half of the preserve, but the actual annual hydrologic budget is relatively small owing to the modest precipitation (25–38 cm). Five major rivers have substantial drainage basins within the boundary of the preserve, including the Serpentine, Cowpack, Nugnugaluktuk, Goodhope, and Noxapaga rivers. Others have only a small portion within or along the boundaries of the preserve. These include the Inmachuk, Kugruk, Koyuk, and Kuzitrin.

Serpentine Hot Springs is the main geothermal resource in the park. There are four areas along a 0.8 km reach of Hot Springs Creek where hot water discharge is visible. Discharge at the upper hot spring area (the location of the wooden bath area) is approximately 106 liters per second, with average temperatures ranging from 61 to 72 °C (Roeder and Graham 1979). Discharge at the lower portion of the spring area is 146 liters per second. The surface water temperature ranges from 15 to 21 °C. There are also several small springs at Pilgrim Springs.

There is little basic information about fish diversity and distribution within BELA. The Alaska Natural Heritage Program identified 25 freshwater species with nine species documented (see Appendix 10). Information on fish presence in BELA appears to come mainly from reconnaissance-type trips to specific locations or from incidental observations by biologists working on other taxa. While there has been considerable work on freshwater and marine/coastal fish in the region by the Alaska Department of Fish and Game and others, very little of that work has occurred within the bounds of the preserve.

Freshwater Resources in Cape Krusenstern National Monument

The lands within CAKR are drained by a number of streams that flow from the uplands and empty into the Chukchi Sea or coastal lagoons. During the ice-free season, some of these streams and associated coastal lagoons provide important habitat for anadromous and freshwater fish populations, birds, and terrestrial mammals. During the winter, stream flow at the surface ceases as waters freeze. In areas where substantial springs exist, water may continue to flow out at the surface and then freeze into successive thin sheets of ice, forming aufeis areas. Both Jade and Rabbit creeks are subject to aufeis formation and have numerous channels and low intervening gravel bars.

Most of the streams in the monument are clearwater streams, exhibiting low levels of suspended solids, turbidity, and nutrients. Water is highly oxygenated, moderately hard to hard, and of the calcium bicarbonate type. At the Red Dog Mine site outside the monument, waters are naturally contaminated with cadmium, lead, and zinc. This contamination occurs because the ore in the ground is of sufficient quantity and concentration to alter the water as it passes over the ore deposit. There are several large lagoons and a few small lakes located within the monument. Ground water information for the monument is currently very scarce.

The Alaska Natural Heritage Program's expected species list for freshwater and anadromous fish in the monument includes 24 species, 18 of which have been documented. Their list of marine fish includes 38 species, with only eight species documented (Appendix 10).

Freshwater Resources in Gates of the Arctic National Park and Preserve

Tributaries of four major river systems originate in GAAR. To the north the Nigu, Killik, Chandler, Anaktuvuk, and Itkillik rivers drain to the Colville River. The Noatak River flows west and the Kobuk River southwest, both from headwaters in the western part of the park. The Reed and the Noatak rivers both start as glacial runoff from the flanks of Mount Igikpak. The John, Alatna, and North Fork of the Koyukuk rivers drain south to the Yukon River. Headwaters of six of the seven rivers that are designated as "wild and scenic" in ARCN are located in GAAR, including the Alatna, John, Kobuk, Noatak, North Fork of the Koyukuk, and Tinayguk rivers.

At least three "warm" springs are located within the park and preserve. The Reed River spring is located near the headwaters of the Reed and had a measured water temperature of 50 °C at the warmest pool (NPS 1982). Spring sources are also located on the lower Kugrak and Alatna rivers.

The expected species list for the fishes of GAAR developed by the Alaska Natural Heritage Program includes 16 species, of which 14 have been documented (Appendix 10). The Kobuk and Koyukuk rivers are major chum salmon spawning streams. Sheefish also spawn in the Kobuk. These fish, along with whitefish, are the most important subsistence fish. Some lake trout and arctic char are also taken from lakes for subsistence use. Recreational fishing is primarily for arctic grayling, arctic char, sheefish, and lake trout.

Freshwater Resources of Kobuk Valley National Park

The Kobuk and Noatak rivers are the largest rivers in northwest Alaska and together drain an area of 63,654 km^2. The Kobuk River drains 31,028 km^2 and has an estimated annual average flow of 438 m^3 per second. The river is 558 km long and 0.30 to 0.45 km wide in its lower and middle reaches. It is clear, except at the highest water stage, and has a generally sandy or gravelly bottom. The river is 50 m above sea level at the eastern boundary of Kobuk Valley National Park. Meander scrolls, oxbow bends, and sloughs are abundant along the river's course. The floodplain of the Kobuk River varies from 1.6 to 12.8 km wide.

The major tributaries of the Kobuk River within the park boundary are the Kallarichuk, Salmon, Tutuksuk, Kaligurichеark, Hunt, and Akillik rivers. All have their headwaters in the Baird Mountains, and all are entirely undeveloped. The Salmon River and its surrounding watershed is 1,709 km and is a designated wild and scenic river. The Tutuksuk, east of the Salmon River, is 48 km long and drains 906 km^2. The Hunt River, in the eastern portion of the park, is 64 km long and drains 1,592 km^2.

Numerous small lakes and ponds lie in the Kobuk watershed, particularly in the lowlands along the river. Some ponds and lakes formed as detached oxbows of the meandering river, while others are thaw ponds, formed where permafrost has melted and caused depressions. Some small lakes of indeterminate origin lie on the north slopes of the Waring Mountains, and some true cirque lakes are found in the Baird Mountains.

Total dissolved solids in most streams in the region are generally less than 200 mg per liter. The Kobuk River at Kiana contains less than 250 mg per liter of dissolved solids. Magnesium and bicarbonate are most prevalent, while calcium and chloride are found in smaller quantities. Sediment loads are comparatively low; the free-flowing waters of northwest Alaska generally have the lowest yield of sediment in the state, due largely to low topographic relief, lack of glaciers, low levels of runoff, and the stabilizing effect of permafrost on soils.

The expected fish species list developed by the Alaska Natural Heritage Program includes 22 expected species, with 16 species documented (Appendix 10). A review of the available literature suggests that fish in KOVA are less well known than in NOAT. Most of the work has been conducted by the Alaska Department of Fish and Game relative to commercial and subsistence fisheries. The pre-ANILCA expedition of Melchior (1976) included some fish inventory work in KOVA.

Freshwater Ecosystems within the Noatak National Preserve

The Noatak National Preserve was, in part, created to maintain the environmental integrity of the Noatak River and adjacent uplands within the preserve to assure the continuation of geological and biological processes unimpaired by adverse human activity. The Noatak River and its surrounding watershed (3,035,200 ha) is also an internationally recognized Biosphere Reserve (UNESCO). The Noatak is the 11th largest river in Alaska in terms of the area it drains. Before flowing into Hotham Inlet of Kotzebue Sound, the river drains 32,600 km^2 and has an average annual flow of 309 m^3 per second. The main artery of the Noatak is 700 km long. Eleven relatively large streams, from 50 to 160 km long, are tributaries to the Noatak, as are 37 smaller streams. The Noatak River is a designated wild and scenic river.

Many lakes are within the Noatak watershed. Feniak Lake is the largest within the preserve boundary. Countless thaw ponds and potholes occur throughout the area, most as a result of permafrost that impedes the downward percolation of water that collects in depressions and thermokarst erosion, boosted by permafrost melting. Other ponds and lakes were formed as detached oxbows of the meandering river or developed as part of the extensive flat delta at the mouth of the Noatak River. Lake waters are generally lower in dissolved solids than river waters. Lowland surface waters, such as tundra lakes, however, are often characterized by a brownish color and are generally high in organic material. Approximately 22 species of fish are found within the Noatak drainage (Appendix 10).

Appendix 6
Coastal Ecosystems of ARCN Parks

The coastal areas of ARCN have an extensive and diverse array of coastal ecosystems, which are relatively undisturbed by human activity. BELA and CAKR shorelines directly abut the Kotzebue Sound, Chukchi Sea, and Bering Strait; however, neither park includes the marine waters off-shore, since NPS boundaries end at the mean high tide mark. Important coastal ecosystems within CAKR and BELA include lagoons, estuaries, and islands as well as potential denning sites, seal haul-outs, and bird nesting and migratory stopover sites important for the marine mammals and birds of the adjacent coastal waters. In addition, both BELA and CAKR have explicit mandates in their establishing legislation for the protection of marine mammal habitat. The U.S. Fish and Wildlife Service (polar bears and walrus) and the National Marine Fisheries Service (seals and whales) oversee management of most marine mammal species in and around these coastal waters.

Near-shore coastal waters and shoreline ecosystems of importance to ARCN include intertidal and subtidal zones, salt-dominanted inlet systems, sandy shores, rocky cliffs, dune systems, and islands. Near-shore coastal waters have varying degrees of wave action and currents. Due to the almost constant exposure to wind and tidal currents, these ecological habitats are often more turbulent than lagoons or estuaries. Lagoon and estuarine ecosystems are common along the ARCN coastline. In fact, much of the land within ARCN is drained by streams that flow from upland into lowland areas, then empty into the Chukchi Sea or coastal lagoons. There are five large coastal lagoons in CAKR, including Imak, Kotlik, Krusenstern, Ipiavik, and Akukulak lagoons. There are two large lagoons in BELA: Ikpek and Cowpack. Several of these lagoons have been a primary fishing ground for Native populations for the past 9,000 years. During the ice-free season, some of these streams and associated coastal lagoons provide important habitat for anadromous and freshwater fish populations, birds, and terrestrial mammals.

Eelgrass beds (*Zostera marina* L.) have been documented as far north as Cape Espenberg in BELA (McRoy 1968), and incidental observations of eelgrass in CAKR have been officially noted over the past decade (McRoy, pers. comm.). These seagrass beds are primary habitat for many species of primary consumers (e.g., zooplankton) and fishes. The fauna of seagrass beds is often richer than areas not dominated by these species, due to the enhanced habitat and energy created by the presence of these beds.

The lagoons between Cape Krusenstern and Sheshalik are heavily used by migrating waterfowl. It is an important fall staging area for thousands of geese, ducks, shorebirds, and gulls. Seabird colonies are present in CAKR on Noatak Island (Aleutian terns), at the Uhl-Williams site (Aleutian and arctic terns), Krusenstern Lagoon (arctic terns and glaucous gulls), Kasik Lagoon (glaucous and mew gulls), and Tasaychek Lagoon (arctic and Aleutian terns). In BELA, seabird colonies are located on the Sullivan Bluffs (glaucous gulls, black-legged kittiwakes, and murres) and on two unnamed islands off the coast of Kongealoruk Creek (glaucous gulls; Alaska Department of Fish and Game 1978). This area is also important for subsistence hunting of waterfowl and egg gathering.

Approximately 18 species of marine mammals use the waters of the Chukchi Sea and Kotzebue Sound adjacent to CAKR and BELA (Table A7.1). Important marine mammal habitat within the park boundaries includes seal haul-out areas on the beaches of Cape Espenberg and the small islands southeast of Cape Espenberg.

Table A6.1. Marine mammal species present in the ocean adjacent to Bering Land Bridge National Preserve and Cape Krusenstern National Monument

Common Name	Scientific Name
Walrus	*Odobenus rosmarus*
Steller's sea lion	*Eumetopias jubatus*
Northern fur seal	*Callorhinus ursinus*
Bearded seal	*Erignathus barbatus*
Ribbon seal	*Phoca fasciata*
Ringed seal	*Phoca hispida*
Spotted seal	*Phoca largha*
Harbor seal	*Phoca vitulina*
Harbor porpoise	*Phocoena phocoena*
Polar bear	*Ursus maritimus*
Right whale	*Baleana glacialis*
Bowhead whale	*Balaena mysticetus*
Minke whale	*Balaenoptera acutorostrata*
Fin whale	*Balaenoptera physalus*
Killer whale	*Orcinus orca*
Gray whale	*Eschrichtius robustus*
Beluga whale	*Delphinapterus leucas*
Narwhale	*Monodon monoceros*

Marine mammals are an important element in the subsistence lifestyle of many villages surrounding the park units—not only villages directly on the coast (such as Wales, Shishmaref, Kivalina, and Deering) but inland villages as well (such as Noatak, Noorvik, Ambler, and Shungnak). Walrus (*Odobenus rosmarus*), bowhead whale (*Balaena mysticetus*), and bearded (*Erignathus barbatus*), ringed (*Phoca hispida*), and spotted seals (*Phoca largha*) are taken most often, but other whales, including beluga (*Delphinapterus leucas*), and seals are also found offshore. Although many of the harvested marine mammals do not actually spend much (or in some cases no) time on NPS lands, there are hunting camps and transportation routes within the parklands that are used in the traditional taking of these and other marine species. The harvest of all species of marine mammals is controlled under the Marine Mammals Protection Act of 1972, which provides for subsistence harvest by Alaska Natives but forbids recreational hunting.

The ringed seal is the smallest of the northern seals, averages 70 kg, and is found in the greatest densities off Cape Krusenstern in June. This seal is a life-sustaining species for people in the region, providing skin, meat, and oil. Traditional hunting of this species is concentrated off the coast of Cape Krusenstern at "Sealing Point." Bearded seals, the largest of the western arctic seals, weigh up to 360 kg. They are widely distributed in the Chukchi and Bering seas, where they feed on shrimp, benthic fish, clams, and worms. They appear in June in the waters adjacent to the monument. Despite the bearded seals' short seasonal presence, the species is a highly important subsistence resource in the area. Spotted seals and ribbon seals are also found off Cape Krusenstern. The spotted seal weighs up to 135 kg and feeds on herring (*Clupea pallasi*), salmon (*Oncorhynchus* spp.), and whitefish (*Coregonus* spp.) along the coast of the Chukchi Sea. The animals concentrate generally along the southern extent of ice pack. The ribbon seal, with its distinctive white bands against a black body, is found in greatest abundance south and east of the Seward Peninsula in the central Bering Sea.

Walrus are uncommon off Cape Krusenstern, although stray animals and carcasses washed ashore are taken for their ivory, blubber, and meat, if usable.

Polar bears are found along the Chukchi Sea coast in winter, where they move into the area with the pack ice. Polar bears have been documented within the boundaries of BELA. These bears are thought to move with pack ice between Russia and the U.S.

Beluga whales, which are small whales about 5 m long, occur throughout the Chukchi and Bering seas. These white whales travel in groups and are prized by subsistence hunters for their edible skin, blubber, and meat. A few beluga are taken from year to year along the monument's coastline when the shoreline becomes ice free or when they appear in open leads in the ice during sealing season (Uhl and Uhl 1980). Bowhead, gray, and finback whales have been observed within the waters of the Chukchi Sea off Cape Krusenstern.

Appendix 7

Summary of Nationally and Internationally Recognized Ecological Features of ARCN Parks

National Natural Landmarks

The National Natural Landmarks Program recognizes and encourages the conservation of outstanding examples of our country's natural history. It is the only natural areas program of national scope that identifies and recognizes the best examples of biological and geological features in both public and private ownership. National natural landmarks are designated by the secretary of the interior. To date, fewer than 600 sites have been designated.

There are two official national natural landmarks in ARCN: Walker Lake and Arrigetch Peaks, both located in Gates of the Arctic National Park and Preserve and designated as national natural landmarks in 1968.

- Walker Lake is a mountain lake at the northern limit of forest growth on the southern slope of the Brooks Range.
- Arrigetch Peaks are located 70 miles west of Bettles in the Brooks Range. Carved by glacial ice and running water, they illustrate several phases of alpine glacier activities. The peaks reveal abrupt transitions from metamorphic to granitic rock and contain both boreal forest and tundra ecosystems.

International Biosphere Reserve

In 1976, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Man and the Biosphere (MAB) Program designated the Noatak River and its surrounding watershed (more than 3,035,200 acres) as an international biosphere reserve. Biosphere reserves are chosen on the strength of their ability to reconcile the conservation of biological diversity and the sustainable use of biological resources. Biosphere reserves are nominated by member states after a process of consultation and coordination with government agencies, local communities, nongovernmental organizations, and private interests with a stake in the areas concerned. The advantages enjoyed by sites designated as biosphere reserves include official United Nations recognition of local and national efforts to promote conservation and sustainable development, a "label of excellence" that is helpful in securing additional funding, and membership in the World Network of Biosphere Reserves, which facilitates the exchange of ideas and scientific research results. The Noatak Biosphere Reserve was established to maintain the environmental integrity of the Noatak River and adjacent uplands, to protect wildlife habitats and populations, and to protect archaeological resources for scientific research.

Outstanding Natural Resource Waters in ARCN

In 1996, Alaska adopted a general antidegradation policy for water bodies, which is identical to federal law and can be found in 18 AAC 70.015. The policy states:

1. existing water uses and the level of water quality necessary to protect existing uses must be maintained and protected;
2. if the quality of a water exceeds levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality must be maintained and protected;
3. if a high-quality water constitutes an outstanding national resource, such as a water of a national or state park or wildlife refuge or a water of exceptional recreational or ecological significance, the quality of that water must be maintained and protected; and
4. if potential water quality impairment associated with a thermal discharge is involved, the antidegradation policy described in this section is subject to 33 USC 1326 (commonly known as Section 316 of the Clean Water Act).

The Environmental Protection Agency also requires the state to develop an antidegradation policy implementation plan; Alaska is in the process of developing this plan. The plan will specify the procedures and criteria used to determine when waters are degraded by point or nonpoint sources of pollution and what social and economic benefit to the state would be necessary to justify any degradation. The plan will also have procedures for nomination and designation of Tier III waters and outstanding natural resource waters (ONRW). There are seven wild and scenic rivers in Alaska, which likely will be designated as ONRWs once the antidegradation policy implementation plan is approved. According to the state, many water bodies have natural water quality that is better than the criteria set by the water quality standards.

Wild and Scenic Rivers

In October 1968, the Wild and Scenic Rivers Act pronounced that "certain selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations." Under the act's authority, Congress created the National Wild and Scenic Rivers System. Wild river areas are defined as those rivers or sections of rivers that are free of impoundments and generally inaccessible except by trail, with watersheds or shorelines essentially primitive and waters unpolluted. Seven rivers in ARCN parks were designated as wild and scenic on December 2, 1980:

- the Alatna River (83 miles or 133 km) and North Fork of the Koyukuk (102 miles or 163 km), which are wholly within Gates of the Arctic National Park and Preserve, in their entirety;
- the 52-mile (83 km) segment of the John River within Gates of the Arctic National Park and Preserve;
- from its headwaters in the Endicott Mountains and Walker Lake, that portion of the Kobuk River that flows through Gates of the Arctic National Park and Preserve (110 miles or 160 km);
- the Noatak River from its source in Gates of the Arctic National Park and Preserve to the Kelly River in the Noatak National Preserve (330 total miles or 528 km);
- the Salmon River within the Kobuk Valley National Park (70 miles or 112 km); and
- the Tinayguk River in Gates of the Arctic National Park and Preserve (44 miles or 70 km).

Appendix 8
Summary of Noteworthy Geology, Landforms, and Soils of ARCN Parks

Much of the central Brooks Range is dominated by sedimentary deposits of Upper and Middle Devonian origin. These include limestone, sandstone, shale, and siltstone with occurrences of conglomerates, chert, and metamorphosed deposits. Notable formations include the Hunt Fork Shale, the Kanayut Conglomerate, the Eli Limestone, and the Nanook Limestone. This wide band of Devonian deposits stretches from the eastern border of Gates of the Arctic National Park and Preserve through the central portion of the Noatak National Preserve. Small but very prominent intrusive formations of early Cretaceous origin also occur within this area. The steep, jagged, and renowned Arrigetch Peaks are part of a granitic intrusion separating the Noatak and Alatna drainages within Gates of the Arctic. Cape Krusenstern National Monument and the western edge of the Noatak National Preserve are dominated by similar sedimentary deposits of older Devonian and Silurian origin. Limestone, dolomite, phyllite, and chert are common components. Smaller pockets of these strata also occur within the central Brooks Range. Notable formations include the Skajit Limestone.

The southern flank of the Brooks Range contains a collection of early Paleozoic and Precambrian deposits, including limestones, sandstones, and shales along with siliceous and calcareous schists. This narrow band stretches from Kobuk Valley National Park east through the southern portions of Noatak National Preserve and Gates of the Arctic National Park and Preserve.

South of the Brooks Range in Kobuk Valley National Park, early and late Cretaceous sedimentary deposits underlie later glacial and fluvial sediments in the broad Kobuk Valley. Shale, sandstone, siltstone, conglomerate, and greywacke dominate these deposits.

Geologic deposits in the uplands of Bering Land Bridge National Preserve are dominated by recent volcanic lava and ash flows dating from the Cretaceous-Tertiary boundary to the late Quaternary Period. Distinct lava flows around Imuruk Lake range in age from 65 million years (the Tertiary Kugruk volcanics) to as recently as 1,000 years (the Lost Jim flow). Older flows occurred on many separate occasions from a variety of vents and are now largely buried by the more recent flows as well as by wind-blown deposits of silt. Exposed volcanic rocks, all dark basaltic material, were originally rather smooth *pahoehoe* flows, with older flows subject to severe shattering by frost action into large angular fragments. Notable Cretaceous granitic intrusions also occur within these formations, with the tors surrounding Serpentine Hot Springs being the best-known example.

Higher peaks of Brooks Range mountains in GAAR are characterized by steep spires flanked by cirques and sharp arêtes as Pleistocene glaciers carved and transported bedrock downslope. Remnant ice left some higher areas dotted with depressions, creating small kettle lakes, while major glaciers gouged typical broad, U-shaped valleys in what are now all of the major river drainages within ARCN. Many smaller mountains to the south and west through the Noatak National Preserve and Kobuk Valley National Park were overtopped by ice sheets and have a rounded or domelike profile with smooth saddles between peaks.

A suite of glacial deposits commonly line toe slopes and valley bottoms in the Brooks Range and its foothills. Kame terraces, recessional and lateral moraines, eskers, and outwash deposits are scattered

throughout the region. Aeolian sand and silt deposits also occur intermingled with other features. Of particular interest are the dune features in Kobuk Valley National Park. Mostly formed during the previous Pleistocene interglacial and covering an area of roughly 90,000 hectares, they are now primarily vegetated, with the exception of the Great Kobuk, Little Kobuk, and Hunt River dunes, which are still active and cover about 8,300 hectares.

Post-glacial processes continue to modify the landscape as seasonal snow, ice, water, and wind continue to weather, transport, and redeposit substrates. Higher elevations typically grade, moving downslope, from bedrock to fell fields and then talus. Valley bottoms consist of fine sediments, sand, and gravel, redistributed as sinuous river systems carve new channels and abandon old ones. Mass wasting landforms produced by rockfall, snow avalanches, and solufluction are common on many hillslopes. Melting permafrost in the form of thermokarst and thaw lakes occurs in pockets in ARCN and may be caused by a combination of natural climatic and disturbance events.

Bering Land Bridge National Park and Cape Krusenstern National Monument are subject to coastal processes as well. Post-glacial isostatic rebounding and subsequent tidal forces shape much of the coast, leading to long, rocky, and gravelly bluffs and beach ridges. Cape Krusenstern is particularly known for the beach ridges made famous by the work of J. Louis Giddings, who described a chronosequence of prehistoric beach habitation in *Beach Ridge Archaeology of Cape Krusenstern* (1986).

Large lagoon systems make up much of the rest of the coast, along with a few prominent river deltas such as that of the Noatak River.

The north coast of the Seward Peninsula in Bering Land Bridge National Park is comprised of marine deposits from the late Pleistocene and Holocene epochs. Most of these sediments originate from the south and west coasts of the Seward Peninsula and are transported by prevailing currents in a continuing, progressive process of coastal erosion and redeposition that includes a highly dynamic series of low barrier islands.

Permafrost underlies much of the terrain within ARCN. Permafrost landforms such as pingos, ice wedge polygons, patterned ground, and thaw ponds are common in and near valley bottoms throughout the region. Permafrost is absent in ARCN only on sites with special thermal conditions such as active river floodplains, south-facing slopes at low elevations, and under water bodies. Small snow fields and several small glaciers still exist within the region, primarily at higher elevations on north-facing slopes within Gates of the Arctic.

Appendix 9
Rare Plant Species Documented or Cited from ARCN Parks

Included are current Alaska Natural Heritage Program (AKNHP) rankings (see below). X indicates species presence has been documented with a voucher specimen, and * indicates species has been cited, but specimens are lacking. List created and reviewed by Carolyn Parker (University of Alaska Museum of the North Herbarium) for the ARCN Vascular Plant Inventory (2006).

	Observed in:				
Species/Rankings	**BELA**	**CAKN**	**GAAR**	**KOVA**	**NOAT**
Aspleniaceae					
Asplenium viride **G4S3**	*			*	
Asteraceae					
Artemisia senjavinensis **G3S2S3**	X				
Erigeron muirii **G2S2**			X		
Erigeron porsildii **G4S3**			X		X
Saussurea triangulata **G1?S1**				X	
Symphyotrichum yukonense **G3S3**			X	X	X
Brassicaceae					
Aphragmus eschscholtzianus **G3S3**			X		
Cardamine microphylla ssp. *blaisdellii* **G4S2S3**	X		X	X	
Draba exalata **G3S3**	X				
Draba pauciflora **G4S1**			X		
Smelowskia porsildii **G5S2S3**			X		X
Thlaspi arcticum **G3S3**			X		
Campanulaceae					
Campanula aurita **G4S3**			X		
Caryophyllaceae					
Arenaria longipedunculata **G3S3**		X	X	X	X
Minuartia biflora **G5S3S4**	X		X		X
Minuartia yukonensis **G4S3**					X
Stellaria alaskana **G3S3**			X		
Stellaria dicranoides **G3S3**	X	X	X	X	X
Stellaria umbellata **G5S2S3**	X		X		
Chenopodiaceae					
Corispermum ochotense var. *alaskanum* **G3G4T?QS2**				X	
Cyperaceae					
Carex deflexa **G5S1S2**			X		
Carex heleonastes **G4S2**			X		
Carex holostoma **G4?S2**	X	X			X
Carex lapponica **G4G5S2**			X	X	
Eleocharis kamtschatica **G4S2S3**				X	
Eriophorum viridicarinatum **G5S2**			X		
Fabaceae					
Lupinus kuschei **G3S2**				X	

	Observed in:				
Species/Rankings	**BELA**	**CAKN**	**GAAR**	**KOVA**	**NOAT**
Oxytropis arctica var. *barnebyana* **G4TS2**	X	X			X
Oxytropis kobukensis **G2S2**				X	
Oxytropis kokrinensis **G3S3**			X	X	X
Oxytropis tananensis **G2G3QS2S3**					X
Gentianaceae					
Gentianopsis detonsa ssp. *detonsa* **G3G4T?S1**		X			
Orchidaceae					
Cypripedium parviflorum **G5S2S3**			X		
Papaveraceae					
Papaver walpolei **G3S3**	X	X		X	X
Poaceae					
X_*Dupoa labradorica*	X	X			
Festuca edlundiae **G3G4S1**			X		
Festuca lenensis **G4G5S3**		X	X	X	X
Glyceria pulchella **G5S2S3**				X	
Glyceria striata ssp. *stricta* **G5S2**			X		
Puccinellia vaginata **G4S1**	X	X			
Puccinellia vahliana **G4S2S3**			X		X
Puccinellia wrightii **G3G4S2S3**	X				X
Schizachne purpurascens **G5S2**			X		
Polygonaceae					
Rumex krausei **G2S2**		X			X
Potamogetonaceae					
Potamogeton subsibiricus **G3S3**		X			
Primulaceae					
Douglasia beringensis **G3S3**	X				
Primula tschuktschorum **G2G3S2S3**	X				
Pteridaceae					
Cryptogramma stelleri **G5S2S3**		X		X	X
Ranunculaceae					
Oxygraphis glacialis **G4G5S2S3**			X		
Ranunculus glacialis ssp. *camissonis* **G4T3T4S2**	X		X		X
Ranunculus monophyllus **G5S1S2**	X				X
Rosaceae					
Potentilla fragiformis **G4S1**		X			
Potentilla rubricaulis **G4S2S3**			X		X
Potentilla stipularis **G5S1**					X
Saxifragaceae					
Saxifraga nudicaulis **G3G4QS2S3**	X				
Violaceae					
Viola selkirkii **G5S3**			*		
Zannichelliaceae					
Zannichellia palutris **L. G5S3**		X			

Rare plant ranking abbreviations

Listed are the abbreviations used for indicating plant rarity that are used by the Nature Conservancy and a network of natural heritage programs and conservation data centers. In Alaska, the Alaska Natural Heritage Program, University of Alaska Anchorage (AKNHP), maintains a tracking list and rankings for the rare biota of Alaska.

G#	global rank, throughout the entire range of the species
S#	state rank, rarity as observed at the state level
1	species is critically imperiled due to extreme rarity (5 or fewer occurrences) or due to some factor of its biology making it especially vulnerable to extinction
2	species is imperiled due to rarity (6 to 20 occurrences) or due to other factors making it very vulnerable to extinction
3	species is either very rare and local in distribution (21 to 100 occurrences) or found within a restricted range
4	species is widespread and apparently secure
5	species is clearly secure
?	a qualifier noting that the ranking is inexact; more information is needed to be certain if the rank shown is supportable
Q	questionable taxonomy: the taxonomy supporting this name is questioned by some botanists
S#S#	indicates rank is uncertain and best described as a range between two rankings
T	indicates ranking is for the listed subspecies or variety

Appendix 10
Fish Species in ARCN Parks

Freshwater and Anadromous Fish Species

		Observed in:				
Common Name	**Scientific Name**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**
Alaska Blackfish	*Dalia pectoralis*	X*	XY	X	X	XY
Arctic Charr**	*Salvelinus alpinus*	XY*	X	XY	X*	X
Arctic Cisco	*Coregonus autumnalis*	X	X			
Arctic Grayling	*Thymallus arcticus*	XY*	XY	XY*	XY	X
Arctic Lamprey	*Lampetra japonica*	X	X		X	X
Bering Cisco	*Coregonus laurettae*	X	XY		X	X
Broad Whitefish	*Coregonus nasus*	X	XY	X	X*	XY
Burbot	*Lota lota*	X	X	XY	X	XY
Chinook Salmon	*Oncorhyncus tshawytscha*	X	X		X	XY
Chum Salmon	*Oncorhynchus keta*	X	XY*	X	XY	XY
Coho Salmon	*Oncorhynchus kisutch*	X	X			X
Dolly Varden**	*Salvelinus malma*	X*	XY	XY	XY	XY
Humpback Whitefish	*Coregonus clupeaformis*	X	XY	XY	X*	XY
Lake Trout	*Salvelinus namaycush*			XY	X*	XY
Least Cisco	*Coregonus sardinella*	XY*	XY	XY	XY*	XY
Longnose Sucker	*Catostomus catostomus*	X	XY	X	X	XY
Nine-Spine Stickleback	*Pungitius pungitius*	XY	XY	XY	X	XY
Northern Pike	*Esox lucius*	X*	XY	XY	XY*	XY
Old Man Charr	*Salvelinus anaktuvukensis*			XY		
Pink Salmon	*Oncorhynchus gorbuscha*	XY	XY		X	XY
Pond Smelt	*Hypomesus olidus*	X*	X		X	
Rainbow Smelt	*Osmerus mordax*	X	XY		X	X
Round Whitefish	*Prosopium cylindraceum*	X	XY	XY*	X*	XY
Sheefish (*Inconnu*)	*Stenodus leucichthys*	X	Y	XY	XY*	X
Slimy Sculpin	*Cottus cognatus*	X*	X	XY*	X	XY
Sockeye Salmon	*Oncorhynchus nerka*					XY
Three-Spine Stickleback	*Gasterosteus aculeatus*		XY			

X = Listed as present in park in NPSpecies
Y = Listed in park in literature review
* = Voucher specimens from park
** Many past reports of arctic charr are now accepted as Dolly Varden charr

Marine Fish Species

		Observed in:		
Common Name	**Scientific Name**	**BELA**	**CAKR**	**NOAT**
Alaska Plaice	*Pleuronectes quadritub*	X	X	
Arctic Alligatorfish	*Aspidophoroides olriki*	X	X	
Arctic Cod	*Boreogadus saida*	X	X	
Arctic Flounder	*Liopsetta glacialis*		Y	
Arctic Sculpin	*Myoxocephalus scorpoides*	X	X	
Arctic Shanny	*Stichaeus punctatus*	X	X	
Arctic Staghorn Sculpin	*Gymnocanthus tricuspis*	X*	X*	
Arrowtooth Flounder	*Atheresthes stomias*	X	X	
Belligerent Sculpin	*Megalocottus platycephalus*	X	XY	
Bering Flounder	*Hippoglossoides robustus*	X	X	
Brightbelly Sculpin	*Microcottus sellaris*	X	X	
Capelin	*Mallotus villosus*	X	X	
Coastrange Sculpin	*Cottus aleuticus*	X	X	
Eyeshade Sculpin	*Nautichthys pribilovius*	X	X	
Fish Doctor	*Gymnelis viridis*	X	X	
Fourhorn Sculpin	*Myoxocephalus quadricornis*	X*	XY	X
Fourline Snakeblenny	*Eumesogrammus praecisus*	X	X	
Leister Sculpin	*Enophrys lucasi*	X	X	
Marbled Eelpout	*Lycodes raridens*	X	X	
Pacific Herring	*Clupea harengus* sp.	X	XY	
Pacific Sand Lance	*Ammodytes hexapterus*	X	X	
Plain Sculpin	*Myoxocephalus jaok*	X	X	
Ribbed Sculpin	*Triglops pingeli*	X	X	
Rough Hookear Sculpin	*Artediellus scaber*	X	X	
Saffron Cod	*Eleginus gracilis*	X	XY	
Shorthorn Sculpin	*Myoxocephalus scorpius*	X	X	
Slender Eelblenny	*Lumpenus fabricci*	X	X	
Snake Prickleback	*Lumpenus sagitta*	X	X	
Spatulate Sculpin	*Icelus spatula*	X	X	
Starry Flounder	*Platichthys stellatus*	X	XY	
Stout Eelblenny	*Lumpenus medius*	X	X	
Wattled Eelpout	*Lycodes palearis*	X	X	
Whitespotted Greenling	*Hexagrammos stelleri*	X	X	
Yellowfin Sole	*Limanda aspera*	X	XY	

X = Listed as present in park in NPSpecies
Y = Listed in park in literature review
* = Voucher specimens from park

Appendix 11
Bird Species Observed in ARCN Parks

		Observed in:				
Common name	**Scientific Name**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**
Alder Flycatcher	*Empidonax alnorum*	X		X	X	X
Aleutian Tern	*Sterna aleutica*	X	X			
American Dipper	*Cinclus mexicanus*				X	
American Golden-Plover	*Pluvialis dominica*	X	X	X	X	X
American Kestrel	*Falco sparverius*			X	X	X
American Pipit	*Anthus rubescens*	X	X	X	X	X
American Robin	*Turdus migratorius*	X	X	X	X	X
American Tree Sparrow	*Spizella arborea*	X	X	X	X	X
American Wigeon	*Anas americana*	X		X	X	X
Arctic Tern	*Sterna paradisaea*	X	X	X	X	X
Arctic Warbler	*Phylloscopus borealis*	X	X	X	X	X
Baird's Sandpiper	*Calidris bairdii*	X	X	X	X	X
Bald Eagle	*Haliaeetus leucocephalus*	X	X	X	X	
Bank Swallow	*Riparia riparia*	X	X	X	X	X
Barn Swallow	*Hirundo rustica*	X				
Barrow's Goldeneye	*Bucephala islandica*	X				
Bar-tailed Godwit	*Limosa lapponica*	X	X	X		X
Belted Kingfisher	*Ceryle alcyon*			X	X	X
Black-bellied Plover	*Pluvialis squatarola*	X	X	X		X
Black-capped Chickadee	*Parus atricapillus*			X	X	
Black-legged Kittiwake	*Rissa tridactyla*	X	X			
Black Scoter	*Melanitta nigra*	X	X	X	X	X
Black Turnstone	*Arenaria melanocephala*	X	X			X
Blackpoll Warbler	*Dendroica striata*	X	X	X	X	X
Bluethroat	*Luscinia svecica*	X	X	X	X	X
Bohemian Waxwing	*Bombycilla garrulous*		X	X	X	X
Bonaparte's Gull	*Larus philadelphia*	X	X	X	X	X
Boreal Chickadee	*Poecile hudsonicus*		X	X	X	X
Boreal Owl	*Aegolius funereus*			X	X	
Brant	*Branta bernicla*	X	X			X
Bristle-thighed Curlew	*Numenius tahitiensis*	X	X			X
Buff-breasted Sandpiper	*Tryngites subruficollis*		X			X
Bufflehead	*Bucephala albeola*	X		X		X
Canada Goose	*Branta canadensis*	X	X	X	X	X
Canvasback	*Aythya valisineria*	X	X	X		X
Cliff Swallow	*Hirundo pyrrhonota*	X		X	X	X
Common Eider	*Somateria mollissima*	X	X			
Common Goldeneye	*Bucephala clangula*	X		X		
Common Loon	*Gavia immer*	X	X	X	X	X
Common Merganser	*Mergus merganser*	X	X	X	X	X
Common Murre	*Uria aalge*	X	X			
Common Raven	*Corvus corax*	X	X	X	X	X
Common Redpoll	*Carduelis flammea*	X	X	X	X	X

		Observed in:				
Common name	**Scientific Name**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**
Crested Auklet	*Aethia cristatella*	X				
Dark-eyed Junco	*Junco hyemalis*	X	X	X	X	X
Downy Woodpecker	*Picoides pubescens*	X				
Dunlin	*Calidris alpine*	X	X			
Emperor Goose	*Chen canagica*	X				
Eurasian Wigeon	*Anas penelope*	X				
Fox Sparrow	*Passerella iliaca*	X	X	X	X	X
Glaucous Gull	*Larus hyperboreus*	X	X	X	X	X
Glaucous-winged Gull	*Larus glaucescens*	X	X			
Golden-crowned Sparrow	*Zonotrichia atricapilla*	X	X	X	X	X
Golden Eagle	*Aquila chrysaetos*	X	X	X	X	X
Gray-cheeked Thrush	*Catharus minimus*	X	X	X	X	X
Gray-crowned Rosy-Finch	*Leucosticte tephrocotis*		X	X	X	X
Gray Jay	*Perisoreus canadensis*		X	X	X	X
Great Gray Owl	*Strix nebulosa*		X	X	X	
Greater Scaup	*Anas marila*	X	X	X	X	X
Greater White-fronted Goose	*Anser albifrons*	X	X	X	X	X
Greater Yellowlegs	*Tringa melanoleuca*			X		X
Green-winged Teal	*Anas crecca*	X	X	X	X	X
Gyrfalcon	*Falco rusticolus*	X	X	X	X	X
Hairy Woodpecker	*Picoides villosus*			X		
Harlequin Duck	*Histrionicus histrionicus*	X	X	X	X	
Hermit Thrush	*Catharus guttatus*		X			X
Herring Gull	*Larus argentatus*	X	X	X	X	X
Hoary Redpoll	*Carduelis hornemanni*		X	X	X	X
Horned Grebe	*Podiceps auritus*	X	X	X	X	X
Horned Lark	*Eremophila alpestris*	X	X	X	X	X
Horned Puffin	*Fratercula corniculata*	X	X			
Hudsonian Godwit	*Limosa haemastica*	X	X			X
Ivory Gull	*Pagophila eburnea*		X			
King Eider	*Somateria spectabilis*	X	X			
Kittlitz's Murrelet	*Brachyramphus brevirostris*		X			
Lapland Longspur	*Calcarius lapponicus*	X	X	X	X	X
Least Auklet	*Aethia pusilla*	X				
Least Sandpiper	*Calidris minutilla*	X	X	X	X	X
Lesser Scaup	*Aythya affinis*	X	X	X	X	
Lesser Yellowlegs	*Tringa flavipes*		X	X	X	X
Lincoln's Sparrow	*Melospiza lincolnii*	X		X	X	X
Long-billed Dowitcher	*Limnodromous scolopaceus*	X	X	X	X	X
Long-tailed Duck	*Clangula hyemalis*	X	X	X	X	X
Long-tailed Jaeger	*Stercorarius longicaudus*	X	X	X	X	X
Mallard	*Anas platyrhynchos*	X	X	X	X	X
Merlin	*Falco columbarius*	X	X	X	X	X
Mew Gull	*Larus canus*	X	X	X	X	X
Northern Flicker	*Colaptes auratus*	X		X	X	X
Northern Goshawk	*Accipiter gentiles*		X	X		X
Northern Harrier	*Circus cyaneus*	X	X	X	X	X
Northern Hawk Owl	*Surnia ulula*		X	X	X	X

		Observed in:				
Common name	**Scientific Name**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**
Northern Pintail	*Anas acuta*	X	X	X	X	X
Northern Shoveler	*Anas clypeata*	X	X	X	X	X
Northern Shrike	*Lanius excubitor*	X	X	X	X	X
Northern Waterthrush	*Seiurus noveboracensis*	X	X	X	X	X
Northern Wheatear	*Oenanthe oenanthe*	X	X	X	X	X
Olive-sided Flycatcher	*Contopus cooperi*			X	X	X
Orange-crowned Warbler	*Vermivora celata*	X	X	X	X	X
Osprey	*Pandion haliaetus*	X		X	X	X
Pacific Golden-Plover	*Pluvialis fulva*					X
Pacific Loon	*Gavia pacifica*	X	X	X	X	X
Parakeet Auklet	*Cyclorrhynchus psittacula*	X				
Parasitic Jaeger	*Stercorarius parasiticus*	X	X	X	X	X
Pectoral Sandpiper	*Calidris melanotos*	X	X	X	X	X
Pelagic Cormorant	*Phalacrocorax pelagicus*	X	X			
Peregrine Falcon	*Falco peregrinus*	X	X	X	X	X
Pigeon Guillemot	*Cepphus columba*		X			
Pine Grosbeak	*Pinicola enucleator*			X	X	X
Pine Siskin	*Carduelis pinus*			X		
Pomarine Jaeger	*Stercorarius pomarinus*	X	X		X	X
Red-breasted Merganser	*Mergus serrator*	X	X	X	X	X
Red-breasted Nuthatch	*Sitta canadensis*			X		
Redhead	*Aythya americana*	X				
Red Knot	*Calidris canutus*		X	X		X
Red-necked Grebe	*Podiceps grisegena*	X	X	X	X	X
Red-necked Phalarope	*Phalaropus lobatus*	X	X	X	X	X
Red Phalarope	*Phalaropus fulicarius*	X	X	X		
Red-tailed Hawk	*Buteo jamaicensis*			X		X
Red-throated Loon	*Gavia stellata*	X	X	X	X	X
Red-throated Pipit	*Anthus cervinus*	X				
Rock Ptarmigan	*Lagpus mutus*	X	X	X	X	X
Rock Sandpiper	*Calidris ptilocnemis*	X	X			
Rosy-Finch	*Leucosticte arctoa*		X	X		X
Rough-legged Hawk	*Buteo lagopus*	X	X	X	X	X
Ruby-crowned Kinglet	*Regulus calendula*		X	X	X	X
Ruddy Turnstone	*Arenaria interpres*	X	X			X
Rusty Blackbird	*Euphagus carolinus*	X	X	X	X	X
Sabine's Gull	*Xema sabini*	X	X			
Sanderling	*Calidris alba*	X	X	X	X	
Sandhill Crane	*Grus canadensis*	X	X	X	X	X
Savannah Sparrow	*Passerculus sandwichensis*	X	X	X	X	X
Say's Phoebe	*Sayornis saya*	X	X	X	X	X
Semipalmated Plover	*Charadrius semipalmatus*	X	X	X	X	X
Semipalmated Sandpiper	*Calidris pusila*	X	X		X	X
Sharp-shinned Hawk	*Accipiter striatus*	X			X	X
Sharp-tailed Sandpiper	*Calidris acuminata*		X			
Short-eared Owl	*Asio flammeus*	X	X	X	X	X
Short-tailed Shearwater	*Puffinus tenuirostris*		X			
Siberian Tit	*Parus cinctus*				X	X

		Observed in:				
Common name	**Scientific Name**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**
Smith's Longspur	*Calcarius pictus*			X		X
Snow Bunting	*Plectrophenax nivalis*	X	X	X	X	X
Snow Goose	*Chen caerulescens*	X	X	X	X	
Snowy Owl	*Nyctea scandiaca*	X	X	X	X	
Solitary Sandpiper	*Tringa solitaria*			X	X	X
Spectacled Eider	*Somateria fischeri*	X	X			
Spotted Sandpiper	*Actitis macularia*		X	X	X	X
Spruce Grouse	*Falcipennis canadensis*		X	X	X	X
Steller's Eider	*Polysticta stelleri*		X			
Surf Scoter	*Melanitta perspicillata*	X	X	X	X	X
Surfbird	*Aphriza virgata*			X	X	X
Swainson's Thrush	*Catharus ustulatus*			X	X	X
Thick-billed Murre	*Uria lomvia*	X	X			
Three-toed Woodpecker	*Picoides tridactylus*			X		X
Townsend's Solitaire	*Myadestes townsendi*			X		
Tree Swallow	*Tachycineta bicolor*	X	X	X	X	X
Tufted Puffin	*Fratercula cirrhata*		X			
Tundra Swan	*Cygnus columbianus*	X	X	X	X	X
Upland Sandpiper	*Bartramia longicauda*			X		X
Varied Thrush	*Ixoreus naevius*	X	X	X	X	X
Violet-green Swallow	*Tachycineta thalassina*			X	X	
Wandering Tattler	*Heteroscelus incanus*	X	X	X	X	X
Western Sandpiper	*Calidris mauri*	X	X			X
Western Wood-pewee	*Contopus sordidulus*					X
Whimbrel	*Numenius phaeopus*	X	X	X	X	X
White-crowned Sparrow	*Zonotrichia leucophrys*	X	X	X	X	X
White Wagtail	*Motacilla alba*	X	X			
White-winged Crossbill	*Loxia leucoptera*			X	X	
White-winged Scoter	*Melanitta fusca*	X	X	X		X
Willow Ptarmigan	*Lagopus lagopus*	X	X	X	X	X
Wilson's Snipe	*Gallinago delicate*	X	X	X	X	X
Wilson's Warbler	*Wilsonia pusilla*	X	X	X	X	X
Yellow Wagtail	*Motacilla flava*	X	X	X	X	X
Yellow-billed Loon	*Gavia adamsii*	X	X	X		X
Yellow-rumped Warbler	*Dendroica coronata*		X	X	X	X
Yellow Warbler	*Dendroica petechia*	X	X	X	X	X
Totals		**129**	**132**	**129**	**114**	**126**

Appendix 12
Mammal Species Observed in ARCN Parks

		Observed in:				
Common Name	**Scientific Name**	**GAAR**	**NOAT**	**KOVA**	**CAKR**	**BELA**
Alaska Marmot	*Marmota broweri*	X	X	X		
Arctic Fox	*Alopex lagopus*	X	X	X		
Arctic Ground Squirrel	*Spermophilus parryii*	X	X	X	X	X
Arctic Hare	*Lepus othus*	X	X			
Arctic Shrew	*Sorex arcticus*	X	X	X		
Barren Ground Shrew	*Sorex ugyunak*	X	X	X	X	X
Beaver	*Castor canadensis*	X	X	X	X	
Black Bear	*Ursus americanus*	X	X	X		
Brown Lemming	*Lemmus trimucronatus*	X	X	X	X	X
Caribou	*Rangifer tarandus*	X	X	X	X	X
Collared Lemming	*Dicrostonyx groenlandicus*	X	X	X	X	X
Common Shrew	*Sorex cinereus*	X	X	X	X	X
Coyote	*Canis latrans*	X				
Dall's Sheep	*Ovis dalli*	X	X	X	X	
Ermine	*Mustela erminea*	X	X	X	X	X
Grizzly Bear	*Ursus arctos*	X	X	X	X	X
Least Weasel	*Mustela nivalis*	X	X	X	X	
Lynx	*Lynx canadensis*	X	X	X	X	X
Marten	*Martes americana*	X	X	X		
Meadow Vole	*Microtus pennsylvanicus*	X				
Mink	*Mustela vison*	X	X	X		
Montane Shrew	*Sorex monticolus*	X	X	X	X	X
Moose	*Alces alces*	X	X	X	X	X
Muskox	*Ovibos moschatus*	X	X	X	X	X
Muskrat	*Ondatra zibethicus*	X	X	X	X	X
Northern Bog Lemming	*Synaptomys borealis*	X	X			
Porcupine	*Erethizon dorsatum*	X	X	X	X	X
Pygmy Shrew	*Sorex hoyi*	X	X	X		
Red-Backed Vole	*Clethrionomys rutilus*	X	X	X	X	X
Red Fox	*Vulpes vulpes*	X	X	X	X	X
Red Squirrel	*Tamiasciurus hudsonicus*	X	X	X	X	
River Otter	*Lontra canadensis*	X	X	X	X	
Singing Vole	*Microtus miurus*	X	X	X	X	X
Snowshoe Hare	*Lepus americanus*	X	X	X	X	
Tiny Shrew	*Sorex yukonicus*	X	X	X	X	
Tundra Shrew	*Sorex tundrensis*	X	X	X	X	X
Tundra Vole	*Microtus oeconomus*	X	X	X	X	X
Wolf	*Canis lupus*	X	X	X	X	X
Wolverine	*Gulo gulo*	X	X	X	X	X
Yellow-Cheeked Vole	*Microtus xanthognathus*	X	X	X		
Total		40	38	36	28	21

Appendix 13
Summary of Monitoring Activities in ARCN Parks

Vegetation and Phenology Map
United States Geological Survey (http://agdc.usgs.gov/data/projects/fhm/)
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Land Use/Landcover Change, Vegetation (general)
Vital Sign: Land Use and Cover
Summary: Vegetation map in grid format developed for the state of Alaska by Michael Fleming, USFS/USGS, using the phenology of a vegetation index (AVHRR/NDVI) collected during the 1991 growing season. 1,000 km cell size, scale 1:2,500,000.

Alaska-Yukon Arctic Ecoregional Assessment
The Nature Conservancy (http://nature.org/wherewework/northamerica/states/alaska/preserves/art13301.html)
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Biodiversity, Birds, GIS datasets, Large Mammals, Management Concern, Small Mammals
Vital Signs: Land Use and Cover, At-risk Biota, Focal Species or Communities
Summary: One of the products of the Alaska-Yukon Arctic Ecoregional Assessment is a map indicating areas of biological significance. Referred to as a portfolio, this map is based on the best available information on the distribution, goals, and viability of selected conservation targets, and it represents areas that, if managed for biodiversity, will likely conserve the native species and ecological communities of the ecoregion. The portfolio is a conservation blueprint to guide public land managers, conservation organizations, private landowners, and others in conserving natural diversity within the ecoregion.

Survey and Inventory Reports
Alaska Department of Fish and Game, Division of Wildlife Conservation (http://www.wildlife.alaska.gov/)
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Large Mammals
Vital Signs: Consumptive Use, Focal Species or Communities
Summary: Management reports are statewide reports of fieldwork with emphasis on management objectives, work accomplishments, harvest information, and wildlife population sizes and distribution. Harvest summaries are primarily based on public surveys, sealing information, or harvest reports.

Alaska Freshwater Fish Inventory
Alaska Department of Fish and Game (http://www.sf.adfg.state.ak.us/SARR/Surveys/index.cfm)
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Fish
Vital Sign: Focal Species or Communities
Summary: The Fish Distribution Database/Anadromous Waters Catalog and Atlas (FDD) is the regulatory tool established by statute to specify the various rivers, lakes, and streams of Alaska that are important to the spawning, rearing, or migration of anadromous fishes.

Anadromous Streams Data
Alaska Department of Fish and Game (http://www.sf.adfg.state.ak.us/SARR/FishDistrib/FDD_gisdata.cfm)
Dataset Type: Biological inventory
Ecological Category: Fish
Vital Sign: Focal Species or Communities
Summary: The Alaska Department of Fish and Game's (ADF&G) Anadromous Streams Data is derived from the ADF&G's GIS shapefiles for the "Catalog of Waters Important for Spawning, Rearing or Migration of Anadromous Fishes" (referred to as the "Catalog") and the "Atlas to the Catalog of Waters Important for

Spawning, Rearing or Migration of Anadromous Fishes" (referred to as the "Atlas"). It is produced for general visual reference and to aid users in generating various natural resource analyses and products. The data depict the known anadromous fish-bearing lakes and streams within Alaska from the mouth to the known upper extent of species usage.

Alaska Landbird Resource Information System

Partners in Flight (http://www.partnersinflight.org/description.cfm)
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Birds
Vital Sign: Focal Species or Communities
Summary: Partners in Flight was launched in 1990 in response to growing concerns about declines in the populations of many land bird species and in order to emphasize the conservation of birds not covered by existing conservation initiatives. The initial focus was on neotropical migrants, species that breed in the Nearctic (North America) and winter in the Neotropics (Central and South America), but the focus has spread to include most landbirds and other species requiring terrestrial habitats. The central premise of Partners in Flight (PIF) has been that the resources of public and private organizations in North and South America must be combined, coordinated, and increased in order to achieve success in conserving bird populations in this hemisphere. Partners in Flight is a cooperative effort involving partnerships among federal, state, and local government agencies, philanthropic foundations, professional organizations, conservation groups, industry, the academic community, and private individuals.

Alaska Natural Heritage Program

Alaska Natural Heritage Program (http://aknhp.uaa.alaska.edu/Default.htm)
Dataset Type: Biological inventory
Ecological Categories: Amphibians, Biodiversity, Birds, Fish, Invasive Species, Large Mammals, Management Concern, Small Mammals, Vascular Plants, Vegetation (general)
Vital Signs: At-risk Biota, Invasive Species
Summary: The Alaska Natural Heritage Program (AKNHP) is Alaska's clearinghouse for information on plant and animal species of conservation concern, natural communities of conservation concern, and invasive non-native plant species. AKNHP collects, validates, and distributes this information and helps natural resource managers and others apply it effectively.

Arctic Network Biological Inventories

National Park Service (http://science.nature.nps.gov/im/units/arcn/index.cfm)
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Birds, Large Mammals, Small Mammals, Vascular Plants
Vital Sign: Focal Species or Communities
Summary: Baseline inventories conducted by the Arctic Network include birds, vascular plants, and mammals. These data were incorporated into the national inventory and monitoring data store, NPSpecies, in 2008 and will be updated regularly and made publicly available after quality assurance and quality control.

Arctic Transitions in the Land-Atmosphere System Climate Stations

Water and Environmental Research Center (http://www.uaf.edu/water/projects/atlas/proposal.html)
Dataset Type: Long-term monitoring
Ecological Category: Climate/Weather/Climate Change
Vital Sign: Weather
Summary: Originated in 1998 as a logical outgrowth of prior studies funded by the National Science Foundation, Arctic Transitions in the Land-Atmosphere System (ATLAS) is a coordinated program to examine the geographical patterns and controls over climate-land surface exchange and develop reasonable scenarios of future change in the Arctic. There are six climate stations for the program located on the Seward Peninsula.

Monitoring and Assessing Water Quality Website

Environmental Protection Agency (http://www.epa.gov/storet/dbtop.html)
Dataset Type: Long-term monitoring
Ecological Categories: Contaminants, Water Quality/Biota/Chemistry
Vital Sign: Water Quality

Summary: The U.S. Environmental Protection Agency (EPA) maintains two data management systems containing water quality information for the nation's waters: the Legacy Data Center (LDC) and STORET. The LDC is a static, archived database. and STORET is an operational system actively being populated with water quality data.

Forest Insect and Disease Conditions in Alaska

Alaska Department of Natural Resources, Division of Forestry (http://agdc.usgs.gov/data/projects/fhm/index.html)
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Disease/Parasites
Vital Sign: Infestations and Disease
Summary: The Forest Insect and Disease Conditions in Alaska dataset represents areas of forest damage due to insect infestation, disease, winter damage, fire, flood, landslides, and windthrow. The information was collected cooperatively by aerial surveys by both the U.S. Forest Service Forest Health Protection and Alaska Department of Natural Resources Division of Forestry. Surveys are conducted primarily in July and August so that pest "signatures" may be identified during the optimal period for symptom development of visual estimation. The aerial survey is coordinated such that the maximum extent of recent bark beetle damage (fading trees) and insect defoliation (discoloration, foliage loss) patterns may be determined. Aerial survey flights are termed as "local" if they can be completed within one day from the survey base and "regional" if more than one day is required to complete the survey reconnaissance. Surveys are flown in southeast, southcentral, and interior Alaska.

Kobuk Landscape Study Database

National Park Service
Dataset Type: Biological inventory
Ecological Category: Land Use/Landcover Change
Vital Signs: Land Use and Cover, Soil Quality
Summary: The Kobuk Landscape Study was initiated by the National Park Service in 1992 in cooperation with the Natural Resources Conservation Service (then Soil Conservation Service; SCS) to collect baseline data on the soils and vegetation in the Kobuk Preserve portion of Gates of the Arctic National Park and Preserve. This information was important in the event a road should be built through the preserve into the Ambler Mining District to the west of the park. Field work for the project was conducted during the summers of 1992 and 1993 by David K. Swanson (Soil Conservation Service) and Donna L. DeVoe (NPS). Soils and vegetation data were collected from soil pits and areas immediately surrounding the pits. Notes on animal activity at these sites were also kept (mostly caribou, voles/small mammals, and birds). An auger and shovel were used to dig sizable soil pits to obtain full description of the soil layers underneath the surface. Pits were dug as deep as possible, reaching to approximately three to four feet deep or to bedrock. At each soil pit, a general description of the vegetation was noted using Viereck's system for classifying vegetation (Viereck et al. 1992). At selected sites, a more detailed description of the vegetation was collected, where all species found within a circumference of about 20 m from the soil pit were listed along with an estimate of percent cover for each species. Color infrared aerial photos were used to plan transect locations and also to mark soil pit locations by pin pricks made in the photos. These pin pricks were later transferred onto paper topographic maps (1:63,360 scale). Soil data were used to delineate regions of soil classes within the Kobuk Preserve Unit on mylar sheets overlaid on topographic maps. These soil classes were later digitized and added to the park's GIS.

Kobuk Preserve Unit Soils Data

National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Soils (chemistry, erosion, contaminants, etc.)
Vital Sign: Soil Quality
Summary: Field data collected for study undertaken by the Soil Conservation Service (SCS) at the request of the National Park Service to provide basic information about the Kobuk Preserve Unit through integrated study of landforms, soils, and vegetation. Fieldwork was completed in 1992–93 by David K. Swanson (SCS) and Donna Devoe (NPS). Data were digitized in 1994 by Resource Data for the NPS Alaska Regional Office.

Landcover: 2004 Bering Land Bridge National Preserve and Cape Krusenstern National Monument

National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: Landcover map of Bering Land Bridge National Preserve and Cape Krusenstern National Monument created for the National Park Service showing ecotypes (local-scale ecosystems) that combine physiography (i.e., coastal, riverine, alpine), bedrock geology, topography (DEM modeling), and spectral characteristics of vegetation derived from image processing (ERDAS 8.6). Ecotypes are modeled from supervised spectral classification and vector layers that best partition geomorphic, hydrologic, pedologic, and vegetative characteristics of the area. Map sources: Landsat TM images from 28 June 2000, 1 Aug. 2002, 3 Aug. 2002; ecological subsections map from NPS for physiography and bedrock geology; USGS National Elevation Dataset for elevation, slope, and moisture index. Map projection: Albers Conical Equal Area; NAD 27 datum. Map prepared by ABR, Inc. File: BELA_Ecotype_02-329-7.mxd, 6 October 2004.

Landcover Map of Bering Land Bridge National Preserve

National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: A 15-class landcover map of the Bering Land Bridge National Preserve and surrounding area produced from Landsat satellite imagery.

Landcover Map of Cape Krusenstern National Monument

National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: Landcover map of the Cape Krusenstern area developed in 1991 from thematic mapper satellite imagery by NPS Alaska Regional Office. Imagery used had 30-meter spatial resolution.

Landcover Map of Gates of the Arctic National Park and Preserve

National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: Unfiltered (pixel level) thematic mapping class landcover product from the GAAR Land Cover Mapping Project (1997–1999) completed by Earth Satellite Corporation and Alaska Natural Heritage Program under contract with NPS Alaska Regional Office as part of the NPS Land Cover Mapping Program.

Landcover Map of Kobuk Valley National Park

National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: A landcover map of Kobuk Valley area developed in 1994 from thematic mapper satellite imagery by the NPS Alaska Regional Office. The imagery has 30-meter spatial resolution.

Landcover Map of Northwestern Parks

National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: A 20-class landcover map for the northwest parks of Cape Krusenstern, Kobuk Valley, and Noatak. Landsat thematic mapper imagery was used. Field observations, aerial photography, and other GIS data were used to refine the map.

Air Chemistry Data

National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/sites/siteinfo.asp?net=NTN&id=AK99)
Dataset Type: Long-term monitoring (2+ years)
Ecological Categories: Air Chemistry, Biogeochemical Processes, Contaminants
Vital Signs: Air Quality, Weather, Non-point Source Human Effects
Summary: The National Atmospheric Deposition Program in cooperation with the National Park Service set up an air chemistry monitoring station near Ambler, Alaska, in May 2004 (National Trends Network Monitoring Location AK99).

National Snow and Ice Data Center

Cooperative Institute for Research in Environmental Sciences (http://nsidc.org/data/)
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Climate/Weather/Climate Change
Vital Signs: Hydrology, Weather
Summary: The National Snow and Ice Data Center (NSIDC) is part of the University of Colorado Cooperative Institute for Research in Environmental Sciences and is affiliated with the National Oceanic and Atmospheric Administration National Geophysical Data Center through a cooperative agreement. NSIDC serves as one of eight Distributed Active Archive Centers funded by the National Aeronautics and Space Administration to archive and distribute data from NASA's past and current satellites and field measurement programs. NSIDC also supports the National Science Foundation through the Arctic System Science Data Coordination Center and the Antarctic Glaciological Data Center.

North America Landcover Characteristics Database

National Aeronautics and Space Administration (http://edc2.usgs.gov/glcc/na_int.php)
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: The Land Processes Distributed Active Archive Center (LP DAAC) was established as part of the NASA Earth Observing System Data and Information System (EOSDIS) initiative to process, archive, and distribute land-related data collected by EOS sensors, thereby promoting the interdisciplinary study and understanding of the integrated earth system.

North American Breeding Bird Survey

United States Geological Survey (http://www.pwrc.usgs.gov/bbs/)
Dataset Type: Historical inventory or monitoring data with adequate documentation
Ecological Category: Birds
Vital Sign: Focal Species or Communities
Summary: The North American Breeding Bird Survey (BBS) is a cooperative effort between the U.S. Geological Survey's Patuxent Wildlife Research Center and the Canadian Wildlife Service's National Wildlife Research Centre to monitor the status and trends of North American bird populations. Following a rigorous protocol, BBS data are collected by thousands of participants along thousands of randomly established roadside routes throughout the continent. Professional BBS coordinators and data managers work closely with researchers and statisticians to compile and deliver these population data and population trend analyses on more than 400 bird species for use by conservation managers, scientists, and the general public.

Northwest Arctic Alaska Environmental Sensitivity Index Maps

National Oceanic and Atmospheric Administration (http://response.restoration.noaa.gov/esi/esiintro.html)
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: At-Risk Populations/Biota, Land Use/Landcover Change, Management Concern
Vital Sign: Point-Source Human Effects
Summary: The most widely used approach to sensitive environment mapping in the United States is the National Oceanic and Atmospheric Administration's Environmental Sensitivity Index (ESI). This approach systematically compiles information in standard formats for coastal shoreline sensitivity, biological resources, and human-use resources. ESI maps are useful for identifying sensitive resources before a spill occurs so that protection priorities can be established and cleanup strategies designed in advance. Using ESIs in spill response and planning reduces the environmental consequences of the spill and cleanup efforts.

FirePro Dataset
National Park Service
Dataset Type: Long-term monitoring (2+ years)
Ecological Categories: Fire, Vegetation (general)
Vital Signs: Fire, Vegetation and Soils
Summary: Over the past 30 years, NPS has assembled a large amount of vegetation information for NPS lands in Alaska through the FirePro field data collection program. The principal purpose for this data was to improve understanding and modeling of fire ecology through quantification of the vegetation (fuels). To gather data on fire effects, three different efforts have established fire effects plots at different times in the parks within the Arctic Network:

1. fire effect paired plots,
2. FirePro Ground Truth and Intensive Mapping Areas/Units program, and
3. Racine plots.

During all these efforts photos were taken to aid in plot relocation and to document the sites. Data from all three efforts is available electronically, but, in the case of the paired plots, additional effort is necessary to completely capture the entire data set.

The fire effects paired plot project began in 1983. This program established paired vegetation plots in burned and representative unburned habitat adjacent to the burned areas of varying ages. Plot data collected include: density of trees and tall shrubs, vegetation cover class, tree cores/cookies, fuels and soils data, and general plot location descriptions.

Under the FirePro Ground Truth and Intensive Mapping Areas/Units program, staff collected vegetation data from sites throughout the ARCN during the late 1980s and early 1990s, including vegetation type and percent cover, landform, drainage, slope, aspect, and soils data.

Between 1978 and 1982, Chuck Racine and colleagues established a series of plots for monitoring vegetation and permafrost recovery after fire in NOAT and BELA. In addition, in 2004 NPS fire staff established plots on the Uvgoon Creek Fire in NOAT. Data collected included estimates of species cover, height, stem density, biomass, production, and fuel, measurement of thaw depths, shrub density, and photos.

Historic Fire Boundaries Dataset
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Fire
Vital Sign: Fire
Summary: Coverage containing historic ignition points of fires that have burned within park boundaries from 1956 to 2004. Data were compiled from Alaska Fire Service, Bureau of Land Management, State of Alaska Department of Forestry, and National Park Service park records. Point coordinates were recorded on fire report sheets and are of variable quality.

Lakes Inventory
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Lake Features and Processes, Wetlands (distribution and abundance)
Vital Sign: Hydrology
Summary: A statewide inventory of lakes was assembled from 17 separate files in the USGS 1:2,000,000 Digital Line Graphs dataset; it includes only those polygons with area greater than 20 acres (80,940 m^2).

Large Mammal Surveys
National Park Service
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Large Mammals
Vital Signs: Focal Species or Communities, Consumptive Use
Summary: The National Park Service monitors populations of large mammals annually in the western arctic parklands and GAAR. Monitored species include moose, sheep, and muskox. Some historical surveys exist for other mammals such as wolf and wolverine.

Surficial Geology Dataset
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Geology
Vital Sign: Geomorphology
Summary: Geology information for the Arctic Network is available through the Alaska Region spatial data stack. Information is available for GAAR, Kobuk River Basin, and Kobuk Dunes.

Red Dog Mine Site Air Monitoring
Teck Cominco (http://www.dec.state.ak.us/air/reddog.htm)
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Air Chemistry
Vital Sign: Air Quality
Summary: Teck Cominco conducts several types of air monitoring in the mine area to evaluate the effectiveness of operational controls in minimizing emissions and to ensure compliance with their air permit. This monitoring includes Environmental Protection Agency Methods 22 and 9. EPA Method 22 is a visible dust emission evaluation method that measures the absence or presence of dust over a period of time. Method 9 measures the opacity of a source.

Remote Automated Weather Stations
National Interagency Fire Center (http://raws.wrh.noaa.gov/-roman/)
Dataset Type: Long-term monitoring (2+ years)
Ecological Categories: Climate/Weather/Climate Change, Fire
Vital Sign: Weather
Summary: There are nearly 1,500 interagency remote automated weather stations (RAWS) strategically located throughout the United States and managed by the National Interagency Fire Center (NIFC). Weather data assists land management agencies with a variety of projects—monitoring air quality, rating fire danger, and providing information for research applications.

SNOTEL Data Network
NRCS National Water and Climate Center (http://www.wcc.nrcs.usda.gov/snotel/alaska/alaska.html)
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Climate/Weather/Climate Change
Vital Sign: Weather
Summary: The Natural Resources Conservation Service (NRCS) installs, operates, and maintains an extensive automated system to collect snowpack and related climatic data in the western United States called SNOTEL (for SNOwpack TELemetry). The resulting real-time snow and climate data are archived at the National Water and Climate Center, which provides state and site specific data, maps and graphs showing snow water equivalent, snow depth, precipitation, temperature, and other climatic elements in hourly, daily, monthly, and yearly increments. These products are used for forecasting and management of water supplies.

Soil Survey Data for Kobuk Preserve Unit, Gates of the Arctic National Park, Alaska
Natural Resources Conservation Service National Water and Climate Center (http://soildatamart.nrcs.usda.gov/Metadata.aspx?Survey=AK648&UseState=AK)
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Soils (chemistry, erosion, contaminants, etc.)
Vital Signs: Soil Quality, Land Use and Cover
Summary: Beginning in 2005, data on physical and chemical properties of soils in the Kobuk Preserve Unit were collected by the U.S. Department of Agriculture as part of the National Cooperative Soil Survey.

Soils: Kobuk River Basin
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Soils (chemistry, erosion, contaminants, etc.)
Vital Sign: Soil Quality
Summary: As part of an interagency agreement between the National Park Service and the U.S. Geological Survey, basin characteristics are being determined for a number of watersheds in national parks of Alaska.

Many of the characteristics are being determined by use of GIS. GIS coverages are being made available to other interested parties.

Spatial Patterns of Cadmium and Lead Deposition On and Adjacent to National Park Service Lands Near Red Dog Mine, Alaska

National Park Service
Dataset Type: Non-inventory or monitoring dataset
Ecological Categories: Contaminants, Human Use Activities (subsistence, cultural eutrophication, mining), Vegetation (general)
Vital Signs: Air Quality, Point-Source Human Effects
Summary: The National Park Service in cooperation with Teck Cominco Alaska, the NANA Regional Corporation, and the Alaska Industrial Development and Export Authority released a report on spatial patterns of cadmium and lead deposition on and adjacent to National Park Service lands in the vicinity of the Red Dog Mine, Alaska (Hasselbach et al. 2004). This research identified elevated levels of lead, cadmium, and zinc in mosses collected during 2001 from throughout Cape Krusenstern National Monument and adjacent areas. The monument is located to the north of Kotzebue, Alaska. The metals are likely associated with dust from the ore concentrate hauling and storage operations of the Red Dog Mine. The ecological effects of artificially elevated cadmium and lead levels on the monument are still being assessed. However, the State of Alaska Department of Health and Social Services Division of Public Health has concluded that the metals found in plants used for subsistence near the Red Dog Mine do not pose a public health hazard.

Surficial Deposits of the Kobuk Sand Dunes

National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Windblown Features and Processes (dunes)
Vital Sign: Geomorphology
Summary: This National Park Service dataset contains digitized polygons representing geomorphological units and an inventory of dune ridges in Kobuk Valley National Park.

Circumpolar Arctic Vegetation Map

University of Alaska Fairbanks (http://www.geobotany.uaf.edu/cavm/)
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Vascular Plants
Vital Sign: Land Use and Cover
Summary: The Circumpolar Arctic Vegetation Map (CAVM) project is an international effort to map the vegetation and associated characteristics of the circumpolar region, using a common base map. The base map is a false color infrared image created from Advanced Very High Resolution Radiometer (AVHRR) satellite data. The colors on the map indicate the differences that occur in the general outward appearance of vegetation (physiognomy). The CAVM team grouped over 400 described plant communities into 15 different physiognomic units based on plant growth forms.

National Wetlands Inventory

U.S. Fish and Wildlife Service (http://www.fws.gov/wetlands/*)*
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Land Use/Landcover Change, Wetlands (distribution and abundance)
Vital Sign: Water Quality
Summary: The U.S. Fish and Wildlife Service is working in cooperation with the U.S. Geological Survey to produce and provide information on the extent and status of the nation's wetlands. The National Wetlands Inventory includes a series of topical maps showing wetlands and deepwater habitats, status and trends reports, and a Wetlands Mapper where digital data can be viewed and downloaded.

Water Resources of Alaska

U.S. Geological Survey Alaska Science Center (http://alaska.usgs.gov/science/water/index.php)
Dataset Type: Long-term monitoring (2+ years)
Ecological Categories: Lake Features and Processes, Stream/River Channel Characteristics and Hydrology, Water Quality/Biota/Chemistry
Vital Sign: Hydrology
Summary: The U.S. Geological Survey Alaska Science Center produces information on Alaska's rivers and streams, ground water, water quality, and many other topics. The USGS operates the most extensive satellite network of stream-guaging stations in the state and provides real-time stream stage and streamflow, water-quality, and ground-water levels for over 200 sites in Alaska.

Hydrography Dataset

National Park Service and U.S. Geological Survey
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Stream/River Channel Characteristics and Hydrology, Wetlands (distribution and abundance)
Vital Sign: Hydrology
Summary: This hydrography data is based on the U.S. Geological Survey Digital Line Graph (DLG) maps at a scale of 1:63,360. Minimum mapping unit for polygons is 50 acres. As part of a combined effort between USGS, the Bureau of Land Management, and other agencies, the hydrography DLG files have been revised using 1977–1985 aerial photography. DLG coverages have been converted to ArcInfo coverages and projected to the Alaska Albers projection by the National Park Service GIS team. Coverages have been split into polygon and line coverages, depending upon the physical feature.

Wetlands: Kobuk River Basin

National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Wetlands (distribution and abundance)
Vital Sign: Hydrology
Summary: As part of an interagency agreement between the National Park Service and the U.S. Geological Survey, basin characteristics are being determined for a number of watersheds in national parks of Alaska. Many of the characteristics are being determined by use of GIS. GIS coverages are being made available to other interested parties.

Appendix 14
Summary of Arctic Initiatives of Importance to ARCN

Much of the knowledge of how arctic terrestrial and aquatic ecosystems respond to change has been generated at large, long-term research stations that are able to facilitate multi- and interdisciplinary science (e.g., the National Science Foundation Long-Term Ecological Research Site at Toolik Field Station). As the Arctic continues to undergo dramatic changes in climate and human land use, there is a paramount need to extend current understanding of how arctic ecosystems function outside these long-term research stations and predict how these changes will influence the future state of the arctic and earth systems. Many integrated monitoring and research networks are already in place or under development throughout the Arctic, and a number of major initiatives are relevant to ARCN. In order for ARCN to develop a successful monitoring program, participation in national and international initiatives will be of the utmost importance. Below is a partial list of some of the significant science programs taking place in the Arctic.

Alaska Ocean Observing System (AOOS)
http://www.aoos.org/
An effort to develop a nationwide backbone for an integrated, sustained ocean observing system is being spearheaded by Ocean.US. The Alaska Ocean Observing System's mission is to improve our ability to rapidly detect changes in marine ecosystems and living resources and predict future changes and their consequences for the public good.

Alaska Satellite Facility
http://www.asf.alaska.edu/index.html
The Alaska Satellite Facility, located in the Geophysical Institute at the University of Alaska Fairbanks, downlinks, processes, archives, and distributes synthetic aperture radar (SAR) data from the European Space Agency ERS-1 and ERS-2 satellites, the National Atmospheric and Space Administration (NASA) JERS-1 satellite, and the Canadian Space Agency RADARSAT-1 satellite. Available SAR products include full-resolution (25 m) images; low-resolution (240 m) images; complex-format SAR data products that retain amplitude and phase information, geocoded images, and uncorrelated (raw signal) SAR data, representing the original backscattered radar signals. ASF is one of several Distributed Active Archive Centers (DAACs) sponsored by NASA as part of the Earth Observing System initiative.

Arctic Alive! Online Educational Program
http://www.arcus.org/ArcticAlive/index.html
Arctic Alive! is a distance-learning environment for learners to be transported virtually to unique and remote locations within the arctic region. Arctic Alive! is not an information internet site but an interactive, real-time, and unique web-based education program. It uses a variety of delivery methods and e-learning strategies to deliver arctic research to the classroom.

Arctic Climate Impact Assessment (ACIA)
http://www.acia.uaf.edu/
An international project of the Arctic Council and the International Arctic Science Committee (IASC) to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. The results of the assessment were released at the ACIA International Scientific Symposium held in Reykjavik, Iceland, in November 2004.

Arctic Coastal Dynamics (ACD)
http://arcticportal.org/acd
The Arctic Coastal Dynamics program is a multidisciplinary, multinational forum to exchange ideas and information. The overall objective of ACD is to improve our understanding of circum-arctic coastal dynamics as a function of environmental forcing, coastal geology and cryology, and morphodynamic behavior.

Arctic Region Supercomputing Center (ARSC)
http://www.arsc.edu/
The mission of the Arctic Region Supercomputing Center is to support high performance computational research in science and engineering with an emphasis on high latitudes and the Arctic. ARSC provides high performance computational, visualization, networking and data storage resources for researchers within the Department of Defense, the University of Alaska, other academic and scientific institutions, and government agencies.

Arctic Studies Center, National Museum of Natural History, Smithsonian Institution
http://www.mnh.si.edu/arctic/
The Arctic Studies Center, established in 1988, is the only U.S. government program with a special focus on northern cultural research and education. In keeping with this mandate, the Arctic Studies Center specifically studies northern peoples, exploring history, archaeology, social change, and human lifeways across the circumpolar world. The center is part of the Department of Anthropology, in the National Museum of Natural History, a section of the Smithsonian Institution. Having pursued northern studies since the 1850s, the Smithsonian possesses one of the world's finest anthropological collections from arctic and subarctic regions.

Arctic System Science (ARCSS) Data Coordination Center
http://www.eol.ucar.edu/projects/arcss/
The Arctic System Science (ARCSS) Data Coordination Center at the National Center for Atmospheric Research is the permanent data archive for all components of the ARCSS Program. Funded by the National Science Foundation's Office of Polar Programs, the focus of the center is to archive and provide access to ARCSS-funded data.

Barrow Arctic Science Consortium (BASC)
http://www.arcticscience.org/
The Barrow Arctic Science Consortium is dedicated to the encouragement of research and educational activities pertaining to Alaska's North Slope, the adjacent portions of the Arctic Ocean, and in Chukotka, Russia. A cooperative agreement between BASC and the National Science Foundation's Office of Polar Programs provides funding for BASC's activities.

Bering Climate and Ecosystem
http://www.beringclimate.noaa.gov/
This website presents the current Bering Sea status, a quick data summary, and the main set of time series that form the basis of a smaller set of Bering climate and ecosystem indices.

Center for Global Change and Arctic System Research
http://www.cgc.uaf.edu/
The Center for Global Change and Arctic System Research was established in 1990 to serve as the focal point at the University of Alaska Fairbanks for developing, coordinating and implementing interdisciplinary research and education related to the role of the Arctic and sub-Arctic in the Earth system, and to stimulate and facilitate global change research in this region.

Cooperative Institute for Arctic Research (CIFAR)
http://www.cifar.uaf.edu/
CIFAR, established in 1994, promotes research collaboration between the National Oceanic and Atmospheric Administration (NOAA) and the University of Alaska Fairbanks, as well as other agencies and institutions involved in arctic research. CIFAR is one of 13 national NOAA-University joint institutes.

Institute of Arctic and Alpine Research (INSTAAR)
http://instaar.colorado.edu/
The Institute of Arctic and Alpine Research (INSTAAR) strives for excellence in research, education, and outreach related to earth system science and global change in high-latitude, alpine, and other environments. INSTAAR is located at the University of Colorado within the graduate school and affiliated with the departments of Anthropology, CEA Engineering, Environmental Studies, Ecology and Evolutionary Biology, Geography, Geological Sciences, and Atmospheric and Oceanic Sciences.

International Arctic Science Committee (IASC)
http://www.arcticportal.org/iasc/
The International Arctic Science Committee is a nongovernmental organization whose aim is to encourage and facilitate cooperation in all aspects of arctic research in all countries engaged in arctic research and in all areas of the arctic region.

Long Term Ecological Research (LTER)
http://www.lternet.edu/ and http://ecosystems.mbl.edu/ARC/
The National Science Foundation established the LTER program in 1980 to support research on long-term ecological phenomena in the United States. The 26 LTER sites represent diverse ecosystems and research emphases. The Arctic LTER site is based at Toolik Field Station in the foothills of the Brooks Range.

Paleoenvironmental Atlas of Beringia
http://www.ncdc.noaa.gov/paleo/parcs/atlas/beringia/
This site provides historical and geologic information on past climates and environments in Beringia (northwestern North America and northeastern Asia).

Study of Environmental Arctic Change (SEARCH)
http://www.arcus.org/SEARCH/index.php
SEARCH is an interagency effort to understand the nature, extent, and future development of the system-scale change presently seen in the Arctic.

U.S. Arctic Research Commission
http://www.arctic.gov/
The United States Arctic Research Commission was established by the Arctic Research and Policy Act of 1984 (as amended, Public Law 101-609). The commission's principal duties are (1) to establish the national policy, priorities, and goals necessary to construct a federal program plan for basic and applied scientific research with respect to the Arctic, including natural resources and materials; physical, biological, and health sciences; and social and behavioral sciences; (2) to promote arctic research, to recommend arctic research policy, and to communicate our research and policy recommendations to the president and Congress; (3) to work with the National Science Foundation as the lead agency responsible for implementing arctic research policy and to support cooperation and collaboration throughout the federal government; (4) to give guidance to the Interagency Arctic Research Policy Committee (IARPC) to develop national arctic research projects and a five-year plan to implement those projects; and (5) to interact with arctic residents, international arctic research programs, and organizations and local institutions, including regional governments, in order to obtain the broadest possible view of arctic research needs.

U.S. National Science Foundation, Office of Polar Programs (OPP)
http://www.nsf.gov/dir/index.jsp?org=OPP
The Office of Polar Programs (OPP) manages and initiates National Science Foundation funding for basic research and its operational support in the Arctic and the Antarctic. The OPP Division of Arctic Sciences supports scientific research in the Arctic, related research, and operational support. Science programs include disciplinary, multidisciplinary, and broad interdisciplinary investigations directed toward the Arctic as a region of special scientific interest and a region important to global systems. Disciplinary interests encompass the atmospheric, biological, physical, earth, ocean, and social sciences. The Arctic System Science (ARCSS) Program provides opportunities for interdisciplinary investigations of the Arctic as a system.

Appendix 15
Protocol Development Summaries

Table A15.1: Protocol Development Summaries for the Arctic Network vital signs. Vital signs that have been grayed out will not be implemented until additional staff or resources become available.

National Ecological Monitoring Framework Level 3 Categories	ARCN Vital Sign/Protocol	Page
Wet and Dry Deposition	Wet and Dry Deposition	220
Air Contaminants	Air Quality	223
Weather and Climate	Climate	225
	Snowpack	227
Coastal/Oceanographic Features and Processes	Coastal Erosion	229
	Sea Ice	231
Soil Function and Dynamics	Permafrost	233
Surface Water Dynamics	Surface Water Dynamics and Distribution	235
Water Chemistry	Lagoon Communities and Ecosystems	237
	Lake Communities and Ecosystems	239
	Stream Communities and Ecosystems	241
Invasive/Exotic Plants	Invasive/Exotic Plant and Animal Species and Diseases	243
Animal Diseases		
Fishes	Fish Assemblages	245
Birds	Landbirds	247
	Yellow-billed Loons	249
Mammals	Brown Bears	251
	Caribou	254
	Dall's Sheep	257
	Moose	260
	Muskox	262
	Small Mammal Assemblages	264
Terrestrial Complex	Terrestrial Vegetation and Soils	266
Point Source Human Effects	Point Source Human Effects	269
Consumptive Use	Subsistence/Harvest	271
Visitor Use	Visitor Use	273
Fire and Fuel Dynamics	Fire Extent and Severity	275
Land Cover and Use	Terrestrial Landscape Patterns and Dynamics	279

Protocol Development Summary

Protocol: Wet and Dry Deposition

Parks Where Protocol will be Implemented: BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

Despite the pristine appearance of the arctic parklands, the steady input of contaminants from both local and global sources make pollution a primary concern in ARCN. Sources of contaminants in ARCN's parklands include point sources, regional sources, and trans-pacific and trans-polar global pollution sources. Point sources include heavy metals, sulfur (S), and nitrogen (N), from the Red Dog Mine, the largest zinc and lead mine in the world. Regional sources include those associated with northwest Alaskan community and industrial development. The furthest-range pollutants are semi-volatile organic compounds (SOC), including persistent organic pollutants (POP), as well as mercury (Hg), S, and N from Asian (and even eastern North American) sources.

There are myriad potential biological consequences from these various pollutants on ARCN resources. ARCN ecologists have recently focused studies on the effects of heavy metals on ecosystem components in CAKR (e.g., impairment of lichen and bryophyte communities, bioaccumulation in fauna, contaminant levels in forage). Bioaccumulation of Hg in piscivorous freshwater fish has begun to receive some attention from the perspective of human health, though food-chain effects for wildlife are less studied. The effects of S and N on vegetation are well known generally but are relatively unknown in Alaska.

Wet and dry deposition is of concern to park management for a number of reasons. First, increasing loads of S and N from Asian coal-burning has the potential to seriously degrade tundra and alpine vegetation and boreal forest epiphytes. These vegetation communities are dominated by nonvascular plant species (i.e., lichens and mosses) that are highly sensitive to these pollutants. Bioaccumulation of heavy metals including Hg and organic toxins is another key concern from the perspectives of food chain health and subsistence hunting. A recent study that included two lakes within the ARCN found that Hg levels in older, piscivorous fish already exceed EPA guidelines for human health and wildlife in some cases (Western Airborne Contaminant Assessment Program: WACAP 2008). With a few notable exceptions, most SOC, including pesticides, do not appear to be concentrating in arctic Alaska's foodchain (WACAP 2008); however, increasing use of toxic SOC in Asia is likely to increase deposition levels in Alaska in the future. Continued monitoring of SOC would therefore be of keen interest.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What are the baseline levels and long-term trends in deposition and accumulation in the Arctic Network of the following elements or compounds: Pb, Zn, Cd, Cu, Cr, Hg, Al, B, Fe, Ti, Total S, Total N, NO_3^-, using the moss *Hylocomium splendens* as a passive sampler of airborne contaminants?
- What are the current levels of Hg and a small suite of SOC (specified by a small working group of experts) in a limited set of piscivorous fish and in lake water?
- What are the trends in heavy metal levels in CAKR along the Red Dog haul road, and what are the consequences for sensitive vegetation?

Objectives are as follows:

- Establish baseline and long-term framework for monitoring concentrations of airborne Pb, Zn, Cd, Cu, Cr, Hg, Al, B, Fe, Ti, total S, total N, and NO_3^- using the moss *Hylocomium splendens* as a passive sampler.
- Calibrate elemental concentrations in *Hylocomium splendens* with concentrations in passive air sampler devices (PASD) in order to be able to use moss concentrations to predict true deposition values on a landscape level.
- Determine current levels of mercury in piscivorous freshwater fish (e.g., lake trout, sheefish) and relate these levels to age and lipid content of the individual fish.
- Link *Hylocomium splendens* tissue sampling with surveys of lichen community structure currently conducted by Vegetation vital sign. This permits a linkage between observed pollutant levels and changes in community structure.
- Monitor changes in deposition of Pb, Cd, and Zn along the Red Dog haul road in CAKR and link deposition levels with changes in sensitive nonvascular plant communities.

Basic Approach

A baseline level of heavy metals, S, N, and SOC will be established in ARCN, using the common moss *Hylocomium splendens*, fish, and small mammals. Collocating sample sites with the aquatic vital signs and the Terrestrial Vegetation and Soils vital sign will allow for determination of baseline values in abiotic components. It is expected that these measures will occur on a decadal basis. The air quality station currently being established by ARCN in Bettles, Alaska, will provide a weekly measure for air pollutants.

ARCN will use a well-established method for monitoring moss-derived contaminant concentrations for point source contamination (i.e., Red Dog Mine mine) that was used previously in ARCN (Hasselbach et al. 2004). These methods will be documented in formal protocols and expanded to other sampling locations in the ARCN parks. Methods for measuring Hg in fish are well established. Methods utilized and reported on in the Western Airborne Contaminant Assessment Program (2008) will utilized and adapt to ARCN needs.

PASD will fill a key need with the vital sign, allowing for a calculation of deposition using the relationship between the elemental contents of *Hylocomium* and the deposition rates established by PASD. PASD are generally small resin tubes or dishes deployed for a period of weeks or months. They require no special infrastructure and are normally put on site using a small portable metal stand. It is expected that between 5 and 10 PASD will be collocated with *Hylocomium* sampling on a vegetation plot.

Principal Investigators and NPS Lead

The NPS Principal Investigators will be Greta Burkart (NPS-ARCN) and Peter Neitlich (NPS-WEAR). The NPS lead is Peter Neitlich (509-996-3917). Cooperators may potentially include Linda Geiser (USDA/Forest Service), Staci Simonich (Oregon State University), Dixon Landers (EPA-Corvallis, OR), Todd Gouin (UAF), Jesse Ford (OSU).

Development Schedule, Budget, and Expected Interim Products

The protocol will be developed on the following schedule:

- FY 2009: PIs meet to coordinate protocol development. Field testing of methods. Development of cooperative agreement for Hg methylation risk map. ($115,000)
- FY 2010: Draft protocol completed by December 1, 2009. Field work for Hg methylation risk map.

- FY 2011: Hg methylation risk map delivered. Protocol reviewed and finalized. Implement (recurring decadal) ($125,000).

In FY2009, we will initiate a cooperative agreement with a research entity to develop a mercury methylation risk map as part of this vital sign's initial development. It is theorized by WACAP scientists (Dixon Landers, pers. comm.) that Hg methylation occurs more rapidly in certain types of environments, notably those high in phosphorus and dissolved organic carbon. By developing a methylation map, we may improve understanding of how landscape patterns (e.g., lithology, vegetation) are related to the rate of Hg transfer. This will be important in designing the sampling scheme for Hg.

Protocol Development Summary

Protocol: Air Quality

Parks Where Protocol will be Implemented: Bettles, AK, as representative for BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

Asiatic and global long-range pollutants deliver significant amounts of airborne contaminants each year to the North American Arctic. Much of this pollution comes in the form of Arctic Haze, a combination of sulfate, particulate matter, nitrate, heavy metals, black carbon, and other minor constituents. Other global pollutants include mercury and semi-volatile organic compounds. Until September 2008, there were no instrumented NPS air quality monitoring stations in arctic Alaska.

Airborne contaminants in ARCN parks have the potential to affect biota and degrade visibility. Nonvascular plants (e.g., lichens, bryophytes, algae), fungi, soil arthropods, and terrestrial and aquatic invertebrates are particularly sensitive to airborne contaminants. In addition, ecosystems with low buffering capacity or areas with high pollution loads are at increased risk for damage. Generally speaking, forest ecosystems, high altitude environments, freshwater ecosystems, peatlands, barrens, and areas dominated by lichen cover are highly susceptible to the numerous forms of air contaminants listed above.

Within the NPS, air quality monitoring is managed by the Air Resources Division (ARD) through participation in several nationwide, interagency monitoring networks, each targeting a specific aspect of air quality. ARCN will use a new ARD-funded site in Bettles, Alaska, to monitor air quality in the network. The network will monitor deposition of airborne contaminants, including mercury, in precipitation. The network will also monitor concentrations of aerosols that affect visibility.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions addressed by this protocol include:

- What are the main components of air pollution in ARCN parks?
- Is air quality changing over time in ARCN Parks?

Objectives are as follows:

- Determine levels of air pollutants in parks and correlate to observed effects.
- Identify and assess trends in air quality.
- Determine compliance with National Ambient Air Quality Standards.
- Provide data for the development and revision of national and regional air pollution control policies.
- Provide data for atmospheric model development and evaluation.
- Use information to inform the public about conditions/trends in national parks.
- Determine which air pollutants in parks contribute to visibility impairment.

Basic Approach

ARCN's air quality monitoring will be administered and guided by ARD as part of its national sampling protocol.

The specific methods for ARCN's air quality monitoring station will be:

- Monitor weekly levels of pH, sulfate, nitrate, ammonium, chloride, calcium, magnesium, potassium, and sodium in precipitation falling at Bettles through participation in the National Atmospheric Deposition Program (NADP).
- Monitor weekly mercury concentrations in precipitation through the Mercury Deposition Network.
- Monitor the chemical composition and mass of aerosols (coarse and fine particulate matter and select gasses) that contribute to visibility impairment through the Interagency Monitoring of Protected Visual Environments (IMPROVE) network.
- Integrate air quality data from the Bettles site with data from other ARCN Vital Signs to monitor the ecological condition of ARCN parks.

The ARCN air quality monitoring protocol consists of the standard operating procedures established by each nationwide air quality monitoring network. These procedures are defined by the respective monitoring network steering committees. One significant aspect of air quality monitoring in the ARCN that needs development is data reporting. Currently, all data are managed at the national level and reported at the national scale (i.e., Bettles in comparison to other sites). Mechanisms to facilitate the integration of the air quality data into Arctic Network reporting and data analysis schemes will be developed through consultation with the network Data Manager.

Principal Investigators and NPS Lead

The ARD will be the PI on this project. NPS coordination will be done by an NPS group including: Jim Lawler (ARCN Network Coordinator), Peter Neitlich (WEAR Botanist), Bud Rice (Alaska Regional Office Environmental Protection Specialist), and Andrea Blakesley (Denali National Park and Preserve Environmental Protection Specialist). Air samples will be collected by technicians stationed in Bettles.

Development Schedule, Budget, and Expected Interim Products

The protocol will be developed on the following schedule:

- May 2008: Build station shed at the Bettles BLM Lightning Detection Monitoring Site (permission and building materials have already been secured).
- September 2008: Begin operation.
- March 2009: Submit final protocols adapted for I&M and ARCN specific needs.

Most of the funding for this vital sign will be covered by ARD. ARD will cover in full: utilities for site operation, sample shipping and analysis, data analysis and reporting on the national level, and data publishing to a data portal. Data reporting and analysis on the ARCN side, especially relating air quality to other network vital signs, will be ARCN's responsibility.

Protocol Development Summary

Protocol: Climate

Parks Where Protocol will be Implemented: BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

Weather and climate are key drivers in arctic ecosystem structure and function. Global and regional scale climate variations will have tremendous impacts on these natural systems (Chapin et al. 1996; Hinzman et al. 2005). The arctic climate is complex due to numerous nonlinear interactions between and within the atmosphere, cryosphere, ocean, land, and ecosystems. Sea ice plays a crucial role in the arctic climate, particularly through its albedo. A reduction of ice extent leads to warming due to increased absorption of solar radiation at the surface. Natural atmospheric patterns of variability on annual and decadal time scales also play an important role in the arctic climate. Such patterns include the North Atlantic Oscillation, the Pacific-North American pattern, and the Pacific Decadal Oscillation, which are associated with prominent arctic regional precipitation and temperature anomalies (IPCC 2007). Average arctic temperatures increased at almost twice the global average rate during the past 100 years, and the Arctic is very likely to warm during this century more than the global mean. Warming is projected to be the largest in winter and smallest in summer. Annual arctic precipitation is very likely to increase (IPCC 2007).

Changes in climate that have already taken place are manifested in the decrease in extent and thickness of arctic sea ice, permafrost thawing, coastal erosion, changes in ice sheets and ice shelves, and altered distribution of species (IPCC 2007). With mean annual temperatures in the ARCN typically below freezing and the ground covered by snow more than 6 months per year, any increases in temperature and or changes in precipitation could have great impact on ecosystem structure and dynamics as well as major impacts on the land surface through changes in glaciers and permafrost. Without climate data, it is impossible to understand the causes of a variety of ecosystem changes now underway. Strategic deployment of climate stations in the ARCN will provide data not heretofore available on the climate patterns in the parks. The data generated by these stations will also contribute significantly to the understanding of Alaska's climate and high latitude manifestations of climate change.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions addressed by this protocol include:

- What are the long-term trends and variations in climate for all ARCN parks?
- What are the frequencies and patterns of extreme climatic conditions for common weather parameters, including air temperature, soil temperature, precipitation, wind speed and direction, and snow depth?

Objectives are as follows:

- Determine long- and short-term trends in climate by recording weather metrics at sites that capture the primary climate gradients within ARCN.
- Provide monthly and annual summaries of climate data, including air temperature, precipitation, wind speed and direction, soil temperature, and snow depth, and identify any extreme climatic conditions.

Basic Approach

There are two networks that have developed climate monitoring protocols in Alaska, the Central Alaska Network (CAKN) and the Southwest Alaska Network (SWAN). The ARCN will use foundation documents drafted by the Western Regional Climate Center (Davey 2006) and the Central Alaska

Network (Sousanes and Adema 2004) to design and develop a strategy that will focus on high-latitude climate issues and remote operations. A robust Alaska NPS climate monitoring program that shares resources will be more effective and efficient than a stand-alone program. It will also provide a more complete understanding of the complexities of the high-latitude climate system that affects all of the Alaska national parks.

A weather and climate scoping meeting was held in 2006 with climatologists and physical scientists who offered opinions and insight on arctic climate issues. The product of the meeting was a document that will also be used to guide protocol development. The meeting attendees were asked where they would place additional climate stations in the network; maps of these locations will be used to site new stations in ARCN (Nolan 2006).

The basic approach will be to:

- ensure that all existing long-term climate and weather stations in and around the network continue to operate and produce high quality data;
- add new climate stations in areas that are not currently represented that measure and record air temperature, soil temperature, wind speed and direction, snow depth, relative humidity, solar radiation, and year-round precipitation (rain, snow and mixed precipitation);
- ensure that the maintenance and calibration of the stations and sensors is a priority;
- engage in partnerships with state and federal agencies involved in climate and weather monitoring in ARCN and work with university researchers interested in high latitude climate changes;
- ensure that the data produced by the new ARCN stations is available for use by NPS staff, researchers, and the public via the internet;
- analyze and summarize the data in useful formats to show averages, totals, trends, and extremes; and
- archive the digital data with the Western Regional Climate Center.

Principal Investigators and NPS Leads

The principal investigator and NPS lead for this project will be Pam Sousanes (ARCN Physical Scientist). Collaborators on this vital sign will be Rick McClure (Natural Resources Conservation Service), Kelly Redmond (Western Regional Climate Center), Rick Thoman (National Weather Service), Matt Nolan and Martha Shulski (University of Alaska Fairbanks), and Chris Daly (PRISM Group, Oregon State University).

Development Schedule, Budget, and Expected Interim Products

Because climate monitoring in ARCN will roughly follow the methodology currently in place in CAKN, we anticipate a rapid development of the protocol. The protocol will be developed on the following schedule:

- FY2008: Protocol development and site evaluation. Purchase nine climate stations for testing and development purposes ($135,000).
- FY2009: Site evaluation review; compliance and permitting. Purchase six additional weather stations. Deploy weather stations. Implement and test protocol ($122,500)
- FY2010: Protocol peer reviewed and finalized. Estimated annual operating costs ($54,000)

Protocol Development Summary

Protocol: Snowpack

Parks Where Protocol will be Implemented: BELA, KOVA, CAKR, NOAT, GAAR

Justification/Issues to be Addressed

Climate is widely recognized as one of the most fundamental drivers of ecological condition, and the predominant feature of climate in high-latitude regions is the presence of a seasonal snowpack. The snowpack is a major influence on hydrology, vegetation, and faunal communities (Jones et al. 2001). Snow affects landscape vegetation patterns, permafrost stability, drainage patterns, nutrient cycling, water quality, productivity of plants and animals, the degree and types of disturbance events, the timing of migratory and breeding events of organisms, predator-prey relationships, and the distribution of plants and animals. Duration of snow on the landscape is also a key indicator of regional climate. Although snowpack is inherently related to climate, the sampling methods for monitoring snow vary enough from those of climate monitoring to warrant a separate protocol.

Records of precipitation are especially important to documenting climate and understanding climate effects on ecosystems, but measuring precipitation where most of the precipitation comes in the form of snow—and where it is windy— is technically quite difficult. While rainfall in summer is relatively easy to measure, transitional fall and winter precipitation events and snowfall in winter are difficult to measure accurately, especially when a station is remote. Total annual precipitation is often greatly underestimated, and comparisons of precipitation patterns among years are difficult because estimates are biased (Yang et al. 1999).

Because of the inherently difficult task of accurately recording year-round precipitation, and because a robust network of snow monitoring sites currently exists in the state of Alaska, the snow monitoring protocol will be developed in coordination with the Alaska Natural Resources Conservation Service (NRCS) and be based mainly on those already developed for the neighboring Central Alaska Network (Sousanes and Adema 2004). The NRCS installs, operates, and maintains an extensive automated system to collect snowpack and related climatic data in the western United States called SNOTEL (for SNOwpack TELemetry). The NRCS network complements the objectives of the snowpack monitoring program and provides opportunities for ARCN park lands to be included in an Alaska-wide snow and climate data collection effort. The protocol will focus on snow monitoring, providing data on depth, density, timing, and duration of the seasonal snowcover.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions addressed by this protocol include:

- What is the extent, timing, and duration of snowcover in ARCN parks, and how are these variables changing?
- What is the depth, density, and snow water equivalent of the snowpack in the ARCN parks, and how does it vary spatially and temporally?

Objectives are as follows:

- Determine long-term patterns of snowpack extent, depth, and duration within ARCN parks by working with the USDA-Natural Resources Conservation Service (NRCS) to establish seasonal snowpack monitoring snow courses and aerial snow markers within ARCN parks.
- Determine long-term trends in total annual precipitation and daily accumulation patterns with high accuracy by working with the USDA-NRCS to establish precipitation recording gauges in each ARCN park as part of the telemetry (SNOTEL) network.

Basic Approach

The most efficient and effective method for monitoring snow within the state of Alaska is to partner with the Natural Resource Conservation Service and expand the network of snow courses, aerial snow markers, and snow telemetry (SNOTEL) sites to the ARCN parks. A comprehensive site evaluation in 2008 will provide the information necessary to locate potential new sites. Proximity to field offices (Nome, Kotzebue, Bettles, and Wiseman) will be key factors in site selection due to the amount of usable daylight hours for winter field surveys in the ARCN parks. Snow course and aerial snow markers will be located so that a 2–3 hour flight transect can be accomplished from these base locations. Between one and five SNOTEL sites will be installed within the ARCN parks. These stations will have the full complement of meteorological sensors plus a year-round shielded precipitation gauge that will accurately record both snowfall and rainfall. Acoustic snow depth sensors will also be located on each climate station being deployed under the climate monitoring protocol (See Climate vital sign). These data will add to and be compared with other NRCS snow monitoring sites near ARCN parks. Nearby Kanuti National Wildlife Refuge currently has an aerial snow marker course, and there are SNOTEL sites at four locations on the eastern boundary of ARCN (Imnaviat Creek, Atigun Pass, Coldfoot, and Gobblers Knob), one site between NOAT and CAKR (Ikalukrok Creek), and one southeast of BELA (Pargon Creek).

Principal Investigators and NPS Lead

The principal investigator and NPS lead for this project will be Pam Sousanes (ARCN Physical Scientist). Collaborators on this vital sign will be Rick McClure (Natural Resources Conservation Service) and Kelly Redmond (Western Regional Climate Center).

Development Schedule, Budget, and Expected Interim Products

Snow monitoring in ARCN will roughly follow the methodology currently in place in CAKN, so we anticipate a rapid development of the protocol.

The protocol will be developed on the following schedule:

- FY 2008: Protocol development and site evaluation. Purchase nine weather stations that include snow monitoring sensors (cost included in Climate PDS) ($27,000).
- FY 2009: Site evaluation review; compliance and permitting. Purchase six weather stations that include snow monitoring equipment (cost included with Climate PDS). Refurbish SNOTEL site in Noatak. Deploy weather stations (cost included with Climate PDS). Implement and test protocol ($30,000).
- FY 2010: Protocol peer reviewed and finalized. Interagency agreement will be established with NRCS for additional snow courses and SNOTEL sites ($40,000).

Protocol Development Summary

Protocol: Coastal Erosion/Sedimentation/Deposition [Short Name: Coastal erosion]

Parks Where Protocol will be Implemented: BELA, CAKR

Justification/Issues being addressed

The total shoreline in ARCN, including bay and barrier island ecosystems, is approximately 450 km (250 miles). This is the third largest block of coastline that the NPS manages. Nearshore coastal waters and shoreline habitats include subtidal zones, sandy shores, barrier spits and islands, lagoons, bays and inlets, tundra bluffs, dune systems, rocky bluffs, deltas, and wetlands. These habitats are critical for bird nesting, seal haul-outs, potential denning sites, freshwater and anadromous fish, and migratory stopover sites for marine mammals and birds. As a result, the coastal zone has a long history of and is still very important for subsistence fishing, egg gathering, and hunting of waterfowl and marine mammals. Many hunting and fishing camps and travel routes associated with subsistence activities are in the coastal zone of BELA and CAKR.

Coastal change consists primarily of coastal erosion and bluff retreat, as well as less common beach accretion, deposition of sediments during extreme storms, and modification to inlets and lagoons. A particular concern is that coastal ecosystems are changing rapidly with arctic warming and other environmental stressors (Arctic Climate Impact Assessment 2005). Coastal and nearshore environments in BELA and CAKR are experiencing dramatic changes (Manley et al. 2007), with impacts on a variety of nearshore marine, terrestrial, and freshwater habitats. Coastal erosion directly impacts beach geomorphology and nearshore ecosystems. Bluff erosion causes loss of terrestrial habitat. Changes in sediment erosion and deposition can lead to capture of thaw-lake basins, migration of barrier inlets, flooding or closure of inlets, and other modifications to freshwater habitats. Release of sediment and organic carbon alters nutrient fluxes in nearshore marine and lagoon ecosystems (Jorgenson and Brown 2005). Protected by sea ice for several months each year, the fragile coastal zone may change rapidly with arctic warming, permafrost melting, sea-level rise, lengthening of the summer sea-ice free season, and changes to storm frequency and severity (Arctic Climate Impact Assessment 2005, Rachold et al. 2005). Coastal change is one of the most observable and sensitive indicators of environmental change for the Arctic. The Coastal Erosion protocol will be linked to other protocols including Climate, Snowpack, Point Source Human Effects, Terrestrial Vegetation and Soils, Bird Assemblages, Stream Communities and Ecosystems, Lake Communities and Ecosystems, Lagoon Communities and Ecosystems, Surface Water Dynamics and Distribution, and Sea Ice.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions addressed by this protocol include:

- What is the rate of beach erosion and deposition in CAKR and BELA?
- What are the long-term effects of coastal erosion and deposition on lagoon formation, stability, and persistence?
- What is the effect of ice cover change and open ocean season on rates of coastal erosion and deposition?
- Will tundra coasts experience accelerated erosion due to thermokarst formation and permafrost thawing?

Objectives are as follows:

- Determine long-term trends and variation of coastline accretion, erosion, and bluff retreat.

- Determine long-term trends in area, volume, or mass fluxes at long-term monitoring sites along the coastline.
- Detect changes in nearshore vegetation and landcover.
- Link coastline monitoring sites and methods with those for the sea ice, permafrost, and lagoons protocols.

Basic Approach

Coastal erosion/accretion will be monitored primarily through remote sensing of the coastline coupled with field mapping and measurements at long-term monitoring sites along the BELA and CAKR coasts. Remote sensing methods will involve repeated acquisition (approximately every 5–10 years) of orthorectified, high-resolution base imagery and Digital Elevation Models (DEM). High-resolution imagery (IFSAR radar imagery, Ikonos or QuickBird satellite imagery, or orthorectified aerial photography) is required for the quantification of erosion at rates of typically 0.1 to 10 m/yr. High-resolution DEMs (from IFSAR or LIDAR) are required to calculate volumetric loss or gain, as well as sediment and carbon fluxes to nearshore marine ecosystems. Standard GIS and remote sensing packages are then used to digitize the base imagery and quantify vector and raster algorithms to show erosion rates, change in erosion rate through time, areas lost and gained, volumes lost and gained, and fluxes. Spatial and temporal patterns can be related to land cover classes and other environmental variables as well as to ground surveys at repeat-measurement sites. Coastal change should be quantified approximately every five years, with additional observations during or after large storm events.

Principal Investigators and NPS Lead

The current NPS contact for the coastal erosion protocol is Scott Miller (ARCN Data Manager). The principal investigators is William Manley (University of Colorado) with collaborators Leanne Lestak and Eric Parrish (University of Colorado).

Development Schedule, Budget, and Expected Interim Products

The protocol will be developed on the following schedule:

- Fall 2005–Fall 2008: Protocol development and baseline imagery acquired for the years ca. 1950, ca. 1980, 2003.
- Fall 2008: Baseline analysis of changes in coastal erosion and accretion for the periods 1950–1980, 1980–2003 completed.
- December 2008: Draft protocol ready for peer review.
- Fall 2009: Protocol finalized and implemented. Estimated annual operating costs, based on protocol development, is $140,000 once every 5 years. Acquisition of new imagery is scheduled for 2013.

Protocol Development Summary (Deferred)

Protocol: Sea Ice

Parks Where Protocol Will be Implemented: CAKR, BELA

Justification/Issues Being Addressed

The maritime climate, ecological dynamics, and taxonomic diversity of the coastal environment of ARCN are governed largely by the extent and duration of sea ice. Sea ice is important because it buffers the water from extreme atmospheric temperatures, it has a high albedo, affecting the amount of sunlight absorbed in the Arctic, and it forms an important biological habitat for seals, polar bear, arctic fox, and other animals that hunt and feed on the ice. Sea ice also forms an important barrier to international shipping lanes, reducing the exposure of ARCN coastlines to ocean-going threats much of the year. Sea ice has been shown to be undergoing dramatic changes in thickness and extent that may profoundly impact ARCN coastlines. Furthermore, sea ice is thought to be a sensitive indicator of climate change in high-latitude areas.

Sea ice is an important hydrologic variable that increases in significance with latitude and produces a diverse array of impacts on physical, chemical, and ecological processes. Formation and movement of coastal sea ice may affect prey and predators directly, by scraping and reworking nearshore habitats and controlling access to open water or preferred habitats, or indirectly, as changes in the sea ice cover affect landscape variables such as coastal erosion.

Over the past few centuries late summer sea ice in the Arctic Ocean has been decreasing at a rate of 10% per decade. Over the past century, years 2007 and 2008 hold the record for having the lowest annual extent of sea ice cover. In 2007, for the first time in a 28-year record, an area the size of California was completely ice-free in September, and the Northwest Passage, a historical barrier to international shipping, was completely ice-free for several weeks during September and August (National Snow and Ice Data Center 2007).

These changes in sea ice will have widespread impacts on the marine and terrestrial ecosystems in BELA and CAKR. Changes in weather patterns, migratory corridors, marine mammal distributions, and vegetation are just a few of the ways in which the coastal environment will be impacted. Alterations to the sea floor due to ice scouring are likely to have profound impacts on the eelgrass populations that persist in the northernmost eelgrass communities. Shrinking sea ice has already impacted the subsistence activities of native peoples in the region. Changes, particularly recent decreases, in shorefast ice extent and duration have significantly altered winter overland travel and subsistence harvest by local residents throughout the Arctic (Whiting 2002, Gearheard et al. 2006). Ice conditions in the shoulder seasons are considerably more dangerous. Longer open water seasons have lengthened the hunting season for caribou and shortened the hunting season for marine mammals on the sea ice. Increasing storm frequency and intensity have already impacted small coastal communities by damaging infrastructure and destroying critical coastline (Arctic Climate Impact Assessment 2005). Collecting data on the extent and distribution of sea ice will provide park managers with critical information for making sound decisions on managing the fragile coastal environments and provide information to communities regarding the condition of the ice.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What is the annual and seasonal variability in timing and extent of shorefast sea ice?
- How is the duration and thickness of sea ice changing?

Objectives are as follows:

- Determine long-term trends and variability in the timing and extent of shorefast ice in BELA and CAKR.
- Determine the long term trend and variability in the ice free period in BELA and CAKR.

Basic Approach

Many organizations are currently monitoring the extent, duration, and thickness of sea ice using a variety of techniques, including multispectral satellite imagery, ice-profiling sonar and submarine-based sonar, and web cams. The NOAA Sea Ice Center, Cold Regions Research and Engineering Laboratory, the University of Alaska Geophysical Institute, and International Arctic Research Center are potential data sources. The most feasible approach for monitoring sea ice along the ARCN coastline is to acquire data from these institutions annually and populate a network database on sea ice. In FY 2009 ARCN will begin scoping the available datasets for shorefast sea ice in the areas adjacent to BELA and CAKR. We will identify long-term sources of data and assess the feasibility of acquiring data annually.

Principal Investigators and NPS Lead

The NPS Lead for protocol development is Scott Miller (ARCN Data Manager).

Development Schedule, Budget, and Expected Interim Products

Detailed protocols for monitoring Sea Ice will occur only if additional resources become available. No costs are currently anticipated for monitoring this vital sign.

Protocol Development Summary

Protocol: Permafrost

Parks Where Protocol will be Implemented: BELA, KOVA, CAKR, NOAT, GAAR

Justification/Issues Being Addressed

Permafrost is ground that has been frozen for two or more years. Since mean annual air temperatures are typically well below freezing in ARCN, virtually the entire area is underlain by continuous or discontinuous permafrost. Above the permafrost is the seasonally unfrozen ground of the active layer, with perhaps an unfrozen talik between them. Various disturbances and changes in surface energy balance can melt permafrost, causing thermokarst, solifluction, and other surface disturbances (Jorgenson et al. 2001, 2006). These disturbances vary depending on the amount of ice frozen in the ground. The more ice in the soil, the larger the surface disturbance.

Permafrost extent and thickness is largely controlled by air temperature, snow thickness and duration, and vegetative cover—each of these parameters is currently changing due to climate warming, and changes in these factors are having cascading impacts on permafrost distribution. The anticipated changes in permafrost will have broad impacts on infrastructure, regional hydrology, soils, biogeochemistry, trace gas emissions, and vegetation patterns and therefore on large-scale ecosystem structure and function. Extensive thermokarsting will lead to altered soil nutrient dynamics in ARCN parklands as formerly icebound soil organic matter reservoirs become available for uptake, evolution, and ultimately redistribution. Thermokarst will likely have significant effects on carbon sequestration in wetter areas, and loss of permafrost may cause drier, more aerobic soil conditions in upland areas.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What is the current trend in surface disturbance (e.g., thermokarst, solifluction) and other permafrost-related features in ARCN parks?
- What is the current distribution of permafrost-related features in ARCN parks (e.g., pingos, ice wedge fields)?
- What are the temperature trends in existing boreholes near ARCN parks?

Objectives are as follows:

- Detect permafrost-related surface disturbance (e.g., thermokarst, solifluction) and determine long-term trends in degradation rates as expressed in km^2/year.
- Identify and map permafrost-related features in ARCN parks and monitor trends in the distribution and abundance of these features.
- Determine long-term temperature trends in existing boreholes gathered by researchers near ARCN parks.

Basic Approach

Protocol development for monitoring permafrost is still in the initial stages of development. The main focus of our protocol will likely be to monitor the spatial extent in thermokarst and other permafrost terrain features through aerial photography or high-resolution space-borne remote sensing. Imagery will provide baseline information on total extent, morphology, and expansion rates of these features.

The proposed remote sensing protocol would modify that used by Jorgensen et al (2006) in their characterization of thermokarst extent in the state of Alaska. Aerial photogaphs or high-resolution satellite

imagery would be acquired and a subsample analyzed for thermokarst. This analysis would initially be done manually, although automated processes may be available eventually. Image acquisition and analysis would be repeated at 10-year intervals.

We are fortunate that there are about 40 permafrost-monitoring boreholes near the ARCN, many of which are along the Dalton Highway. Permafrost temperatures from these boreholes can be used to monitor climate change and trends in permafrost stability. The data from these boreholes is archived by the Global Terrestrial Network for Permafrost at http://www.gtnp.org/. These boreholes are monitored on an irregular basis by other researchers. Any new data will be collected on an annual basis, and trends pertinent to the ARCN will be summarized and reported.

Principal Investigators and NPS Leads

This protocol will initially be developed by a team of NPS scientists. The NPS Principal Investigators are Pam Sousanes (ARCN Physical Scientist), Dave Swanson (ARCN Terrestrial Ecologist) and Amy Larsen (NPS Water Resources Division [WRD] Aquatic Ecologist). Collaborators may include Mike Goosef (Pennsylvania State University), Jeremy Jones (University of Alaska Fairbanks), Torre Jorgenson (ABR, Inc.), and Matt Nolan (University of Alaska Fairbanks).

Development Schedule, Budget, and Expected Interim Products

A Permafrost Monitoring Protocol with Standard Operating Procedures will be completed for peer review by March 2010. The protocol will be developed on the following schedule:

- Winter 2008–09: Develop draft protocol.
- Winter 2010–11: Protocol peer-reviewed and finalized. Imagery acquired (cost to be determined but will likely be included with the Terrestrial Landscape Patterns and Dynamics vital sign).

Protocol Development Summary

Protocol: Surface Water Dynamics and Distribution

Parks Where Protocol will be Implemented: BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

Aquatic ecosystems in the ARCN are abundant and diverse. More than 200 turbid headwater streams originate from glaciers in the ARCN with even more clear-running streams and rivers. Tens of thousands of lakes and ponds are distributed throughout the network. Lagoons and estuaries are embedded along the coastlines. A complex mosaic of wetlands forms the interface between terrestrial and aquatic ecosystems. The fluvial geomorphology of the ARCN is largely dictated by interactions between hydrology and permafrost. Climate warming will undoubtedly alter these interactions.

Climate warming in the Arctic is expected to accelerate the hydrologic cycle, increasing soil water holding capacity and altering the balance between precipitation and evapotranspiration, leading to a warmer, drier Arctic (Chapin et al. 2002). By increasing depth of the active layer, melting of permafrost will increase hydraulic conductivity, soil water-holding capacity, and connections between water flowing from the soil to groundwater. These subsurface changes may decrease connectedness, size, and number of lakes, streams, and rivers across the ARCN. Decreases in quantity of water and connectedness of lakes and streams may place further limitations on the abundance and distribution of fish populations surviving in an already extreme environment.

In the past 5 years several studies in arctic and subarctic regions have documented declines in lake surface area (Riordan et al. 2006, Smith et al. 2005, Yoshikawa and Hinzman 2003) and an increase in permafrost melting and degradation that is associated with a rise in temperature in high-latitude regions. Extensive permafrost degradation has been documented in western Canada (Bielman et al. 2001), Russia (Pavlov 1994), China (Ding 1998), Mongolia (Shakuu 1998) and interior Alaska (Osterkamp et al. 2000). The cascading effects of warming conditions on aquatic ecosystems will be magnified in this region where ice plays such an important role in the hydrologic cycle.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be address by this protocol include:

- What are the long-term trends and natural level of variation in streams, lake, and lagoon surface area and distribution of water bodies?
- How are hydrologic networks changing?
- What is the natural variation in flood frequency and extent?
- What is the natural variation in the duration and timing of the open water season?
- Is changing land cover affecting the distribution and characteristics of streams, lakes, and lagoons?

Objectives are as follows:

- Determine long-term trends and variability in lake surface area and number of lakes in BELA and KOVA.
- Determine long-term trends in key characteristics (eg., node frequency, sinuosity, distance between nodes, network patterns, bifurcation rates) of stream networks in intensively monitored watersheds in KOVA, GAAR, NOAT, BELA, and CAKR.

Basic Approach

Aspects of the vital sign will be monitored under the Lake Communities and Ecosystems, Stream Communities and Ecosystems, and Lagoon Communities and Ecosystems vital signs. Work specific to this vital sign will only occur if additional resources become available. If resources do become available, the following approach will be taken:

Lake surface area and abundance: Routine remote sensed images will be collected from select index sites annually to estimate lake surface area and number. These images will be used in combination with historic photographs and satellite images to identify long-term trends in lake surface area and number. Initially a retrospective analysis of available imagery will take place. Specific protocols for this metric will be developed via cooperative agreements.

Stream networks: A small subset of watersheds in the ARCN will be monitored for changes in key characteristics, including node frequency, sinuosity, distance between nodes, network patterns, bifurcation rates, and erosion rates. These characteristics will be monitored via remote sensed imagery every 5 years. An initial retrospective analysis using historic images will occur.

Principal Investigators and NPS Lead

The NPS contacts for protocol development is Greta Burkart (ARCN Aquatic Ecologist). Ben Jones (USGS) and Guido Grosse (University of Alaska Fairbanks) may be contracted to develop remote sensing techniques for this vital sign.

Development Schedule, Budget, and Expected Interim Products

Detailed protocols for monitoring Surface Water Dynamics and Distribution will occur only if additional resources become available. No costs are currently anticipated for monitoring this vital sign.

Protocol Development Summary

Protocol: Coastal Lagoon Communities and Ecosystems [short name: Lagoons]

Parks Where Protocol will be Implemented: CAKR

Justification/Issues being addressed

The total shoreline in the ARCN, including bay and barrier island ecosystems, is approximately 450 km (250 miles). This is the third largest block of coastline that the NPS manages. Cape Krusenstern National Monument, located along this coastline, contains five coastal lagoons, Akulaaq, Imik, Kotlik, Krusenstern, and Sisualik. These lagoons are likely to be essential fish nurseries, over-wintering habitats, and major feeding locations along coastal bird migration routes (ARRT 2001). The lagoons provide critical habitat for subsistence resources, mainly whitefish (Uhl and Uhl 1977, Georgette and Shiedt 2005). Residents from nearby Kivalina, Noatak, and Kotzebue utilize the monument for subsistence activities, one of which is harvesting whitefish from the lagoons (Reynolds et al. 2005). One of the overarching objectives of the ARCN is to better understand the interaction between subsistence activities and ecosystem dynamics. To capture this interaction, we will simultaneously collect data on social science and natural science to allow for a comparative and more comprehensive understanding of CAKR lagoon ecosystems. Little data exist on the five coastal lagoons in CAKR, which makes management of these lagoons difficult. Key reasons for monitoring the coastal lagoons in CAKR include:

- lagoons provide habitat for subsistence resources;
- minimal baseline data exist for the lagoons;
- lagoons are identified in the Alaska Coastal Management Program as areas of management concern;
- lagoon monitoring is identified in the General Management Plan for CAKR as a management objective;
- monitoring will increase understanding of shallow arctic coastal lagoons and provide information about these under-studied systems; and
- monitoring will provide insight into climate change in the Arctic.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What is the temporal variability of water quality parameters in the lagoons?
- What is the temporal variability in the water level of each lagoon?
- What is the surface area of each lagoon, and how is it changing over time?
- What is the species richness and relative abundance of biota in the lagoons?
- What is the annual variability of subsistence activities in the lagoons, and is it changing over time?

Objectives are as follows:

- Determine seasonal and long-term trends in dissolved oxygen, salinity, conductivity, and pH on a semiannual basis in the coastal lagoons of CAKR.
- Determine long-term trends in water level in each CAKR lagoon.
- Determine long-term trends in nutrient concentrations (total N and total P), zooplankton biomass, and phytoplankton biomass in CAKR lagoons.
- Detect changes in the hydrologic structure (open or closed to oceanic inputs) and surface area of CAKR coastal lagoons.

- Identify the resident fish species, determine the contaminant load of key subsistence fish resources, and determine long-term trends in contaminant load for each identified species.
- Identify subsistence activities in the lagoons, and determine long-term trends in human use patterns.

Basic Approach

There will be a three-tiered approach to monitoring the coastal lagoons in CAKR. Tier 1 samples will be collected on a semiannual basis, once during ice-covered conditions and once during open water conditions. The samples collected will include: water quality parameters (temperature, dissolved oxygen, salinity, conductivity, and pH), meteorological parameters (air temperature, wind speed, and wind direction), ice thickness, and snow depth. Continuous data loggers will be deployed into the water column after ice break-up and will be retrieved at the onset of ice formation in the lagoons. Existing weather stations (Kivalina, Red Dog Mine, and Kotzebue) will be utilized to collect continuous meteorological data. Traditional Ecological Knowledge (TEK) interviews will be conducted annually during the open water sampling period as well as on an opportunistic basis. We will work collaboratively with other agencies and organizations (i.e., ADF&G, Maniilaq) during their harvest surveys if lagoon resources are part of the surveys. During the first year of sampling, TEK interviews will be open-ended and semi-directed. Structured interviews will then be conducted based on the information collected from the open-ended and semi-directed interviews. These structured interviews will then be conducted on an annual basis. Tier 2 samples will be collected every 5 years and will include: fish species richness and abundance, zooplankton biomass, phytoplankton biomass, and nutrients. Tier 3 samples will be collected every 10 years and will include: aerial photos, surface area, sediment contaminants, contaminant testing of subsistence fisheries, and genetic testing of subsistence fisheries.

All samples in Tier 1, Tier 2, and Tier 3 will be collected during the first year of monitoring. This will establish a baseline and allow comparative changes to be documented throughout time. These data will provide park managers with information to help make informed management decisions.

Existing protocols (e.g. USGS-NAWQA, EPA-EMAP, USFWS, AMAP) will be utilized to collect natural resource data, but modifications will be made to accommodate for site-specific challenges (e.g. logistics, weather, types of sampling gear, etc.). Many of these challenges have been identified (Reynolds et al. 2005), so exploratory research will not be needed for protocol development.

Existing protocols (e.g., EPA, ADF&G, Romney et al. 1986, Weller and Romney 1988, D'Andrade 1989, Johnson 1990, and Johnson and Griffith 1998) will be utilized to collect and analyze social science data. Modifications will be made to accommodate for site-specific challenges. Exploratory research will not be required for protocol development.

Principal Investigators and NPS Lead

Principal Investigators will be Melinda Reynolds and Terry Reynolds, both East Carolina University Ph.D. candidates. NPS Lead will be Amy Larsen (WRD Aquatic Ecologist).

Development Schedule, Budget, and Expected Interim Products

The protocol will be developed on the following schedule:

- FY 2008: Produce a draft protocol ready for external peer review by September 30, 2008 ($24,000).
- Fall 2008: peer review and revision.
- Spring 2009: Protocol finalized.
- Summer 2009: Protocol implemented (~$30,000).

Protocol Development Summary

Protocol: Lake Communities and Ecosystems

Parks Where Protocol Will be Implemented: BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues being addressed

The water quality portion of the ARCN inventory and monitoring program has been tasked with providing park managers information regarding the status and trends of aquatic resources in the park units. According to the NPS Water Resource Division (WRD), this information should provide multiple lines of evidence to discern between various stressors. The information gained should also be useful in formulating and defending regional and national environmental policies (WRD and Natural Resource Challenge Mission).

Lakes in ARCN provide important habitat for aquatic primary producers, zooplankton, macroinvertebrates, and secondary consumers such as fish and waterfowl. Because these lakes are important to wildlife, subsistence users, and the scenic quality of the park, the NPS Organic Act and ANILCA mandate that their value and status be understood and protected.

Because lake ecosystems act as integrators of catchment-scale processes, changes in water quality are often indicative of local, regional, and global stressors to local environments. In ARCN these stressors may include visitor use, contaminant deposition, increased air temperatures, melting permafrost and glaciers, and alterations in the hydrologic cycle and terrestrial biogeochemistry. Recent studies have documented high rates of change in the formation and disappearance of many high-latitude lakes.

Measurements of lake levels and discharge are fundamental to understanding the availability of aquatic habitats and to the biophysical characteristics of the ARCN park environment. Water quality (especially temperature, specific conductance, pH, dissolved oxygen, turbidity, and nutrients) is important to the survival, growth, and reproduction of aquatic organisms.

The majority of lakes in ARCN are shallow thaw ponds and oxbow lakes found in river valleys. Shallow oxbow lakes tend to be productive and often serve as important fish rearing habitat when connected to rivers during critical time periods. Because depths of oxbow lakes and the potential for accessibility by fish are closely related to river discharge, these shallow lake ecosystems are sensitive to stressors, such as climate change, that are predicted to alter the flow regime of arctic rivers.

Large lakes in ARCN were formed by volcanic explosions, geologic rifts, and glacial activity. These large deep lakes support diverse fish populations, are important to subsistence users, and are renowned for their sport fishing. The largest lakes in ARCN, Walker and Imuruk Lakes, are National Natural Landmarks.

Specific Monitoring Questions and Monitoring Objective to be Addressed by the Protocol

Some of the specific monitoring questions that will be addresses by this protocol include:

- What are the long-term trends in water level of shallow lakes? What are the long-term trends in water budgets for deep lakes?
- What are the long-term trends in water temperature of shallow lakes? What are the long-term trends in seasonal water temperatures, including the presence, timing, and strength of thermal stratification in deep lakes?
- What are the long-term trends in light availability and water chemistry in deep and shallow lakes?
- What are the long-term trends in biological indicators in deep and shallow lakes?

Objectives are as follows:

- Detect decadal scale changes in water level in shallow lakes. Determine long-term trends in water level and surface water inputs and outputs of deep lakes.
- Determine long-term trends in surface water temperature in shallow lakes. Determine long-term trends and seasonal variation in water temperature in deep lakes.
- Determine long-term trends in turbidity, light penetration, pH, dissolved oxygen, specific conductivity, and nutrients in deep and shallow lakes.
- Determine long-term trends in community composition of phytoplankton and resident fish in deep lakes.

Basic Approach

The ARCN plans to monitor long-term trends in chemical, physical, and biological characteristics of lake ecosystems using a watershed perspective. Our primary monitoring efforts will inform park managers about the current status and trends in the condition of particularly important lakes and their surrounding catchments. Our secondary monitoring efforts will focus on integration of lake monitoring efforts with other ARCN vital signs that may affect the catchments of the aquatic systems. These other vital signs include Stream Communities and Ecosystems, Snowpack, Climate, Permafrost, Fire Extent and Severity, and Wet and Dry Deposition.

We will monitor shallow lakes in areas where they are highly concentrated within BELA, KOVA, and NOAT. Lakes in each of the parks will be selected according to a generalized random tessellation stratified sample (GRTS). Twenty to thirty lakes will be selected in each park unit following a power analysis. This spatially balanced sampling design will allow us to extrapolate our findings to these critical regions within BELA, KOVA, and NOAT. Sites will be revisited every three years. The Principal Investigator for this vital sign is also monitoring shallow lakes in Central Alaska Network and will apply the same methodology in both networks. Therefore, we anticipate a rapid development of the protocol.

For large lakes, we will use a spatially balanced sampling design, and our population of interest will include lakes that are accessible by float plane (most will have a maximum linear dimension greater than 1.5 km). Lakes will be selected using a GRTS model stratified by physiography and vegetation. Lakes of management concern will be forced into the model, and FY2008 monitoring efforts will focus on these lakes. Each year, 10 lakes will be sampled. A revisit design will be selected following consultation with a statistician. Monitoring of large lakes will be conducted in concert with the development of an outreach program. A key part of this program will be to provide a visual context for monitoring data.

Principal Investigators and NPS Leads

The Principal Investigators are:

- Shallow lakes: Amy Larsen (WRD Aquatic Ecologist)
- Deep lakes: Greta Burkart (ARCN Aquatic Ecologist), and Chris Luecke (Utah State University).

Development Schedule, Budget and Expected Interim Products

- Summer 2008: Protocol development and site evaluation: shallow lakes ($60,000), deep lakes ($40,000)
- December 2008: Draft protocol ready for peer review.
- Summer 2009: Finalize and implement protocol ($100,000).

Protocol Development Summary

Protocol: Stream Communities and Ecosystems

Parks Where Protocol Will be Implemented: BELA, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

There are seven National Wild and Scenic Rivers in ARCN, including the Noatak, Salmon, Kobuk, Alatna, John, Tinayguk and North Fork of the Koyokuk rivers. The Kobuk and Noatak rivers are the largest rivers in northwest Alaska and together drain an area of 63,654 km^2. More than 200 turbid headwater streams originate from glaciers in the Brooks Range; however, the majority of streams in ARCN run clear. Due to the stabilizing effect of permafrost on soils, relatively low topographic relief, and low levels of precipitation, average sediment loads in many ARCN streams and rivers are low compared to sediment loads in other Alaskan rivers. There are several spring streams, including tributaries of the Reed River, Kugrak River, and Alatna River. Traditional knowledge indicates these springs do not freeze solid during winter and are an important habitat for overwintering resident and anadromous fish species. The Noatak River, which originates in GAAR, flows into NOAT, where the river and its surrounding watershed have been designated as an internationally recognized Biosphere Reserve (UNESCO).

Potential local impacts on flowing waters in ARCN include consumptive use of stream and river resources, road construction, industrial development, mining, and nonpoint source petrochemical pollution from snowmobiles and motor boats. Potential global stressors on flowing waters in ARCN include wet and dry deposition of contaminants and climate change. These local and global stressors are likely to affect water quantity and quality and species diversity within these systems.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- How is water quantity and/or temperature changing in wadeable streams and large receiving rivers within ARCN watersheds?
- What are the trends in diatom and macroinvertebrate assemblages in streams, and how do the status and trends of these communities relate to trends in hydrology, temperature, and water quality?
- How do changes detected in watershed characteristics measured by other inventory and monitoring initiatives in ARCN relate to the current status of streams and large rivers?

Objectives are as follows:

- Determine long-term trends in water temperature, pH, conductivity, dissolved oxygen, flow/stage/level, total N, total P, and chlorophyll a in selected wadeable streams and large receiving rivers in ARCN parks.
- Determine variability and long-term trends in species composition of macroinvertebrate and diatom communities in ARCN streams and rivers.

Basic Approach

Because watersheds act as integrators of the atmosphere and surrounding landscape, we intend to use watershed monitoring as a tool for understanding the natural variability and cumulative effects of local, regional, and global stressors on aquatic ecosystems. We will monitor stream communities and ecosystems in a phased approach. Data collected during Phase 1 will be used to determine general status and trends of chemical, physical, and biological characteristics of aquatic resources. During Phase 1, we will intensively sample stream ecosystems and surface water dynamics and distribution in six primary watersheds. In Phase 2, several extensive watersheds will be sampled less intensively

on a rotating basis. These sites will provide data for model input and verification. Watersheds will be selected to represent extreme ends of physiographic gradients and by interconnectedness with other vital signs, in particular Climate, Permafrost, Snowpack, and Terrestrial Vegetation and Soils. Ground-based sampling will be conducted every four years. Between ground-based sampling efforts, data loggers will continuously record temperature and discharge.

During Phase 1 we hope to make efficient use of existing data to refine an existing thermal-hydrologic model for arctic systems (Zhang et al. 2000). Meteorological data will be used for model input. Physical data will be used for model verification and refinement of the hydrologic model. Additional chemical and biological data will be used in combination with NRCS soils data and ARCN vegetation data to create and validate biogeochemical and biological aspects of this process-based model. This model will allow us to assess the efficiency of our ground-based water quality sampling efforts and may ultimately allow us to decrease ground-based sampling efforts in favor of remotely sensed data, meteorological data, and computer simulation modeling during Phase 2.

When logistically feasible, we will use methods developed by the National Ecological Monitoring and Assessment Plan. Many of these methods will be modified to deal with specific needs of working in remote arctic locations. NPS leads will collaboratively devise protocols with university cooperators and solicit advice from others as needed.

Principal Investigators and NPS Lead

NPS Lead will be Greta Burkart (ARCN Aquatic Ecologist).

Development Schedule, Budget and Expected Interim Products

- Summer 2008: Protocol development and site evaluation ($40,000)
- FY 2009: Draft protocol and test methodology ($40,000).
- FY 2010: Finalize and implement protocol ($40,000).

Protocol Development Summary (Deferred)

Protocol: Invasive/Exotic Plant and Animal Species and Diseases

Parks Where Protocol will be Implemented: BELA, KOVA, CAKR, NOAT, GAAR

Justification/Issues Being Addressed

Invasive and/or exotic plant or animal species and diseases are a concern in the Arctic Network. Invasive species often possess reproductive characteristics that allow them to compete with and dominate native species. They tend to have short reproductive cycles and produce prolific offspring. Exotic species often lack predators, which further enables them to outcompete and/or dominate local populations. These characteristics may eventually allow exotic plant species to form monocultures. Exotic taxa frequently harbor diseases to which they are resistant but which, once introduced into a new environment, attack native species that lack resistance. Pack animals, pets, and migratory species may also harbor disease organisms novel to resident wildlife. Some taxa, once introduced, are even capable of altering ecosystem structure and function (e.g., pike).

Potential pathways for introduction of invasive and exotic species and diseases are road corridors, river corridors, ATV trails, aircraft landing sites (including float plane lakes), migratory species, pack animals, pets, animal feed, and visitor use. Climate change and human use of the parks are expected to increase the rate of introduction of nonnative species and diseases to the Arctic. The monitoring protocol for this vital sign must be responsive to the needs of both the individual parks and the network as a whole, in particular regarding monitoring those species and organisms that are predicted to have a quick and/or profound impact on native species and communities. Because it is critical to detect the appearance and rate of change regarding exotic/invasive species and disease, this vital sign will be a component of monitoring protocols for several vital signs, including Terrestrial Vegetation and Soils, Lagoon Communities and Ecosystems, Lake Communities and Ecosystems, Stream Communities and Ecosystems, Fish Assemblages, Bird Assemblages, Brown Bears, Caribou, Dall's sheep, Moose, Muskox, and Small Mammal Assemblages.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What exotic species and diseases are present in the ARCN, and where are they established?
- Are exotic and invasive species and diseases becoming more common in the ARCN?

Objectives are as follows:

- Detect and document the presence of exotic and invasive plant and animal species and diseases in the ARCN parks.
- Develop and maintain a list of target species that do not currently occur in the parks, occur in localized areas, or are extremely rare, but that would cause major ecological problems if they were to become established.

Basic Approach

The general strategy the network will use to monitor Invasive/Exotic Plant and Animal Species and Diseases will be to gather information in conjunction with other vital signs that have been given higher priority by the ARCN technical committee or by harvesting data collected by other entities.

For plants, presence data of exotic species will be collected during any of the vegetation monitoring. Monitoring specifically for exotic plants in Alaska parks is conducted primarily by the NPS-Alaska

Exotic Plant Management Team (NPS-EMPT). Alaska EPMT survey data (species distribution and control monitoring) are stored in the Alien Plant Control and Management (APCAM) database and will be acquired by ARCN staff. Procedures for data collection and management are documented in the APCAM procedures manual (APCAM 2005). Many other agencies also conduct exotic plant surveys and control actions in Alaska. These data, including the NPS-EPMT data, are captured in the Alaska Exotic Plants Information Clearinghouse (AKEPIC) and database (AKEPIC 2004). The AKEPIC database will be reviewed annually. If invasive plants are reported in or near ARCN parks, tabular and geographical data will be downloaded from AKEPIC into ARCN databases.

For exotic animals and diseases, the main strategy will be to rely on the Alaska Department of Fish and Game and other sources for general information about range changes and introductions of animal species and diseases. The annual network report will include updated information on exotic animals of potential concern to ARCN parks. When information suggests that an exotic animal or disease may be extending its range into a ARCN park, park managers will be alerted so that appropriate action can be taken.

If additional resources become available, more targeted investigation into invasive and exotic species may occur. Many protocols are already developed by other groups monitoring various species. For exotic plants, monitoring high-risk areas along road corridors, villages, access points, and heavily traveled transportation routes (airstrips, navigable waters etc.) will be a priority. For animal diseases, blood and tissue samples of captured or hunter-killed animals may be used.

Principal Investigators and NPS Lead

The NPS/ARCN lead on this vital sign will vary by taxa. For exotic plants, the ARCN Terrestrial Ecologist, David Swanson, will be the lead. NPS wildlife biologists Brad Shults, Kyle Joly, and Melanie Flamme will contribute to monitoring exotic animals and wildlife diseases. The data management lead will be ARCN Data Manager, Scott Miller. GAAR Natural Resource Specialist, Jobe Chakuchin, will be a collaborator. Cooperators for exotic plants will include Jeff Hayes (NPS exotic plant ecologist) and for wildlife disease, Kimberlee Beckman (Alaska Department of Fish and Game Veterinarian).

Development Schedule, Budget and Expected Interim Products

Detailed protocols for monitoring Invasive/Exotic Plant and Animal Species and Diseases will occur only if additional resources become available. No costs are currently anticipated for monitoring this vital sign.

Protocol Development Summary (Deferred)

Protocol: Fish Assemblages

Parks Where Protocol will be Implemented: BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

Fish populations and their associated habitats are particularly important to residents who rely on subsistence resources within and near park units. Coastal lagoons in ARCN have been the primary fishing areas for local indigenous populations for the past 9,000 years. Under ANILCA, because subsistence fish species and their associated habitats are important to local communities, they must be managed, protected, and preserved. Fish are also important to visitors who may be attracted to some parks because of the quality of sport fishing and/or unique species available. Many of the large deep lakes in ARCN (e.g., Chandler, Selby, Feniak, Matcharak, and Walker Lakes) are renowned for their fisheries resources. Because productivity in northern lakes is low, there is a potential for over exploitation. Despite their remoteness, the arctic park units receive disproportionately high levels of deposition of semi-volatile organic compounds, such as mercury (Hg) and persistent organic pollutants from global industries. Long-lived fish species occupying higher trophic levels, such as northern pike, burbot, and sheefish, provide a useful means of assessing bioaccumulation of contaminants (Jewett and Duffy 2007) across landscapes, which may vary in their ability to process and, in some cases, biomagnify contaminants. A 2006 survey that included two lakes in ARCN (Landers et al. 2008) found that concentrations of methylated Hg in lake trout in these lakes were higher than recommended for consumption: however, fish from the rest of ARCN have not been sampled. Thus, there is a strong need to conduct contaminant sampling in high subsistence areas.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Specific monitoring questions that will be addressed with this protocol include:

- What are the trends in fish species distribution and habitat associations in ARCN streams, lakes, rivers, and coastal lagoons and how do these trends relate to presence of exotic species/diseases and trends in water quality, hydrologic, and habitat alterations in these ecosystems?
- How are consumptive use and/or intense human use of habitat impacting fish assemblages and size distributions in lagoons and large deep lakes?
- What are the status and trends of contaminant concentrations in piscivorous and benthivorous fish?

Objectives are as follows:

- Determine long-term trends in fish community composition and condition (length-weight relationship) during monitoring of stream, lake, and lagoon ecosystems in ARCN.
- Determine long-term trends in abundance and size of targeted fish species (e.g., species that are harvested) from selected sites in highly accessible large deep lakes and lagoons and remote lakes and lagoons.
- Determine select contaminant concentrations in piscivorous and benthivorous fish captured while monitoring stream, lake, and lagoon ecosystems in ARCN.

Basic Approach

Because freshwater and anadromous fish are good integrators of long-term landscape-scale change, trends in fish distributions, contaminant concentrations, harvest, and habitat quality will be linked to several other vital signs being monitored by ARCN. These vital signs include Lake Communities and Ecosystems, Stream Communities and Ecosystems, Lagoon Communities and Ecosystems, Surface Water Dynamics and Distribution, Subsistence Harvest/Use, Invasive/Exotic Species and Diseases, Fire

Extent and Severity, Terrestrial Vegetation and Soils, Terrestrial Landscape Patterns and Dynamics, Snowpack, Climate, Wet and Dry Deposition, Point Source Human Effects, and Visitor Use vital signs.

We plan to share data and collaborate with the Alaska Department of Fish and Game (ADF&G), employing their methods when feasible. Since the early 1980s, ADF&G has conducted periodic surveys of anadromous fish in and around the ARCN parks units. We will use ADF&G harvest reports to monitor trends in fish harvest. In 2008, ADF&G will conduct sampling of sheefish movement and distributions in reaches of the Kobuk River near GAAR and KOVA. This study will provide valuable information informing development of a fish monitoring program in the ARCN.

We will work with the Central Alaska Network Aquatic Ecologist and University of Alaska Fairbanks fish biologists to further develop protocols for monitoring fish assemblages. We will also solicit advice and assistance from fisheries experts at U.S. Fish and Wildlife Service, local consulting agencies, and Utah State University. We will pursue development of protocols and processing of samples for biocontaminants in fish. Future collaborations may include Alaska Department of Environmental Conservation, environmental toxicologists, and fish biologists. Field work involving collection of freshwater and anadromous fishes will be conducted in conjunction with sampling efforts for aquatic vital signs when possible. High priority lakes, streams, rivers, and lagoons may be sampled every 2 to 5 years, while low priority systems will be sampled every 5 to 15 years or on a one-time only basis.

Principal Investigators and NPS Lead

The NPS Lead will be Greta Burkart (ARCN Aquatic Ecologist).

Development Schedule, Budget, and Expected Interim Products

Detailed protocols for monitoring Fish Assemblages will occur only if additional resources become available. No costs are currently anticipated for monitoring this vital sign.

Protocol Development Summary

Protocol: Landbirds

Parks Where Protocol will be Implemented: BELA, CAKR, GAAR, NOAT, KOVA

Justification/Issues Being Addressed

All five ARCN park units are mandated under ANILCA to protect bird habitats and various assemblages of avian species. Under ANILCA [Section 201(8)], protection of populations of and habitat for waterfowl, raptors, and other species of birds is specifically mandated in NOAT. For BELA, ANILCA specifies that the preserve shall be managed to protect habitat for internationally significant populations of migratory birds. For CAKR, ANILCA mandates protections including habitat for and populations of birds. In addition, several international treaties, federal laws, and initiatives provide protections for migratory birds and require action by NPS (Migratory Bird Treaty Act, Endangered Species Act, North American Bird Conservation Initiative).

The landbirds assemblage (passerines, near-passerines, and galliformes) was chosen by the ARCN for long-term monitoring because it encompasses a great variety of species that spend the majority of their life in terrestrial environments. Standardized methods for monitoring landbirds are well established and currently utilized by several networks. Landbirds are an important component of park ecosystems, and their high body temperature, rapid metabolism, and high ecological position in most food webs make them good indicators of the effects of local and regional changes in ecosystems (Fancy and Sauer 2000). Changes in landbird ecology and demography have been demonstrated to be indicators of global climate change (Sillett et al. 2000). Passerine birds comprise more than 50% of the bird species in ARCN.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What are the population trends in six common passerine species (gray-cheeked thrush, varied thrush, golden-crowned sparrow, American tree sparrow, savanna sparrow, and white-crowned sparrow) in selected sites across ARCN during the breeding season (June)?
- What are the long-term trends in landbird species composition and distribution in selected sites across ARCN during the breeding season (June)?
- In what habitat/vegetation associations are the six common passerine species found in selected sites across ARCN during the breeding season (June), and how are these changing over time?

Objectives are as follows:

- Determine biennial long-term trends in density and frequency of occurrence of six common passerine species in selected sites across ARCN during the breeding season (June).
- Determine biennial long-term trends in landbird species composition and distribution in selected sites across ARCN during the breeding season (June).
- Improve understanding of breeding bird-habitat relationships and climatic changes on bird populations by correlating changes of six common passerine species with changes in habitat and climate variables.

Basic Approach

The first two objectives are the top priorities for the landbird monitoring program. The third objective provides valuable insight into the health and status of landbirds in the selected sites of ARCN where monitoring will occur. Collection of vegetation and environmental variables will be collected for

objectives 1 and 2 in association with the landbird survey as per Alaska Landbird Monitoring Survey (ALMS) and Guldager (2003). Habitat data, including species composition, percent cover of various shrubs, grasses, mosses, lichens, and other vegetation as well as classification of 100 m radius of vegetation to Viereck Level III (Viereck et al. 1992), will be collected around each point. The third objective will be approached adaptively depending on funding, staffing, and allocation of time to this vital sign.

For the first two objectives, methods for monitoring landbirds are well established and have been refined and implemented by several networks. However, the extensive land areas of the ARCN present logistical and fiscal challenges for landbird monitoring. Some sampling designs are cost-prohibitive due to the dependence on extensive fixed-wing and/or helicopter support for remote access to sampling sites. For this reason, landbird monitoring for relative population levels and bird-community composition and distribution in ARCN will be accomplished biennially using modified ALMS (Handel and Cady 2004) protocols with limited inference space along riparian corridors as per Guldager (2003, 2005). These affordable surveys were designed for two-person crews to sample 12 transects (of 12 point-transects each) along major river corridors throughout ARCN. The survey consists of a systematic sampling design with a random start point, using variable circular plot methodology with unlimited distance estimation. Surveys are conducted during the breeding season (June) as early as river access is possible after spring thaw.

Principal Investigators and NPS Lead

The NPS leads on this vital sign will be Melanie Flamme (YUGA Biologist). Collaborators in this process will be Teri McMillan (YUGA Ranger), Susan Sharbaugh (Alaska Bird Observatory Biologist) and Brad Shults (WEAR Biologist).

Development Schedule, Budget, and Expected Interim Products

A cooperative agreement will be established with the Alaska Bird Observatory to write protocols, train and hire technicians, and provide staff to perform some of the field work and analyses.

Full development of the protocol will proceed on the following schedule:

- Spring 2009: Draft protocols and SOPs of survey techniques ready for peer review
- Spring 2010: Implement and test protocol ($20,000—two crews on two rivers)
- Spring 2011: Protocols reviewed and finalized.

Protocol Development Summary

Protocol: Yellow-billed Loons

Parks Where Protocol will be Implemented: BELA, CAKR

Justification/Issues Being Addressed

The yellow-billed loon (*Gavia adamsii*) is a species of concern with a global population estimated at 16,650–21,000 (Fair 2002, Earnst 2004). The breeding range in Alaska is restricted to large lakes (>7 hectares; North and Ryan 1989) on the Arctic Coastal Plain of Alaska north of the Brooks Range and in western Alaska on the Seward Peninsula, including Bering Land Bridge National Preserve (BELA), and Cape Krusenstern National Monument (CAKR). Yellow-billed loon distribution and population levels were poorly documented in western Alaska until 2005. In 2005, results from aerial surveys funded by the ARCN and conducted in and around BELA and CAKR generated population estimates for yellow-billed loons and nests of 418 (90% confidence range = 314–521) and 85 (90% confidence range = 56–115), respectively (Mallek et al. 2006). Yellow-billed loons in BELA accounted for 76% (319) of the total population estimate and 76% (65) of the total nest estimate in western Alaska. In CAKR, the yellow-billed loon population and nest estimates accounted for 5% (22) and 4% (4) of the total estimate in western Alaska, respectively. Due to its small population size and restricted distribution, the U.S. Fish and Wildlife Service is currently evaluating a petition to list this species as Threatened or Endangered under the Endangered Species Act.

As a piscivorous species, yellow-billed loons are top predators in lake ecosystems. As top predators, loons are good indicators of water quality and contaminant levels in aquatic systems. Yellow-billed loons are harvested for human subsistence, and this is cause for concern because they may bioaccumulate contaminant loads (i.e., Hg, POPs; Schmutz pers. comm. 2007).

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What are the trends in occupancy of yellow-billed loons in selected sites of BELA and CAKR during the breeding season?
- What are the status and trends in density estimates of yellow-billed loons in selected sites of BELA and CAKR during the breeding season?
- What types and levels of contaminants are present in yellow-billed loons in selected sites of BELA and CAKR during the breeding season, and how are they changing over time?

Objectives are as follows:

- Determine triennial trends in occupancy of yellow-billed loons in selected sites of BELA and CAKR during the breeding season (June).
- Determine triennial status and trends in density estimates of yellow-billed loons in selected sites of BELA and CAKR during the breeding season (June).
- Monitor the types and levels of common contaminants (e.g., mercury, POPs) present in yellow-billed loons in selected sites of BELA and CAKR during the breeding season (June).

Basic Approach

The first two objectives (listed above) are the top priorities for the yellow-billed loon monitoring program. The third objective provides valuable insight into the health and status of the yellow-billed loon population in the selected sites of BELA and CAKR where monitoring will occur. Collection of contaminants sampled from yellow-billed loons involves additional logistics and costs of a fixed-wing

aircraft and/or helicopter, aviation fuel, ground-based sample collection, personnel with this expertise, and sample analyses. To examine contaminants in loons, ARCN will contract with the USGS Biological Resources Division to collect adult feathers (Hg), eggs (organic and inorganic contaminants), and other biological samples to assay for an array of common contaminants. This objective will be approached adaptively depending on funding, staffing, and allocation of time to this vital sign and could potentially be co-located with the Lake Communities and Ecosystems vital sign.

The first two objectives will be achieved through triennial aerial surveys using well-established methodology developed for loons and utilized by U.S. Fish and Wildlife Service in BELA and CAKR in 2005 (Mallek et al. 2006). Adopting these methods will minimize costs and effort for protocol development. Protocol development and surveys will be accomplished by the ARCN and U.S. Fish and Wildlife Service through cooperative agreements. Surveys will be conducted with fixed-wing aircraft with one pilot and one observer counting all loons and nests observed and will occur during the breeding season (mid-June) to increase the opportunity to encounter loons on nests. Population estimates and variances will be derived from expanded density estimates from the selected sample plots using standard statistical techniques for strip/plot survey analysis (Cochran 1977, Smith 1995) as per Mallek et al. (2006).

Extensive collaborative research on various aspects of yellow-billed loon breeding-season ecology and abundance has been ongoing on the north slope of Alaska, and additional studies developing habitat models for the north slope and western Alaska are being proposed (Schmutz pers. com. 2007, Schmutz et al. 2008). Preliminary results indicate that some lakes are consistently observed with breeding birds and others consistently lack them, implying some habitat effects on population dynamics (Schmutz et al. 2008). Results of these studies may prompt refinements in techniques currently utilized to survey yellow-billed loons (Mallek et al. 2006). Improved habitat models may prove useful for selection of sites in BELA and CAKR where monitoring will occur.

Principal Investigators and NPS Lead

The NPS leads for developing this monitoring program will be Melanie Flamme (YUGA Biologist) and Brad Shults (WEAR biologist/pilot). Collaborators in this process will be: Joel Schmutz (USGS Biological Resources Division, Alaska Science Center), Ed Mallek (U. S. Fish and Wildlife Service) and Angela Matz (U. S. Fish and Wildlife Service).

Development Schedule, Budget, and Expected Interim Products

Full development of the protocol will proceed on the following schedule:

- Spring 2010: Draft protocols and SOPs of survey techniques ready for peer review.
- Summer 2011: Implement and test protocol ($30,000).
- Spring 2012: Peer review and finalize protocol.

Protocol Development Summary

Protocol: Brown Bear (*Ursus arctos*) Population Monitoring and Distribution

Parks Where Protocol will be Implemented: BELA, CAKR, NOAT, GAAR

Justification/Issues Being Addressed

Brown bears (*Ursus arctos*) are good indicators of long-term habitat change within park ecosystems because they are a long-lived species, require large quantities of resources from their habitat, and populations have the potential to respond to long-term changes in resources conditions. These animals play important ecological roles as top predators influencing population dynamics of other species including moose and caribou (National Research Council 1997). Brown bears are mentioned in the enabling legislation for BELA, KOVA, NOAT, and GAAR. Brown bears may be harvested by subsistence users throughout the ARCN parks and only in the preserves by sport hunters. Managing brown bear populations presents biological, cultural, and legal challenges for park managers. Baseline ecological data are lacking for brown bear populations in ARCN despite increasing harvest and viewing demands from the public. Brown bear abundance may be a parameter that can be estimated across the network if a logistically simple, statistically rigorous, and cost effective estimator of brown bear abundance can be developed and implemented often (i.e., every 3–5 years in each sampling area).

Two statistical techniques have been predominantly used for monitoring bears in Alaska. The first approach uses capture-mark-recapture (CMR) techniques to estimate abundance and density of bears (Miller et al. 1997). This CMR approach has been used widely across Alaska and has been used for both black (*Ursus americanus*) and brown bears (*U. arctos*). The analytical techniques used for estimation are based on well-developed theory (Pollock et al. 1990). A potential logistical and financial limitation of this approach is that a radio-marked sample of bears must be established and maintained to estimate probability of detecting bears, to monitor movements of bears between the marking and observation period, and ultimately to estimate abundance and density of bears. Therefore, this technique may be of limited application for large study areas where frequent population monitoring is of interest.

More recently, distance sampling with line transects has been employed to estimate bear density (Quang and Becker 1996). During line transect sampling, a transect is traversed and animals are observed at varying distances. The observation distances are used to model the probability of detecting animals at varying distances from the transect (i.e., the detection function) with the assumption that detection of individuals on the line is perfect. This detection function is in turn used to correct raw counts of animals for detection probability and to estimate density. The assumption of perfect detection on the line has been relaxed for aerial surveys because individuals cannot be observed directly beneath the aircraft (i.e., while flying on the transect). Aerial line transect methods have been further modified for bear surveys to allow the use of covariates (e.g., habitat type) related to sightability of individual animals (Quang and Becker 1996), application in mountainous terrain where distance from lines varies with relief (Quang and Becker 1999), and the use of ancillary data (i.e., double count data from two observers) to further relax the assumption of perfect detection on the transect. Like CMR techniques, line-transect estimation has been successfully applied for bear surveys in several areas around Alaska (Becker 2003), and the sampling and analytical components of this approach are based on sound theory (Borchers et al. 2003). However, sample size needs may not be met in areas with low densities of bears (i.e., may require multiple annual surveys), and independence among observers using the double count procedure has been questioned. Therefore, an alternative technique may be useful to monitor bear populations in some areas of Alaska.

ARCN, with the cooperative help of researchers from the University of Alaska, has developed a third methodology better suited to the needs of the vast landscape of the ARCN network. This technique is based upon occupancy sampling and modeling (MacKenzie et al. 2006) and classical statistical estimators that offer statistically valid and cost-effective methods to estimate brown bear populations across the network. This occupancy modeling methodology, as applied to brown bears, was developed following three years of pilot work and testing. This technique will rely more on direct aerial observation of bears during one sampling period which could make it more cost-effective than the current line-transect technique used in Alaska, which may require multiple years of effort to obtain one estimate and is therefore more expensive.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What is the population of brown bears in each sample area and ARCN?
- What is the distribution of brown bears in ARCN parks, and how is it changing?
- How do populations and distribution of brown bears vary in relation to human presence and/or human development?

Objectives are as follows:

- Determine statistically defensible estimates of brown bear populations.
- Develop models of brown bear presence and absence. Incorporate human development metrics into occupancy modeling of brown bears.
- Determine long-term trends in brown bear abundance in the ARCN.

Basic Approach

Statistical Methodology-Occupancy/Distribution

ARCN has field tested and plans to implement occupancy sampling and modeling methodology (MacKenzie et al. 2006) for monitoring brown bear populations in ARCN. Occupancy models are used to estimate the probability of occupancy of sampling units within the larger study area. These models were selected for this species and area because CMR and distance sampling techniques, as traditionally applied to brown bears, are likely not viable in ARCN due to logistical, financial, or statistical restrictions. Occupancy sampling is conducted by visiting a sample of sites within a larger study area and observing individual animals. Sites with no bears present are also recorded. Sampled sites are visited at least twice by independent observers usually within a time period short enough to restrict the probability of births, deaths, immigration, and emigration in sites during the sampling period. From these data, models are used to estimate the probability of detecting presence given a site is occupied, and detection probability is used to correct raw observations of presence to estimate occupancy probability—the proportion of sites within the larger study area that are occupied (MacKenzie et al. 2006)—thus avoiding bias caused by false absences. Estimates of occupancy are calculated with R statistical programs (R-project 2006).

Although the concept of presence/absence sampling has been around for some time, occupancy or presence/absence modeling has gained attention in recent years because some species in some situations can not easily be sampled and modeled using techniques commonly used for more abundant or easily observed species. More importantly, recent developments have provided a more rigorous framework for modeling occupancy and avoiding simplified and unrealistic assumptions about perfect detection of presence (MacKenzie et al. 2006). Occupancy may be considered a surrogate of abundance, particularly for territorial species where the size of the sampling unit is roughly equivalent to

the territory size. However, Garshelis and McLellan (2006) provide necessary advice and caution on the extension of occupancy to abundance, so we have chosen to estimate abundance with a classical parametric estimator. Others view occupancy probability as the appropriate parameter for monitoring programs (Manley et al. 2004), and occupancy modeling is currently being used for monitoring avian, mammalian, and amphibian species (MacKenzie et al. 2006).

Statistical Methodology-Abundance Estimation

Brown bear abundance is estimated with a stratified simple random sample estimator originally developed for estimating the abundance of moose (Gasaway et al. 1986). The resulting estimate is "corrected" for visibility bias provided by double sampling (Graham and Bell 1989). Sampling variance for the corrected abundance estimate is calculated according to Goodman (1960). However, additional estimators may be more appropriate for these data, especially the estimator developed by Royle and Nichols (2003). An appropriate abundance estimator will be chosen prior to implementation in 2009.

Principal Investigators and NPS Lead

Protocol development will be accomplished through a cooperative agreement with the University of Alaska Fairbanks (UAF) for occupancy modeling. Abundance estimation will be developed with the University of Alaska Fairbanks and a contract with Ver Hoef Statistical Consulting. Principal NPS Investigator will be Brad Shults. Project cooperator will include Alaska Department of Fish and Game Unit 22 and 23 Area Biologists.

Development Schedule, Budget, and Expected Interim Products

Protocol development has occurred over the last three field seasons. Full development of this protocol will progress on the following schedule:

- Summer 2008: Final protocol testing and evaluation ($60,000).
- December 2009: Draft protocol ready for peer review.
- Summer 2009: Finalize and implement protocol ($60,000).

Protocol Development Summary

Protocol: Western Arctic Caribou Herd [short name: Caribou]

Parks Where Protocol will be Implemented: BELA, KOVA, CAKR, NOAT, GAAR

Justification/Issues being addressed

Caribou (*Rangifer tarandus*) have consistently ranked high as a vital sign for the ARCN. At an estimated population size of over 490,000 animals (Western Arctic Herd Working Group 2003), the Western Arctic Herd (WAH) is the largest caribou herd in Alaska and a significant ecological force in northwestern Alaska. The WAH has a substantial cultural impact in that the heritage and traditions of Alaska Natives in approximately 40 subsistence-based communities in the region have been shaped by the availability of these caribou (Western Arctic Herd Working Group 2003). The availability of WAH also affects the economics of this region. The presence and relative abundance of WAH caribou have substantial impacts on the populations of wolves, bears, and wolverines in the area. Caribou are good integrators of regional conditions in northwestern Alaska because of their migratory nature. Caribou may have substantial effects on plant and lichen communities and by extension wildlife communities, either directly through browsing and grazing or indirectly through biogeochemical cycling. Key reasons for monitoring the WAH in network parks are that caribou are:

- an extremely important subsistence species that occur in all park units within this network;
- specifically identified in the management objectives of GAAR, KOVA and NOAT;
- directly impact reindeer and reindeer herders in BELA;
- considered good indicators of the condition of park ecosystems because they consume lichens and fungi making them good bio-indicators of environmental toxins; and
- the focus of national and international datasets for caribou herds and caribou ecology across the arctic region.

Successful monitoring of the WAH by ARCN and NPS staff will require integration with existing efforts by the Alaska Department of Fish and Game (ADF&G), U.S. Fish and Wildlife Service (FWS), and the Bureau of Land Management (BLM).

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- Are the movements, and distribution of WAH caribou changing in ARCN?
- What is the physical condition of the WAH?
- How do caribou utilize and affect plant and lichen communities?*

** Note: It is recognized that the effect of caribou on plant and lichen communities may not be considered baseline monitoring. This question, however, will be addressed through integrating with other vital signs and other natural resources activities in the ARCN parks and will not cost additional funds other than staff time.*

Objectives are as follows:

- Determine long-term trends in caribou distribution and movements using GPS locations.
- Determine long-term trends in physical condition of WAH caribou either by recording body weights and measurements (as outlined by the CircumArctic Rangifer Monitoring and Assessment protocol) or by stable isotope analysis.

- Determine long-term trends in habitat condition by evaluating plant communities and forage availability.
- Determine long-term trends in sex and age composition of WAH caribou.*

** ADF&G is the lead agency monitoring these indices using capture data, satellite and conventional radiocollars, annual fall (October) composition surveys, spring (April or May) recruitment surveys, and June calving surveys. ARCN will develop protocols to enhance and assist these ongoing efforts following consultation with ADF&G, FWS, and BLM.*

Basic Approach

The ADF&G has taken the lead role in monitoring WAH caribou for a number of years. In recent years other natural resource agencies, including the Alaska Department of Natural Resources (ADNR), BLM, FWS, and NPS have become more involved. This involvement, as well as the involvement of a number of stakeholders, is apparent in the development of the Western Arctic Caribou Herd Working Group and the Western Arctic Caribou Herd Technical Committee. The working group was developed to exchange information and reach consensus on recommendations for research, monitoring, regulation, allocation, and enforcement (Western Arctic Caribou Herd Working Group 2003). The basic approach, questions, and objectives presented in this protocol development summary are taken from the Western Arctic Caribou Herd Cooperative Management Plan (Western Arctic Caribou Herd Working Group 2003). Many of these questions and objectives are also being asked at the international level by the CircumArctic Rangifer Monitoring and Assessment Network (CARMA; http://www.rangifer.net/carma/).

ARCN will cooperate with the ADF&G, ADNR, BLM, and FWS to monitor caribou. Monitoring of WAH caribou in ARCN will employ the use of radiocollars and radiotelemetry. The use of radiotelemetry is standard throughout Alaska and parts of Canada for monitoring caribou populations. In past years the NPS has contributed to monitoring WAH caribou by purchasing satellite and conventional radiocollars that have been deployed by ADF&G. ARCN will continue to purchase radiocollars, but we will begin to add satellite GPS collars to those currently being deployed. The use of satellite GPS collars will minimize the time and money spent on aircraft to radiotrack animals. GPS radiocollars will aid in locating groups of caribou for ADF&G photocensus work as well as sex and age composition, recruitment, and calving monitoring. GPS telemetry data can also be used to track the timing and direction of seasonal movements. The availability of location data from GPS collars provides the opportunity to collaborate with outside researchers who may be interested in detailed habitat work on the WAH.

Body condition will be monitored in one of two ways. Either body weights, morphometric measurements, and/or blood samples will be taken if caribou captures are undertaken by the NPS using helicopters or during boat captures at Onion Portage. If captures are not undertaken, a program to get samples from local subsistence hunters may be tried. Alternatively, fecal samples and urine samples will be collected annually in the late winter to monitor the late winter body condition of WAH caribou using stable isotopes. Fecal nitrogen is derived from undigested nitrogen and endogenous secretions (Barboza and Parker unpublished data). Stable isotopes in urea are a result of metabolic processes within the animals and can indicate the relationship between dietary nitrogen supply and body protein stores (Parker 2003, Parker et al. 2005). The isotopic signatures of urea and fecal pellets can thus be used to evaluate the late winter body condition of caribou.

Habitat condition for the WAH will be monitored as part of the monitoring efforts for other ARCN vital signs such as Terrestrial Vegetation and Soils, Fire Extent and Severity, and Climate. Fecal pellets will be collected in late winter and used to examine trends in winter diet of caribou.

As mentioned above, many protocols for monitoring WAH caribou have already been developed by ADF&G, CARMA, and other groups. An important component of tracking this vital sign by the ARCN network will be to gather the data produced by other natural resource agencies as well as local users. In addition, collaboration with other natural resources agencies and local users will be a critical component in making this monitoring effort successful.

Principal Investigators and NPS Lead

Principal investigators for the NPS will be Kyle Joly, Brad Shults, and Peter Neitlich. We anticipate other principal investigators will include Jim Dau (ADF&G), Tony Gorn (ADF&G), Kimberlee Beckmen (ADF&G), Peter Bente (ADF&G), Charlotte Westing (ADF&G), Lincoln Parrett (ADF&G), Lee Anne Ayers (FWS), Tina Moran (FWS), Nate Olson (FWS).

Development Schedule, Budget, and Expected Interim Products

Protocols exist for monitoring caribou populations. Protocol development will not require field research and will consist primarily of writing a protocol that meets NPS standards (Oakley et al. 2003) and through establishment of cooperative agreements. Protocol development will be done through coordination and consultation with the University of Alaska (UAF), the Alaska Department of Fish and Game (ADF&G), the U.S. Fish and Wildlife Service (FWS) and the Bureau of Land Management (BLM). Full development of this protocol will progress on the following schedule:

- Fall 2008: Meet with cooperators and discuss cooperative effort.
- Spring 2009: Draft protocol completed.
- Summer 2009: Field testing.
- Spring 2010: Protocol finalized.
- Fall 2010 Protocol implemented ($135,000).

Protocol Development Summary

Protocol: Dall's Sheep

Parks Where Protocol will be implemented: CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

Dall's sheep (*Ovis dalli*) occur throughout the alpine areas of ARCN parks, and the Brooks Range is the northernmost extent of their range. The National Park Service is mandated by the Alaska National Interest Lands Conservation Act (ANILCA) "to protect . . . populations of . . . Dall's sheep" (Section 201 (4)(a)), "to provide the opportunity for continued subsistence uses" (Section 801 (4)), and "[to conserve] natural and healthy populations" (Section 814(1)). Dall's sheep can be legally hunted in all of the ARCN units by qualified subsistence users, and sport hunting for sheep is permitted in the preserve portion of Gates of the Arctic and in Noatak National Preserve. For park visitors, Dall's sheep are the most reliably viewed large mammal within the parks because they do not migrate, and they are more numerous than are moose, wolves, bears, or muskoxen.

ARCN harbors a substantial proportion of the world's population of Dall's sheep, which was estimated at 100,000 animals in 1990 (Valdez and Krausman 1999). In the early 1980s, Singer (1983, 1984) estimated 15,000 Dall's sheep were estimated in the approximately 41,000 km^2 of sheep habitat in the ARCN park units. In 2005, 2006, and 2007, aerial surveys were conducted to update the population estimate based on stratified random sampling of survey units. In 2005, 9950 sheep (±2568 95% CI) were estimated for the region; 9304 sheep (±3265 95% CI) in 2006; and 8115 sheep (±3134 95% CI) in 2007, after the minimum count for those survey years were analyzed using Gasaway et al. (1986). Dramatic changes in Dall's sheep populations, such as the decline observed in the Brooks Range in the 1990s, have been attributed to environmental conditions, such as severe winters (Brubaker and Whitten 1998, Lawler 2004). Sheep population trends are a good indicator of local environmental change because of the stationary nature of sheep and their sensitivity to environmental conditions.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What is the abundance of Dall's sheep in ARCN?
- What is the sex and age composition of sheep at two areas of high management concern in ARCN (Itkillik Preserve in GAAR and Baird Mountains in NOAT)?
- Are sheep diets changing in these two selected areas?

Our specific objectives are to:

- Determine status and long-term trends in Dall's sheep abundance across ARCN where there is available sheep habitat.
- Determine status and trends in Dall's sheep sex and age composition at two areas of high management concern in ARCN (Itkillik Preserve and Baird Mountains).
- Determine long-term trends in Dall's sheep diets in the Itkillik Preserve and Baird Mountains.

Basic Approach

The first two objectives are the top priorities for the Dall's sheep monitoring program. The third objective provides valuable information regarding the health and status of Dall's sheep populations in two areas of high management concern. These two areas are of high management concern because the majority of Dall's sheep hunting pressure in ARCN occurs in these two areas. Data collected in these two areas will provide valuable information regarding the status of local sheep populations that may

be representative of regional trends, but this objective will be approached adaptively depending on funding and time allocated to this vital sign over the life of the ARCN I&M program.

Surveys for abundance and distribution will be done on a tiered basis. Tier 1 involves intensive surveying in two reference areas in ARCN where there is relatively high sheep density, long term population datasets, sport hunting pressure and more easily accessible survey areas: Itkillik Preserve in GAAR and Baird Mountains in NOAT. For these two areas, aerial direct count surveys will be conducted using small fixed-wing aircraft with one pilot and one observer. These areas will be surveyed as a census every three years. Sightability during aerial surveys may vary considerably from year to year suggesting the need to utilize a sightability index when estimating sheep populations from survey data. Udevitz et al. (2006) determined a sightability index for Dall's sheep in the Baird Mountains that will be applied to Tier 1 surveys.

Tier 2 surveys will be conducted ARCN-wide on a less frequent basis (every five years) to update the population and distribution estimates for the region. Tier 2 surveys will be conducted using distance sampling theory (Buckland et al. 2001) with the goal of generating abundance estimates for two target sampling areas:

- GAAR as a whole, and
- delineated sheep habitat in WEAR (NOAT, CAKR, KOVA).

Contour transects will be selected randomly throughout each study area to provide an abundance estimate for the entire park/unit. These methods will also provide annual sightability estimates, which have been problematic in the past. The plan is to alternate distance sampling between the two areas so that each is sampled at least every five years.

Interest in monitoring Dall's sheep is not restricted to ARCN. The Central Alaska Network (CAKN) also lists Dall's sheep as a vital sign and has investigated different methodologies for monitoring. The feasibility of using distance sampling for Dall's sheep is unknown. For this reason, we will collaborate with CAKN to develop methodology that can be utilized by both networks. In years 2009 and 2010 we will test contour transects as a means of estimating abundance using distance sampling, and we will compare our results to the abundance estimates derived in 2005, 2006, and 2007 from stratified random sampling of the region.

Ground surveys are also planned in the Itkillik Preserve (GAAR) and the Baird Mountains (NOAT) to monitor sheep diets. Fecal pellets will be collected where sheep are observed to be actively grazing both in the late winter and in the summer post-lambing. The pellets will be analyzed using microhistological methods to examine diet composition during those seasons. Integration with the Vegetation and Soils vital sign will provide insights into Dall's sheep diets and will provide valuable information for researchers. Our understanding of Dall's sheep ecology will be improved by correlating Dall's sheep abundance and composition trends with climate, weather, and snow monitoring data. This vital sign will also be linked with the Subsistence/Harvest vital sign.

Principal Investigators and NPS Lead

The principal investigators for developing this monitoring program will be Kumi Rattenbury (ARCN Ecologist) and Josh Schmidt (CAKN Data Manager).

Development Schedule, Budget, and Expected Interim Products

ARCN began a network-wide Dall's sheep survey in 2005 with sampling in the summers of 2005, 2006, and 2007. Population estimates have been derived for the network using Gasaway et al. (1986). Field

work in FY 2008 involved census aerial surveys of the Itkillik Preserve and Baird Mountains, although the Baird Mountains could not be surveyed due to weather. The protocol will be developed on the following schedule:

- December 2008: Draft protocols and SOPs of census and microhistological work ready for peer review.
- Summer 2009: Field test methodology ($60,000).
- Fall 2009: Evaluate and modify methodology for contour transects.
- Summer 2010: Final field testing of methodology ($20,000).
- December 2010: Draft protocols and SOPs for contour transects completed.
- Spring 2011: Complete protocol reviewed, finalized, and implemented.

Protocol Development Summary (Deferred)

Protocol: Moose

Parks Where Protocol will be Implemented: BELA, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

Moose (*Alces alces*) are an integral component of the boreal ecosystem in the ARCN. Moose have the potential to alter the structure and function of vegetation communities through browsing and biogeochemical cycling. Abundance of this species in the boreal forest is tightly linked to disturbance regimes, in particular fire. Moose are considered good indicators of long-term habitat change within park ecosystems because they require large quantities of resources from their habitat year round, and populations have the potential to respond dramatically to long-term changes in resource conditions. Moose are crucial to many subsistence communities as a primary source of food throughout most NPS lands in Alaska in addition to being harvested by the general public on NPS Preserve and Monument lands.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What are the long-term trends in moose population numbers in the ARCN?
- How are abundance, sex and age composition, and distribution changing in the ARCN?
- What are the trends in moose harvest by subsistence and sport hunters in ARCN?

Objectives are as follows:

- Determine long-term trends in abundance, distribution, and composition of moose in ARCN.
- Determine long-term trends in calf survival and recruitment success for moose in ARCN.
- Estimate trends in human harvest of moose in ARCN.

Basic Approach

Monitoring moose populations in ARCN will employ the use of an aerial survey method developed by Gasaway et al. (1986) and modified by Ver Hoef (2001, 2002). These survey methods are in wide use across the state and allow for comparison across survey areas. The survey areas are delineated using a Geographical Information System (GIS), and survey areas have been identified for the ARCN parks. Survey areas are divided into grids of rectangular sample units of 2° latitude and 5° longitude. Sample units will be stratified into high or low density based on habitat characteristics or stratification flights conducted before the surveys. High and low units will be randomized for order of sampling at the start of the survey. Fall surveys will provide information on population levels as well as sex and age composition of the moose population. Survey areas will sampled on a rotational basis. The survey methodology that will be used in ARCN is the same as that being used in the Central Alaska Network (CAKN).

Principal Investigators and NPS Lead

NPS principal investigators will be Brad Shults, Kyle Joly, and John Burch. Cooperators will include Jim Dau (ADF&G), Glen Stout (ADF&G), Tony Gorn (ADF&G), Nate Olson (USFWS), Lisa Saperstein (USFWS), and Tim Craig (BLM).

Development Schedule, Budget, and Expected Interim Products

Regional protocols already exist for conducting moose surveys. Therefore, protocol development will not require field research. ARCN will employ the same protocol as developed by CAKN. Protocol development for this vital sign will consist of modifying the CAKN protocol narrative and SOPs for

ARCN parks. ARCN specific modifications will include descriptions and maps of the survey area and documenting development of an ARCN database for moose. The parks within ARCN have historically been responsible for monitoring moose. ARCN's role in moose monitoring will consist primarily of reporting on park moose monitoring activities.

- Fall 2009: Modify CAKN moose protocol to ARCN specific needs (survey areas and locations) and submit for review draft protocols
- Spring 2010: Finalize protocols and SOPs. No funds are budgeted for this protocol.

Protocol Development Summary

Protocol: Muskox

Parks Where Protocol will be Implemented: BELA, CAKR

Justification/Issues Being Addressed

By the middle of the 19th century muskoxen (*Ovibos moschatus*) were extirpated from Alaska (review in Lent 1999). Muskoxen were re-established in Alaska in the 1930s and specifically on the Seward Peninsula, AK, and near Cape Krusenstern, AK, in the 1970s. Currently, viable muskoxen populations occur in four locations in Alaska; two of these ranges overlay park units in ARCN. Since their establishment, muskoxen have become an important subsistence food for local residents and are highly prized sport hunting resources. Muskoxen tend to occupy small home ranges in comparison to migratory species so are good integrators for local environmental conditions; meta-populations of this species are found throughout the year within the boundaries of the ARCN (i.e., residents). Muskox populations may have substantial effects on plant communities and by extension wildlife communities through effects on vegetation, either directly through browsing and grazing or indirectly through biogeochemical cycling. Muskoxen are rare worldwide. Within the U.S. National Park system (NPS), muskoxen only occur in the ARCN. Key reasons for monitoring muskoxen are that muskox are:

- an important subsistence species;
- may impact reindeer and caribou in the ARCN;
- as an arctic obligate species, are a good integrator of the condition in arctic park ecosystems.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What are the long-term trends in herd sex and age composition?
- What is the late winter physical condition of muskoxen in BELA and CAKR?
- Is the distribution of muskoxen changing?

Objectives are as follows:

- Determine long-term trends in muskoxen sex and age composition and how they potentially relate to herd productivity. This monitoring question is currently being addressed cooperatively with the Alaska Department of Fish and Game (ADF&G).
- Determine long-term trends in late winter physical condition of muskoxen.

Basic Approach

Monitoring of muskoxen population size and sex and age composition of the herd will continue with annual surveys with cooperators. Sex and age composition are determined using a spotting scope to classify muskoxen. A helicopter is used to ferry observers from one group of animals to the next. Muskoxen groups are located by a fixed-wing aircraft immediately before the survey.

If funding is available, fecal samples and urine samples will be collected annually in the late winter to monitor the late winter body condition of muskoxen using stable isotopes. Fecal nitrogen is derived from undigested nitrogen and endogenous secretions (Barboza and Parker unpublished data). Stable isotopes in urea are a result of metabolic processes within the animals and can indicate the relationship between dietary nitrogen supply and body protein stores (Parker 2003, Parker et al. 2005). The isotopic signatures of urea and fecal pellets can thus be used to evaluate the late winter body condition of muskoxen.

Principal Investigators and NPS Lead

The NPS lead for the muskox vital sign will be Brad Shults (WEAR Biologist). Cooperators include: Jim Dau (ADF&G), Charlotte Westing (ADF&G), Tony Gorn (ADF&G), Letty Hughes (ADF&G), Peter Bente (ADF&G), and Nate Olson (USFWS).

Development Schedule, Budget, and Expected Interim Products

- Spring 2009: Draft protocols and submit for review.
- Summer 2009: Conduct muskoxen composition survey ($15,000).
- Spring 2010: Revise protocols and SOPs.
- Summer 2010: Conduct muskoxen composition survey ($15,000).
- Fall 2010: Finalize protocols and SOPs.

Protocol Development Summary (Deferred)

Protocol: Small Mammal Assemblages

Parks Where Protocol will be implemented: BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

Small mammals occurring or expected to occur in Arctic Network parks include shrews (*Sorex* spp.), voles (*Clethrionomys* spp. and *Microtus* spp.), lemmings (*Dicrostonyx groenlandicus, Lemmus trimucronatus, Synaptomys borealis*), weasels (*Mustela* spp.), porcupine (*Erethizon dorsatum*), arctic ground squirrels (*Spermophilus parryii*), tree squirrels (*Tamiasciurus hudsonicus*), and hares (*Lepus* spp.) (Cook and MacDonald 2006). On park administered lands, species of small and mid-sized mammals unique to the ARCN include tundra hare (*Lepus othus*) and Alaska marmots (*Marmota broweri*). Most small mammals are inconspicuous members of the faunal community in the boreal forest and tundra due to their morphology and daily habits, yet these species represent a large proportion of biomass on the landscape (Krebs et al. 2001).

Population parameters and distribution of small mammals in the ARCN are indicators of both short- and long-term environmental conditions. Small mammals play an important ecological role by influencing species above and below them in the food chain. Population levels of small mammals and fluctuations of these populations are affected by and in turn have large effects on plant communities, bird communities, and mammal communities in boreal and alpine/arctic areas. Data suggest that annual fluctuations in small mammal populations are strongly related to abiotic factors (Rexstad and Debevec 2002), including fire, as they may be more abundant in burned areas (Swanson 1996).

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Monitoring questions:

- How is the relative abundance of common small mammals changing over time?
- What are the spatial and temporal patterns of small mammal abundance and distribution?
- How is the species richness of small mammals changing over time and space?

The specific objectives for monitoring small mammals are to:

- Determine the long-term trends in abundance and presence/absence of small mammals at sites collocated with the Vegetation and Soils vital sign.
- Determine long-term trends in reproductive status of small mammals.

Basic Approach

We will use live trapping and, in some cases, snap traps to monitor small mammals in the ARCN. Because small mammal populations can vary substantially in time and space, developing abundance estimates across a large landscape is difficult at best. Initial work and protocol development for this vital sign will focus on presence/absence of species and density estimates of common species in defined areas. Areas selected for monitoring will represent a range of gradients across habitats, elevations, and longitudes. Statistical methods will focus on mark/recapture and occupancy modeling. In areas close to point sources of pollution (i.e., mines), small mammals will be sampled for contaminants.

Principal Investigators and NPS Lead

The NPS lead on this project will be Jim Lawler (ARCN Coordinator). Principal investigators on this project may include Jay Ver Hoef (Ver Hoef Statistical Consulting) and researchers from the University of Alaska.

Development Schedule, Budget, and Expected Interim Products

Detailed protocols for monitoring this vital sign will occur only if additional resources become available. No costs are currently anticipated for monitoring this vital sign.

Protocol Development Summary

Protocol: Terrestrial Vegetation and Soils

Parks Where Protocol will be Implemented: BELA, KOVA, CAKR, NOAT, GAAR

Justification/Issues Being Addressed

Terrestrial vegetation communities have been identified as a top vital sign for the Arctic Network. Arctic ecosystems, particularly vegetation and underlying substrate, are extremely sensitive to external influences such as changes in climate, disturbances, and human impacts. While human activity in arctic regions may cause localized changes in vegetation and soils (Hasselbach et al. 2005), the impact of global climate change may have regional consequences (Stow et al. 2004). Studies have begun to show changes in arctic and subarctic vegetation patterns due to climate change (Tape et al. 2006). Vegetation is the primary foundation for wildlife habitat and nutrient availability for other ecosystem processes and is tightly linked to aquatic ecosystems. Spatial and temporal shifts in terrestrial primary productivity reflect changes in dominant plant species vigor, range, and composition which are, in turn, the products of large-scale processes and events. Changes in community structure are key to ecosystem processes and to our understanding of changes in climate, air quality, herbivore/ungulate use patterns, succession, fire, and other disturbance. Climatic warming affects vegetation both directly through changes in the length and warmth of the growing season and indirectly through more rapid nutrient cycling and changes in soil wetness due to permafrost thaw.

The ARCN has also received considerable inputs of heavy metal pollution from mining operations and is expected to receive higher inputs of S and N from local development and trans-Pacific transport. All of these contaminants have ecosystem-altering properties, especially for sensitive tundra and nonvascular-dominated communities.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What changes in vegetation structure and composition are occurring in the ARCN and where?
- How are forest and shrub biomass and productivity in the ARCN changing?
- How are soil properties important to plant growth changing over time?

Monitoring Objectives

- Determine long-term trends in plant community structure (species cover, diversity, biomass, tall shrub and tree density) at selected focal areas.
- Determine long-term trends in active layer depth, organic layer thickness, and heavy metal inputs to soils.
- Determine major trends in soil temperature.

Basic Approach

We envision a terrestrial monitoring program that uses a combination of ground data and remote sensing to provide extensive coverage at a landscape level in the parks. Detailed measurements of community structure will be taken on the plot level at a series of nodes chosen for accessibility to minimize cost to ensure that revisits will occur even as costs of logistics continue to climb. Each node will include a number of ground plots in a diverse set of vegetation associations. Ground data will be used to calibrate remote sensing products, and remote sensing will be used to extrapolate plot results to a landscape level. Data from both levels will be analyzed in concert with input from other linked

vital signs such as Wet and Dry Deposition, Climate, Surface Water Dynamics and Distribution, Permafrost, Terrestrial Landscape Patterns, and the mammal and bird vital signs.

Vegetation composition will be quantified through highly repeatable plot-based measurements of plant cover on permanent plots at chosen ARCN nodes The plot level work will also involve measurement of ecosystem variables that characterize the geomorphic setting and soil. Soil descriptions and sampling for lab analysis will be made on the initial visit for site characterization purposes. A set of active layer thickness measurements will be made according to the Circumpolar Active Layer Monitoring (CALM) protocols (Brown et al. 2000). Samples of nonvascular plants will be collected and analyzed for metal composition by the protocol outlined above for Wet and Dry Deposition to track soil inputs of heavy metals. A grid of points to measure organic horizon thickness may also be established. The re-measurement interval for measurement of organic horizon thickness would be longer than other data collected at the plots due to the slow change typical of this feature. Plots will serve as calibration sites for aerial photograph interpretation.

Nodes will be chosen using the following criteria:

- Access,
- Subsection physiography,
- Land cover classes,
- Climate zones,
- A subset of the nodes will be in selected areas of high management interest,
- Distribution of plots within each park unit, and
- Colocation with watershed and shallow lake monitoring, weather station monitoring, wildlife monitoring, and existing clusters of vegetation composition and cover data (landcover mapping sample sites, non-vascular plant inventory sites) that would provide additional calibration data for aerial photograph interpretation.

Plot locations within nodal areas will be allocated among local landscape strata in a design that allows objective extrapolation across these strata. Plots will be located within a day's walk of the node center point site. There will be approximately 30 nodes with approximately 24 plots per node. The field season will be mid-July to mid-August, with two or three crews of two people each visiting a total of six nodes per year. Initial sampling will be completed in five years and repeated every 10 years.

Detailed maps of vegetation in the nodal areas will be produced by interpretation of aerial photographs and used to extrapolate results over a larger area. The size of the map area will be variable and depend on the distance from which data from the node can be reliably extrapolated.

Soil temperature will be monitored by installation of sensors at various depths in the soil at the weather stations established as a part of the Climate vital sign. Sensors will be deployed at the same time as the weather stations and soil descriptions made at that time. Data will be collected using the same data loggers and site visits as the weather data, resulting in a negligible additional expense. Data will be archived annually and summarized on a 5- or 10-year basis.

Principal Investigators and NPS Lead

NPS principal investigators will be Dave Swanson (ARCN Terrestrial Ecologist).

Development Schedule, Budget, and Expected Interim Products

- Winter 2008–09: Meet with cooperators and discuss cooperative effort; develop draft protocol; purchase soil temperature monitoring equipment; acquire imagery for a subset of proposed nodes.
- Summer 2009: Field test vegetation sampling protocol; deploy soil climate monitoring stations($15,000).
- Winter 2009–10: Revise protocols.
- Summer 2010: Implement and test protocols ($100,000).
- Spring 2011: Protocol peer reviewed and finalized.

Protocol Development Summary (Deferred)

Protocol: Point Source Human Effects

Parks Where Protocol will be Implemented: CAKR, GAAR, NOAT

Justification/Issues Being Addressed

ARCN is roadless and sparsely inhabited, thus human effects in ARCN and surrounding areas are largely traceable to point sources. Non-point source effects such as air contaminants are monitored by other vital signs. Human-caused pollution and landscape impacts have the potential to dramatically affect ecosystem integrity. The time scale of the effect may be immediate, as in an oil spill washing ashore, or gradual, as in the case of dust palliative leaching into stream systems. Some point sources of pollution are industrial sources, community development impacts, and regional infrastructure impacts. One of the major industrial sources of pollution in the ARCN is the Teck Cominco Red Dog Mine. Impacts of the mine to surrounding park ecosystems include ore spills, haul road dust, dust palliatives, fuel spills, power plant and combustion engine emissions, and heavy metal accumulation. Additional mining and oil exploration and development has been proposed just north of NOAT. The 21 neighboring and local zone rural communities may also cause ecological impacts in the ARCN through road construction, gravel quarries, noise from aircraft, and trash and sewage disposal into rivers and streams. Infrastructure impacts include beach erosion due to beach stabilization methods (e.g., Shishmaref) and all-terrain vehicle (ATV) traffic. Point-source, human-caused pollution and landscape alteration may affect vegetation composition and distribution, primary productivity, groundwater and surface water quality, faunal composition, distribution, behavior, and health, noise level, and visibility. Point-source human effects associated with Subsistence/Harvest and Visitor Use are monitored by protocols for those specific vital signs. The Point-Source Human Effects vital sign is also linked to Air Contaminants, Wet and Dry Deposition of Pollutants, Coastal Erosion, Invasive/Exotic Species and Diseases, Lakes, Streams, and Lagoons Communities and Ecosystems, Terrestrial Vegetation and Soils, Bird Assemblages, Fish Assemblages, and various mammal vital signs.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What is the water quality in streams and lakes near Red Dog Mine, the port site, and the haul road, and is the water quality changing over time?
- What is the water quality downstream from villages?
- What is the water quality in lakes used for float plane landings, and what are baseline levels in case of fuel spills?
- What are the levels of contaminants in flora and fauna along the Red Dog haul road? Are levels changing over time?

Objectives are as follows:

- Determine current and long-term trends in contaminant loads in flora and fauna near the Red Dog Haul Road.
- Determine long-term trends in water temperature, pH, conductivity, dissolved oxygen, flow/stage/level, total N, total P, and chlorophyll a in streams, lakes, and lagoons downstream or near Red Dog Mine, the port site, and the haul road, as well as near-shore waters at the port site.
- Determine long-term trends for heavy metals and other pollutants in lakes and streams downstream from villages within ARCN parks.

Basic Approach

The main focus of the monitoring protocol for the Point Source Human Effects vital sign will be impacts from the Red Dog Mine Haul Road and port in CAKR. Current park projects (Hasselbach et al. 2004) and ARCN's monitoring protocol for the Terrestrial Vegetation and Wet/Dry Deposition vital signs include long-term monitoring of vegetation and soils along the Red Dog Haul Road. The Small Mammals protocols may include monitoring of animal tissue for presence and bioaccumulation of contaminants associated with the Red Dog Mine. Water quality will be sampled for heavy metals at select sites along the Haul Road and near the port site for the Red Dog Mine in conjunction with sampling for the Streams, Lakes, and Lagoons protocols. Additionally water quality measurements will be made downstream from villages and camps within ARCN parks where sites coincide with monitoring for the Streams, Lakes, and Lagoons vital signs. Additionally ARCN staff will track economic development meetings, planning, and activities within and around the ARCN parks to include new sites for monitoring. A database will be created of current and potential development sites that may warrant water quality, vegetation, and other sampling. The database will also include information about other point-source monitoring programs conducted by other agencies and organizations in the region. When developed we will collaborate with other agencies including the Alaska Departments of Environmental Conservation and Fish and Game, U.S. Fish and Wildlife Service, Environmental Protection Agency, local village and tribal organizations, and Native corporations that currently monitor or are responsible for monitoring point-source impacts.

Principal Investigators and NPS Lead

NPS contact for this protocol is Jim Lawler (ARCN Network Coordinator). Principal NPS investigators include Peter Neitlich (WEAR Botanist), Greta Burkart (ARCN Aquatic Ecologist), and Lois Dalle-Molle (NPS Cooperative Ecosystems Studies Unit Coordinator).

Development Schedule, Budget, and Expected Interim Products

Detailed protocols for monitoring Point Source Human Effects will occur only if additional resources become available. No costs are currently anticipated for monitoring this vital sign.

Protocol Development Summary

Protocol: Subsistence/Harvest

Parks Where Protocol will be Implemented: BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

The enabling legislation for ARCN parklands (ANILCA Public Law 96-487) provides for the traditional subsistence use of resources by 21 neighboring and resident zone communities. These resources include but are not limited to: fish, wildlife, timber resources (for subsistence cabins and firewood), water, and berries and other edible plant material. Additionally, Noatak National Preserve, Bering Land Bridge National Preserve, and the preserve portions of Gates of the Arctic are open to sport hunting. Increasing human populations within the region and increasing sport hunting in the preserve lands raise concerns about the long-term health of fish, wildlife, and plant populations; landscape impacts from consumptive use; and the status of the resources available for harvest. Monitoring for this vital sign includes understanding the status and health of harvested resources and of the surrounding habitat because of the importance of these resources to local residents for subsistence use. Additionally, changes in subsistence activities may indicate changes in the presence/absence or distribution of a species, and Local or Traditional Ecological Knowledge (TEK) based on long-term resource use and observation can significantly enhance information about local ecological linkages for park managers and the monitoring program (Drew 2005, Huntington et al. 2004). This vital sign is linked to the Bird Assemblages, Fish Assemblages, Terrestrial Vegetation and Soils, Lake Communities and Ecosystems, Stream Communities and Ecosystems, Lagoon Communities and Ecosystems, Point Source Human Impacts, Visitor Use, and various mammal vital signs.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions to be addressed by this protocol include:

- What resources are being harvested in ARCN parks?
- When is harvest occurring?
- Where is harvest occurring

Objectives are as follows:

- Summarize harvest data from studies and databases maintained by the Alaska Department of Fish and Game, the Federal Subsistence Board, regional and local Native corporations and organizations, and other resource management entities.
- Establish outreach venues whereby information gathered by the ARCN about subsistence resources is reported back to local residents.

Basic Approach

Subsistence and sport harvest data for wildlife species and fish are collected and maintained by the Alaska Department of Fish and Game (ADF&G), the Federal Subsistence Board, and some of the Alaska Native Corporations in northwestern Alaska. The Subsistence/Harvest protocol for ARCN relies on collaboration with these agencies and organizations to acquire this data and incorporate it into ARCN data streams. Our data focus will be for those species targeted by other protocols including brown bear, caribou, Dall's sheep, moose, muskox, and fish assemblages (in particular those fish species monitored for contaminants). Additionally, where there may be data gaps, ARCN and NPS subsistence staff may consider coordinating with other agencies and organizations to conduct additional harvest surveys at the community and household level. Comprehensive baseline surveys about all harvested species are recommended at least once per human generation (approximately every 20 to

30 years) for each of the resident zone communities. The protocol for this vital sign will include collaborative arrangements with village and tribal organizations that establish a mutually agreed upon exchange of information including harvest surveys, TEK about harvested resources, reporting to local residents about data collected on subsistence resources, and local residents' input into the monitoring programs for other vital signs such as Fish, Birds, and various mammal vital signs.

Principal Investigators and NPS Lead

The NPS Principal Investigator is Kumi Rattenbury (ARCN Ecologist).

Development Schedule, Budget, and Expected Interim Products

- FY 2009: Initiate and organize scoping meetings for developing this vital sign with NPS, USFWS, BLM, ADF&G, and regional and local Native organizations ($5,000).
- FY 2010: Draft protocols. Gather existing data from ADF&G and other agencies.
- FY 2011: Revise protocols.
- FY2012: Protocol peer reviewed and finalized (cost allocated to this vital sign to be determined).

Protocol Development Summary (Deferred)

Protocol: Visitor Use

Parks Where Protocol will be Implemented: BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

Adequate information on the levels and patterns of human use is essential for sound long-term stewardship of park areas. Visitors to ARCN parks can have unexpected and significant effects on ecosystems and ecosystem processes. Humans can serve as a vector for exotic plant and animal species and diseases, which may alter ecological communities. Heavy use can fragment the landscape for sensitive wildlife, modify wildlife behavior through conditioning or avoidance, and lead to overharvest in fragile areas. Information about the spatial and temporal distribution of visitor use can help managers identify potential recreation-related threats to the natural resources. In ARCN parks, documentation of visitor impacts is difficult because of the remoteness of ARCN's nearly 19 million acres of parklands and the dispersed presence of visitors at any one time. Additionally, not all visitors stop at designated visitor centers in Fairbanks, Nome, Kotzebue, Bettles, Anaktuvuk Pass, or Coldfoot before entering the parks. Most visitors access these parks by commercial float plane or by walking in from resident zone communities or the Dalton Highway. No rigorous methods or protocols exist to determine park visitation. The primary purpose of this protocol is to systematically compile information that is already collected by park staff about visitation to ARCN parks and to make this information available for analysis. This vital sign focuses on the patterns of recreational visitors to ARCN parks. The effects of subsistence and sport hunting and fishing in ARCN parks will be covered by the Subsistence/Harvest vital sign protocol. Data for the Visitor Use vital sign will be closely related to data collected for several other vital signs: Fish, Bird, and Mammal Assemblages, Subsistence/Harvest, Stream, Lake, and Lagoon Communities and Ecosystems, Terrestrial Vegetation, and Point Source Human Effects.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- How is the number of visitors changing in ARCN parks?
- How are the types of visitor use, timing of visits, and areas of use changing in ARCN parks?
- How are visitors accessing ARCN parks, and where are modes of access changing?

Objectives are as follows:

- Determine long-term trends in numbers and distribution of recreational visitors in ARCN parks.
- Determine long-term trends in in entry points and access methods used by visitors, timing of visits, activities, and destinations of visitors.
- In collaboration with other vital signs, monitor impacts of visitor use on vegetation and water quality.

Basic Approach

Visitor use monitoring plans will be developed in collaboration with park staff. ARCN parks currently do not require visitor registration or permits. There are, however, visitation data already collected and analyzed by law enforcement and interpretation personnel in the individual park units. These include:

1. Park visitor logs at visitor centers at which a portion of park visitors stop for park information, orientation, registration, and bear-resistant canister loans;

2. Direct visual observations by NPS personnel at specific focal locations such as landing strips and float-plane accessible lakes, river corridors for wilderness float trips, high-use fishing and hunting areas, and popular back-country hiking routes;
3. Existing reporting systems such as those for commercial uses (in particular float plane companies) or other required procedures of concession operators, such as the Incidental Business Permit (IBP) process.

Data collected by these methods will be added to an ARCN Visitor Use database every five years to complement visitor numbers reported annually by Western Arctic Parklands (BELA, CAKR, NOAT, and KOVA) and GAAR. Additionally, visitor impacts will be monitored at specific sites designated for monitoring the Terrestrial Vegetation, Lagoons, Streams, and Lakes vital signs by comparing changes in vegetation, water quality, or presence of exotic/invasive plant species with known visitor use data.

Principal Investigators and NPS Lead

The Principal Investigator for this vital sign will be Jim Lawler (ARCN Network Coordinator). NPS collaborators will include Scott Miller (ARCN Data Manager) and ranger staff at all ARCN parks.

Development Schedule, Budget, and Expected Interim Products

Detailed protocols for monitoring Visitor Use will occur only if additional resources become available. No costs are currently anticipated for monitoring this vital sign.

Protocol Development Summary

Protocol: Fire Extent, Severity, and Effects

Parks Where Protocol will be Implemented: BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

Current and future climatic changes will impact the occurrence, extent, and severity of fires in the ARCN and will have cascading effects on other ecosystem processes. Fire can exert strong landscape scale effects on vegetation composition and distribution, permafrost dynamics, nutrient cycling, carbon gain or loss, and primary productivity. Wildland fire is one of the largest natural disturbance processes in the boreal and tundra ecosystems of the Arctic Network. Fire affects all of the parks within ARCN; in the past 50 yrs over 1 million acres have burned in the network. Fire influences not only vegetation succession and distribution, but also wildlife population and distribution, soil parameters (e.g., permafrost and nutrient cycling), hydrology, water quality, and air quality. In addition, the natural fire regime (fire frequency, fire extent, and severity) and secondary fire effects are likely to respond to local and global climate changes (Rupp et al. 2000; Goetz et al. 2005). Baseline monitoring of fire parameters such as the number of fires, fire extent, and burn severity will provide explanatory variables for ecological changes detected through the I&M program, while long-term monitoring of fire effects on vegetation will provide a foundation to elucidate the complex relationship between fire and the landscape.

Specific Monitoring Questions and Monitoring Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What are the long-term trends and natural level of variation in the frequency, extent, and burn severity of fires?
- How does the time since fire and burn severity affect the species composition, vegetation structure, and ground cover among varying vegetation types?
- How does the time since fire and burn severity affect soil parameters (soil temperature, soil moisture, depth of active layer, thermokarst development)?
- How does the time since fire and burn severity affect water quality and air quality? **
- How does the time since fire and burn severity affect the abundance, distribution and composition of the wildlife populations (i.e., moose, caribou, small mammals, birds)?**

** *Note: It is recommended that baseline fire parameters and fire effects on vegetation be monitored; the remaining questions, however, should be addressed through other protocols that utilize fire as an explanatory variable of change.*

Objectives are as follows:

- Work with the NPS Fire Management Program in the Alaska Region to determine annual variation and long-term trends in fire frequency (number of fires/year), average fire size, maximum fire size, and total area affected by fire in ARCN parks.
- Work with the NPS Fire Management Program in the Alaska Region to determine the trends and variability in burn severity on fires larger than 300 acres in ARCN.
- Work with the NPS Fire Management Program in the Alaska Region to determine the effects of fire and burn severity on vegetation species composition (species and % cover), vegetation structure (tree diameters and heights), and ground cover (% cover and depth) of varying vegetation types (long-term monitoring).

Basic Approach

The basic approach of the Fire Extent and Severity vital sign will be to work cooperatively with the Fire Management Program of the NPS Alaska Region. Data on frequency, extent, and burn severity is currently being collected by the Fire Management Program in ARCN as well as in CAKN; therefore this is an excellent opportunity to collaborate with an existing NPS program and another Inventory and Monitoring network to broaden our understanding of fire effects in northern Alaska. We anticipate ARCN's primary role in maintaining the Fire Extent and Severity vital sign is to ensure that this vital sign is integrated with other vital signs in the program, particularly the Terrestrial Vegetation and Soils vital sign, and to focus on fire effects monitoring through monitoring of the fire effects monitoring plots in ARCN.

Fire Occurrence and Extent Monitoring

Sampling: Fire location and extent are collected for all fires occurring within the ARCN parks each year through the NPS fire management program. Fire extent or fire perimeters are measured by physical mapping (hand drawn or GPS) or with remote sensing platforms. The final perimeter is mapped for all fires greater than 100 acres. Data collected for all fires includes year, start/end date, fire number, fire cause (natural/human caused), acreage, vegetation types, closest weather station, fire management activities. For the origin of the fire, data collected includes lat/long, topography, slope, aspect, and elevation. This data is stored in a national fire reporting system called WFMI (Wildland Fire Management Information) and is required for all fires. The link to the data collection protocol is located at the following web page (current as of Aug 7, 2008): https://www.nifc.blm.gov/nsdu/fire_reporting/NPS/doc/index.html

In addition to this data collection, the NPS Alaska Regional Fire Management program has developed an Access database that incorporates all of the data from WFMI and also determines the number of acres burned within park boundaries for fires that span inside and outside park boundaries. The procedure for accessing and utilizing this data for ARCN will need to be determined.

Analysis: Data will be summarized annually for each park within ARCN to present the number of fires/year, the total area burned/year, average fire size/year and presented graphically within a report provided to the ARCN.

Burn Severity Monitoring

The heterogeneous pattern of fire on the landscape results from varying burn severity within a fire. A method for mapping burn severity using Landsat satellite imagery has been developed by applying the differenced Normalized Burn Ratio (dNBR) to pre and post fire Landsat imagery (Sorbel and Allen 2005, Key and Benson 2006). Burn severity maps can be used to identify unburned areas within the fire perimeter, as well as provide a measure of the likely effect of fire on the vegetation and soils. Monitoring Trends in Burn Severity (MTBS) is a multi-year project designed to consistently map the burn severity and perimeters of fires across all lands of the United States for the period spanning 1984 through 2010. The data generated by MTBS will be used to identify national trends in burn severity. The project is being conducted through a partnership between the U.S. Geological Survey National Center for Earth Resources Observation and Science (EROS) and the USDA Forest Service Remote Sensing Applications Center (RSAC). The link to the MTBS methods and data collection protocol is located at the following web page (current as of Aug 7, 2008): http://www.mtbs.gov.

Burn severity maps can be acquired for all fires occurring within ARCN that are greater than 300 acres. Depending on product availability and quality, acres burned by severity class and vegetation cover type will be summarized for fires annually. MTBS burn severity layers are 5 class thematic images depicting severity as unburned/undetectable, low, moderate, high, and increased post-fire vegetation response.

Fire Effects Monitoring

The sampling strategy will involve monitoring the effects of fire using ground-based plots within five fire-prone vegetation community types within the Arctic Network. The vegetation types are as follows:

- Forest-black spruce,
- Shrub tundra,
- Tussock-shrub tundra,
- Lichen-tundra, and
- Lichen-woodland forest.

Plots would be remeasured every five to 10 years, depending on access and colocation using preexisting ground based plots. There are three sets of fire effects plots that have already been established in the Arctic Network. The basic methods for the preexisting plots are described below.

Racine Plots (NOAT, BELA): Between 1978 and 1982 Dr. Charles Racine and colleagues established a series of plots for monitoring vegetation and permafrost recovery post-fire in Noatak National Preserve and Bering Land Bridge National Preserve. In 1978 Racine and others established eight permanently marked plots in a 1977 fire along a topographic gradient on Nimrod Hill, on the east side of Imuruk Lake in Bering Land Bridge. Pre-fire data was available from a 1973 soils and vegetation survey. The BELA plots have since been re-measured in 1978, 1979, 1981, 1983, 2001 and 2002 (Racine et al. 2004). During 1981 and 1982, eight tundra post-fire plot sites were established by Racine and others in the Noatak NP in burned areas of varying ages, ranging from 2–4 wks post fire, 4–5 years and 10 years post fire (1972, 1977, and 1982 fires). As part of the Arctic Network Inventory & Monitoring Program, Racine and NPS personnel relocated and re-measured the Noatak fire plots in 2005 (Racine et al. 2006). For both studies, at each site 10 1 m x 1 m plots were sampled. Data collected include: ocular estimates of vascular and non-vascular species cover, maximum height and stem density estimates of shrubs, thaw depth measurements, site descriptions (soil samples in 1981–82), and photographs. The Racine plots will continue to be monitored by NPS Fire Staff. We intend to re-measure all Racine plots in 2009 and 2010, with a re-measurement occurring every 10 years.

2004 Uvgoon Fire (NOAT): NPS fire staff established six plots in 2004 on the Uvgoon Creek Fire in Noatak. There are three pairs of burned and unburned plots. This area has had three fires in the past 20 years. Plots were established in 2004 immediately after the fire and re-measured in 2005 and 2007. Plots are 30 m x 1 m belt transects. Plot data collected includes: ocular estimates of vascular and non-vascular species cover, point intercept along a 30 m transect (includes ground cover, vasculars, and basic non-vasculars), tree density by size class and species within 30 m^2 belt transect, shrub density by species for alder, willow, and dwarf birch within 30 m^2 area, thaw depth measurements (10 per plot), burn severity at 10 points along transect, and photos. Methods follow a protocol developed by the Alaska Interagency Fire Effects Task Group (2007).

Fire Effects Paired Plots (NOAT, BELA, KOVA, GAAR): Four of the parks have historic fire effects plots ("Paired Plots") that were established during the 1980s. Fire staff established paired vegetation plots in burned and representative unburned habitat adjacent to the burned areas of varying ages. From 1983 to 1988, a total of 198 plots were established in the Arctic Network. Plot data collected include: photographic slides of plot, tree density by size class and species on 15 m x 30 m quadrats, vegetation cover class for 30 Daubenmire frames (20 x 50 cm), tree cores/cookies, fuels and soils data (on some plots), and general plot location descriptions. The data have been entered into an Access database, and plot locations have been digitized from hard-copy maps and aerial AHAP photos. Some of the plot locations were permanently marked. None of these plots have been re-measured since the late 1980s, but we are interested in determining whether any of these plots would make good candidates for permanent monitoring. Data and photos need to be assessed to determine if it is possible to revisit these plots.

Park	I&M	Burn	Control	Other	Grand Total
GAAR	ARCN	30	23		53
KOVA	ARCN	30	28	3	61
NOAT	ARCN	31	30		61
BELA	ARCN	12	11		23

Principal Investigators and NPS Lead

The Principal Investigator for protocol development is Jennifer Allen (NPS Alaska Regional Fire Ecologist).

Development Schedule, Budget, and Expected Interim Products

Regional protocols already exist for collecting fire occurrences, extent, and burn severity. A protocol for the NPS Fire Plots has been completed. However, site selection of the fire plots needs to be assessed statistically. Protocol development will not require field research and will consist primarily of writing a protocol that meets NPS standards (Oakley et al. 2003) and incorporates existing standard protocols. This vital sign will be integrated with the Alaska Regional Fire Management Program, and they are willing to commit personnel and resources towards this vital sign. Full development of this protocol will progress on the following schedule:

Fire Extent and Severity:

- Winter 2009: Draft protocol completed for fire extent and severity.
- Summer 2009: Protocol finalized for fire extent and severity.
- Fall 2009: Annual report completed for fire extent and severity.

Fire Effects Plots:

- Winter 2009: Assess current data sets to determine logistics and plot sample allocation within pre-existing data sets.
- Spring 2009: Draft protocol completed ($2,000).
- Summer 2009: Racine BELA plots re-measured ($5,000).
- Winter 2010: Protocol finalized.
- Spring 2010: Protocol implemented ($20,000).

Protocol Development Summary

Protocol: Terrestrial Landscape Patterns and Dynamics

Parks Where Protocol will be Implemented: BELA, CAKR, GAAR, KOVA, NOAT

Justification/Issues Being Addressed

This vital sign refers to terrestrial landscape patterns, heterogeneity, and dynamics. Landscape dynamics in ARCN are heavily driven by low temperatures and perennially frozen soils. Additional, important influences on landscape patterns and dynamics include: permafrost distribution, biogeochemical cycling, snowpack persistence, vegetation changes, ice dynamics, changes in lake/pond levels, slope and riverbank slumping, active layer thickness, solifluction, changes in channel morphology, distribution of waterbodies, and habitat fragmentation.

Remote sensing is a cost-effective way to monitor status and trends in vegetation in ARCN's 19.1 million acres of remote, roadless areas. Remote sensing may be used, for example, to monitor changes in the extent of boreal forest and shrub-dominated ecosystems (Chapin et al. 2005), loss of heathlands and lichen barrens, waterbody extent, and lake drying and formation (Stow et al. 2004). Changes in plant production in this vast area may impact every component of associated foodwebs, including humans, via changes to the accessibility and quality of subsistence resources. Current and future climatic change is expected to impact vegetation and landcover in ARCN parks. This will have cascading effects on other ecosystem processes, such as permafrost dynamics, nutrient cycling, carbon gain or loss, and primary productivity. Protocols and data collection associated with this vital sign will be integrated with other vital signs including Climate, Terrestrial Vegetation and Soils, Snowpack, Surface Water Dynamics and Distribution, Permafrost, Invasive/Exotic Species, and Fire Extent and Severity.

Specific Monitoring Questions and Objectives to be Addressed by the Protocol

Some of the specific monitoring questions that will be addressed by this protocol include:

- What is the distribution of vegetation classes across the ARCN landscape, and how is it changing?
- What is the distribution and characteristics of water resources across the ARCN landscape, and how is it changing?
- How is ARCN biodiversity affected by landscape-level changes in habitat type and distribution?
- How is treeline changing in ARCN parks? How is shrubline changing in ARCN parks?

Monitoring Objectives

- Develop landcover maps that can be integrated with other vital signs monitoring efforts, specifically the Surface Water Dynamics and Distribution, Permafrost, Terrestrial Vegetation, Fire Extent and Severity, and various mammal and bird vital signs.
- Determine trends in major indicators of vegetation phenology and productivity that can be tracked by remote sensing: maximum and seasonally integrated NDVI, date of green-up, date of senescence, total days of greenness, beginning and end of snow melt, and date of first total snow cover.
- Determine landscape-scale trends in tree and shrub cover and height.

Basic Approach

Landcover maps derived by classification of satellite imagery are critical information that is used for stratification and extrapolation of results in many other monitoring studies. Satellite-derived landcover maps are currently not considered accurate enough for change detection through comparison of multiple dates, but periodic updates (every 10 to 20 years) of these maps will be needed to provide more accuracy as methods improve.

Long-term landscape scale shifts in phenology and primary productivity may be monitored by using AVHRR (Advanced Very High Resolution Radiometer) and MODIS (Moderate Resolution Imaging Spectroradiometer) sensors. Indices that can be used to track phenology and productivity changes over large areas are computed from this imagery and are publicly available from U.S. Government websites. We will research the available products to determine those most useful for phenology change detection, acquire the image products for ARCN lands (probably on an annual basis), organize them into convenient time-series, and report on changes significant to ARCN resources.

Major shifts in vegetation structure and composition has been tracked with some success by multidate comparisions of remotely sensed images (Chapin et al. 2005, Stow et al. 2004). Studies to date have utilized the spectral properties of vegetation, which has been effective at identifying major species groups such as coniferous trees or deciduous shrubs. With the advent of LIDAR imagery we now have the capability to remotely sense the vertical structure of vegetation, which should prove especially useful in tracking the expansion (both horizontal and vertical) of trees and tall shrubs in the Arctic. We plan to test the ability of LIDAR data to measure the height and horizontal extent of tree and shrub canopies in the ARCN.

Principal Investigators and NPS Lead

The NPS Lead and Principal Investigator for this protocol is Dave Swanson (ARCN Terrestrial Ecologist). Cooperators on this project will include Torre Jorgenson (ABR, Inc.).

Development Schedule, Budget, and Expected Interim Products

A current landcover classification and mapping inventory is being conducted by ABR, Inc. for all five ARCN parks. GAAR is the last park for field surveys for this project, and field work for GAAR was completed in the summer of 2008.

- December 2008: Field progress report for forth and final year completed ($180,000 for FY 2008).
- FY 2009: Determine the most useful set of remotely derived indices from AVHRR and MODIS data for monitoring of phenology and productivity. Scope acquisition of these imagery products and begin download and organization of publicly available image products. Scope acquisition of LIDAR imagery for a test tree- and shrub-line monitoring site.
- FY2010: Finalize landcover map for all five ARCN parks (no additional costs). Analyze LIDAR data and determine protocol for monitoring tree- and shrubline; choose sites for monitoring; obtain baseline LIDAR data.
- FY2011: Protocol peer reviewed and finalized.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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