Strategic Science Plan

Arctic Landscape Conservation Cooperative

Advancing Science, Understanding Change.

Public Review Draft

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1. EXECUTIVE SUMMARY

Climate is changing worldwide, but the Arctic is warming at a rate almost twice the global average and will likely continue to warm throughout the next century. In Alaska the effects of warming, such as thawing permafrost, accelerating coastal erosion, and changes in landcover can already be seen. Resources managers and other stakeholders must have access to the information needed to conserve natural resources. The Arctic Landscape Conservation Cooperative (Arctic LCC) will focus primarily, but not exclusively, on climate change. Our emphasis at this time is on terrestrial, freshwater, and nearshore marine systems. With respect to the marine system, our main focus will be on linkages with terrestrial/freshwater systems.

This Strategic Science Plan was developed with guidance from the Arctic LCC Steering Committee and is intended to provide overall direction for a program of work for a ten-year period. A more specific Science Implementation Plan will be developed and updated annually to guide project selection within a 1-2 year time horizon.

There are three general activities detailed in this plan:

Describe and Forecast Ecosystem Change.

This activity has three components: implement a Terrestrial Environmental Observation Network; conduct interdisciplinary climate response research; and model ecosystem response to climate.

Implement a Terrestrial Environmental Observation Network (TEON) for Change Detection: TEON will collect, distribute, and synthesize long-term observational data needed to detect, describe, and forecast effects of a changing hydroclimate and permafrost regime on wildlife, habitat, and human infrastructure in northern Alaska. TEON will focus work in a limited number of focal watersheds that collectively represent the diversity of landscape settings at the ecoregional scale, take advantage of existing science infrastructure and logistics capacity, and provide opportunities to build on existing long-term data sets. Assessment and monitoring of coastal processes may occur at locations other than TEON focal watersheds.

Conduct Interdisciplinary Climate Response Research: The study of ecosystem response to climate change is intrinsically inter-disciplinary in nature. The Arctic LCC will promote interdisciplinary studies that examine linkages between biophysical drivers and response of biota. Preference will be given to topics that have greater potential to inform management actions or address impacts to natural and cultural resources.

Model Ecosystem Response to Climate: Resource managers are asked to consider the effects of climate change as part of the planning process and in environmental impact analyses, yet, there are few tools available with which to visualize potential future landscapes. The Integrated Ecosystem Model (IEM) project is designed to meet resource managers' need to understand the nature and rate of landscape change and is capable of generating maps and other products that show how arctic and boreal landscapes may be altered by climate-driven changes to vegetation, disturbance, hydrology, and permafrost. The Arctic LCC will continue to support development of the Integrated Ecosystem Model (IEM).

Provide Information to Meet Near-term Management Needs

The Arctic LCC will remain alert for opportunities to address more immediate information needs expressed by the Steering Committee and partners. The emphasis will largely be on projects relevant to resource management at the landscape scale.

Improve Data Integration and Management

The Arctic LCC will identify high-priority data sets needed to understand trends in key environmental drivers and response variables, at scales ranging from watershed to ecoregion. Special emphasis will be placed on acquiring spatial data, especially imagery for change detection, thematic baseline maps, thematic trend maps, and modeled environmental conditions. In addition, we will support efforts to aggregate data into formats that facilitate discovery, distribution, and analysis. Investigators supported by the Arctic LCC will be required to adhere to the Arctic LCC Data Sharing Policy, or a similar data sharing policy that sets out standards for creation of a data management plan, archiving of data, and submission of metadata.

2. INTRODUCTION

The intent of the Arctic LCC Strategic Science Plan (Plan) is to describe a suite of activities that address the over-arching Conservation Goals adopted by the Steering Committee. The Plan provides overall direction for a program of work for a ten-year period, but retains enough flexibility to undertake diverse activities without requiring frequent revision. A more specific Science Implementation Plan will be developed and updated annually to guide project selection within a 1-2 year time horizon.

In 2010, the Arctic LCC Steering Committee identified four priority conservation goals:

- Better understand and predict effects of climate change and other stressors on landscape level physical and ecosystem processes.
- Better understand the impacts of environmental change on subsistence and cultural resources.
- Provide support for resource conservation planning.
- Contribute to improved data management and integration.

The Arctic LCC will focus on activities that are relevant to resource managers, and that complement existing programs and missions of the organizations represented on the Steering Committee, as well as our partners. Because our stated conservation goals are broad, this Plan more precisely defines the niche of the Arctic LCC and identifies major areas of emphasis. The Arctic LCC can contribute to resource conservation by 1) supporting the study of environmental change at broad spatial scales and multi-decadal time scales, 2) promoting open data sharing and improved data management, 3) leveraging resources across agencies and partners to more efficiently address information needs, and 4) communicating information in formats that are readily useable by management agencies, the public, and the research community.

2.A. Background

The Department of Interior (DOI) established Climate Science Centers (CSCs) and Landscape Conservation Cooperatives (LCCs) as a means to integrate science and management expertise within DOI and its partner organizations in a coordinated landscape-scale response to climate change (Secretarial Order 3289) and other landscape-scale stressors (Landscape Conservation Cooperatives and Climate Science Centers Implementation Guidance, January 11, 2011). Each LCC functions within a specific geographic region, but is also part of a national, and ultimately, international network. LCCs are true cooperatives, composed of land, water, wildlife and cultural resource managers, and interested public and private scientific organizations. Federal, state, tribal, and local government and non-governmental organizations are all invited as LCC participants. Each LCC is directed by a Steering Committee representing partners working in that region. The Arctic LCC was one of nine initial LCCs established in 2010. Four other LCCs cover the state of Alaska, three of which (Arctic, Northwest Boreal, and North Pacific LCCs) have boundaries extending into Canada.

2.B. Mission and Scope

The Arctic LCC's mission is to ***identify and provide information needed to conserve natural and cultural resources in the face of landscape scale stressors, focusing on climate change, through a multidisciplinary program that supports coordinated actions among management agencies, conservation organizations, communities, and other stakeholders.***

The geographic boundary of the Arctic LCC encompasses northern Alaska and Canada and adjacent marine waters within the US and Canada Exclusive Economic Zone (Figure 1). The focus for the Arctic LCC at this time is on terrestrial, freshwater, and nearshore marine systems. Within the marine system, priority will be given to topics that address linkages between that system and terrestrial or freshwater systems.

Until we more fully develop partnerships with Canadian land-management authorities and partners, the initial efforts of the Arctic LCC will be within the geographic areas influencing management issues in the Alaska portion of the LCC. Because many Arctic species are distributed in a circumpolar manner, conservation concerns for shared populations are expected to motivate work that spans international boundaries.

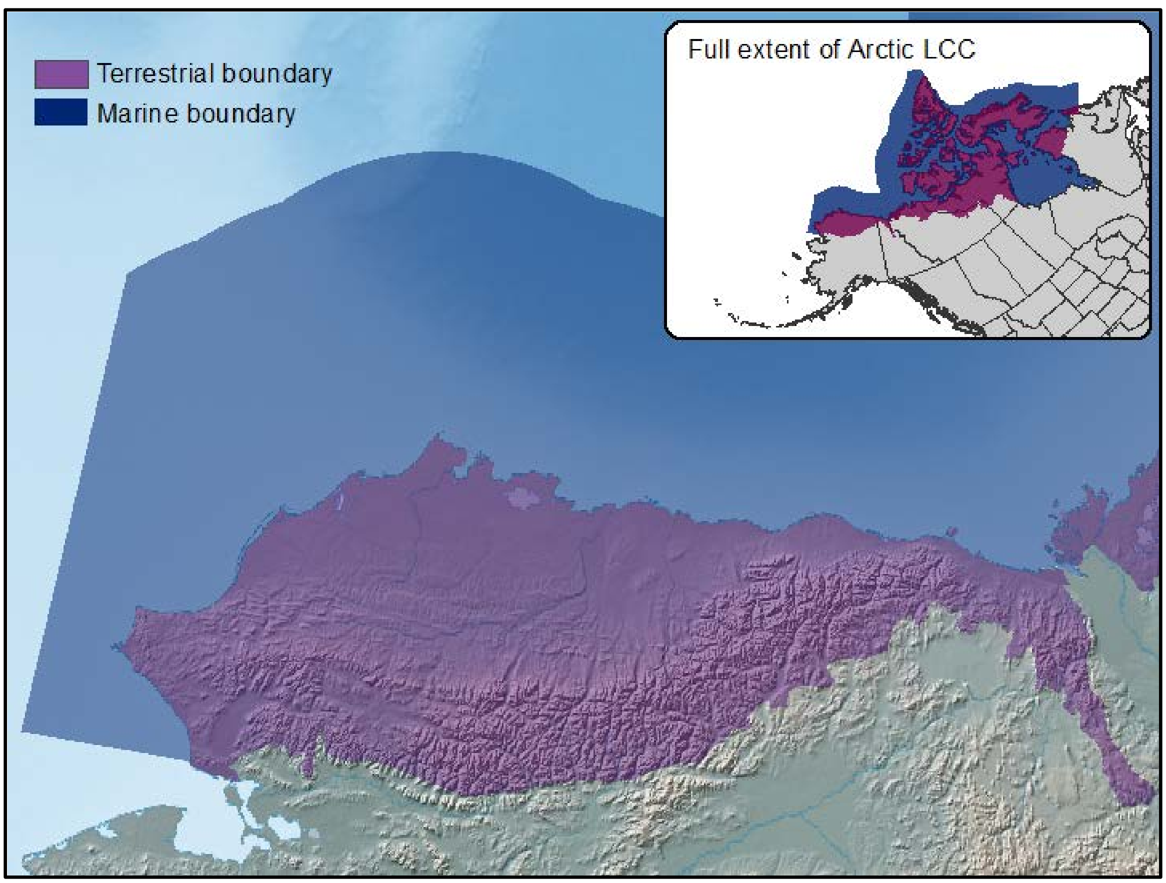

Figure 1. Spatial domain of the Arctic LCC within the United States and western Canada, with the full extent of the Arctic LCC depicted in the inset.

3. SCIENCE ACTIVITIES TO ADVANCE ARCTIC LCC GOALS

As envisioned by the Department of the Interior, a major goal of the LCC network is to help DOI agencies "work together, and with other federal, state, tribal, and local agencies to develop landscape-level strategies for understanding and responding to climate change impacts" (Secretarial Order 3289). Arctic LCC goals are consistent with this vision. In pursuit of our goals, we will undertake an interdependent set of activities intended to provide the best information possible regarding aspects of ecosystem change pertinent to management and conservation of natural resources. The Arctic LCC's scope may include any ecosystem stressor that operates at broad scales, but it is recognized that climate change is likely to be a primary driver of change over the next century, and is our primary focus.

3.A. Describe and Forecast Ecosystem Change

Observations since the 1950's show that climate change in the Arctic occurred more rapidly than elsewhere on the planet, and global circulation models agree that this trend will continue (ACIA 2005). We will undertake efforts to describe historical trends and forecast future resource condition, through adaptive monitoring (Lindemayer and Likens 2009), interdisciplinary research, and modeling activities.

Earth system models that forecast climate conditions are continually being improved, but their projections are subject to uncertainty from various sources. There are a wide range of plausible scenarios for end-of-century greenhouse gas concentrations, each of which produce different projections of future climate conditions. Complex physical processes controlling the climate system are incompletely understood and represented differently by different models. Another layer of uncertainty comes from the lack of models that link global climate change to regional ecosystem response. Against this backdrop of uncertainty, resource managers in the Arctic are faced with a conundrum: while the general magnitude of ecosystem change is expected to be large, the type and rate of changes relevant to managed resources are largely unknown. ***A principal task of the Arctic LCC is to provide the best possible projections of future natural resource conditions, presented in forms that are useful to resource managers and other stakeholders***. ***This requires collecting observations of ecosystem change, incorporating them into modeling frameworks, and communicating results in a manner that can be understood by non-specialist audiences.*** Improved data collection, availability and management are required to support both near-term and long-term management actions. Spatially explicit (i.e., map) data depicting both baseline and projected future and historical conditions are useful both as visualization tools and model input. Data management tasks are embedded in all activities, but are highlighted in Section 3.A.3 for emphasis.

3. A.1. Conduct Climate Change Vulnerability Assessments

The Arctic LCC's primary niche in climate science pertains to the potential effects of climate change on conservation of natural resources, including habitats, species, and biological communities. "Vulnerability assessments" are scientific activities undertaken with the intent of identifying, quantifying, or evaluating the degree to which natural or cultural resources are likely to be affected by changing conditions. From a conservation standpoint, it is particularly relevant to assess the vulnerability of ecosystems, and their components (i.e., habitats and species), to climate change.

Vulnerability[1] can be characterized as a function of sensitivity (potential responsiveness to a change in conditions), exposure (how much change the habitat or species is likely to experience), and adaptive capacity (ability to cope with environmental change). Understanding how habitats are responding to climate change is essential to our understanding of species' exposure, and understanding how species are actually responding to changes in the physical environment is essential to refining our perceptions of sensitivity and adaptive capacity. We may support qualitative vulnerability assessments, such as development of conceptual models, literature synthesis, and expert panels, as one tool for setting priorities. While acknowledging the value of qualitative assessments as a starting point, the Arctic LCC aims to improve understanding of climate change vulnerability through a portfolio of more quantitative approaches, including: monitoring, research, and modeling, as outlined below.

3.A.1.a. Implement a Terrestrial Environmental Observation Network (TEON) for Change Detection

The Arctic LCC will place a high priority on developing the necessary partnerships to establish a durable terrestrial environmental observing network for northern Alaska. The need to establish sites where integrated time-series data sets on physical, chemical, and biological attributes are collected has been expressed repeatedly in Arctic science plans (Vörösmarty et al. 2001, SEARCH 2005, AON 2010, Streever et al. 2011, IARPC 2012), yet little progress has been made in organizing observing activities into a coherent network. Although full implementation of such an observation network is beyond the current capacity of the Arctic LCC, we can contribute funding, staff-time for coordination and data management, and advocate for observing activities that address the needs of the resource management community.

The Arctic LCC will support creation of a Terrestrial Environmental Observatory Network (TEON) to collect, distribute, and synthesize long-term observational data that will help us to interpret the effects of a changing hydroclimate/permafrost regime on wildlife, habitat, and human infrastructure in northern Alaska. Ideal observation sites provide frequent, synchronous measurements of physical, chemical, and biological attributes that are uplinked to a central data portal. No single spatial framework is optimally suited to addressing the full array of questions related to environmental change, but several planning documents have recommended watersheds, with "nested catchments" (Figure 2) forming the basis for scaling up from *in situ* measurements to the landscape scale (Vörösmarty et al. 2001, SEARCH 2005). As proposed, TEON will focus work in a limited number of watersheds that (1) collectively represent the diversity of landscape settings and dominant ecological processes at the ecoregional scale, (2) take advantage of existing science/logistics capacity for the sake of efficiency, and (3) provide opportunities to build on existing long-term data sets.

[1] Although the term "vulnerability" often has the connotation of a negative effect, we recognize that climate change may result in a local increase in the abundance of some species and habitats, and may result in a net increase in some ecosystem metrics such as productivity and species diversity.

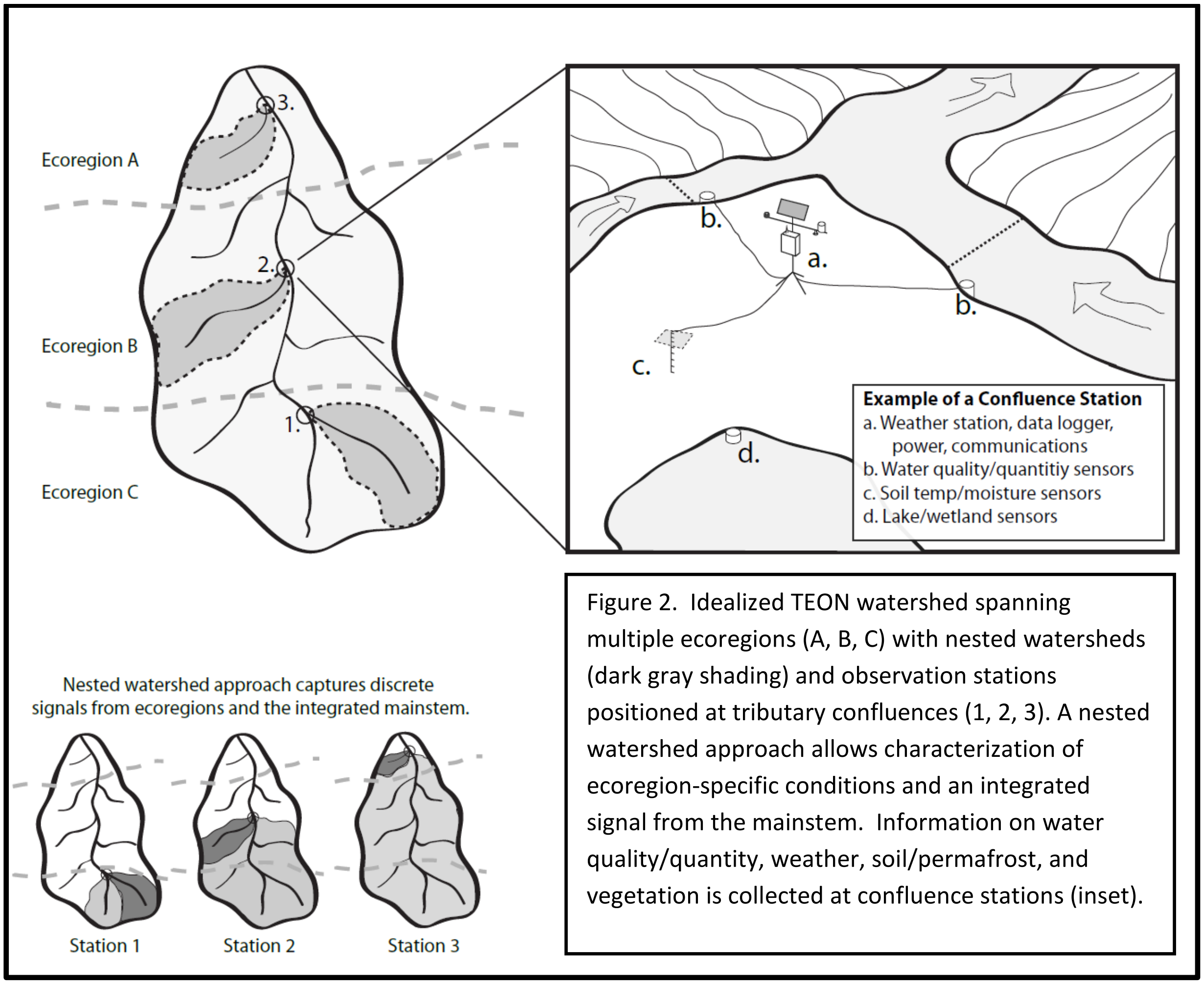

Figure 2. Idealized TEON watershed spanning multiple ecoregions (A, B, C) with nested watersheds (dark gray shading) and observation stations positioned at tributary confluences (1, 2, 3). A nested watershed approach allows characterization of ecoregion-specific conditions and an integrated signal from the mainstem. Information on water quality/quantity, weather, soil/permafrost, and vegetation is collected at confluence stations (inset).

The intent of TEON is to measure key system drivers and processes in a standard fashion across sites. Variables to be measured fall into 4 coarse categories: meteorology, surface waters, soil/permafrost, and vegetation (Table 1). These categories provide the most basic information relevant to the broadest array of users while minimizing costs of installation and maintenance. The particular parameters in each category are relatively simple, robust and can be measured using either automated environmental sensors or infrequent manual measurements. This 'core' suite of parameters will be observed with the same frequency and accuracy at each of the sites and inform users about the basic habitat template available at each site. If active research efforts require the measurement of variables beyond the core suite at a particular site, these can be added to the existing infrastructure of power and communications. At some of the existing sites that we hope to incorporate into TEON, parameters or protocols differ slightly different from what we propose. Over time, as hardware requires replacement, we will transition existing stations toward a uniform suite of instrumentation and protocols

Candidate sites (Figure 3) include those with active science programs (e.g., Barrow/Meade River, Kuparuk River, Fish Creek, Hulahula/Jago rivers) supported by both NSF and federal resource agencies, as well as geographic areas that have been less studied, e.g., Kokolik River on the Chukchi Sea coast.

We will explore options for developing potential "joint venture" sites with the Northwest Boreal LCC on the south slopes of the Brooks Range, such as the Noatak and Koyukuk river drainages. A preliminary list of potential partners in implementing activities for the candidate sites are listed in Table 4 (Section 5.A). The Arctic LCC will strengthen the observational activities at each of these locations by providing overall coordination, data management services, and funding to fill data collection gaps.

TEON is primarily intended to provide a synoptic picture of environmental change at the ecoregional scale. An important motivation for TEON is that many models lack the observational data needed to accurately calibrate model parameters, or evaluate the accuracy of model output, and TEON data would support these activities. Long-term, regional-scale data on trends in environmental conditions are expected to be pertinent to many local management applications. Among these uses are: control data for impact analyses that must distinguish local from regional trends, explanatory variables for observed changes in demographics of wildlife populations, and infrastructure design problems (such as river-crossings)which often require extending inferences derived from local, short-term data sets by correlation with longer records that better represent natural variability. The power of the network approach is in the aggregation of comparable data sets across the entire region. Each site, however, is also expected to have utility for addressing more local resource management concerns (Table 2).

Table 1. Core suite of variables to be measured in a standardized fashion at all TEON sites.

Variable
Meteorology
Radiation energy balance
Air temperature
Relative humidity
Barometric pressure
Wind speed and direction
Liquid precipitation
Snow depth
Surface Water Observations
Water level (stage)
Stream discharge
Water temperature
Conductivity
Turbidity
pH
Dissolved Oxygen
Biogeochemistry
Total suspended solids
Soils and Permafrost
Shallow Temperature Profile (0-1.5m)
Deeper Temperature Profile (1.5 -3 m)
Soil heat flux
Water table height
Active layer thickness
Soil properties (e.g., ice content, bulk density)
Vegetation
Species composition
Abundance (percent cover)

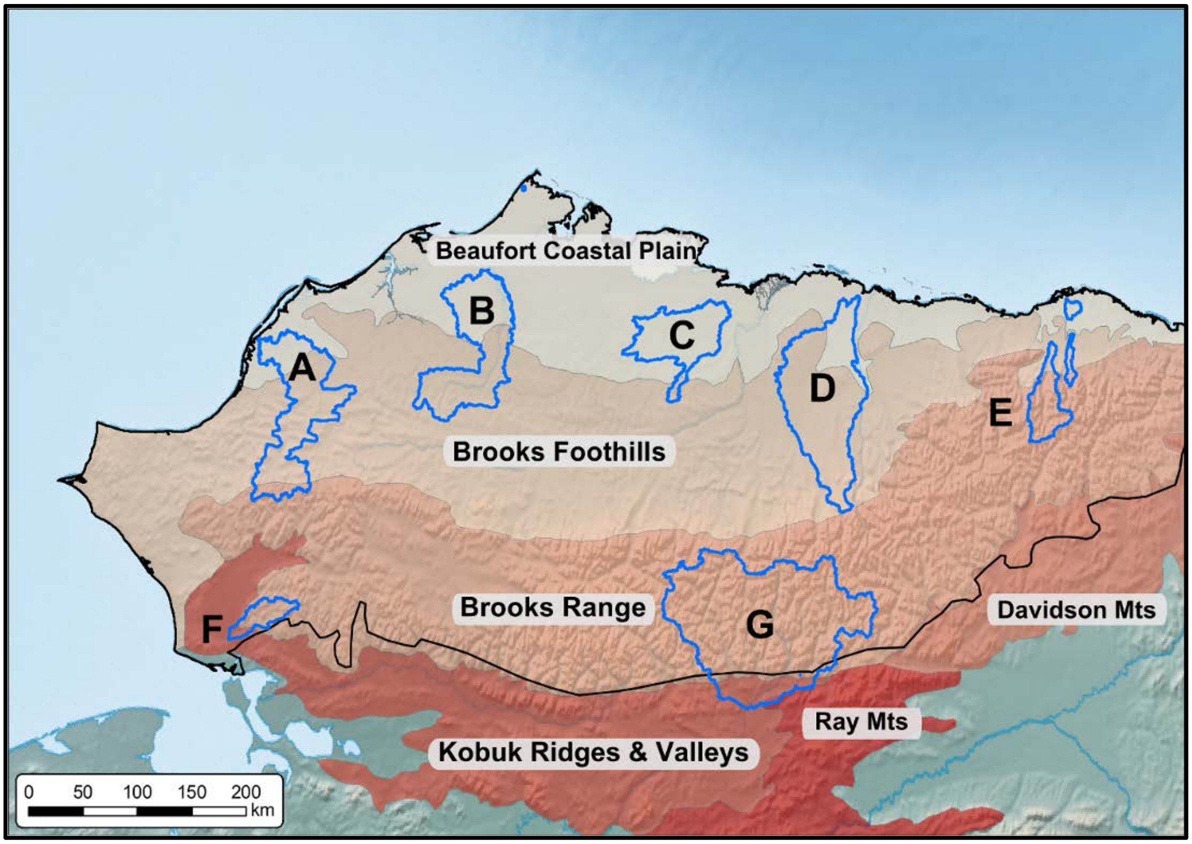

Figure 3. Candidate watersheds for TEON include A) Kokolik River, B) Barrow/Meade River, C) Fish/Judy Creek, D) Kuparuk River, E) Hulahula/Jago Rivers, F) Agashashok River and G) Upper Koyukuk. Collectively, these watersheds sample the major ecoregions and the longitudinal range represented within the Alaska portion of the Arctic LCC.

Table 2. Example management applications specific to individual proposed TEON watersheds.

Watershed	Location-specific Management Applications
Kokolik R.	• Baseline for Natural Resource Damage Assessment, oil spill contingency planning, and other actions related to potential oil and gas development in the Chukchi Sea. • Subsistence use by residents of Pt. Lay.
Barrow/Meade R.	• Infrastructure planning for Barrow. • Infrastructure planning and permitting for NPR-A. • Subsistence use by residents of Barrow and Atqasuk.
Fish Creek	• Baseline for assessment of impacts for oilfield development. • Subsistence use by village of Nuiqsut.
Kuparuk R.	• Baseline for environmental assessment within the current oilfield region and TAPS corridor. • Infrastructure planning and permitting within the oilfield region.
Hulahula/Jago R.	• Water availability for subsistence uses by residents of Kaktovik. • Water availability for recreational use of Hulahula River corridor. • Freshwater system effects on estuaries near Kaktovik.

The watershed spatial framework is not ideally suited to the study of coastal processes. Because of the importance of the coastal zone as a "hot-spot" of both biological and human activity, the Arctic LCC will continue to work with partners to promote improved assessment and monitoring of key coastal processes, including erosion rates, inundation, and sedimentation. The selection of coastal study sites will not necessarily be restricted to locations within TEON's focal watersheds.

One concern regarding the focal watershed approach is the degree to which inferences drawn from non-randomly chosen and geographically-limited areas may be extrapolated to an ecoregion, or region. The Arctic LCC will work with partners to extrapolate watershed-scale results to the ecoregional scale through modeling and sampling and/or mapping products using remote sensing methods. The Arctic LCC will also work with partners who wish to use TEON data to develop statistically based sampling designs.

A detailed description of the structure and function of TEON, as proposed, is contained in Appendix A.

3.A.1.b. Conduct Interdisciplinary Climate Response Research

The Arctic LCC will actively promote interdisciplinary studies that examine linkages between biophysical drivers and response of biota – particularly fish, wildlife, and their habitats. The study of ecosystem response to climate change is intrinsically interdisciplinary in nature, and requires a structure that encourages collaboration among organizations and experts in different fields. Preference will be given to topics that have the potential to inform management actions or address impacts to culturally important resources. In 2011, the Arctic LCC convened a "Species and Habitat Working Group" to identify the biophysical process shifts associated with climate change considered most influential to broad species assemblages. The working group identified the mechanisms by which fish and wildlife would be affected by each projected habitat change and identified 1) which species or species assemblages were thought to be most sensitive, and 2) the primary influences on access to subsistence resources for residents of northern Alaska villages. Fish, birds, mammals, and subsistence resources were considered by separate sub-groups. Despite the large number of issues addressed by the individual sub-groups, a few themes were broadly influential across taxonomic divisions, and pertinent to people's ability to access subsistence resources (Table 3, themes in bold). The resultant list of themes reinforces the importance of long-term monitoring and data synthesis in the areas of weather, hydrology, permafrost, and vegetation, and also suggests that coastal processes should receive special attention. The full report of the Species and Habitat Working Group is attached as Appendix B.

A coherent and consistent program of long-term physical process monitoring, targeted at the most relevant indicators of change as outlined in Section A.1.a, will provide the foundation for addressing questions regarding climate effects on biological resources, but more is needed. Interdisciplinary studies promoted by the Arctic LCC will encourage collaboration among scientists specializing in different fields to obtain a better understanding of how climate drivers interact to affect fish, wildlife and habitat. Potential interdisciplinary study topics identified as high priority by the Species and Habitat Working Group are contained in Appendix B, Tables 4-7. A limited number of short-duration (2-5 years) projects addressing these topics may be undertaken by the Arctic LCC at any given time, and will be solicited through a request-for-proposals. We also hope that by providing ready access to long-term monitoring and trend data, we will encourage researchers to explore such topics with external funding.

Table 3. Cross-cutting themes (in bold) and key environmental indicators of change considered most influential to species life history and ecology and/or to people's access and use of subsistence resources.

Biophysical Process Themes and Environmental Indicators	Birds	Fish	Terrestrial Mammals	Access to Subsistence Resources
Climate and Weather				
Air temperature, precipitation	X	X	X	X
Frequency of extreme events (e.g., storms, drought)	X	X	X	X
Windiness	X			X
Water/Hydrologic Processes				
Surface storage/soil moisture	X	X		
Streamflow/connectivity		X		
Formation of new drainage networks	X	X		
Lake volume/lake drainage	X	X		
Snow Characteristics (depth, water equivalent)		X	X	
Winter Icing Events	X		X	X
Water temperature		X		
Water chemistry		X		
Glacier input (sediments and water)	X	X		
Permafrost Warming				
Soil temperatures				X
Food-chain (Trophic) Relationships				
Vegetation change/shrub encroachment	X		X	X
Aquatic/semi-aquatic invertebrate abundance	X	X		
Coastal/Marine Processes				
Lagoon water chemistry/productivity	X	X		
Coastal erosion, inundation	X	X		
Sea ice and related sea state conditions				X
Sediment and freshwater input to estuaries	X	X		
Seasonal Effects				
Lake/river break-up and freeze-up	??	X		X
Snow-on/snow-off	X		X	X
Green-up/peak greenness	X		X	
Insect emergence/activity levels	X	X		

3.A.1.c. Model Ecosystem Response to Climate

Modeling is essential to the task of projecting future conditions for the benefit of resource managers and other stakeholders. It is important for the Arctic LCC to have a modeling framework that makes use of data generated by the monitoring and research activities, so that there is a method by which new understanding of trends and processes can be used to improve the accuracy of our forecasts.

The Arctic LCC will continue to work closely with the Alaska CSC to create and improve spatially explicit models of landscape change. In the near term, the overarching model framework will be the Integrated Ecosystem Model (IEM). IEM is designed to meet resource managers' need to understand the nature and rate of landscape change and it is capable of generating maps and other products that show how arctic and boreal landscapes may be altered by climate-driven changes to vegetation, disturbance, hydrology, and permafrost. IEM is comprised of three different models:

- The Alaska Frame-Based Ecosystem Code (ALFRESCO). ALFRESCO simulates wildland fire, vegetation establishment, and succession.
- The Terrestrial Ecosystem Model (TEM). TEM models characteristics of organic soils, hydrology, vegetation succession and biomass, and carbon balance in soil.
- The Geophysical Institute Permafrost Lab model (GIPL). GIPL simulates permafrost dynamics such as active layer thickness (the depth of summer seasonal thaw in perennially frozen ground) and mean annual soil temperatures.

From 2013-2016, the modeling team will expand IEM so that three additional ecosystem dynamics can be simulated:

- Tundra fire and treeline dynamics.
  Incorporation of tundra fire and treeline & tundra succession dynamics into IEM will allow us to better forecast changes in landscape structure and function.
- Landscape-level thermokarst dynamics.
  Landscape-level thermokarst changes are important to incorporate into IEM because subsidence associated with the thawing of ice-rich permafrost can result in substantial changes in vegetation and habitat.
- Wetland dynamics
  Wetland dynamics are important to represent as well because much of Alaska and Northwest Canada are covered by wetlands and changes in wetland habitats has the potential to affect numerous species.

The individual models provide important information on how the Alaskan and Northwest Canada landscapes may respond to climate change, however, these processes do not act in isolation. Linking ALFRESCO, GIPL, and TEM provides for a more integrated approach to assess whole ecosystem-level responses because it allows the models to simulate known interactions of ecosystem components and physical processes. The expected data products can be categorized as one of the following: climate, disturbance, landcover and landscape, model code and documentation, ecosystem dynamics, and soil properties. Examples of outputs include: vegetation distribution, historical burned area, fire size distribution, forest age class distribution, vegetation biomass, thickness of soil organic horizons, soil carbon stocks, leaf area index, soil temperature, soil moisture, snow water content and distribution.

A primary role of the Arctic LCC within the IEM is to facilitate communication between land managers and the modeling team and to ensure that the form and content of model output is useful to the management community. The Arctic LCC will give strong consideration to creation of improved ecological data layers that are used as model input (e.g., updated land cover and permafrost maps). Further, the Arctic LCC will elicit identification of data gaps from the IEM team, and look for opportunities to fill those gaps through research and monitoring.

The IEM fills the niche of a regional terrestrial system model, but cannot adequately address all identified questions. The Arctic LCC will also support process-specific modeling that addresses a particular climate-associated effects effect in detail. Examples could include: coastal erosion and inundation, snow conditions, water body connectivity, sediment loading, contaminant deposition, and habitat selection. "Resource impact models" centered on response of habitat and populations should be coupled with the IEM (Figure 4), or other physical process models.

Model simulations are imperfect representations of the real world, and as such, their projections are uncertain. For the purpose of this document, the term "uncertainty" means that there are a range of plausible outcomes. Walsh (2012) provides a good discussion of the sources of uncertainty in the context of climate models. The three main sources of uncertainty are:

1. Uncertainty arising from the range in plausible emission scenarios. Although the assumptions regarding economic activity and societal responses differ among scenarios, greenhouse gas concentrations differ by only small amounts through 2050. For the second half of the century, however, choice of emissions scenario contributes greatly to the range in predictions.

2. Structural differences among the models. Different models use different approaches for representing the same physical processes, so their simulations will differ, even for the same emission scenario and the same time period.

3. Natural temporal variability in the climate system. The Pacific Decadal Oscillation is an example of an influential source of decadal variability in Alaska's climate that is overlaid upon long-term (century-scale) trend. Although different climate models may converge in their estimates of temperature mean and variance, the predicted timing of warm and cool periods differs among models.

A model's simulated time frame (i.e., number of years into the future for which the model generates output) has differing influence, depending on the source of uncertainty. A longer time frame exacerbates uncertainty related to choice of emissions scenarios, and may also amplify structural differences when they result in cumulative divergence of forecasts in successive time-steps. With respect to simulation of natural variability, however, models may be in greater agreement regarding long-term statistical trends than predictions for the near-term. Beyond a few decades, the contribution of natural variability as a percentage of the change from present becomes smaller and smaller; thus, there may actually be more useful information in the longer-range projections than those covering the next decade or two (J.E. Walsh, IARC, pers. comm).

In all of its products, the Arctic LCC will strive to communicate the assumptions and limitations inherent in model forecasts.

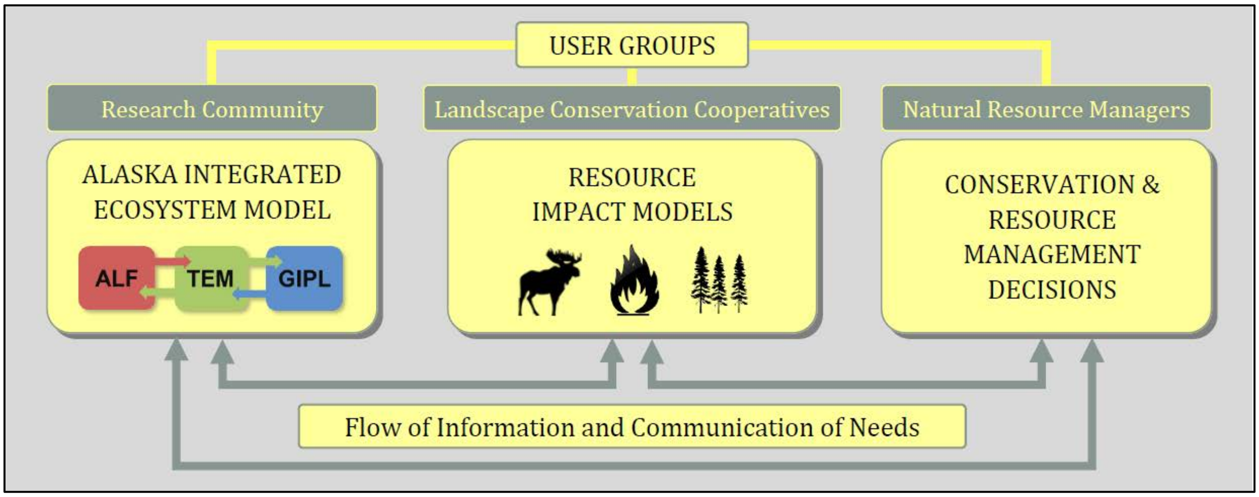

Figure 4. The Integrated Ecosystem Model will serve both the management and research communities.

3.B. Provide Information to Meet Near-term Management Needs

A focus on climate change entails a long-term view, as the effects will be observed over time scales of decades and centuries. The Arctic LCC will remain alert, however, for opportunities to address near-term information needs of its partners. The Arctic LCC will be responsive to the near-term information needs of resource managers, identified through input from the Steering Committee and other needs-assessment tools. Our emphasis will be on projects relevant to resources at the landscape scale: the Arctic LCC will generally not conduct site-specific investigations unless there are aspects that are broadly applicable and of interest to multiple partners. Projects that meet these criteria need not be focused primarily on climate change.

3.B.1. Provide Data Management and Integration Services that Meet Near-term Needs

The Arctic LCC can serve the resource management community by aggregating data across land-management jurisdictions and from multiple sources, making these data available to a broad community of users. The Arctic LCC will support the creation of spatial data products that provide managers with visualizations of current and historical resource distribution. Examples of past or current projects include:

- ShoreZone (geo-referenced oblique imagery of shoreline allowing detailed mapping of coastal resources) imagery and maps that will aid in oil spill planning and response.
- Eider and yellow-billed loon distribution geospatial databases that will aid in Endangered Species Act Section 7 consultations and preparation of National Environmental Policy Act documents
- Model to predict in-season distribution of polar bear denning habitat that will help those conducting activities during winter months comply with the Marine Mammal Protection Act.

3.C. Data Integration and Management

Studies of ecosystem function require integrative analysis of historical and contemporary data, thus the ability to readily discover and access data is essential. There is increasing recognition of the importance of effective data sharing and stewardship in the conduct of science, particularly in the realm of complex topics such as ecological systems and climate change (Hanson et al. 2011; Reichman et al. 2011; Whitlock et al. 2010). The Arctic LCC will adopt policies that promote open data sharing and responsible archiving of all data generated by Arctic LCC-supported projects. Further, the Arctic LCC will continue to undertake projects that aggregate data into formats that facilitate discovery and analysis, and will provide derived products that synthesize data over broad spatial and temporal scales.

3.C.1. Data Sharing Policy and Data Management Practices

Effective data management imposes obligations both on investigators and institutions. Investigators supported by the Arctic LCC will be required to adhere to a data sharing policy that sets out standards for creation of a data management plan, archiving of data, and generation of metadata (Appendix C). The Arctic LCC expects investigators to make data and supporting materials publicly available within a reasonable time period. Arctic LCC data management staff (data manager, geospatial specialist) will assist investigators with aspects of these requirements that may be outside the investigators' area of expertise. The Arctic LCC will provide a mechanism to archive, maintain, and distribute data, although other institutional data clearinghouses may also be used.

The obligations and business practices of the Arctic LCC with respect to data management will be set out in a Data Management Plan (DMP). The DMP will address data management practices and requirements of both the investigators and the Arctic LCC. The objective of the DMP is to provide guidance on managing data throughout its lifecycle, from planning to permanent archival. The DMP will address: data planning, capture, collection and maintenance, quality assurance and control, documentation, archiving, delivery, and discovery. A "best-practices" guide that provides concise, practical guidance for managing data will be made available to supplement the DMP.

The Arctic LCC will work with partners, such as the Alaska Data Integration Working Group (ADIwg), to adopt and implement data and metadata standards. Currently, ADIwg standards apply to project-level metadata only (i.e., information that describes projects). Adoption of this standard allows information about Arctic LCC projects to be viewed on the web sites of partners such as the Geographic Information Network of Alaska (GINA). The ADIwg data metadata standards (i.e. information that describes the structure and content of data sets) are currently under development. The Arctic LCC will adopt ADIwg standards as they are developed. In the interim, the Arctic LCC will adhere to broadly accepted standards such as ISO 19115 for spatial data.

3.C.2. Data Integration and Synthesis

Ecological data are typically contained in relatively small sets held by numerous researchers and institutions (Reichman et al. 2012). This is a challenging situation for resource managers, who typically must respond to issues within a time-line and budget that does not allow for extensive data discovery, integration and synthesis. Furthermore, there is little incentive for agencies to expend effort in collating data over large regions (across jurisdictional boundaries) or over decadal time spans. The study of environmental change, however, requires that we do both. To fill this gap, the Arctic LCC will identify high-priority data sets needed to understand trends in key environmental drivers and response variables, at scales ranging from ecoregion to watershed. Some examples are provided below.

3.C.2.a. Spatial Data

The Arctic LCC will place special emphasis on acquiring spatial data, of which the following categories are of particular interest:

> *Imagery for Change Detection* – Many change detection methods rely on a time series of remote sensing data. The Arctic LCC will make past and current imagery available to researchers in

"analysis-ready" (orthorectified and mosaicked) form, when those baseline data can help address a specific question of importance.

Thematic Baseline Maps – Interpreted remote sensing data may be used to produce thematic maps for environmental attributes. Some features, such as vegetation, permafrost/ground ice, and topography are expected to change at time scales of decades or longer, and may be considered "baseline" maps. Gridded topography, i.e., digital elevation models, merit particular mention because they are critical to many applications, including classification of terrain types and hydrologic modeling. Other attributes, such as the NDVI ("greenness") index of primary productivity, vary seasonally and from year to year. The Arctic LCC will emphasize data sets that pertain to trends in environmental attributes that are climate-sensitive, particularly those needed to represent initial baseline conditions in models of environmental change.

Modeled Environmental Conditions – Spatially explicit models of environmental change use gridded data as input and output. Model output may be either hindcasts of past conditions or projections of future conditions. Model algorithms commonly include assimilation of field data, interpolated and distributed over the geographic domain of the model. Applications include maps of precipitation, air temperature, and snow conditions.

Thematic Trend Maps – Products from change detection analyses will be provided in graphic formats that display historical and expected trends in climate and related ecosystem conditions. Examples include shoreline erosion rates, timing of snow melt, potential evapotranspiration, and river discharge.

3.C.2.b. Regional Hydroclimate Data

Moving forward, it is essential to have a solid grasp of regional trends in climate and water balance. The Arctic LCC has taken some initial steps to overcome barriers that hinder access to existing baseline data, and to performing trend analysis. We devoted considerable effort to aggregating historical data under the auspices of the 2010 Arctic LCC project "Hydrometeorological Data Rescue," which included compilation of an "Arctic Hydroclimate Database." The Arctic LCC will actively engage partners to manage and deliver the compiled data set. It is beyond the initial staffing capacity of the Arctic LCC to unilaterally maintain, manage, and update the Hydroclimate Database, but we will work with partners to implement a shared-cost solution, over either a regional or state-wide domain.

4. SCIENCE PLANNING PROCESS

4.A. Planning Timetable

The Arctic LCC Strategic Science Plan is intended to guide scope and priorities for a period of ten years, but will be reviewed, and potentially amended, at 3-year intervals. Upon approval by the Steering

Committee, an amended Plan will be circulated for external review by our partners. Following external review, Arctic LCC staff will revise the draft Plan and submit it to the Steering Committee for final approval.

Science Implementation Plans (Implementation Plans) will outline work to be accomplished within a 2-year time-frame, and will be revised annually with input from the Steering Committee. The Implementation Plan will articulate objectives and recommend projects or solicitations intended to meet the objectives. The contents of Arctic LCC Requests for Proposals (RFPs) will be based on the Implementation Plan recommendations. Arctic LCC staff will work with the Alaska Climate Science Center to ensure that, whenever practical, the timing of selections for annual science priorities, RFP processes, and identification of cross-LCC opportunities/needs will be aligned to ensure the maximum leveraging of funds and collective expertise.

4.B. Role and Composition of Technical Working Groups

The Arctic LCC will retain the existing "Geospatial" and "Species and Habitat" Technical Working Groups (TWGs). Four existing Working Groups – "Climate," "Hydrology," "Permafrost," and "Coastal Processes" will be merged into a single "Physical Processes" Working Group in 2013. TWGs will review the Strategic Science Plan, provide recommendations for priority tasks to be included in the Science Implementation Plans, and address other issues as requested by the Steering Committee. The "Species and Habitat" and "Physical Process" TWGs will work together to define appropriate topics to develop as interdisciplinary study plans (see Section III.A.1.b).

Technical working group members will be recruited from the agencies and organizations with Steering Committee representation, academic institutions, non-governmental organizations, arctic residents and others with subject-matter expertise pertinent to the groups' work. Participation will be voluntary and in most cases non-compensated.

4.C. Local Input Into the Science Planning Process

The Arctic LCC is receptive to incorporating local concerns into the science planning process, particularly those issues related to environmental change and access to subsistence resources. Information needs of communities can be brought to the attention of the Arctic LCC by Steering Committee representatives of local government and tribal organizations. We also recognize the value of regular direct communication with community members, supplemental to the Steering Committee venue. The best structure for facilitating such communication is yet to be determined. Alternative approaches include initiation of a new working group (i.e., an LCC Cultural Resources Working Group), or working through existing structures such as the Northwest Arctic Borough's subsistence mapping advisory group, and the North Slope Borough's Fish and Game Management Committee. The Arctic LCC will choose an option in consultation with partners, and take action by 2014.

5. PARTNERSHIPS AND RELATION TO OTHER PROGRAMS

There are dozens of organizations and institutions involved in climate-related research and resource management issues in arctic Alaska. Comprehensive coordination among all of these entities poses a significant challenge, and one that is beyond the scope of the Arctic LCC. The Arctic LCC can most effectively contribute to improved coordination by:

- Identifying, and working with, key partners to achieve science objectives outlined in this document.
- Coordinating actions by its member agencies for efficiency and cost-sharing.
- Advocating for the needs of resource managers to both public and private research organizations.
- Fostering opportunities for arctic residents to become more involved in community-relevant science.

Close communication with neighboring LCCs and the Alaska Climate Science Center is a priority. To the extent that staff and the Steering Committee are able, the Arctic LCC will continue to work with other arctic and related state-wide initiatives. These include Department of Interior's Arctic Coordination Group, the Interagency Arctic Research Policy Committee, and the North Slope Science Initiative. Other key partners in implementing aspects of this Plan are identified below.

5.A. Key Partners to Achieve Arctic LCC Priorities

There are numerous potential partners who can help the Arctic LCC complete short-term projects, and these will vary over time. This discussion will focus primarily on key partnerships anticipated to help the Arctic LCC meet long-term objectives identified in this document.

5.A.1. Key Partners for Coordinated Long-term Monitoring

Successful implementation of TEON requires the participation and collaboration of organizations represented on the Arctic LCC Steering Committee, as well as parties external to the Arctic LCC. Table 4 lists some of the essential partners with current or planned activities that align with TEON. The Arctic LCC will actively seek collaborative support from others with an interest in monitoring activities, including the energy industry, local government, Alaska Native Tribal Health Consortium, and conservation organizations. The Arctic LCC will continue to explore opportunities for coordination with Canadian monitoring efforts, such as those implemented by Parks Canada, and international efforts led by the Arctic Council.

Table 4. Potential collaborators for the proposed TEON. Where applicable, specific sites of special interest to each organization are listed.

Organization/Program	Site
National Science Foundation – Arctic Observing Network (AON)	General
National Science Foundation – National Ecological Observatory Network (NEON)	Kuparuk, Barrow/Meade
National Park Service – Arctic Network, Inventory and Monitoring Program	Noatak, Koyukuk,General
US Fish and Wildlife Service – Inventory and Monitoring Program	Jago/Okpilak/Hulahula
Bureau of Land Management – Assessment, Inventory, and Monitoring Program	General
Bureau of Land Management – NPR-A Monitoring Program	Fish Creek, Kokolik R., Barrow/Meade
University of Alaska – Toolik Lake Field Station	Kuparuk , Barrow /Meade
University of Alaska – Water and Environment Research Center	Kuparuk, Fish Creek
USGS – Alaska Science Center	Jago/Okpilak/Hulahula, Kuparuk, Barrow/Meade
USGS – Climate Science Center	General
Bureau of Ocean Energy Management	General --North Slope Borough community input and Local/Traditional Knowledge

5.A.2. Key Partners For Data Integration and Management

The Arctic LCC will maintain an active participatory role in data integration initiatives operating at the regional and national level. On the regional level, the Arctic LCC is committed to working with ADIwg and will maintain close ties to the North Slope Science Initiative's project with the Geographic Information Network of Alaska (GINA). At the national level, the Arctic LCC will collaborate through participation in the National LCC Network's Data Management Work Group.

5.B. Community Involvement in Science

Twelve communities are located within the Alaska portion of the Arctic LCC (Figure 4). The Arctic LCC will work with tribal and local government representatives to involve local residents in developing science priorities and participation in studies. The best structure for facilitating such participation is yet to be determined.

5.B.1. Developing Science Priorities

Local residents' observations of environmental change are a valuable source of information for documenting environmental change. Communication of local observations and concerns may occur through existing advisory groups (e.g., Federal Subsistence Regional Advisory Councils, North Slope Borough Fish and Game Management Committee), agency community liaisons, and social science research activities. The work of International bodies, such as the Arctic Council's Conservation of Arctic Flora and Fauna working group, and the Borderlands Ecological Knowledge Cooperative, can help inform evolving Arctic LCC science priorities.

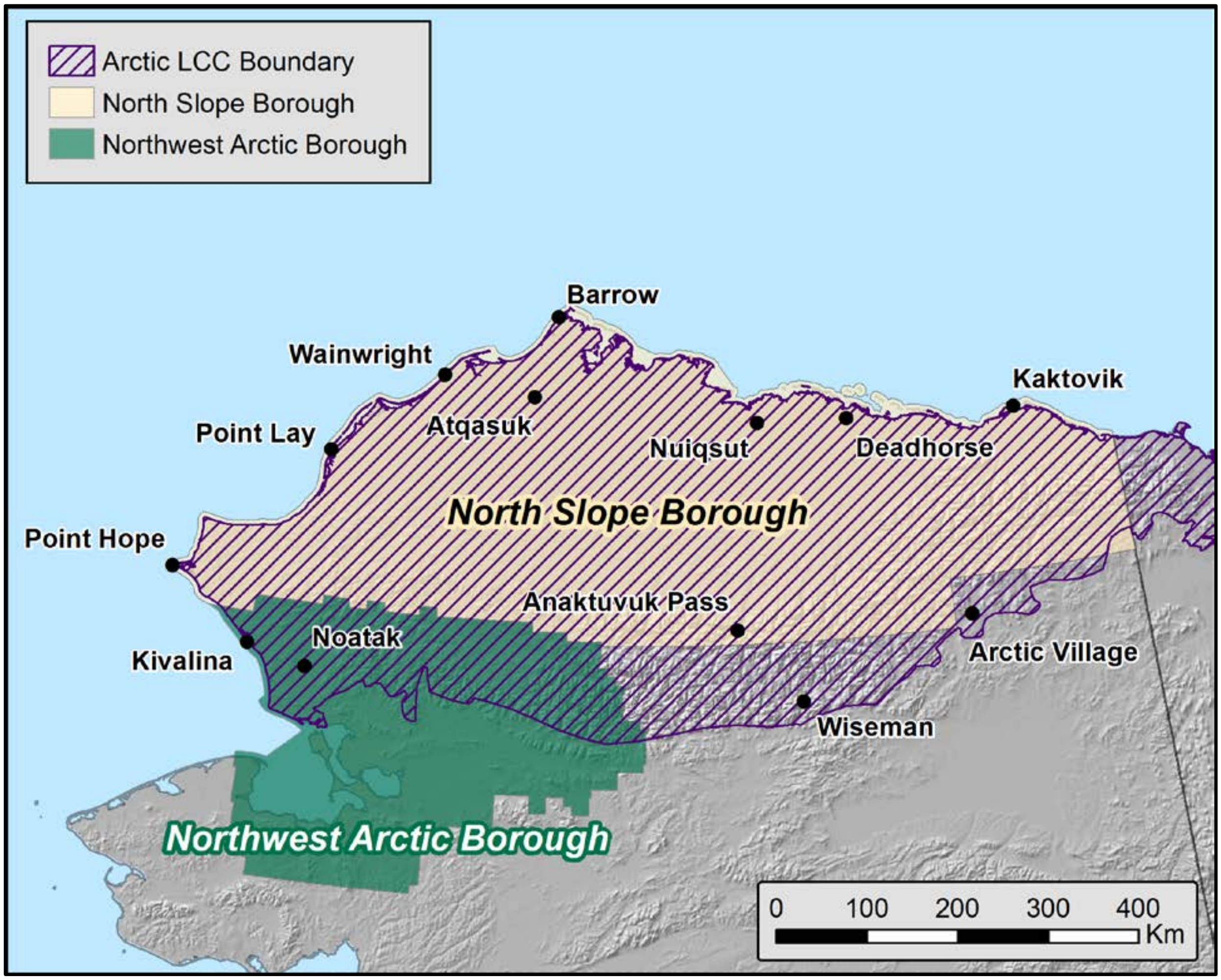

Figure 4. Communities located within the Alaska portion of the Arctic LCC. Eight communities are within the North Slope Borough, two within the Northwest Arctic Borough, and two outside of an organized borough.

5.B.2. Community-based Monitoring

Community-based monitoring projects provide opportunities to connect community concerns and scientific understanding, linking local observations with gaps and questions in current science. At their best, they support and encourage true collaboration of community members and scientists. While such observational activities should ideally mesh well with regional monitoring activities, the Arctic LCC recognizes value in locating scientific activities within communities, irrespective of other siting considerations. Ideally, data collection would occur as a cooperative activity engaging both professional scientists and local residents. The Arctic LCC will pursue opportunities to collaborate with other interested entities, including the North Slope and Northwest Arctic boroughs, the Bureau of Ocean Energy Management, the North Slope Science Initiative, Alaska Native Tribal Health Consortium, Alaska SeaGrant, North Pacific Research Board, and National Science Foundation.

5.C. Interagency Coordination

Arctic LCC Steering Committee meetings will facilitate exchange of information among member organizations regarding planned or ongoing studies, with the goal of identifying common study objectives that could be strengthened by adopting common protocols, pooling data, and expanding the geographic scope of analysis. Steering Committee meetings provide a venue for identifying priority science needs and conservation goals that can be advanced by pooling the capacities and resources of the partnership. Steering Committee members are encouraged to pursue opportunities to direct their individual organization's resources toward implementation of the Strategic Science Plan.

5.D. Representing Resource Management Concerns to the Research Community

Arctic LCC staff will endeavor to keep the Steering Committee informed of opportunities for communicating science needs to external research providers, and to pursue opportunities to provide such input and advice. Such organizations include (but are not limited to) various programs of the National Science Foundation (including AON, Arctic System Science, Arctic LTER), NASA, Department of Energy, North Pacific Research Board, and various University of Alaska programs and institutes. Potential partners also include non-governmental organizations with an interest and capacity for arctic research and data analysis, such as The Wildlife Conservation Society, National Audubon Society, Nature Conservancy, and Wilderness Society.

Opportunities to provide input to the research community include sustained participation on advisory boards, such as the North Slope Science Initiative Science and Technical Advisory Panel and Senior Staff Committees; Study of Environmental Arctic Change (SEARCH) Steering Committee, and Toolik Environmental Data Center advisory board. When possible, we will also participate in workshops that are periodically organized by NSF, USGS, and others.

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APPENDIX A. TERRESTRIAL ENVIRONMENTAL OBSERVATORY NETWORK PLAN

APPENDIX B. REPORT OF THE SPECIES AND HABITAT WORKING GROUP

APPENDIX C. DATA SHARING POLICY

Appendix A. The Terrestrial Environmental Observation Network (TEON): Objectives and Implementation

Prepared for the Arctic LCC by Benjamin T. Crosby, Idaho State University

Public Review Draft – February 2013

The Terrestrial Environmental Observation Network (TEON): Objectives and Implementation

Contents

1. Summary

One of the greatest challenges facing arctic scientists and land managers is the establishment and maintenance of long-term environmental observation networks. Most networks are designed and implemented to support short-term, local objectives and are typically discontinued at the end of the project. Over the last decade, Arctic science plans and scoping documents have emphasized the need to establish and maintain a network of persistent observation sites (Brabets 1996, Vörösmarty et al. 2001, SEARCH 2005, Martin et al. 2009, AON 2010, Streever et al. 2011, IARPC 2012, UNEP, 2012). Ideal observation sites provide frequent, synchronous measurements of physical, chemical, and biological attributes that are uplinked to a central data portal. As of yet, very little progress has been made to organize observing activities in northern Alaska into a coherent, consistent network. For the first time, the Arctic Landscape Conservation Cooperative (Arctic LCC) has the collective interagency capacity to design, implement and support a Terrestrial Environmental Observation Network (TEON) that fills this longstanding gap. The Arctic LCC has the unique capacity to coordinate a broad array of science teams and unify the array of disparate of observation stations into one entity. In data-poor regions, new installations have become more feasible due to the decreasing cost and increasing rigor of environmental sensors and communication platforms. The proposed TEON network can remedy issues faced in previous attempts at creating a network by explicitly meeting the following criteria:

- The network of sites are responsive to the collective needs of a diverse suite of federal, state, academic and industrial stakeholders working in the Arctic LCC domain.
- Individual sites are broadly distributed, and characterize the spatial and temporal variability in bio-physical conditions. Replication within ecoregions supports inter-site comparisons.
- Site are selected which minimize the cost of installation, operation, access and maintenance while maximizing the representativeness of the network and continuance of existing data archives.
- Parameters measured and protocols used, are consistent among sites and include a common suite of variables relevant to diverse users (hydrology, meteorology, permafrost, etc.).
- Data streams are relevant and accessible to supporting agencies and partners for use in change detection, basic science, model calibration and verification and applied decision making.

Following the criteria defined above and the feedback from the Arctic LCC technical work groups and the Arctic LCC Steering Committee, we suggest that the Arctic LCC support the development and coordination of an observation network organized around 7 representative focal watersheds (Figure 1). These include the Kokolik River area, the Barrow/Meade River area, the Fish/Judy Creek area, the Kuparuk River area, the Hulahula/Jago River area, the Agashashok River area and the Upper Koyukuk area. Data will be collected by automated sensors at a suite of mainstem/tributary confluences within each watershed. Because these sites are stratified by ecoregion, terrestrial and tributary data will record local meteorological, hydrological and soil/permafrost conditions while mainstem measurements reflect the integrated upstream environment.

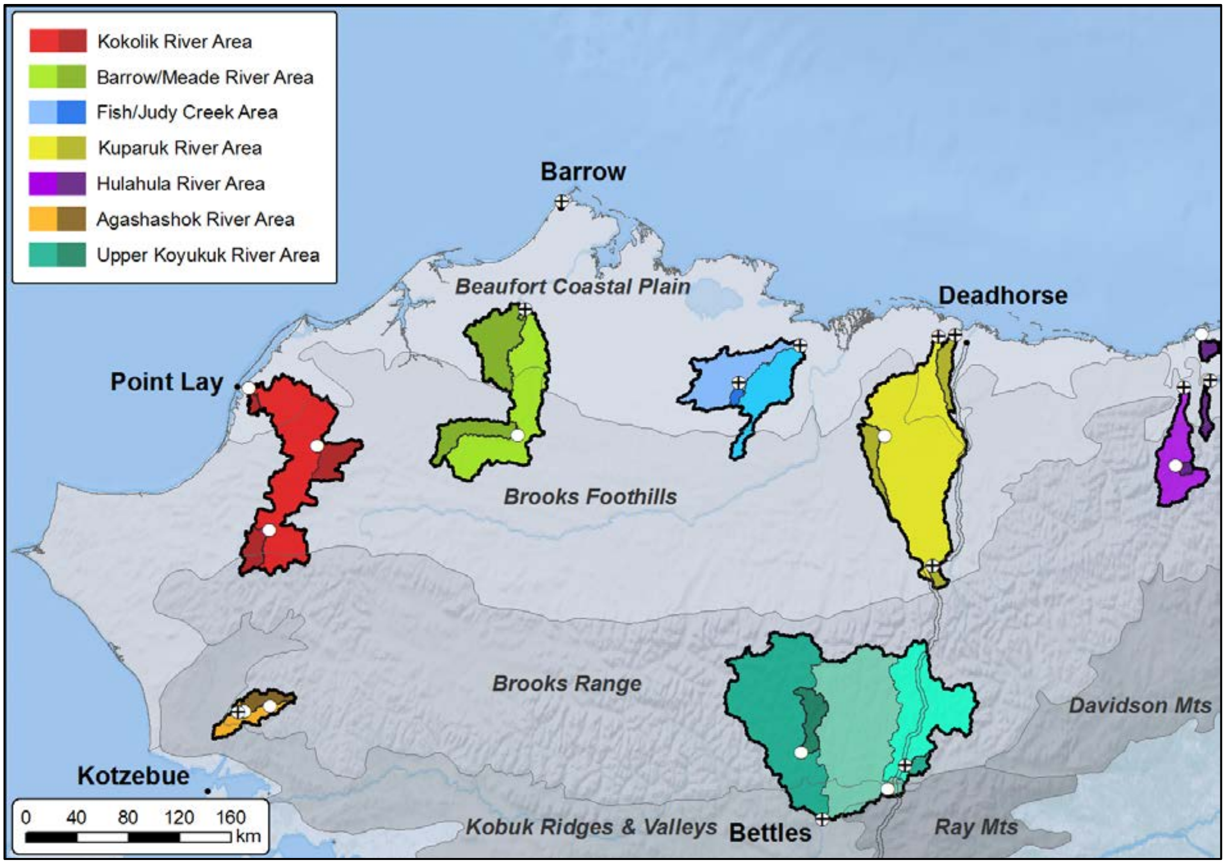


Figure 1: Regional map showing the locations of the 7 proposed focal watersheds (colored polygons). Note that watersheds cross multiple ecoregions (grey shading) and are located (when possible) near villages or along roads. D arker shading represents nested watersheds (see Figure 3). White circles denote the locations of proposed TEON stations; those with crosses indicate sites with existing infrastructure or data. The extent of the map roughly corresponds to the extent of the Arctic LCC domain.

2. Network Criteria

TEON sites are selected to satisfy a set of criteria, as discussed in summary above. The following section elaborates on the general rationale for site selection.

2.1 Network is Responsive to Stakeholder Needs

The development and maintenance of TEON requires the financial and intellectual commitment from a diverse array of benefiting agency and academic partners. This section briefly outlines how the network provides a valuable return on investment to a broad array of users.

Land Managers: Changing climate alters the timing and magnitude of biological and physical processes. These changes influence the abundance, distribution and behavior of managed species (and their habitat), such as caribou or waterfowl. These changes in environmental conditions specifically impact transportation (both roaded and unroaded) as well as the terrain stability required for infrastructure such as pipelines. Though an individual agency may have a limited jurisdiction relative to the Arctic LCC as a whole, the distributed nature of TEON provides valuable insight into regional trends that impact local management activities. In particular, the hydrological concerns focus on changes to timing and amount of discharge, lake distribution, snowpack characteristics (amount and distribution), and water availability. The network also provides a framework for state, federal and academic scientists to work collaboratively at research sites with existing science infrastructure and established, predictable logistics. Change-detection cannot be done without a well-distributed network of consistent observation stations.

Physical and Biological Modelers: In order to simulate the behavior of a system, observational data are necessary to calibrate parameters and validate the results. This process typically requires long duration observational records from sites distributed across a domain of interest. The current density and duration of observational stations is insufficient to confidently construct models that either hindcast or forecast environmental conditions. Current records are short duration, collected with inconsistent instrumentation and insufficiently distributed to help ecophysical modelers distinguish trends from the noise and drive modern numerical simulations.

Field Scientists: Baseline data are hard to come by in remote locations in Northern Alaska. Barrow and Toolik field station attract researchers as a consequence of having well maintained records of physical and biological parameters, but these two hot-spots of scientific inquiry are not very representative of the region. The proposed TEON sites provide a formalized network with baseline data and established logistics that spans the hydrological, meteorological and ecological variability in the Arctic LCC region. These sites will function as long term natural laboratories where new investigations can take advantage of the foundational Arctic LCC data to accomplish projects that extend beyond the scope of TEON. We hope that TEON sites will become an integral component within the NSF-supported Arctic Observing Network (AON) effort as well as other programs such as CALM and GTN-P.

Industry Stakeholders: The oil and gas industry works closely with state and federal land managers to assure that their current operations conform to regulatory requirements and that their future plans are both logistically and legally viable. The TEON network will provide valuable, well-distributed data to these uses for a variety of applications including road construction (ice and gravel pad) and pipeline stability (present and proposed). In a larger context, the TEON data will drive modeling efforts that will be useful for generating short term forecasts as well as distinguishing whether current conditions are the consequence of long term environmental change (natural variability) or the consequence of anthropogenic activities. Some sites within the network are near to existing or planned industrial activities.

2.2 Sites Must Capture the Spatial and Temporal Variability

The Arctic LCC domain is a vast and complex region characterized by extremes; high relief, glacially sculpted mountains are contrasted against expansive coastal plains dotted with thermokarst lakes. Superimposed onto this topographic gradient are patterns in climate driven not only by elevation but by high interannual variability in sea ice extent thus affecting proximity to moisture sources and the paths of storm tracks. Much of what we know about climate in northern Alaska is based on models calibrated using extremely sparse and incomplete instrumental data (Fleming et al. 2000, Shiklomanov and Nelson 2002, Serreze et al. 2003 Simpson et al. 2005). Weather, climate, and hydrologic information in this vast geographic area are relatively sparse and particularly in regards to long-term records. For example, Alaska has one stream gauge per 4,600 sq miles compared to an average of 1 gauge/470 sq miles in the Western US, excluding Alaska (Klein 2011). These calibration data come largely from Barrow and the Toolik/Kuparuk/Dalton Highway areas and many have argued that they are not necessarily representative of the larger Arctic LCC domain. Modeled conditions suggest that liquid precipitation and snow accumulation are highest in the mountains while annual air temperatures are lowest in the mountains and coastal plains but warmest in the foothills (SNAP website, 2012). Casual observations made by travelers in the region support the assertion that that large spatial and temporal gradients in climate exist in the region but these remain unconfirmed by real data. Many key species (caribou, fish, birds) migrate annually along these gradients in climate and terrestrial ecosystems are shown to be adapted to local conditions (Walker et al., 2008, Jorgenson, 2012).

As a consequence of this spatial variability, biologically relevant environmental parameters such as timing of snowmelt, peak runoff or maximum active layer depth are asynchronous across the Arctic LCC domain (Smith, 2010; Romanovsky, and Osterkamp, 1995). In order to capture this variability, we built upon the efforts of previous workers (e.g. Brabets, 1996) who designed (but were unable to implement) observation networks intended to capture this heterogeneity. Anticipated shifts in seasonality are also expected to have a significant impact on the timing and magnitude of these events (McNamara et al., 2008), potentially conflicting with the life histories of species in the region. In order to quantify the true variability in the region and demonstrate shifts in the location and timing of environmental processes, we propose that a network of observation stations will improve not only our records of change but also our ability to interpret and predict it.

Though the above suggests the need for a well distributed array of independent stations, we assert that the sensor network should also provide an opportunity for inter-comparison between sites. After considering numerous categorizations of the arctic landscape, we propose that the most robust framework for stratifying TEON sites uses the ecoregional framework proposed by Gallant et al. (1995) and further refined by Nowacki et al (2011) and Jorgenson (2012). Gallant et al. (1995) described how the ecoregional framework was derived for Alaska.

> *The map of Alaskan ecoregions was derived by synthesizing information on the geographic distribution of environmental factors such as climate, terrain (including information on physiography, geology, glaciation, permafrost, and hydrologic features), soils, and vegetation. This synthesis was a qualitative assessment of the distributional patterns and relative importance of these factors for influencing the character of the landscape from place to place.*

The ecoregional concept partitions the Arctic LCC region into roughly three domains based on physical characteristics that support distinct ecosystems. These include the Beaufort Coastal Plain, the Brooks Foothills and the Brooks Range (Figure 1). Small portions of the Davidson Mountains and Kobuk Ridges and Valleys lie along the southern fringe of the Arctic LCC area. Though more highly resolved maps of ecological domains have been generated for the Arctic LCC region (Jorgenson 2004, 2012 and

Jorgenson et al., 2009), we found that our sites were representative of both the coarser ecoregions and the finer, more nuanced classifications.

Based on the "Ecological Landscape" units delineated by Jorgenson (2012), we compared the categorical composition of the 7 TEON focal watersheds (in aggregate) to the bulk composition of the Alaska portion of the Arctic LCC. Ecological Landscape units (Figure 2) integrate climate, surficial geology, and lithology. This classification delineated 31 landscape units in northern Alaska, 27 of which occur within the boundaries of the terrestrial portion of the Arctic LCC within Alaska. Of these, 22 are represented within the 7 TEON watersheds (Table 1). The "missing" Ecological Landscape units are all aquatic, e.g. marine, or freshwater (Teshekpuk Lake). The only landscape unit under-represented (difference > 5%) is Arctic Rocky Alkaline Alpine, which occurs mostly in the eastern Brooks Mountains.

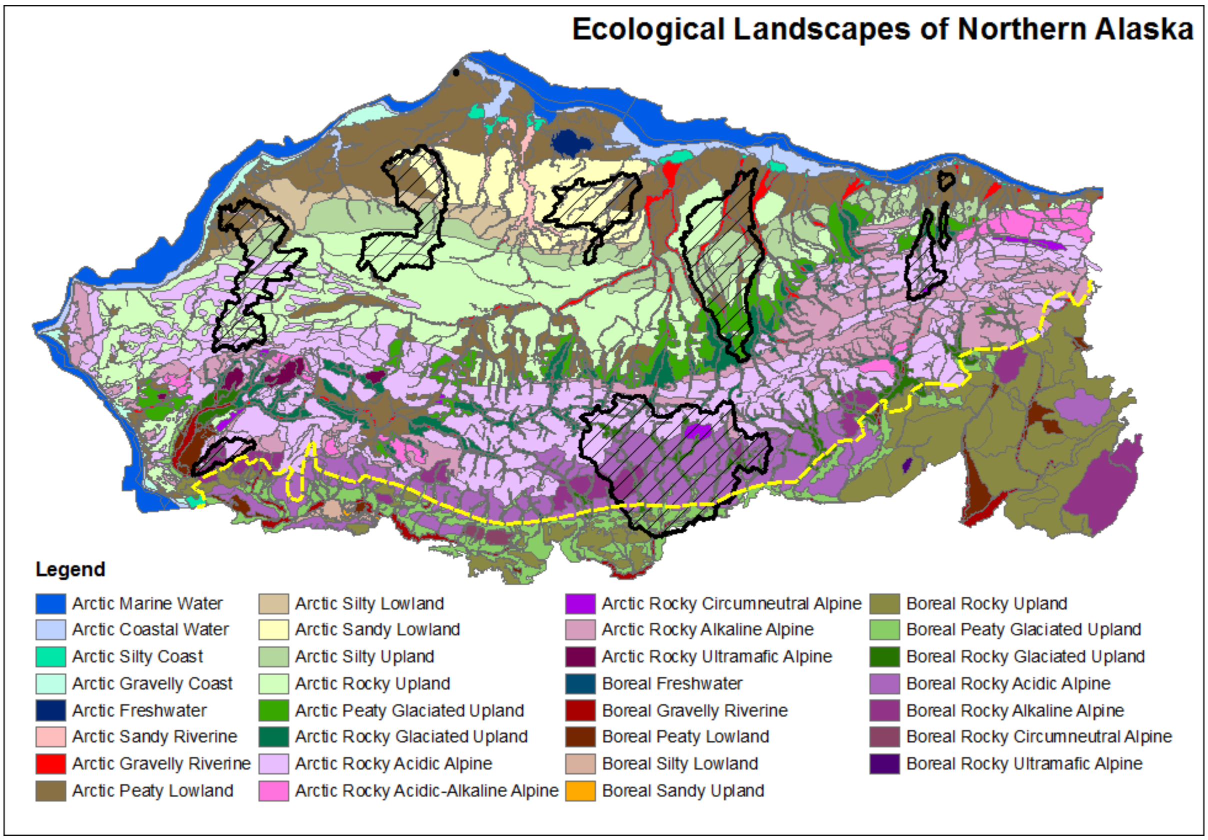


Figure 2: Map of 'Ecological Landscapes' in northern Alaska (Jorgenson, 2012). Arctic LCC boundary is represented by the dashed yellow line, and proposed TEON watersheds are shown in black cross-hatch.

Ecological Landscape Units	% of AK Arctic LCC	% of TEON	Difference in %
Arctic Rocky Alkaline Alpine	8.00	1.52	-6.48
Arctic Rocky Acidic Alpine	20.82	16.18	-4.64
Arctic Peaty Lowland	14.45	10.18	-4.26
Arctic Rocky Glaciated Upland	4.63	1.63	-3.00
Arctic Rocky Acidic-Alkaline Alpine	1.58	0.07	-1.52
Arctic Rocky Upland	16.92	15.71	-1.21
Arctic Gravelly Riverine	3.20	2.04	-1.16
Arctic Silty Coast	0.47	0.00	-0.47
Arctic Gravelly Coast	0.44	0.03	-0.41
Arctic Peaty Glaciated Upland	3.76	3.44	-0.33
Boreal Rocky Upland	0.35	0.02	-0.32
Boreal Peaty Lowland	0.36	0.05	-0.31
Arctic Rocky Ultramafic Alpine	0.41	0.10	-0.30
Arctic Coastal Water	0.29	0.00	-0.29
Arctic Freshwater	0.28	0.00	-0.28
Arctic Marine Water	0.03	0.00	-0.03
Boreal Freshwater	0.02	0.00	-0.02
Boreal Peaty Glaciated Upland	0.71	0.86	0.15
Arctic Silty Lowland	2.11	2.33	0.22
Boreal Gravelly Riverine	0.58	0.91	0.33
Arctic Sandy Riverine	1.18	1.56	0.38
Arctic Rocky Circumneutral Alpine	0.39	1.03	0.63
Boreal Rocky Alkaline Alpine	1.50	2.98	1.48
Boreal Rocky Glaciated Upland	1.89	3.95	2.06
Arctic Silty Upland	5.54	9.63	4.09
Arctic Sandy Lowland	4.46	8.98	4.51
Boreal Rocky Acidic Alpine	5.61	16.81	11.20

Table 1. Coverage of Ecological Landscapes (Jorgenson, 2012) within the Alaska portion of the Arctic LCC, compared to the aggregate area of the proposed 7 TEON watersheds. Landscape units in gray are not represented within TEON watersheds. The "Difference in %" shows those units that are present but significantly under-represented (pink) and those that are significantly over-represented (green).

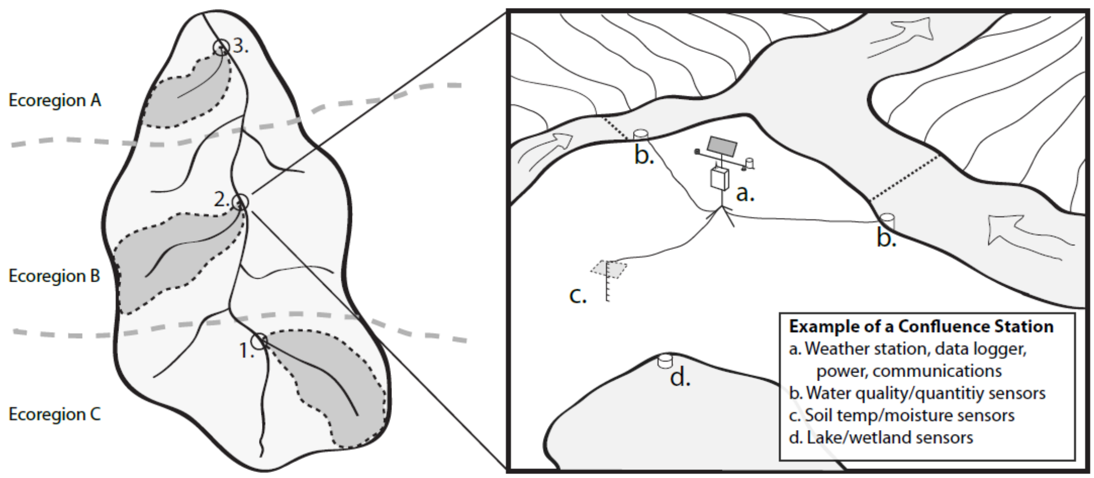
We also used Jorgenson and Heiner's (2004) ecotype map of northern Alaska as the basis for comparing vegetation/cover types represented within TEON watersheds. Because this dataset does not include the 2 southern focal watersheds, our analysis only considers the 5 northern watersheds. For most ecotypes, the composition within TEON watersheds is within a few percentage points of that for the Alaska portion of the Arctic LCC area (Table 2). Exceptions are Lowland Moist Sedge-Shrub Tundra and Upland Tussock Tundra, which are both over-represented, and Alpine Noncarbonate Dwarf Shrub

Tundra, which is under-represented. All 12 ecotypes that represent at least 1% of the region are present within TEON watersheds. Several rare ecotypes are missing however, including two coastal types, four alpine types, and spruce forest. Many of these omissions are covered by the 2 southern watersheds which were excluded from this analysis.

Ecotype	% of AK Arctic LCC	% of TEON	Difference in %
Coastal Barrens	0.23	0	-0.23
Coastal Wet Sedge Tundra	0.63	0	-0.63
Coastal Grass and Dwarf Shrub Tundra	0.68	0.03	-0.64
Riverine Barrens	0.83	0.54	-0.29
Riverine Willow Shrub Tundra	0.56	0.57	0
Riverine Moist Sedge-Shrub Tundra	2.41	2.97	0.56
Riverine Wet Sedge Tundra	0.98	0.96	-0.03
Riverine Waters	0.64	0.43	-0.2
Riverine Dryas Dwarf Shrub Tundra	0.13	0.05	-0.08
Lowland Wet Sedge Tundra	7.56	8.06	0.5
Lowland Lake	4.86	5.38	0.52
Lowland Moist Sedge-Shrub Tundra	9.63	14.37	4.74
Lowland Low Birch-Willow Shrub	1.12	1.38	0.26
Upland Tussock Tundra	8.43	12.47	4.04
Upland Dryas Dwarf Shrub Tundra	1.24	1.08	-0.16
Upland Shrubby Tussock Tundra	21.59	22.36	0.77
Upland Low Shrub Birch-Willow Tundra	17.85	15.36	-2.5
Upland Moist Sedge-Shrub Tundra	6.64	8.49	1.85
Upland Tall Alder Shrub	0.1	0.06	-0.04
Upland Spruce Forest	0.02	0	-0.02
Alpine Glaciers	0.1	0.12	0.02
Alpine Noncarbonate Barrens	4.02	1.94	-2.09
Alpine Carbonate Barrens	0.05	0	-0.05
Alpine Mafic Barrens	0.05	0	-0.05
Alpine Noncarbonate Dwarf Shrub Tundra	7.91	3.19	-4.71
Alpine Carbonate Dwarf Shrub Tundra	0.06	0	-0.06
Alpine Mafic Dwarf Shrub Tundra	0.09	0	-0.09

Table 2. Representation of ecotypes (Jorgenson and Heiner, 2004) within the Alaska portion of the Arctic LCC, compared with the 5 northern proposed TEON watersheds. Ecotypes missing within TEON watersheds are shaded in gray. Ecotypes that are significantly over-represented in TEON watersheds are shaded in green; those that are significantly under-represented are shaded in pink

Because a random, stratified sampling design would preclude prioritization of watersheds with legacy data, we suggest organizing sites along transects that follow rivers that progressively cross (and sample) the three main ecoregions (Figure 1). If located at tributary junctions, individual sites can support both local measurements (climate, vegetation, ground temperatures and hydrology) that characterize a particular ecoregion while also supporting measurements of mainstem river fluxes (water, nutrients and sediment) that integrate the diversity of all upstream environments (Figure 3). By selecting observation sites nested along watersheds, we gain both breadth in landscape characteristics while also supporting studies that examine additive interactions between ecoregions. For example, a series of tributary and mainstem stations in a given watershed supports not only the investigation of how the timing and magnitude of local (tributary) peak discharge varies across the Arctic LCC but how contributions integrate to generate the oft-measured mainstem signal. In the event that an observation site for a particular ecoregion cannot be established inside a particular focal watershed, we suggest that a site be selected in an adjacent watershed that shares similar characteristics.



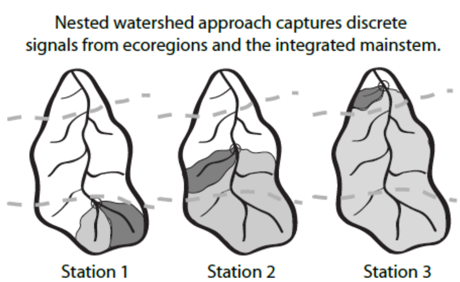


Figure 3. Idealized TEON watershed spanning multiple ecoregions (A, B, C) with nested watersheds (dark gray shading) and observation stations positioned at tributary confluences (1, 2, 3). A nested watershed approach allows characterization of ecoregion-specific conditions and an integrated signal from the mainstem. Information on water quality/quantity, weather, soil/permafrost, and vegetation is collected at confluence stations (inset).

2.3 Sites Minimize Costs While Maximizing Legacy Data Preservation

The cost of installation, operation and maintenance of complex observation networks is often prohibitive. Numerous committees and synthesis reports have expounded upon the dire need for an improved environmental observation network in northern Alaska (references above), yet because of the cost and effort required to access most of this remote region, this burden has been too great for one agency or entity to sustain independently. The cooperative structure of the LCC makes this task attainable. To increase the affordability of the network, we suggest taking advantage of existing installations with legacy data and agency or academic investment or interest. Because the Arctic is characterized by large interannual variability, change detection requires long duration records to detect trends in a noisy signal. Sustaining an existing data stream is always more valuable than initiating a new one because a significant baseline already exists from which to detect change. Working with existing installations also reduces costs because of the preexisting infrastructure and reduces uncertainty because these sites have already proven to be stable, accessible and desirable. Incorporating existing sites within the larger TEON framework reduces the burden on field crews and data managers because they become supported by a larger, more robust and consistent infrastructure.

Regions within the Arctic LCC domain that lack observing networks will require installation of new observation stations. These new sites are selected to minimize access and installation costs while also assuring the completeness of the network and serving stakeholder needs. New sites were not selected to support particular entities, but rather be responsive to the needs and concerns of multiple agencies while producing data that are relevant to a broad, interdisciplinary audience. Where possible, new sites are located near roads, rivers or villages or where year-round access is relatively easy and inexpensive (near airstrips). For sites that are more difficult or expensive to access by air, we have considered using inflatable boats to float between sites along a given drainage. By positioning sites near tributary junctions, multiple useful measurements can be made within walking distance from the landing zone. Though not all sites can offer the following attributes, an ideal site provides safety, power, and communications, access to tools and materials, and/or shelter for technicians.

2.4 Observed Variables are Relevant and Consistent Among Sites

In designing the suite of variables to be observed throughout TEON, we consulted the Arctic LCC technical work groups and a suite of scientists already operating and maintaining sites in the arctic. From this feedback we were able to generate a 'most favored' suite of variables, instruments and protocols. Variables fall into 4 coarse categories: meteorology, surface waters, soil/permafrost and vegetation. These categories provide the most basic information relevant to the broadest array of users while minimizing costs of installation and maintenance. The particular parameters in each category are relatively simple, robust and can be measured using either automated environmental sensors or infrequent manual measurements. This 'core' suite of parameters will be observed with the same frequency and accuracy at each of the sites and inform users about the basic habitat template available at each site. If active research efforts require the measurement of variables beyond the core suite at a particular site, these can be added to the existing infrastructure of power and communications. At some of the existing sites that we hope to incorporate into TEON, parameters or protocols differ slightly different from what we propose. Over time, as hardware requires replacement, we will transition existing stations toward a uniform suite of instrumentation and protocols

2.4.1 Meteorological Observations:

In order to serve a diverse community of users (modelers, operational logistics, hydrologists, etc.), while minimizing costs, meteorological observations at TEON sites focus on measuring basic fluxes of energy and water. More complex parameters such as evapotranspiration require instrumentation such as flux towers or lysimeters that are either too expensive, too power intensive, or too difficult to maintain at all of our remote, unmanned sites. These parameters can be added to some of the sites as required by local investigators, but will not be a part of the common suite of variables measured at all sites. For now, we will collect data that allow us to estimate the more complex parameters.

- The **radiation energy balance** between incoming short-wave and long-wave infrared radiation relative to surface-reflected short-wave and outgoing long-wave infrared radiation is measured using a net radiometer. This measurement is valuable for understanding energy fluxes in and out of the soil and quantifying the effects of seasonally varying albedo. The selected instrument describes the net flux but if affordable should be upgraded to measure the 4 fluxes independently.
- **Air temperature and relative humidity** measurements are made 2 meters above the ground surface. This characterizes the more mixed, near-surface air and is less sensitive to local variations driven by vegetation or micro-topography.
- **Barometric pressure** is measured to characterize the movement of storms through the region and provide necessary data for the calibration of water level and water quality sensors.
- **Wind speed and direction** are measured at 3 meters height to help estimate evapotranspiration losses during the warm season and snow redistribution during the winter.
- **Liquid precipitation** is measured using a tipping-bucket rain gage. This sensor records the magnitude, duration and intensity of liquid precipitation events with the incremental precision of 0.1mm. These data are especially valuable as precipitation is one of most poorly constrained parameters in climate models.
- **Snow depth** is measured using an acoustic snow level sensor that looks down at the ground surface and measures the distance from the sensor to the top of the snowpack. Though this instrument does not give information about the snow water equivalent (SWE), is provides a good measure of the accumulation and persistence of snow cover which has a large influence on the thermal state of the subsurface. If feasible, some sites will be visited during the early spring (April 1) to make physical measurements of snow characteristics along transects (depth, density, structure, etc.). Other types of instruments such as snow pillows are not affordable or maintainable. Snow accumulation will be measured with a Nipher snow gage. We have discussed the possibility of coordinating with the NRCS to install their future SnoTel sites near our installations.

2.4.2 Surface Water Observations:

Measurements of surface water conditions focus on both the quantity and quality of water in both river and lake/wetland environments. These measurements are responsive and tied to the meteorological parameters and impact industrial operations such as ice road construction or water withdrawals as well as management priorities such as waterfowl and fisheries. Because of the unpredictable, destructive nature of ice-out events in streams and lakes, some of the following observations will be only available during the ice-free season.

- **Water level** (stage) is measured using a pressure transducer. Depending on the stability and location of the installation, transducers may either be cabled to the data logger or autonomous. Depending on the installation, transducers may also be vented or unvented (requiring barometric correction). Water level will be recorded in streams and in lakes. In streams, infrequent measurements of **stream discharge** (volumetric water flux) will be paired with measurements of stage (water level) to construct a mathematical relationship between the two variables. This stage-discharge relationship allows the high frequency stage data to be converted to continuous estimates of discharge. Discharge measurements will be made in the spring and fall, near the annual extremes using standard USGS techniques and an Acoustic Doppler Current Profiler (ADCP) or Acoustic Doppler Velocimeter (ADV).
- **Water quality** parameters are numerous but a core suite can function as robust indicators of stream health and are responsive to environmental changes. Multi-parameter sondes are low profile, robust and, for some parameters, do not require calibration during the summer deployment. The suggested parameters for the TEON sites are **water temperature, conductivity, turbidity, pH and dissolved oxygen**. The last two are the most sensitive to sensor-drift and may require more frequent calibration. Depending on the particular location, this suite of parameters might be collected in streams and lakes or just streams. **Biogeochemical sampling** of surface waters occurs infrequently during technician visits twice a year. Though the list of analyses is still under development, we suggest measurements of dissolved inorganic carbon, dissolved organic carbon, particulate organic carbon and a suite of nutrients. Less frequent measurements of cation and anion concentrations and stable isotopes would be useful as well. Analyses would all occur at the same laboratory under strict QA/QC protocols.
- **Sediment flux** in arctic rivers provides an important measure of upstream disturbances and aquatic habitat quality. Autonomous measurements of turbidity made by the multi-parameter sonde can be correlated to infrequent in-field water sampling for **total suspended solids** (TSS). Though there are demonstrated issues with correlating turbidity to TSS, this procedure is easy, inexpensive and provides a valuable measure of water quality and bed conditions.

2.4.3 Soil/Permafrost Observations:

The design of our installations is based on the existing transect of ground and borehole temperature measurements maintained by the Permafrost Laboratory at the Geophysical Institute at UAF. Their data demonstrate that ground temperatures are rising and that the nature of that change is a function not just of latitude, but local soil, vegetation and topographic setting. Automated measurements in the shallow subsurface are relatively easy and robust compared to meteorological or surface water measurements because they require less calibration and protection against exposure, weather and abuse.

- **Shallow temperature profiles (0-1.5m)** are measured at each site using a thermistor string with sensors at 16 different depths, extending to a depth of 1.5 meters. Typical maximum active layer thicknesses in this region are ~50-70 cm so this installation allows the detection of the progressive deepening of the active layer. The thermistor string can be manufactured using inexpensive parts and proven techniques developed by the Permafrost group at the GI at UAF. The large number of measurement depths requires a multiplexer.
- **Deeper temperature profiles (1.5 – 3m)** do not require as many thermistors but extend from 1.5 m to a total of 3m depths, well below the active layer. These data are valuable to understanding the propagation of thermal signals from the surface to the deeper frozen ground. During installation, careful collection and characterization of the subsurface materials will be done. The bore holes for both temperature profiles are drilled with a rechargeable rotary hammer drill and auger bit.
- **Soil heat flux** measurements are made by placing a sensor plate at the base of a soil pit, typically around 0.5 m in depth. In the same pit, three **soil moisture probes** and three **soil temperature sensors** are co-installed at three different depths, in three different soil materials to characterize how water retention varies through time in response to precipitation events and air temperature fluctuations. We will follow the protocols outlined by the AmeriFlux program: measure absolute soil moisture at many depths (preferably in the root zone at 5, 10, 20, 30, 50 and 100cm), compare soil moisture measurements to soil moisture predictions generated from remote sensing datasets. We recommend units of m^3/m^3.
- **Water table height** can be measured using shallow (<1m) PVC wells and capacitance water level probes. Traditional methods involving pressure transducers are problematic because they are sensitive to freezing and the water table can appear to drop even though it is constant and only the frost table is dropping. Investigators are currently struggling to find the best technique to make this important measurement. Water table height in the active layer controls the persistence of anoxic conditions and thus the rate and extent of biogeochemical processes that affect nutrient availability and greenhouse gas (GHG) production.
- **Soil characteristics** will be measured during the initial installation of the hardware and should include parameters such as ice content, gas fluxes, bulk density, soil organic matter (SOM) and carbon and nitrogen concentrations.
- **Active layer thicknesses** will be measured using the well-established Circumpolar Active Layer Monitoring (CALM) protocols and include transects and gridded measurements.

2.4.4 Vegetation Observations:

At each TEON site, infrequent (2-5 years) visits by experts in botany will characterize the diversity and abundance of different species and their structural form using transects, point measurements or counting frames. Each transect should, for example, characterize the diversity of plant communities near the observation site, along a riparian-to-upland transect and along transects radiating away from the edge of a lake or wet sedge environment to a higher and drier environment. Besides transects, the team of experts will make careful observation of the vegetation above the soil and permafrost instrumentation. The vegetation team returns to the site less frequently because the rate of change in their domain is slower than the instrumental measurements. Numerous protocols exist for vegetation monitoring including those established by the Arctic National Wildlife Refuge (Jorgenson et al. 2010) the BLM's AIM program (MacKinnon et al. 2011) and the International Tundra Experiment (ITEX) group (Molau and Mølgaard, 1996). Explicit protocols will be determined before sites are established.

2.4.5 Remote Sensing:

We also suggest that recurring observations expand beyond the *in situ* field sites to include the acquisition and analysis of remote sensing data including high resolution topography (LiDAR or interferometric synthetic aperture radar (IFSAR)) and multi- or hyper-spectral imagery. These datasets are becoming more broadly available, less expensive and serve numerous important purposes including landcover classification, hydrologic flow routing and other landscape scale analyses. These analyses include, but are not limited to, *snow characteristics* (initiation of coverage, duration of coverage, timing and patterns of snowmelt), *ice characteristics* (freeze-up and ice out on lakes and rivers) and *vegetation indices* (NDVI variation through growing season, NDVI variation between years, variations in plant communities, post-fire succession, etc.). Infrequent ground surveys and measurements will be made to ground-truth the classification schemes. At the more local scale, interval cameras collecting hourly images will track snow, ice, lake, river and vegetation changes through the year. File sizes for these data are too large to send out via satellite communications but will be downloaded during visits.

2.5 TEON Data are Discoverable, Organized and Available

Though the data management strategy of the larger Arctic LCC is addressed in other documents, this section suggests how TEON data should be handled. TEON will generate vast amounts of diverse data that will require careful and thoughtful management. This is a concern and opportunity for a variety of environmental disciplines (Porter et al., 2011 and Michener and Jones, 2012). Data from automated sensors operating in the field will be uploaded to a central server via Iridium satellite communications. These data will be immediately formatted for ingestion into the central database and made available to the public online as 'v0' or raw data. Though the Arctic LCC makes no assurance as to the accuracy of the raw data, it is better to make it immediately available to the wide spectrum of users than to wait for it to be vetted. Arctic LCC staff will periodically review blocks of data for anomalous values indicative of damaged sensors. This information will be tracked and used to inform field technicians of potential issues that will need to be addressed during early summer or late fall visits. Once data undergo QA/QC analysis to remove spurious values or apply shifts to sensors that are drifting out of calibration, these refined data will be categorized as 'v1' data. If there are portions of the time series that are beyond repair, data managers have the option to use statistical or correlative techniques to fill the gaps with modeled data. These continuous data that include modeled values are considered 'v2.' All steps of data versioning are carefully and thoroughly documented in metadata that are associated with each variable at each station. Infrequent but recurring measurements (e.g. water discharge) will also be posted to the same database as the streaming data for consistency. These data can be managed and distributed through a variety of mechanisms: (1) Arctic LCC maintains an in-house, independent data storage and distribution system, (2) field-site-specific data portals are supported and maintained by each project lead, but are pointed to via a TEON page on the Arctic LCC website or (3) all data stored on a common external database (CUAHSI-HIS, IARC, WERC, USGS, etc.) assuring the most uniform management and long-term data security. Arctic LCC staff will need to ensure that legacy data are brought into a common database with new data, so that the pre and post-TEON data are as seamless as possible. All changes in instrumentation and protocols will be detailed in the metadata for each variable at each site.

Interval camera data will be published as time series movies and raw blocks of imagery for download. Vegetation data will be transferred from field sheets to digital forms and uploaded to the LCC distribution site in a consistent manner after each survey. Raw remote sensing data acquired for the Arctic LCC domain may not be posted for free distribution due to licensing limitations but derivative products generated from that data could be distributed from the Arctic LCC while the data are stored on a centralized system such as GINA. Datasets that use the TEON framework to create interpolated maps of meteorological, hydrologic or other characteristics will also be posted and distributed via a centralized geospatial clearinghouse such as GINA.

3. Proposed Network

3.1 The Nested Watershed Approach

This section describes the rationale and character of the proposed TEON focal watersheds. The network is designed to capture the spatial and temporal variability in environmental conditions within the Arctic LCC domain and thus spans across the three prominent ecoregions in northern Alaska: the Brooks Range, the Brooks Foothills and the Beaufort Coastal Plain (Figure 1). Focal watersheds are also distributed from west to east across the Arctic LCC domain, capturing gradients in moisture availability and the effect of sea-ice duration. Each focal watershed contains two to four nested TEON sites that characterize both local conditions within a particular ecoregion as well as an integrated measure of basin characteristics observed in the mainstem river (Figures 1 and 3). Each site provides a unique contribution to the TEON network and was carefully selected from a larger suite of candidate sites. Though the network may expand over time, we suggest that the following suite of 7 core sites be incorporated into TEON based on the value of their existing legacy data and anticipated future data.

3.1.1 Kokolik River Area

Motivation for Site Selection

This watershed was suggested by the Arctic LCC Steering Committee for two reasons. First, the western North Slope has almost no existing observation stations. Second, recently permitted off-shore oil exploration in the Chukchi Sea will require terrestrial baseline data to support impact assessments. Discussion of the potential construction of a new pipeline further emphasized the need for pre-development observations in the region. The watershed drains directly to Point Lay village and the furthest downstream site is easily accessible from that site, decreasing logistics costs (Figure 4, site 3). The two upstream sites will require bush-plane or helicopter access and can be accessed from Point Lay, Kotzebue or Red Dog Mine. The two upstream sites are located where Brabets (1996) suggested installations of gaging stations to support an ideal regional streamflow network (Arctic 5 and 6). The 3 selected sites characterize each of the main ecoregions, though the Brooks Range area is disproportionately small.

Existing Infrastructure and Data

Table 3. Characterization of existing resources at each sampling location in the Kokolik River Area.
Table under construction.

Topographic and Environmental Characteristics

The Kokolik River drains from the northwestern corner of the Brooks Range south and west to Kasegaluk Lagoon and the Chukchi Sea (Figure 4). It crosses the three ecoregions but has very little high elevation area (Table 4). Folded and faulted carbonate and siliclastic rocks create a unique ridge and valley topography. Historic resource exploration has occurred in this region but there are no developed oil or gas fields. Land in the watershed is primarily managed by the BLM (eastern half of the basin), though the downstream station near the village is on native land and the upstream site is on state patented land.

Sampling location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Kokolik River tributary 1	307.16	1148.54	567.26	6.27	39.93	-9.0	541.6	516.35
Kokolik River tributary 2	98.08	622.23	254.66	3.33	22.11	-9.4	384.0	748.93
Kokolik River mainstem 1	306.34	1262.6	583.26	7.44	47.75	-8.6	540.0	984.76
Kokolik River mainstem 2	91.00	1262.6	460.36	5.74	47.75	-8.9	482.1	3128.41
Kokolik River mainstem 3	6.33	1262.6	282.01	3.49	47.75	-9.3	398.6	6390.80

Table 4. Environmental characteristics at each sampling location in the Kokolik River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

At present, we are not aware of any active participants collecting observations in this watershed. Potential agency partners that have expressed interest include BOEM, EPA and NOAA. Potential local partners could include the Native Village of Point Lay and the North Slope Borough. Site 3 is on Native Corporation land, and Site 1 is on state land, so appropriate permissions and permits would have to be obtained.

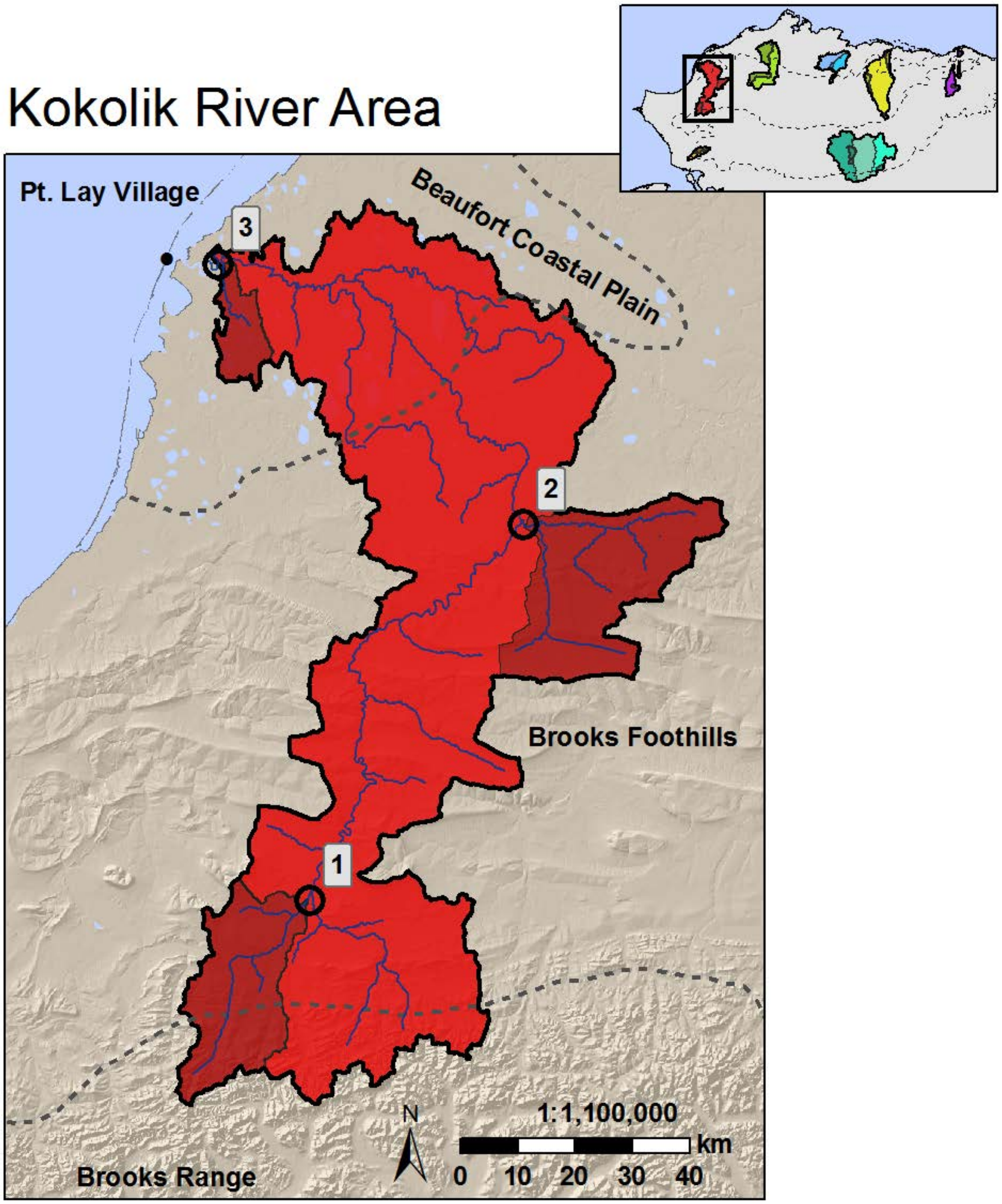


Figure 4: Map outlining the extent of the Kokolik River Area including the locations of observation stations (circles with numbers) and an inset regional map showing the distribution of all focal watersheds. Note that the downstream site [3] is close to Point Lay village and that the upstream site [1] is a mix of the Brooks Range and Foothill ecoregions.

Kokolik River Area						
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Per-Item Costs**
Logger/Power/Communications			Kokolik R and Tingmerkpuk R	Kokolik R and Avingak C	Kokolik R and Unnamed Trib	
	Data logger	1440	1	1	1	4320
	Multiplexer	600	1	1	1	1800
	Enclosure	290	1	1	1	870
	Battery enclosure	200	1	1	1	600
	Solar Panel	500	1	1	1	1500
	Charge Regulator/Controller	100	1	1	1	300
	Battery bank, storage	500	1	1	1	1500
	Tripod and mast	250	1	1	1	750
	Iridium radio and antenna, subscription	1500	1	1	1	4500
Meteorology						0
	Solar Radiation (net incoming and outgoing)	2000	1	1	1	6000
	Air temperature and RH -2m	650	1	1	1	1950
	Barometric Pressure	800	1	1	1	2400
	Wind Speed and Direction -3m	1000	1	1	1	3000
	Tipping bucket rain gage	410	1	1	1	1230
	Acoustic snow level sensor	1150	1	1	1	3450
Streams: Mainstem						0
	Water level (stage)	2000	1	1	1	6000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	24000
Streams: Tributary						0
	Water level (stage)	2000	1	1	1	6000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	24000
Wetland-Lake						0
	Water level (stage)	600	1	1	1	1800
	Temp	0				0
	Conductivity	700	1	1	1	2100
Soil-Permafrost						0
	thermistor probe, 16 measurements (1.5m?)	500	1	1	1	1500
	deep borehole (3m?, necessary?)	500	1	1	1	1500
	soil moisture (3 different depths)	1200	1	1	1	3600
	temp sensors with soil moisture probes	500	1	1	1	1500
	heat flux	700	1	1	1	2100
	water table height - capacitance water level probe	1000	1	1	1	3000
Etc.						0
	Interval Camera	500	2	2	2	3000
		37590				**114270**
Installation Costs						
Shipping	Fed Ex, UPS, USPS to FAI	2000				2000
Transport to s	Plane, Helo, Truck, Boat, etc.	20000				20000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000				5000
	Field installation, 4 days per site?	5000				5000
	Field visits 2 day per site (spring and fall)	5000				5000
		37000				**37000**
Recurring Costs; Field Activities/Collections/Measurements						
Personnel and Transportation						
	Plane, Helo, Truck, Boat, etc.	15000				15000
	Preparation for field maintenance (1 person)	1000				1000
	Time spent in field (spring and fall visits, 2 people)	3000				3000
Logger/Power/Communications						
	Confirm that all systems are operational and in good health	0	1	1	1	0
	Download any internal memory	0	1	1	1	0
	Replace batteries?	200	1	1	1	600
	Download interval camera	0	1	1	1	0
	Iridium data per year	600	1	1	1	1800
Meteorology						
	lysimeter measurements?	0	1	1	1	0
	Empty precip sampling container?	100	1	1	1	300
	Confirm that all systems are calibrated and level	0	1	1	1	0
Streams						
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	600
	Suspended Sediment Flux (TSS)	200	1	1	1	600
	Calibration of water quality sensors	100	1	1	1	300
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	3000
	Install/remove water level and water quality sensors	0	1	1	1	0
Wetland-Lake						
	Expansion/Contraction surveys?	0	1	1	1	0
	Water Chemistry	1000	1	1	1	3000
Soil-Permafrost						
	soil moisture, sample for calibration?	0	1	1	1	0
	Carbon Content	100	1	1	1	300
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	600
	Ice content	100	1	1	1	300
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	0
	Install/remove water level sensors	0	1	1	1	0
						30400

Table 5. Itemized budget for the purchase, installation and maintenance of stations in the Kokolik River Area. Site numbers correspond to the indexing on the map. Note that all sites require the full suite of hardware and that the travel costs are the highest in the Arctic LCC. This reflects the potential need for helicopter support at sites [1] and [2].

3.1.2 Barrow/Meade River Area

Motivation for Site Selection

Combining the Meade and Barrow regions into a single focal area provides a good, though discontinuous, transect across the central foothills and coastal plain. Barrow has served as a nexus for a wide array of focused research projects over the last two decades. Access is relatively easy via scheduled flights and because most research takes place only a short distance outside of town. Barrow offers one of the longest meteorological records in the circum-arctic and supports both coastal and terrestrial investigations. Near Barrow (Figure 5, site 3), recent terrestrial work has focused on characterizing low-relief tundra/patterned ground and lakes.

Though Barrow lacks a large nearby watershed, the Meade River is just 50 km to the south of town and drains south-to-north toward Barrow. Many scientists have already measured gradients or compared observations between Barrow and Atqasuk Village. We will extend this transect further south, into the Foothills ecoregion, to the Meade River headwaters. This uppermost site (Figure 5, site 1) is located at the same location as Brabets (1996) Arctic 15 suggested site. The central site (Figure 5, site 2) is close to Atqasuk village where there is an active USGS gaging station on the Meade River. In Atqasuk, a diverse suite of meteorological instrumentation is maintained by a variety of research and agency scientists. At present, there is no instrumentation or record for the Nigisaktuvik River, a major Coastal Plain tributary to the Meade River. Because this tributary is just downstream of Atqasuk Village, access will be inexpensive, requiring only a boat with an outboard motor.

Existing Infrastructure and Data

Barrow has a long climate record and has been recently augmented by extensive atmospheric monitoring through the DOE Atmospheric Radiation Measurement (ARM) program and the NOAA Earth System Research Laboratory (ESRL) investment in the Barrow Observatory. A smaller ARM observation site was established at Atqasuk Village. Barrow also has been a focus of the North Slope Science Initiative (NSSI), an intergovernmental and industrial effort to increase collaboration between stakeholders in the region. The Barrow Environmental Observatory (BEO) is a site of focused long term, high resolution measurements. The DOE's Next Generation Ecosystem Experiment (NGEE) is actively focused on quantifying the physical, chemical, and biological behavior of terrestrial ecosystems around Barrow and at the BEO site. The USGS maintained a gage on a very small stream near Barrow (Nunavak Creek, USGS 15798700) but this was discontinued in 9/2004. We intend to reestablish this station. Extensive soil/permafrost observations are already operational in Barrow.

Barrow contains an unusually long-term data set of directly measured evapotranspiration (1999-present) thanks to multiple individual research grants. Hydrological research in Barrow has also included precipitation measurements, snow cover characteristics, and the impact of polygonal surface features on hydrology. Prior to 2006, hydrologic monitoring in Barrow focused on water balance components in different smaller local watersheds (< 8 km2). The Biocomplexity Experiment study (2006-2010) included simultaneous measurements of all components of the water balance (fluxes in and out) including directly measured evapotranspiration and fine-resolution DEM's (0.25 m horizontal resolution). This type of data set is rarely available for Arctic environments.

At Atqasuk Village, ~100km south of Barrow, a USGS gaging station (USGS 15803000 Meade River at Atkasuk AK) records water stage and discharge just downstream of the village. Daily discharge data are available between 9/2005 and the present. There was one ice-free season of data collected in 1977. The gage is jointly supported by the USGS and the BLM. Also in Atqasuk Village are different meteorological sensors (ARM program starting in ~2004 and a COOP station started in 1960). Temporary measurements of air temperature and precipitation are collected at the USGS station, but they are deleted after 120 days because they are not fully QA/QC'd by that agency. Water temperature measurements were made and archived during the ice-free periods between Fall 2005 and Fall 2008. Air temperature was also recorded and is available from Fall 2006 – Fall 2007. USGS precipitation data exist for the summer of 2007 only. Numerous water quality parameters were measured infrequently between 1976 and 1978. Another, very limited, suite of water quality measurements were made between 2006 and 2008. Discharge measurements are currently made with a frequency of 4-5 times per year typically between the end of May and the end of September. There are no data available from the proposed upstream and Nigisaktuvik River sites.

Table 6. Characterization of existing resources at each sampling location in the Barrow/Meade River Area. **Table under construction.**

Topographic and Environmental Characteristics

This area only includes the Brooks Foothill and Coastal Plain Ecoregions. The watershed does not extend into the Brooks Range. The watershed is almost entirely within BLM lands except for the area around Atqasuk and Barrow which belong to the villages.

Sampling location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Barrow	7.83	19.87	13.32	0.35	3.6	-10.4	208.5	8.23
Meade River tributary 1	43.2	375.7	138.82	2.35	17.23	-10.2	304.7	956.87
Meade River mainstem 1	43.2	468.99	191.73	3.16	30.79	-10.0	331.4	1488.15
Meade River tributary 2	8.96	90.69	36.65	0.46	12.08	-10.2	250.9	1790.26
Meade River mainstem 2	8.96	468.99	117.44	1.99	30.79	-10.1	290.3	4620.04

Table 7. Environmental characteristics at each sampling location in the Barrow/Meade River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

As listed above, numerous stakeholders have worked and continue to work in this region. In particular, the Meade River region is of interest to the BLM (NPR-A) with support from the USGS for the operation of the gage at Atqasuk Village. Anna Liljedahl, Sveta Stuefer, Doug Kane, John Lenters, Matthew Sturm (hydrologists) and Jessica Cherry (hydro-climatologist) from UAF are both engaged in current research at Barrow as is Malcolm Butler (NDSU), Richard Lanctot (USFWS), Vladimir Romanovsky (UAF), Kenji Yoshikawa (UAF), Fritz Nelson, Ken Hinkel, Craig Tweedie (Texas) and a host of other principal investigators from both agency and academic organizations. The North Slope Borough and Native Village of Barrow are stakeholders already invested in research in the region.

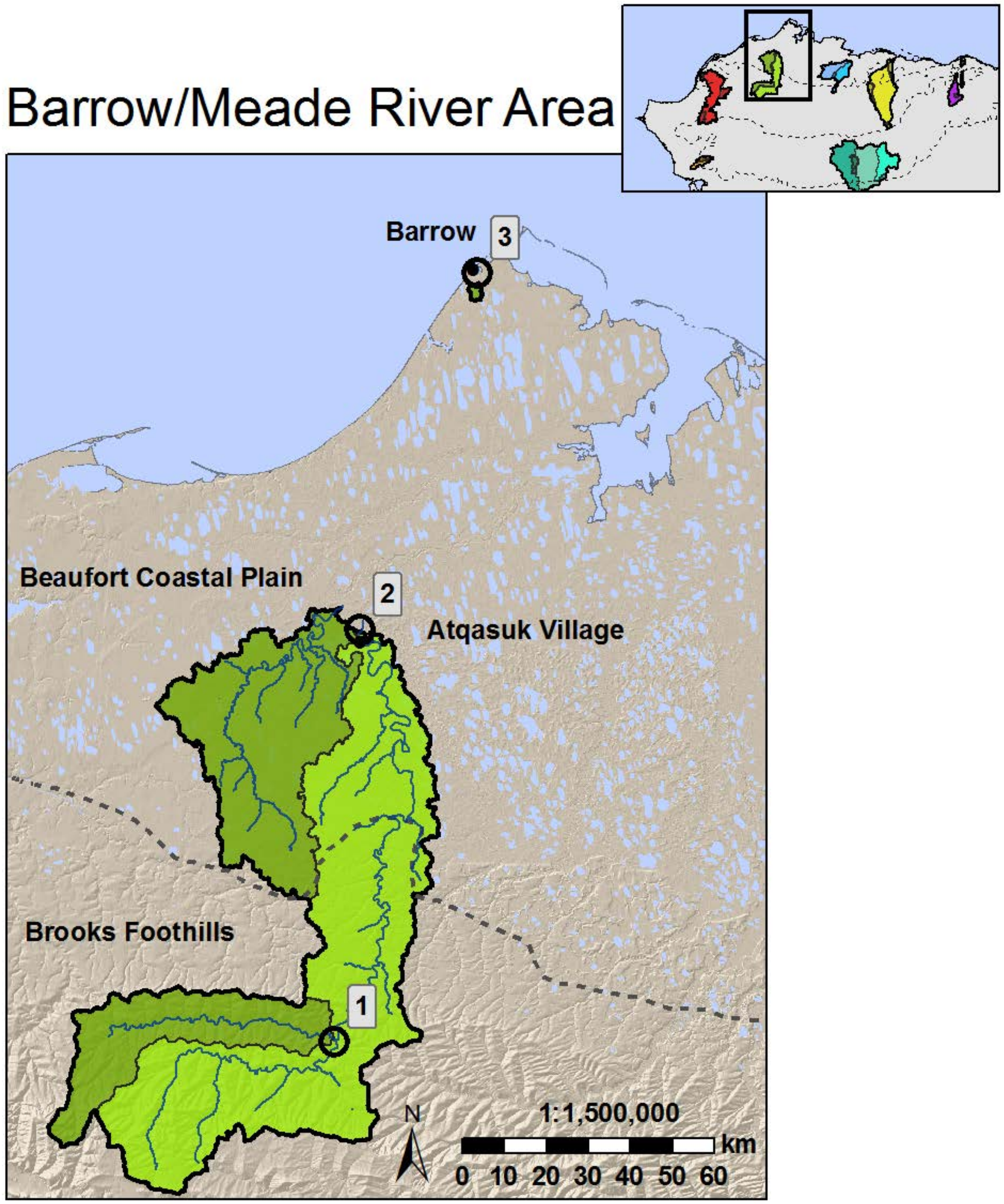


Figure 5: Map outlining the extent of the Barrow/Meade River Area including the locations of observation stations (circles with numbers) and an inset regional map showing the distribution of all focal watersheds. Note that site [1] is entirely in the Brooks Foothills and that site [2] is in the Coastal Plain ecoregion. Nunavak Creek is the small watershed just south of Barrow at site [3].

Barrow/Meade River Area						
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Per-Item Costs**
Logger/Power/Communications			Meade R and Shaningarok C	Meade R and Nigisaktuvik R	Barrow and Nunavak Ck?	
	Data logger	1440	1	1	1	4320
	Multiplexer	600	1	1	1	1800
	Enclosure	290	1	1	1	870
	Battery enclosure	200	1	1	1	600
	Solar Panel	500	1	1	1	1500
	Charge Regulator/Controller	100	1	1	1	300
	Battery bank, storage	500	1	1	1	1500
	Tripod and mast	250	1	1	1	750
	Iridium radio and antenna, subscription	1500	1	1	1	4500
Meteorology						0
	Solar Radiation (net incoming and outgoing)	2000	1			2000
	Air temperature and RH -2m	650	1			650
	Barometric Pressure	800	1			800
	Wind Speed and Direction -3m	1000	1			1000
	Tipping bucket rain gage	410	1			410
	Acoustic snow level sensor	1150	1			1150
Streams: Mainstem						0
	Water level (stage)	2000	1		1	4000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	24000
Streams: Tributary						0
	Water level (stage)	2000	1	1		4000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1		16000
Wetland-Lake						0
	Water level (stage)	600	1	2	2	3000
	Temp	0				0
	Conductivity	700	1	2	2	3500
Soil-Permafrost						0
	thermistor probe, 16 measurements (1.5m?)	500	1	1		1000
	deep borehole (3m?, necessary?)	500	1	1		1000
	soil moisture (3 different depths)	1200	1	1		2400
	temp sensors with soil moisture probes	500	1	1		1000
	heat flux	700	1	1		1400
	water table height - capacitance water level probe	1000	1	1		2000
Etc.						0
	Interval Camera	500	2	2		2000
		37590				**87450**
Installation Costs						
Shipping	Fed Ex, UPS, USPS	2000				2000
Transport to si	Plane, Helo, Truck, Boat, etc.	10000				10000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000				5000
	Field installation, 4 days per site?	5000				5000
	Field visits 2 day per site (spring and fall)	5000				5000
		27000				**27000**
Recurring Costs; Field Activities/Collections/Measurements						
Personnel and Transportation						
	Plane, Helo, Truck, Boat, etc.	6000				6000
	Preparation for field maintenance (1 person)	1000				1000
	Time spent in field (spring and fall visits, 2 people)	3000				3000
Logger/Power/Communications						
	Confirm that all systems are operational and in good health	0	1	1	1	0
	Download any internal memory	0	1	1	1	0
	Replace batteries?	200	1	1	1	600
	Download interval camera	0	1	1	1	0
	Iridium data per year	600	1	1	1	1800
Meteorology						
	lysimeter measurements?	0	1	1	1	0
	Empty precip sampling container?	100	1	1	1	300
	Confirm that all systems are calibrated and level	0	1	1	1	0
Streams						
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	600
	Suspended Sediment Flux (TSS)	200	1	1	1	600
	Calibration of water quality sensors	100	1	1	1	300
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	3000
	Install/remove water level and water quality sensors	0	1	1	1	0
Wetland-Lake						
	Expansion/Contraction surveys?	0	1	1	1	0
	Water Chemistry	1000	1	1	1	3000
Soil-Permafrost						
	soil moisture, sample for calibration?	0	1	1	1	0
	Carbon Content	100	1	1	1	300
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	600
	Ice content	100	1	1	1	300
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	0
	Install/remove water level sensors	0	1	1	1	0
						21400

Table 8. Itemized budget for purchase, installation and maintenance of stations in the Barrow/Meade River Area. Note that only the furthest upstream site [1] requires the full suite of hardware while others require a subset of components to bring the stations into compliance with TEON standards.

3.1.3 Fish and Judy Creeks Area

Motivation for Site Selection

The Fish/Judy Creek research area has received interdisciplinary research attention from agency and academic scientists since the late 1990s. Weather and subsurface observations supported by the Global Terrestrial Network for Permafrost (GTN-P) are associated with more recent installations of hydrologic instruments in streams (2002 - present) and lakes (2011-present). Though previous research has supported measurements from a third stream, the Ublutuoch, the Arctic LCC cannot support measurement of three watersheds in the same region. Hydrologic measurements will be made at existing stations (Figure 6) including Fish Creek near Inigok (site [1]), Fish Creek near Judy Creek (site [2]) and Judy Creek above Fish Creek (also at site [2]).

The unique features of the Fish/Judy Creek area include high lake density, high number of beaded streams, and high rate of permafrost degradation. Climate and permafrost data (GTN-P) in this region suggest significant warming of both air and ground temperature since monitoring began in the 1998, though this data have not been published yet in the primary literature. Analysis of aerial photography in 1945, 1982, and 2001 suggested an abrupt increase in melting of ice wedges in portions of the Fish Creek, which altered surface topography and hydrology (Jorgenson et al. 2006). InSAR measurements of regional deformation also suggest that this watershed may be experiencing rapid permafrost degradation (Liu et al 2010). Lake change studies conducted in the upper portion of the Fish Creek watershed showed considerable interannual variability in lake surface area related to precipitation and a trend towards decreasing ice thickness (Jones et al 2008).

Lakes in the Fish Creek watershed have a very wide range of morphometry and depth ranging from shallow with bedfast ice to relatively deep (>5 m). This diversity of lakes and wetlands (drained lake basins), along with high density of both beaded stream and alluvial rivers, likely provide a broad habitat mosaic for both fish communities during varying parts of the year and water-birds in the summer. Efforts are underway to couple the physical structure of this watershed with the habitat it provides and how both are responding to climate change. Further, anticipated land-use change in the form of petroleum development in the northern portion of the watershed will provide the opportunity to understand the interactions of localized human activities with regional climate forcing mechanisms and the ability to separate these impacts on permafrost, hydrology, and biological resources.

Existing Infrastructure and Data

The longest records of observation in this region are associated with the GTN-P programs (1998-present) which include both meteorological data and ground temperature data. Subsequent additions of gaging/weather stations at the outlets of Judy, Fish and Ublutuoch occurred in 2002 and data collection continues to the present. Smaller installations at streams and lakes in the region continued incrementally up to the present. We suggest formalizing the station near Inigok (FWCO_Hannahbear Creek) with a more complete gaging station to be associated with the existing meteorological station nearby. Beyond the measurement of physical parameters noted above, research into fish habitat has been ongoing under direction of Matt Whitman at the BLM.

Table 9. Characterization of existing resources at each sampling location in the Fish/Judy Creek Area. **Table under construction.**

Topographic and Environmental Characteristics

Fish and Judy Creeks are almost entirely within the Beaufort Coastal Plain Ecoregion, though a small portion of Judy Creek extends into the Brooks Foothills.

	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
Sampling location	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Fish Creek mainstem 1	36.55	119.74	62.15	1.42	9.9	-10.3	202.0	126.73
Judy Creek mainstem 1	5.51	335.66	57.64	0.9	24.27	-10.3	199.9	1774.18
Fish Creek mainstem 2	5.51	119.74	49.4	1.04	13.42	-10.2	205.6	2135.85

Table 10. Environmental characteristics at each sampling location in the Fish/Judy Creek Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

Work at the Fish/Judy Creek area has been supported through the efforts largely of the BLM, though recent investments from the USGS have helped expand the scope of studies. Matt Whitman (BLM), Horacio Toniolo (UAF) and Chris Arp (UAF) are the most central points of contact for hydrologic work and Ben Jones (USGS) is the best contact for active lake work. The watershed overlaps proposed expansion of oil production facilities, so there may be potential for partnering with industry to operate this portion of TEON.

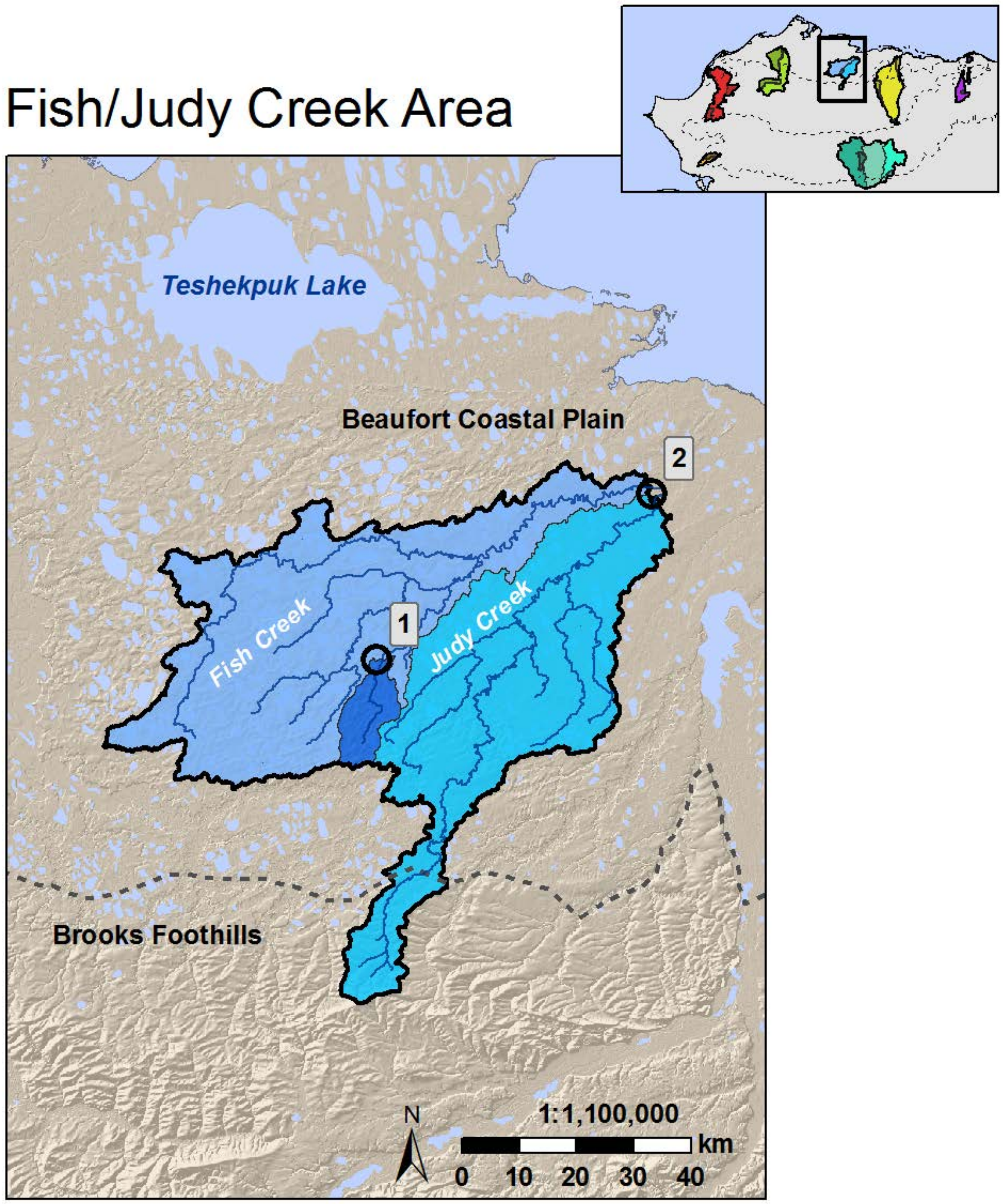


Figure 5: Map outlining the extent of the Fish/Judy Creeks Area including the locations of observation stations (circles with numbers) and an inset regional map showing the distribution of all focal watersheds. Note that this watershed is almost entirely in the Coastal Plain ecoregion. Weather, stream gaging, lake monitoring and ground temperature monitoring are active at sites [1] and [2].

Fish/Judy Creeks Area					
Hardware for Automated Observations		Cost	Site 1	Site 2	Per-Item Costs
Logger/Power/Communications			Fish Ck nr Inigok, Hannahbear	Fish/Judy Creek Confluence nr Nuiqsut	
	Data logger	1440	1	1	2880
	Multiplexer	600	1	1	1200
	Enclosure	290	1	1	580
	Battery enclosure	200	1	1	400
	Solar Panel	500	1	1	1000
	Charge Regulator/Controller	100	1	1	200
	Battery bank, storage	500	1	1	1000
	Tripod and mast	250	1	1	500
	Iridium radio and antenna, subscription	1500	1	1	3000
Meteorology					0
	Solar Radiation (net incoming and outgoing)	2000			0
	Air temperature and RH -2m	650			0
	Barometric Pressure	800			0
	Wind Speed and Direction -3m	1000			0
	Tipping bucket rain gage	410			0
	Acoustic snow level sensor	1150			0
Streams: Mainstem					0
	Water level and Temp (stage)	2000	1		2000
	Conductivity, Turbidity, DO, pH	8000	1	1	16000
Streams: Tributary					0
	Water level and Temp (stage)	2000			0
	Conductivity, Turbidity, DO, pH	8000		1	8000
Wetland-Lake					0
	Water level and Temp (stage)	600	2	2	2400
	Conductivity	700	2	2	2800
Soil-Permafrost					0
	thermistor probe, 16 measurements (1.5m?)	500			0
	deep borehole (3m?, necessary?)	500	1	1	1000
	soil moisture (3 different depths)	1200	1	1	2400
	temp sensors with soil moisture probes	500	1	1	1000
	heat flux	700	1	1	1400
	water table height - capacitance water level probe	1000	1	1	2000
Etc.					0
	Interval Camera	500	2	2	2000
		37590			**51760**
Installation Costs					
Shipping	Fed Ex, UPS, USPS	2000			2000
Transport to si	Plane, Helo, Truck, Boat, etc.	15000			15000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000			5000
	Field installation, 4 days per site?	5000			5000
	Field visits 2 day per site (spring and fall)	5000			5000
		32000			**32000**
Recurring Costs; Field Activities/Collections/Measurements					
Personnel and Transportation					
	Plane, Helo, Truck, Boat, etc.	12000			12000
	Preparation for field maintenance (1 person)	1000			1000
	Time spent in field (spring and fall visits, 2 people)	3000			3000
Logger/Power/Communications					
	Confirm that all systems are operational and in good health	0	1	1	0
	Download any internal memory	0	1	1	0
	Replace batteries?	200	1	1	400
	Download interval camera	0	1	1	0
	Iridium data per year	600	1	1	1200
Meteorology					
	lysimeter measurements?	0	1	1	0
	Empty precip sampling container?	100	1	1	200
	Confirm that all systems are calibrated and level	0	1	1	0
Streams					
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	400
	Suspended Sediment Flux (TSS)	200	1	1	400
	Calibration of water quality sensors	100	1	1	200
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	2000
	Install/remove water level and water quality sensors	0	1	1	0
Wetland-Lake					
	Expansion/Contraction surveys?	0	1	1	0
	Water Chemistry	1000	1	1	2000
Soil-Permafrost					
	soil moisture, sample for calibration?	0	1	1	0
	Carbon Content	100	1	1	200
	Gas Flux (CO2, CH3, NOx)	200	1	1	400
	Ice content	100	1	1	200
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	0
	Vegetation transects, samples?	0	1	1	0
	Install/remove water level sensors	0	1	1	0
					23600

Table 11. Itemized budget for purchase, installation and maintenance of stations in the Fish/Judy Creeks Area. Though there are existing infrastructure at all sites, a subset of components will need to be replaced to bring the stations into compliance with TEON standards.

3.1.4 Kuparuk River Area

Motivation for Site Selection

The hydrologic research that began at the Kuparuk River (8140 km2) basin in the mid-1980's based out of UAF-WERC provides one of the longest sets of hydrologic observations in Arctic North America, extending beyond summer runoff monitoring. This extensive record is facilitated by the watershed's close proximity to the Dalton Highway ("haul road") and the Deadhorse camp near the mouth of the watershed. The measurements have resulted in a multitude of internationally recognized peer-reviewed publications (e.g. Kane et al. 2000). The measurements of spring and summer runoff, snow accumulation, snow ablation, soil thermal and moisture regime, as well as weather, represent an invaluable dataset that is unmatched elsewhere in Alaska. Alongside the hydrological monitoring and modeling efforts in the last three decades are aquatic, lake and plant-level ecological studies based out of Toolik Field Station.

The upper Kuparuk (site [1] on Figure 7) and Imnaviat watersheds have a long legacy of detailed observation and provides a good measure of the weather and discharge behavior of the southern part of the Brooks Foothills. Further downstream, near the discontinued west Kuparuk meteorological station, we propose installing another gaging station that measures flux from a mid-slope tributary and the mainstem Kuparuk (site [2] on Figure 7). This site characterizes the middle of the Brooks Foothills Ecoregion and takes advantage of existing meteorologic data and existing infrastructure for data communications. Near the outlet, the mainstem Kuparuk River is gaged by the USGS (15896000). There are no small tributaries to the Kuparuk at this location that would be representative of the Beaufort Coastal Plain. Instead, we select the Putuligayuk River as a good alternative representative of this ecoregion because there is existing data (15896700 and WERC) and the station is easily accessible. Weather data for this northern region can come either from the Betty Pingo meteorological station or the West Dock station. Extensive ground temperature and moisture sensors are installed at West Dock.

At present, we have not included a Brooks Range tributary for this watershed because the Kuparuk watershed's headwaters are in the Foothills ecoregion. This transect could be expanded to include the USGS gaging station at Atigun River below Galbraith Lake. The only concern with this station is that the lake could mute the hydrologic and biogeochemical signal from the upper basin, but lake-effects are a concern for many rivers that drain glaciated regions in the central Brooks Range.

Existing Infrastructure and Data

The longest running dataset in this region is the Imnaviat meteorological station that became operational in 1986 and continues to the present. The upper Kuparuk meteorological site (site [1] on Figure 7) is closer to the gaging site but began in 1993 (Kane 2000). Measurements of discharge in the Upper Kuparuk became regular in 5/96 and continues (with Arctic LCC support) to the present

The mid-basin site at [2] on Figure 7, has no record of instrumented discharge observations. The Kuparuk west meteorological station is close by and operated between 7/95 and 6/08. The TEON network would bring this data station back online. Some historic data are available from the USGS (see links above) and the WERC website. The Arctic LCC will help support the continued maintenance and distribution of the gaging station and weather station data. The NRCS maintains a suite of SnoTel sites along the Dalton Highway that would be valuable to characterizing conditions in the Kuparuk River area.

Table 12. Characterization of existing resources at each sampling location in the Kuparuk River Area. ***Table under construction.***

Topographic and Environmental Characteristics

The Kuparuk area watershed spans from the upper Brooks Foothills to the Coastal Plain Ecoregions.

Sampling Location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Putuligayuk River	9.00	357.06	67.88	0.38	10.25	-10.0	190.3	565.49
Kuparuk River tributary 1	99.01	461.34	166.59	0.80	10.28	-10.0	189.7	600.19
Kuparuk River mainstem 1	733.38	1509.99	977.22	6.14	44.53	-8.7	371.4	147.76
Kuparuk River mainstem 2	99.00	1509.99	525.87	2.49	44.53	-9.0	252.7	1313.12
Kuparuk River mainstem 3	8.00	1509.99	267.56	1.50	44.53	-9.5	209.1	8599.07

Table 13. Environmental characteristics at each sampling location in the Kuparuk River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

The greatest supporters of continuing work in this watershed have been the NSF, WERC and the Arctic LCC. With continued support, it would make sense for the WERC team (Kane, Arp, Schnabel, etc.) to continue the maintenance of the stations they established and gradually increment in new sensors that are consistent with the rest of the Arctic LCC observation network. As the Kuparuk is central to industrial activity based out of Deadhorse, the oil field operators may also want to be involved in maintenance and measurements at the station. Though the NEON-STREON program will focus on Oksiukuyik Creek to the east of the Kuparuk basin, there may be opportunities to take advantage of some of the infrastructure that this new development brings.

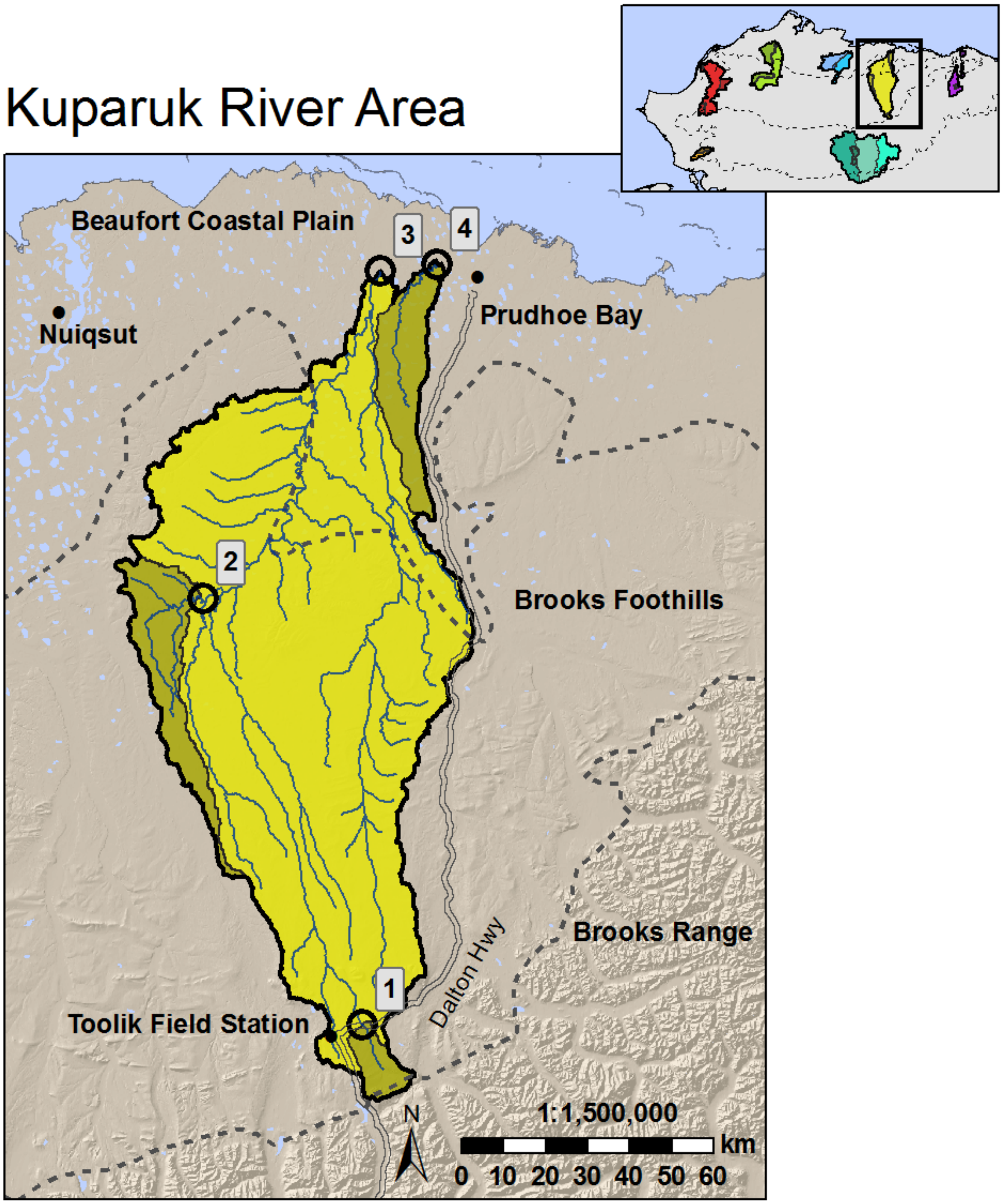


Figure 7: Map outlining the extent of the Kuparuk River Area including the locations of observation stations (numbered circles) and an inset regional map showing the location on the North Slope. Note that the upper sites are along the Dalton Highway, near Toolik Field Station. Site [2] is off the road system and would require helicopter or inflatable access. This site is the only one without existing infrastructure.

Kuparuk River Area						
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Per-Item Costs**
Logger/Power/Communications			Kuparuk R at Dalton Hwy	Western Kuparuk R and Tributary	Kuparuk R and Putuligayuk R at Deadhorse	
	Data logger	1440		1		1440
	Multiplexer	600		1		600
	Enclosure	290		1		290
	Battery enclosure	200		1		200
	Solar Panel	500		1		500
	Charge Regulator/Controller	100		1		100
	Battery bank, storage	500		1		500
	Tripod and mast	250		1		250
	Iridium radio and antenna, subscription	1500	1	1	1	4500
Meteorology						0
	Solar Radiation (net incoming and outgoing)	2000		1		2000
	Air temperature and RH -2m	650		1		650
	Barometric Pressure	800		1		800
	Wind Speed and Direction -3m	1000		1		1000
	Tipping bucket rain gage	410		1		410
	Acoustic snow level sensor	1150		1		1150
Streams: Mainstem						0
	Water level (stage)	2000		1		2000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	24000
Streams: Tributary						0
	Water level (stage)	2000		1		2000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000		1	1	16000
Wetland-Lake						0
	Water level (stage)	600	1	1	2	2400
	Temp	0				0
	Conductivity	700	1	1	2	2800
Soil-Permafrost						0
	thermistor probe, 16 measurements (1.5m?)	500	1	1		1000
	deep borehole (3m?, necessary?)	500	1	1		1000
	soil moisture (3 different depths)	1200	1	1		2400
	temp sensors with soil moisture probes	500	1	1		1000
	heat flux	700	1	1		1400
	water table height - capacitance water level probe	1000	1	1		2000
Etc.						0
	Interval Camera	500	2	2	2	3000
		37590				**75390**
Installation Costs						
Shipping	Fed Ex, UPS, USPS	2000				2000
Transport to s	Plane, Helo, Truck, Boat, etc.	10000				10000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000				5000
	Field installation, 4 days per site?	5000				5000
	Field visits 2 day per site (spring and fall)	5000				5000
		27000				**27000**
Recurring Costs; Field Activities/Collections/Measurements						
Personnel and Transportation						
	Plane, Helo, Truck, Boat, etc.	5000				5000
	Preparation for field maintenance (1 person)	1000				1000
	Time spent in field (spring and fall visits, 2 people)	3000				3000
Logger/Power/Communications						
	Confirm that all systems are operational and in good health	0	1	1	1	0
	Download any internal memory	0	1	1	1	0
	Replace batteries?	200	1	1	1	600
	Download interval camera	0	1	1	1	0
	Iridium data per year	600	1	1	1	1800
Meteorology						
	lysimeter measurements?	0	1	1	1	0
	Empty precip sampling container?	100	1	1	1	300
	Confirm that all systems are calibrated and level	0	1	1	1	0
Streams						
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	600
	Suspended Sediment Flux (TSS)	200	1	1	1	600
	Calibration of water quality sensors	100	1	1	1	300
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	3000
	Install/remove water level and water quality sensors	0	1	1	1	0
Wetland-Lake						
	Expansion/Contraction surveys?	0	1	1	1	0
	Water Chemistry	1000	1	1	1	3000
Soil-Permafrost						
	soil moisture, sample for calibration?	0	1	1	1	0
	Carbon Content	100	1	1	1	300
	Gas Flux (CO_2, CH_3, NO_x)	200	1	1	1	600
	Ice content	100	1	1	1	300
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	0
	Install/remove water level sensors	0	1	1	1	0
						20400

Table 14. Itemized budget for purchase, installation and maintenance of stations in the Kuparuk River Area. Though there is existing infrastructure at two sites, a subset of components will need to be added to bring these stations into compliance with TEON standards.

3.1.5 Hulahula/Jago Rivers Area

Motivation for Site Selection

Compared to the other focus watersheds, this site offers the greatest opportunity to study the character of a glacially-influenced Brooks Range ecoregion. A large proportion of the Hulahula River watershed is within the Brooks Range and our proposed monitoring site near the confluence of East Patuk Creek and the mainstem Hulahula offers an opportunity to make hydrologic and meteorological observations in the heart of this region (site [1] on Figure 8). The Hulahula River is an important subsistence use area, providing opportunities to harvest Dolly Varden and good winter access into the Brooks Range. It is also popular for recreational float trips and sport hunting. This site is accessible via wheeled plane using the East Patuk Creek gravel runway identified by the Arctic NWR staff. If this runway proves too difficult, the sampling team could land at the more popular Grassers strip and float down to the observation sites. Our measurements at this site will also characterize the influence of small headwater glaciers on the fluxes from the headwaters of East Patuk Creek and the Hulahula River. Other ongoing measurements in McCall Creek, a tributary to the upper Jago, could be used to augment our inference regarding the unique and changing contributions from glaciers. If current trends continue, these glaciers will likely largely disappear within 50-100 years, causing a substantial change in runoff and sediment export.

Because of the glacier inputs, the ecosystems downstream of the glaciers within these watersheds differ from ecosystems elsewhere on the North Slope. The Hulahula River supports a subsistence use fishery of Dolly Varden. The fish overwinter in pools, migrate during the spring freshet, and return in late July before glacial melt stops. In addition, the deltas of all these glaciated rivers support enormous populations of migratory birds. The deltas are much siltier than deltas elsewhere because of glacial inputs. Birds feeding at the siltier deltas appear to fatten more quickly than sandier deltas nearby. River banks may be eroding more tundra than elsewhere due to the glacial melt and therefore provide more nutrients to the nearshore environment.

Around 70 km downstream, beyond the range front of the Brooks (site [2] on Figure 8), a recently installed USGS gaging station measures both river discharge and a limited set of meteorological parameters. Though this site is not at a tributary confluence, it serves to measure the integrated flux from both the Brooks Range and Brooks Foothills ecoregions. Because both the Hulahula and Jago watersheds become very narrow as they cross the foothills and coastal plain, there are very few tributaries within which to apply the nested watershed approach. To measure an independent tributary that is entirely in the Foothills region, we step ~25 km to the east to Okpirourak Creek, a tributary to the Jago River (site [3] on Figure 8). This location is easily accessed by wheeled plane using the Bitty Strip at the confluence of the Jago River and Okpirouak Creek. This site is also close to two Arctic NWR long-term ecological monitoring plots and a suite of 15 thermokarst terrain monitoring sites that are visited on a 5-year interval. Though it is non-ideal to sample outside the Hulahula watershed, there are too few tributary drainages to employ the nested approach in that single watershed and we believe that the meteorological drivers are similar between the drainages. This assumption will be tested with observations made at both sites over the first few years of the installation.

To characterize the Beaufort Coastal Plain Ecoregion, we had to select another watershed outside of the Hulahula and Jago river basins. Our proposed site is an unnamed tributary that drains the Coastal Plain directly inland from Kaktovik Village. This tributary is along a south to north transect with the Hulahula and Jago rivers. It would be accessible from the village via small boat and not require leaving the lagoon. This will reduce expenses and increase the frequency of visits to this site. The installation will require consultation with Kaktovik Inupiat Corporation which owns the land at the proposed installation site. This concern is present at other alternative Coastal Plain sites.

Existing Infrastructure and Data

In the upper Hulahula basin, a small number of grab samples have been collected that characterize the chemistry, water flux and stream ecology of that region. To date, there have been no persistent measurements made in this part of the basin. The USGS gaging station downstream (15980000) was installed and operational from 9/2010 until present, supported by 14 field measurements of discharge. Besides the known vegetation and thermokarst data at the Bitty Strip confluence (site [3] in Figure 8), there are no known meteorological or hydrological measurements from that site. A weather station was operated at Kaktovik (Barter Island Station) from 1949-1988, but there are no currently-operating stations near site [4].

Table 15. Characterization of existing resources at each sampling location in the Hulahula/Jago River Area. ***Table under construction.***

Topographic and Environmental Characteristics

This focal watershed provides the greatest opportunity to characterize conditions within and fluxes from the northern Brooks Range ecoregion. Though the Foothills region is extensive, the watersheds

Sampling Location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Kaktovik coastal tributary	13.34	116.87	57.06	0.44	5.19	-10.2	112.4	181.86
Okpirourak Creek	144.17	2302.52	659.39	6.87	50.84	-9.0	165.2	242.67
Hulahula River tributary 1	636.71	2425.42	1431.46	23.21	51	-10.0	268.2	110.75
Hulahula mainstem 1	635.77	2502.28	1457.83	23.98	58.97	-10.7	274.5	713.86
Hulahula River mainstem 2	190.75	2728.59	1281.94	20.65	60.82	-10.0	254.4	1779.90

Table 16. Environmental characteristics at each sampling location in the Hulahula/Jago River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

These sites lie within the boundary of the Arctic National Wildlife Refuge (Arctic NWR), administered by the USFWS. Their team has maintained the thermokarst and vegetation sampling sites up to this point and we hope that they can continue to partner with the Arctic LCC in the development of this portion of TEON. Dr. Matt Nolan, a research scientist at UAF has a long legacy of work in the uppermost reaches of these basins studying, among other things, glacial mass balance for these shrinking glaciers. His efforts to characterize the impacts of this change on downstream ecosystems prompted the selection of sites in this region and the installation of the USGS gaging station on the Hulahula River. Gary Clow from the USGS has been involved in creating and maintaining a meteorological network in this region, though his stations appear to fall outside the Hulahula/Jago Rivers Area. Though we have not initiated a discussion, we look forward to involving the Native Village of Kaktovik in this process as well. Good opportunity for collaboration with wildlife and physical scientists such as Jeff Adams (USFWS), Abby Powell (UAF), Roy Churchwell (UAF), Ken Dunton (Texas) and Jim McClelland (Texas) working in the river and delta regions should not be overlooked.

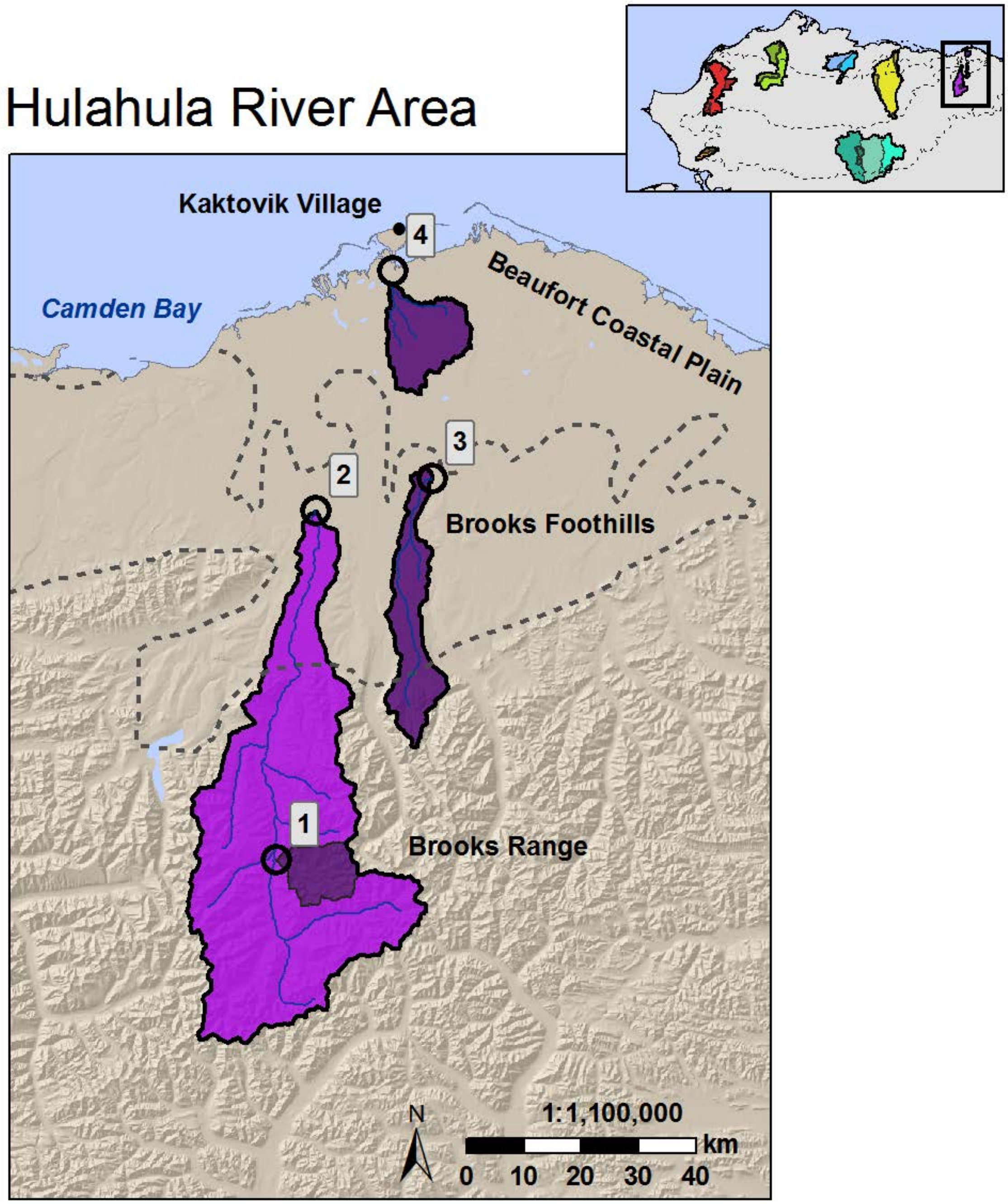


Figure 8: Map outlining the extent of the Hulahula River Area including the locations of observation stations (numbered circles) and an inset regional map showing the location on the North Slope. Note that the upper sites are in the center of the Brooks Range ecoregion (site 1), and an integrated mainstem site [2] includes a portion of the Foothills region. Site [3] uniquely characterizes the foothill region while [4] characterizes the coastal plain. There is no existing infrastructure at [1], [3] or [4].

Hulahula/Jago River Area							
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Per-Item Costs**
Logger/Power/Communications			Hulahula R and E Patuk Ck	Hulahula R nr Kaktovik	Okpirourak C and Jago R	Unnamed Trib nr Kaktovik	
	Data logger	1440	1		1	1	4320
	Multiplexer	600	1	1	1	1	2400
	Enclosure	290	1	1	1	1	1160
	Battery enclosure	200	1	1	1	1	800
	Solar Panel	500	1	1	1	1	2000
	Charge Regulator/Controller	100	1	1	1	1	400
	Battery bank, storage	500	1		1	1	1500
	Tripod and mast	250	1		1	1	750
	Iridium radio and antenna, subscription	1500	1	1	1	1	6000
Meteorology							0
	Solar Radiation (net incoming and outgoing)	2000	1	1	1	1	8000
	Air temperature and RH -2m	650	1	1	1	1	2600
	Barometric Pressure	800	1	1	1	1	3200
	Wind Speed and Direction -3m	1000	1	1	1	1	4000
	Tipping bucket rain gage	410	1	1	1	1	1640
	Acoustic snow level sensor	1150	1	1	1	1	4600
Streams: Mainstem							0
	Water level (stage)	2000	1		1	1	6000
	Temp	0					0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	1	32000
Streams: Tributary							0
	Water level (stage)	2000	1		1		4000
	Temp	0					0
	Conductivity, Turbidity, DO, pH	8000	1		1		16000
Wetland-Lake							0
	Water level (stage)	600	1	1	1	2	3000
	Temp	0					0
	Conductivity	700	1	1	1	2	3500
Soil-Permafrost							0
	thermistor probe, 16 measurements (1.5m?)	500	1	1	1	1	2000
	deep borehole (3m?, necessary?)	500	1	1	1	1	2000
	soil moisture (3 different depths)	1200	1	1	1	1	4800
	temp sensors with soil moisture probes	500	1	1	1	1	2000
	heat flux	700	1	1	1	1	2800
	water table height - capacitance water level probe	1000	1	1	1	1	4000
Etc.							0
	Interval Camera	500	2	2	2	2	4000
		37590					**129470**
Installation Costs							
Shipping	Fed Ex, UPS, USPS	2000					2000
Transport to si	Plane, Helo, Truck, Boat, etc.	20000					20000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000					5000
	Field installation, 4 days per site?	5000					5000
	Field visits 2 day per site (spring and fall)	5000					5000
		37000					**37000**
Recurring Costs; Field Activities/Collections/Measurements							
Personnel and Transportation							
	Plane, Helo, Truck, Boat, etc.	15000					15000
	Preparation for field maintenance (1 person)	1000					1000
	Time spent in field (spring and fall visits, 2 people)	3000					3000
Logger/Power/Communications							
	Confirm that all systems are operational and in good health	0	1	1	1	1	0
	Download any internal memory	0	1	1	1	1	0
	Replace batteries?	200	1	1	1	1	800
	Download interval camera	0	1	1	1	1	0
	Iridium data per year	600	1	1	1	1	2400
Meteorology							
	lysimeter measurements?	0	1	1	1	1	0
	Empty precip sampling container?	100	1	1	1	1	400
	Confirm that all systems are calibrated and level	0	1	1	1	1	0
Streams							
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	1	800
	Suspended Sediment Flux (TSS)	200	1	1	1	1	800
	Calibration of water quality sensors	100	1	1	1	1	400
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	1	4000
	Install/remove water level and water quality sensors	0	1	1	1	1	0
Wetland-Lake							
	Expansion/Contraction surveys?	0	1	1	1	1	0
	Water Chemistry	1000	1	1	1	1	4000
Soil-Permafrost							
	soil moisture, sample for calibration?	0	1	1	1	1	0
	Carbon Content	100	1	1	1	1	400
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	1	800
	Ice content	100	1	1	1	1	400
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	1	0
	Install/remove water level sensors	0	1	1	1	1	0
							34200

Table 17. Itemized budget for purchase, installation and maintenance of stations in the Hulahula River Area. Though there is some existing infrastructure at site [1], most of the sites will require new hardware.

3.1.6 Agashashok River Area

Motivation for Site Selection

The southern and western portions of the Arctic LCC domain are more poorly instrumented than those on the North Slope. Few sites have long-term legacy data or relatively easy access. The Agashashok River in the Noatak National Preserve is one of the few places where research teams have been returning to for over a decade to maintain measurements. Most work at this site has focused on tree-line biogeochemistry (Rhodes et al, 2001; Stottlemyer, 2001; Stottlemyer et al., 2002, 2003; Sullivan and Sveinbjörnsson, 2010) but other workers have also focused on nutrient fluxes through the soil column and soil gas efflux (Binkley et al., 1994, 1995, 1997; Sullivan, 2010). Weather station, soil temperature and stream flow measurements in a small tributary basin (Asik watershed, Figure 9, site 3) have been intermittently maintained over a good portion of the research record. The site is accessible via bush plane from Kotzebue with a good landing strip nearby. Discussions with the Frank Hays, Superintendent of the Western Arctic National Parklands, suggested that of the available options, this basin would be the best place for scientific research that continues to support the acquisition of data at a site with an existing legacy of science activity. If establishing observation stations in the Agashashok River is not feasible, the Salmon River in Kobuk Valley National Park and the Squirrel River on BLM land near Kiana village (where mineral extraction is being considered) would also work, though there is no legacy data at either site.

Existing Infrastructure and Data

The first visits to the Asik site (site [3] on Figure 9) occurred in 1990 and more detailed seasonal meteorological measurements began in 1992. These have been intermittently maintained since then. New installations of weather stations by the NPS Inventory and Monitoring Program will augment this fragmented record in this region. The two upper sites ([1] and [2] on Figure 9) have no existing data or infrastructure but will do a good job of providing replicated measurements of Brooks Range conditions in both pure mountainous and mixed terrains.

Table. Characterization of existing resources at each sampling location in the Agashashok River Area.
Table under construction.

Topographic and Environmental Characteristics

This focal watershed is in the southwest corner of the Arctic LCC and largely drains the Brooks Range ecoregion with a small portion of the lower basin in the Kobuk Ridges and Valleys ecoregion. The braided character of the lower river prevents us from suggesting a long term gaging station in that location though there are a few isolated, narrow regions.

Sampling Location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
Agashashok River tributary 1	274.5	955.36	516.4	18.39	39.97	-6.6	563.2	12.21
Agashashok River tributary 2	122.52	1245.01	417.39	11.24	59.35	-6.5	553.4	393.56
Agashashok River tributary 3	89.39	669.62	301.42	12.65	33.14	-5.8	497.0	8.59
Agashashok River mainstem 1	275.37	1188.68	561.8	18.97	50.32	-7.0	586.9	60.29
Agashashok River mainstem 2	122.56	1188.68	363.7	10.75	50.32	-6.2	532.4	296.41
Agashashok River mainstem 3	5.22	1245.01	315.63	9.4	59.35	-6.0	520.5	1061.37

Table 19. Environmental characteristics at each sampling location in the Agashashok River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

This site is in the Noatak National Preserve (NPS) and has been primarily investigated by Dr. Bob Stottlemyer of the USGS. In recent years Dr. Paddy Sullivan from Univ. of Alaska Anchorage has continued to work in this region. Dr. Ben Crosby continues to study water discharge, aufice and sediment transport in the adjacent Knapp Creek watershed.

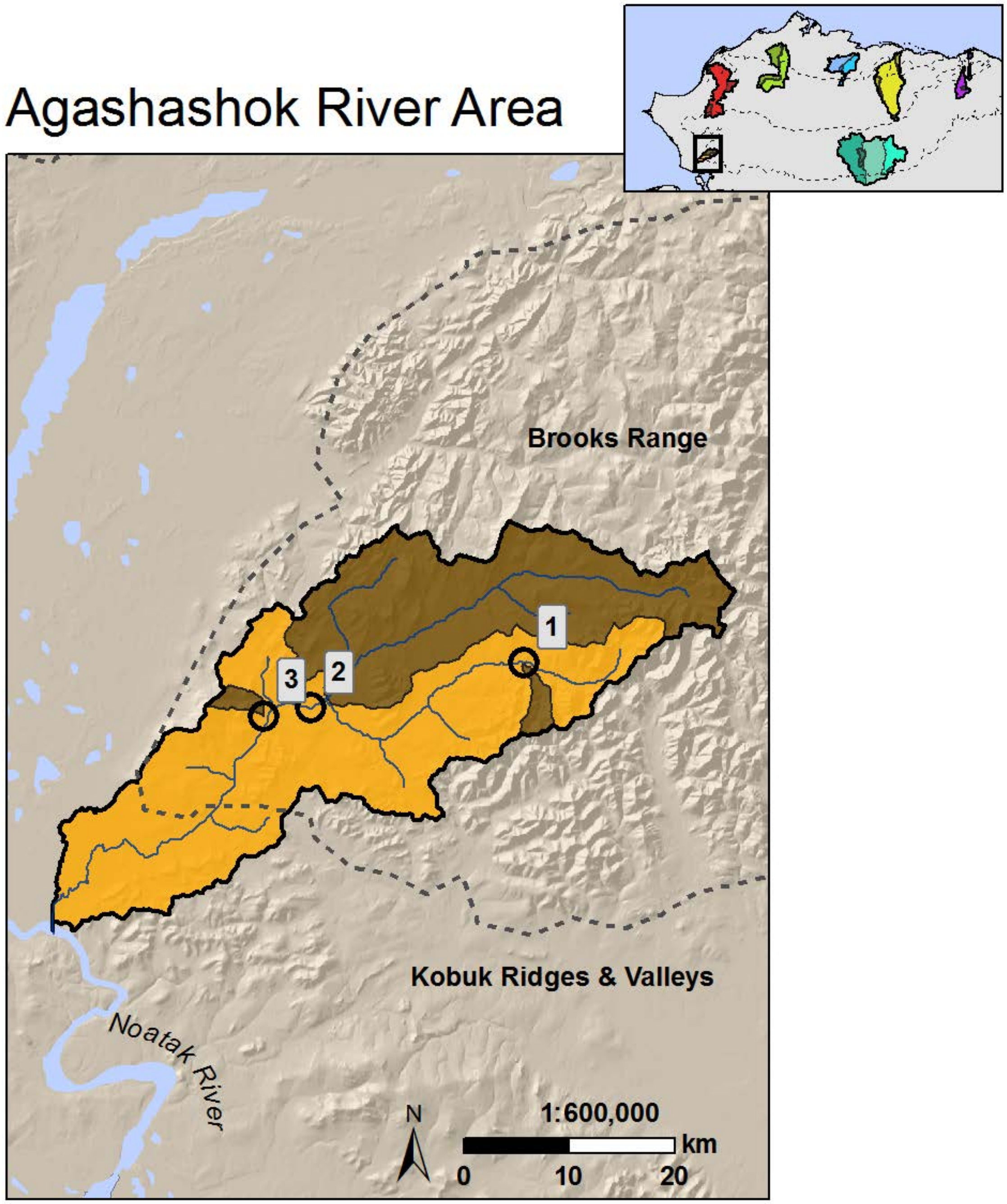


Figure 9: Map outlining the extent of the Agashashok River Area including the locations of observation stations (numbered circles) and an inset regional map showing the location on the North Slope. Photograph shows the lower Agashashok River near the Asik Creek, site [3]. There is no existing infrastructure at this site. Sites [1] and [2] would be accessed via bush planes landing on gravel bars.

Agashashok River Area						
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Per-Item Costs**
Logger/Power/Communications			Agashashok R and Mtn Trib	Agashashok R and Large Trib	Asik Tributary	
	Data logger	1440	1	1	1	4320
	Multiplexer	600	1	1	1	1800
	Enclosure	290	1	1	1	870
	Battery enclosure	200	1	1	1	600
	Solar Panel	500	1	1	1	1500
	Charge Regulator/Controller	100	1	1	1	300
	Battery bank, storage	500	1	1	1	1500
	Tripod and mast	250	1	1	1	750
	Iridium radio and antenna, subscription	1500	1	1	1	4500
Meteorology						0
	Solar Radiation (net incoming and outgoing)	2000	1	1	1	6000
	Air temperature and RH -2m	650	1	1	1	1950
	Barometric Pressure	800	1	1	1	2400
	Wind Speed and Direction -3m	1000	1	1	1	3000
	Tipping bucket rain gage	410	1	1	1	1230
	Acoustic snow level sensor	1150	1	1	1	3450
Streams: Mainstem						0
	Water level (stage)	2000	1	1		4000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1		16000
Streams: Tributary						0
	Water level (stage)	2000	1	1	1	6000
	Temp	0				0
	Conductivity, Turbidity, DO, pH	8000	1	1	1	24000
Wetland-Lake						0
	Water level (stage)	600	1	1	1	1800
	Temp	0				0
	Conductivity	700	1	1	1	2100
Soil-Permafrost						0
	thermistor probe, 16 measurements (1.5m?)	500	1	1	1	1500
	deep borehole (3m?, necessary?)	500	1	1	1	1500
	soil moisture (3 different depths)	1200	1	1	1	3600
	temp sensors with soil moisture probes	500	1	1	1	1500
	heat flux	700	1	1	1	2100
	water table height - capacitance water level probe	1000	1	1	1	3000
Etc.						0
	Interval Camera	500	2	2	2	3000
		37590				**104270**
Installation Costs						
Shipping	Fed Ex, UPS, USPS to FAI	2000				2000
Transport to si	Plane, Helo, Truck, Boat, etc.	10000				10000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000				5000
	Field installation, 4 days per site?	5000				5000
	Field visits 2 day per site (spring and fall)	5000				5000
		37000				**27000**
Recurring Costs; Field Activities/Collections/Measurements						
Personnel and Transportation						
	Plane, Helo, Truck, Boat, etc.	10000				10000
	Preparation for field maintenance (1 person)	1000				1000
	Time spent in field (spring and fall visits, 2 people)	3000				3000
Logger/Power/Communications						
	Confirm that all systems are operational and in good health	0	1	1	1	0
	Download any internal memory	0	1	1	1	0
	Replace batteries?	200	1	1	1	600
	Download interval camera	0	1	1	1	0
	Iridium data per year	600	1	1	1	1800
Meteorology						
	lysimeter measurements?	0	1	1	1	0
	Empty precip sampling container?	100	1	1	1	300
	Confirm that all systems are calibrated and level	0	1	1	1	0
Streams						
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	600
	Suspended Sediment Flux (TSS)	200	1	1	1	600
	Calibration of water quality sensors	100	1	1	1	300
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	3000
	Install/remove water level and water quality sensors	0	1	1	1	0
Wetland-Lake						
	Expansion/Contraction surveys?	0	1	1	1	0
	Water Chemistry	1000	1	1	1	3000
Soil-Permafrost						
	soil moisture, sample for calibration?	0	1	1	1	0
	Carbon Content	100	1	1	1	300
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	600
	Ice content	100	1	1	1	300
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	0
	Install/remove water level sensors	0	1	1	1	0
						25400

Table 20. Itemized budget for purchase, installation and maintenance of stations in the Agashashok River Area. Though there is some existing infrastructure at site [3], it will have to be updated to support the TEON protocols.

3.1.7 Koyukuk River Area

Motivation for Site Selection

Though the Brooks Range ecoregion drains largely to the south, most of the proposed TEON effort is on north-draining watersheds. Opportunity exists to take advantage of good access to river sites along both the Dalton Highway and near Bettles village to measure conditions and fluxes from south-draining rivers within the Arctic LCC. Future opportunities in this region may arise if a road to Ambler village is constructed. The location of almost all existing gaging stations are south of the Arctic LCC domain but still represent the processes active in the watersheds upstream.

Existing Infrastructure and Data

A long term gage is operational at a site near old Bettles within the Kanuti National Wildlife Refuge (NWR), near the confluence with the John River. The gage is approximately 5 miles down-river from the Bettles airport and Kanuti NWR office (Figure 10, site 4). It is a real-time site that sends data thru the NOAA satellite system and is currently funded by NWR - Water Resources until ~2014. After that, Kanuti NWR and NPS have committed to cooperatively maintain the gage. We propose to add a gaging station on the John River, just upstream of the gage at Old Bettles. Access to this site [4] is via outboard boat from Bettles village.

3 Hydro-meteorological stations were recently installed and operated by William Schnabel at UAF for the DOT along the proposed road to Ambler. These stations are located very close to the boundary between the Arctic LCC and the Interior LCC. UAF also installed and maintains four meteorological stations at mid-elevations in the Brooks Range for the DOT. The greatest concern with supporting/continuing the UAF/DOT sites is that they almost all require helicopter access for maintenance. The NRCS maintains a SnoTel site at Bettles.

A gaging station and weather station are located near Coldfoot (site [1] in Figure 10), along the Dalton Highway. The gaging station (USGS) is on Slate Creek a small tributary to the Middle Fork Koyukuk River. Though it would be preferable to do so, it is too difficult to gage the mainstem MF Koyukuk at this location because the river is wide and braided. Instead, we suggest gaging the MF Koyukuk above Chapman Island, south along the Dalton Highway where the channel narrows to a single thread (site [2] in Figure 10). No data exist at this location.

We suggest also developing a gaging site near the Crevice Creek landing strip on the John River and a tributary to it, Allen River (site [3] on Figure 10). These rivers would give a good measure of conditions in the interior of the Brooks Range ecoregion and pair well with the John River measurement made near Old Bettles.

Table 21. Characterization of existing resources at each sampling location in the Koyukuk River Area. ***Table under construction.***

Topographic and Environmental Characteristics

This large area drains the southern Brooks Range ecoregion and extends downstream into the Kobuk Ridges and Valleys outside of the Arctic LCC boundary. Compared to other sites in TEON, these rivers are larger basins and reflect higher relief landscapes.

Sampling Location	Elevation (m)			Slope (degrees)		Annual Temp. °C	Annual Precip. mm	Area
	Min	Max	Mean	Mean	Max	Mean	Total	km^2
John River tributary 1	244.99	1725.32	838.14	17.14	51.69	-7.7	357.1	683.70
John River mainstem 1	244.00	2057.01	963.37	17.79	66.04	-8.2	425.3	4502.34
John River mainstem 2	183.00	2057.01	849.99	16.51	66.04	-7.6	412.1	7044.91
Koyukuk River tributary 1	314.49	1548.14	716.62	11.99	43.45	-6.5	465.0	207.97
Koyukuk River mainstem 1	278.33	2071.55	943.38	18.5	68.11	-7.9	360.5	3946.97
Koyukuk River mainstem 2	183.00	2212.98	847.81	16.75	70.27	-7.5	393.2	18022.68

Table 22. Environmental characteristics at each sampling location in the Koyukuk River Area. Data sources: elevation and slope derived from NED 30m DEM for Alaska; temperature and precipitation derived from CRU TS3.1 data for the period between 2000 and 2009.

Proposed Partners/Stakeholders

When added to TEON, sites in this region could be a joint venture providing mutual benefit to the Arctic and Northwest Boreal LCC. Proposed stations are located within, or close to Kanuti NWR, and the Refuge has initiated a 5 year hydrologic investigation into streams in this region. Two of these sites are outside of the Arctic LCC. The gage near Old Bettles will be cooperatively maintained by Kanuti NWR and NPS after 2014. New meteorological and gaging stations have been installed by William Schnabel at UAF in support of DOT efforts to build a road through this region. These sites might be worth supporting as they make direct measure of conditions within the Brooks Range ecoregion of the Arctic LCC.

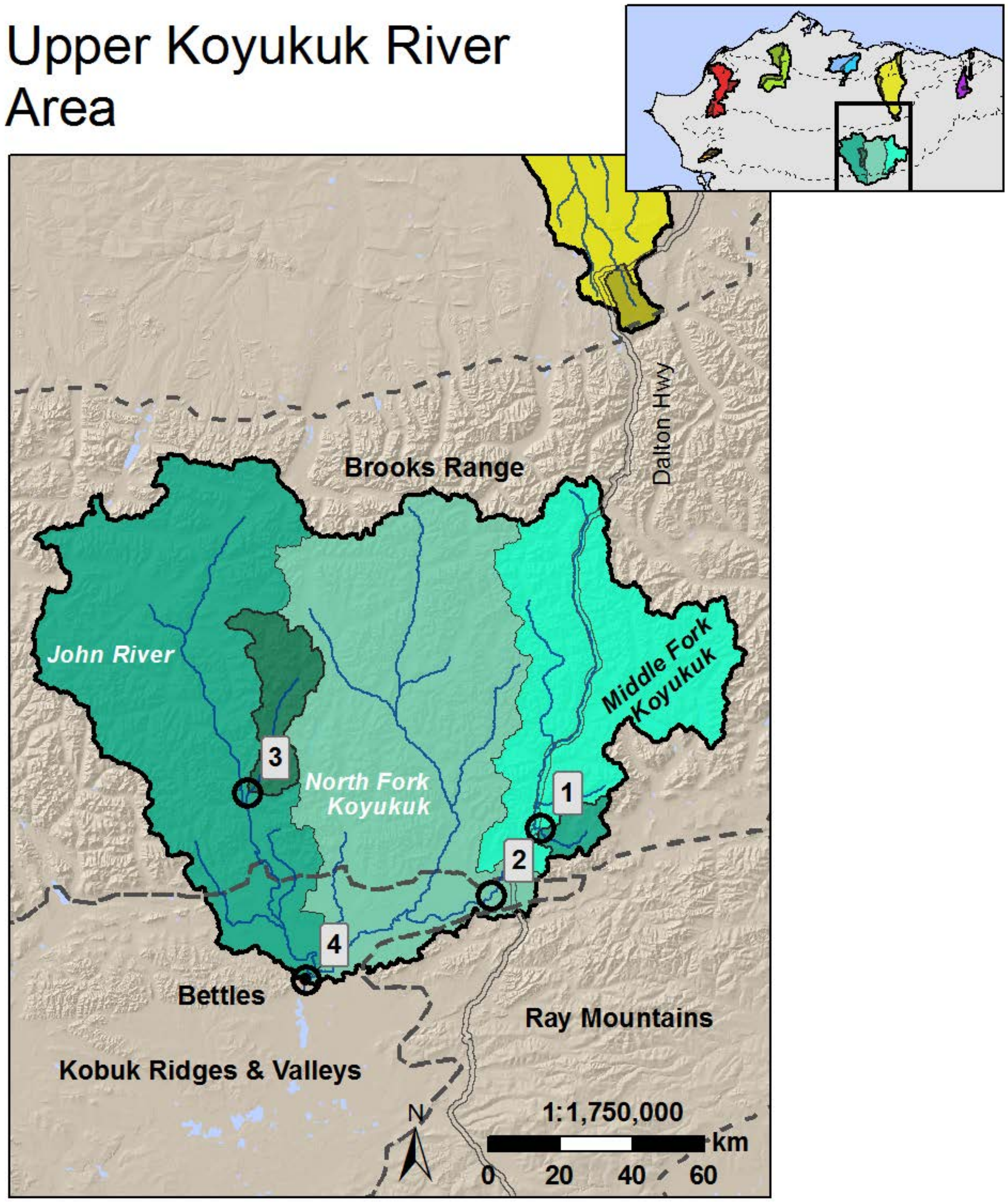


Figure 10: Map outlining the extent of the Koyukuk River Area including the locations of observation stations (numbered circles) and an inset regional map showing the location on the North Slope. Site [1] is on Slate Creek and is maintained by the USGS. At site [2] there is no existing infrastructure but a road leads from the Dalton Highway to the Chapman Island area. Site [3] is accessed by air, landing at the well maintained Crevice Creek airstrip. Site [4] at Old Bettles is accessible from Bettles village via outboard boat. Note that the north/south divide in the Brooks Range is far north of the center of the range.

Upper Koyukuk River Area							
Hardware for Automated Observations		**Cost**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Per-Item Costs**
Logger/Power/Communications			Slate Ck at Coldfoot	WF Koyukuk R at Chapman Bar	John R and Allen River at Crevice Creek	Koyukuk R and John R at Old Bettles	
	Data logger	1440	1	1	1	1	5760
	Multiplexer	600	1	1	1	1	2400
	Enclosure	290	1	1	1	1	1160
	Battery enclosure	200	1	1	1	1	800
	Solar Panel	500	1	1	1	1	2000
	Charge Regulator/Controller	100	1	1	1	1	400
	Battery bank, storage	500	1	1	1	1	2000
	Tripod and mast	250	1	1	1	1	1000
	Iridium radio and antenna, subscription	1500	1	1	1	1	6000
Meteorology							0
	Solar Radiation (net incoming and outgoing)	2000	1	1	1	1	8000
	Air temperature and RH -2m	650	1	1	1	1	2600
	Barometric Pressure	800	1	1	1	1	3200
	Wind Speed and Direction -3m	1000	1	1	1	1	4000
	Tipping bucket rain gage	410	1	1	1	1	1640
	Acoustic snow level sensor	1150	1	1	1	1	4600
Streams: Mainstem							0
	Water level (stage)	2000		1	1	1	6000
	Temp	0					0
	Conductivity, Turbidity, DO, pH	8000		1	1	1	24000
Streams: Tributary							0
	Water level (stage)	2000			1	1	4000
	Temp	0					0
	Conductivity, Turbidity, DO, pH	8000	1		1	1	24000
Wetland-Lake							0
	Water level (stage)	600	1	1	1	1	2400
	Temp	0					0
	Conductivity	700	1	1	1	1	2800
Soil-Permafrost							0
	thermistor probe, 16 measurements (1.5m?)	500	1	1	1	1	2000
	deep borehole (3m?, necessary?)	500	1	1	1	1	2000
	soil moisture (3 different depths)	1200	1	1	1	1	4800
	temp sensors with soil moisture probes	500	1	1	1	1	2000
	heat flux	700	1	1	1	1	2800
	water table height - capacitance water level probe	1000	1	1	1	1	4000
Etc.							0
	Interval Camera	500	2	2	2	2	4000
		37590					**130360**
Installation Costs							
Shipping	Fed Ex, UPS, USPS	2000					2000
Transport to si	Plane, Helo, Truck, Boat, etc.	10000					10000
Personnel	Initial assembly, Confirm all parts functional, Pack materials for field	5000					5000
	Field installation, 4 days per site?	5000					5000
	Field visits 2 day per site (spring and fall)	5000					5000
		27000					**27000**
Recurring Costs; Field Activities/Collections/Measurements							
Personnel and Transportation							
	Plane, Helo, Truck, Boat, etc.	10000					10000
	Preparation for field maintenance (1 person)	1000					1000
	Time spent in field (spring and fall visits, 2 people)	3000					3000
Logger/Power/Communications							
	Confirm that all systems are operational and in good health	0	1	1	1	1	0
	Download any internal memory	0	1	1	1	1	0
	Replace batteries?	200	1	1	1	1	800
	Download interval camera	0	1	1	1	1	0
	Iridium data per year	600	1	1	1	1	2400
Meteorology							
	lysimeter measurements?	0	1	1	1	1	0
	Empty precip sampling container?	100	1	1	1	1	400
	Confirm that all systems are calibrated and level	0	1	1	1	1	0
Streams							
	Discharge Measurement (ADCP or Flow Tracker)	200	1	1	1	1	800
	Suspended Sediment Flux (TSS)	200	1	1	1	1	800
	Calibration of water quality sensors	100	1	1	1	1	400
	Water Chemistry (POC/DOC?, Stable Isotopes?, etc.)	1000	1	1	1	1	4000
	Install/remove water level and water quality sensors	0	1	1	1	1	0
Wetland-Lake							
	Expansion/Contraction surveys?	0	1	1	1	1	0
	Water Chemistry	1000	1	1	1	1	4000
Soil-Permafrost							
	soil moisture, sample for calibration?	0	1	1	1	1	0
	Carbon Content	100	1	1	1	1	400
	Gas Flux (CO2, CH3, NOx)	200	1	1	1	1	800
	Ice content	100	1	1	1	1	400
	Distribution of Active Layer depths (CALM Protocols)	0	1	1	1	1	0
	Vegetation transects, samples?	0	1	1	1	1	0
	Install/remove water level sensors	0	1	1	1	1	0
							29200

Table 22. Itemized budget for the purchase, installation and maintenance of stations in the Koyukuk River Area. Though there is some existing infrastructure at site [1] and [4], some of it will have to be updated to support the TEON protocols.

3.2 Network Adaptability

The design of TEON is primarily focused on supporting and augmenting sites with existing legacy data. New sites with limited or no data have been selected to fill gaps in our distribution and increase the representativeness of the network. Though the network is rooted in providing long-term data for change detection and modeling efforts, it is not intended to remain static. As new variables become important to scientists and managers, sensors can be added to the existing power, datalogger and uplink infrastructure. As new opportunities motivate the expansion of the network (e.g. road building) TEON will already have the station installation experience and data management infrastructure to rapidly and efficiently support new sites. This allows the network to retain its core sites while being responsive to new opportunities. For projects outside of the TEON domain, the ArcticLCC will continue to fund RFP-initiated projects that may take advantage of TEON data, but do not need to be situated at those sites.

3.3 Integration across the Network

The TEON network is designed not to simply support measurements at points within the Arctic LCC domain, but rather to support comparative and synthetic analyses that make use of many, if not all, of the stations. The distribution of observations covers the range of ecoregions and ecological landscapes present in the Arctic LCC. These data can be used to either characterize variability within individual domains or make comparisons between domains. The network provides a good distribution of consistent measurements that will be valuable for calibrating and validating regional biophysical models. It would be advantageous for program sustainability and applicability if the Arctic LCC were able to incorporate other programs (e.g. CALM, ITEX, AON, other LCCs, etc.) into their protocol development. Because the data are intended to be used in a synthetic manner, the Arctic LCC will need to assure that some basic level of data management, QA/QC and interpretation are done to facilitate external studies. Higher level, more focused analyses on single or multiple sites could be achieved through RFPs. Remote sensing data will be very valuable in interpolating conditions in regions outside the TEON network. Many of these kinds of studies are already underway and require more ground-truthed data to support their efforts (Chris Potter, ABoVE, NASA, etc.). This integrated analysis across the TEON network will provide a model that other LCCs in Alaska and beyond can potentially adopt. The network provides a structure for multiple agencies/academics to work together under one collective purpose, while still supporting their local, site-based needs.

4. Implementation Plan

Because TEON is largely built around the necessity to support legacy sites, the greatest implementation challenge will be establishing consistency between the new and existing sites. A diverse array of instrumentation, collection techniques, communication protocols and data formats are found at the different legacy sites and will have to be gradually migrated into a unified, consistent system. At new sites, such as the Kokolik River Area, the installations will be more costly but less complicated because the instrumentation, protocols and data management are new. If existing sites elect to replace older sensors with new ones, we suggest that records from the different sensors overlap for ~1 year. This redundant data will be used to recalibrate the historic data so that it is consistent with the readings from the new sensor.

Of the 22 observation stations distributed in the 7 TEON watersheds in the Arctic LCC, 11 are either fully or partially operational and 11 will require completely new installations. Though this section of the document does not provide a timeline or suggested sequence of events, we outline which steps are necessary in each focal watershed. Instead of activating the network all at once we suggest incrementally adding focal watersheds through time. We attempt to keep the annual Arctic LCC expenditures around $350k during the installation. This is enough funding to install ~2 expensive stations per year or three inexpensive stations (Table 23). Note that in year 2, the costs will include the second installations and the maintenance of the sites installed in the first year. As the installations are completed, the annual cost of maintenance will become more and more significant. Once the network is installed, costs will stabilize around $180k per year. Though stakeholder needs can affect installation prioritization, we suggest first working at well-established, easily-accessible sites to develop skills and familiarity with the process. This also allows for preservation of legacy data that might be in jeopardy of shutting down. The incremental installations allow the Arctic LCC to distribute the cost of installation over multiple years, to learn from prior experience, to develop strong partnerships with agency and academic partners, and to develop a sound method for data ingestion, formatting and distribution.

Once a station is installed, we suggest spring and fall visits. Before the spring visit, technicians will use the streaming data to know ahead of time if any of the sensors are not functional and plan for repairs. During the spring, technicians deploy ice-sensitive sensors and provide routine maintenance and sampling tasks as described above in the tables above. During the fall, besides routine maintenance and sampling tasks, technicians will focus on winterization of the stations, removing ice-sensitive sensors and assuring adequate power and communication through the winter. The costs associated with these two visits depend largely on who does the work, how they access the site, if there is broken hardware and what level of analyses are run on the samples collected. Sites accessible by road, near a village with easy air logistics are considerably less expensive to maintain. Once the installation is complete, transportation costs at more remote sites can be reduced if technicians are able to travel by inflatable boat between stations rather than requiring closed support from a helicopter or bush plane. In Table 24 we provide rough estimates of the cost of these 2 visits for each site. Though the hardware is expected to last ~10 years, items will need to be infrequently replaced if they are damaged or become prematurely worn. These costs are not accounted for, but could be assessed by simply amortizing the cost of a new station over a 10 year period. Because these sites are intended to persist into the foreseeable future, there is no removal plan, but all stations and installed components can be removed as necessary.

	Hardware and Install	Maintenance	Total	Watersheds
Year 1	300600	0	**300600**	Barrow, Fish, Kuparuk
Year 2	282540	65400	**347940**	Kokolik , Agashashok
Year 3	169220	121200	**290420**	Hulahula
Year 4	157360	155400	**312760**	Upper Koyukuk
Year 5	0	184600	**184600**	
Year 6	0	184600	**184600**	
Year 7	0	184600	**184600**	
Year 8	0	184600	**184600**	
Year 9	0	184600	**184600**	
Year 10	0	184600	**184600**	

Table 23. Possible sequence of installations that keep program costs close to $300k per year. In the first year, 3 stations are installed, 2 in the second year and 1 station in years 3 and 4. The number of installations must go down because the cost of station maintenance increases over time. This suggests that the 7 stations can be installed and operational in 4 years.

Focal Watershed	Hardware	Installation	Annual Maintenance
Kokolik R Area	114270	37000	30400
Barrow/Mease R Area	87450	27000	21400
Fish/Judy Ck Area	51760	32000	23600
Kuparuk R Area	75390	27000	20400
Hulahula/Jago R Area	132220	37000	34200
Agashashok R Area	104270	27000	25400
Upper Koyukuk Area	130360	27000	29200
Total	695720	214000	184600

Table 24. Summary table of costs associated with each site. Hardware and installation costs would occur only in the first year but maintenance would recur each year. The maintenance costs are largely in accessing sites, personnel time to maintain the site and perform analyses.

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Linking Climate and Habitat Change in Arctic Alaska: Recommended Monitoring and Modeling Activities.

Report of the Arctic Landscape Conservation Cooperative Species & Habitat Working Group

Arctic Landscape Conservation Cooperative

Advancing Science, Understanding Change.

Philip Martin, Arctic Landscape Conservation Cooperative, Editor

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Introduction: Process and Objectives

The Arctic Landscape Conservation Cooperative (ALCC) convened four Technical Work Groups devoted to physical processes in the fall of 2010: Climate, Permafrost, Hydrology, and Coastal Processes. Each group was provided with a list of questions/science needs, informed by previous multiagency efforts[1] to identify information gaps relative to climate change. Using this list as a starting point, the groups were asked to address the following questions:

1. What general approaches (e.g., long-term monitoring, hypothesis-driven research, modeling, etc.) and discrete work elements are needed to address each question?

2. To what extent are current efforts adequate? What additional work is needed?

3. What would be the order-of-magnitude (50k, 500k, or 5 million) estimates for effort/cost for each work element (both initial and fixed annual costs)?

Species and Habitat Working Group: Need and Function

The physical process work groups were able to provide preliminary recommendations, but the number and complexity of the issues suggested that additional filters would help set priorities. We needed input regarding the questions that biologists and managers felt were most pertinent to resources of management concern. The "Species and Habitats" Work Group was convened to provide that input, and to guide the recommendations of the other work groups to narrow the focus on issues that best linked climate change to habitat condition/availability. The first meeting of the ALCC Species and Habitat Work Group was held on 20 May, 2011. ALCC staff provided an overview of the ALCC mission and structure. The group subdivided into specialist sub-groups: fish, mammals, birds, and subsistence resources. Each sub-group was asked to review the conceptual models in the WildREACH (Martin et al. 2009) report, as a starting point for discussion. Groups were invited to either accept the models or suggest modifications. The sub-groups were charged with the following tasks:

Species and Habitat sub-Group Tasks

The Subsistence sub- group was asked to identify which of the subsistence-harvested species may be most vulnerable to direct and indirect effects of changing climate.

> By 1 September, 2011, develop a list of about 5 (more than 3, less than 10) species or species assemblages of importance to the subsistence harvest, which you consider most vulnerable to climate change. For each, develop a narrative that explains ***what***

[1] Alaska Climate Change Sub-Cabinet (2009), Martin et al. (2009), Alaska Climate Change Executive Roundtable (unpub), Zack and Liebezeit (2010), NSSI (2011)

> (ecosystem or climate-driven) change is projected, and ***how*** (by what mechanism) it would affect that species' ***populations*** or ***availability for harvest***.

The "taxon-oriented" work groups (Birds, Fish, and Mammals) were asked to do the following:

> By 1 September, 2011, develop a list of about 5 (more than 3, less than 10) biophysical process shifts associated with climate change that you consider the strongest influence to broad species assemblages within your taxon. For each, develop a narrative that explains ***what*** (ecosystem or climate-driven) change is projected, ***how*** (by what mechanism) it would affect fish and wildlife populations, and ***which*** species or species assemblages are most sensitive to the projected change.

The biophysical process shifts could involve direct or indirect influences on biota. For example: change in seasonality of peak run-off, greater frequency of rain or thaw during the snow season, shift from sedge to shrub vegetation, longer ice-free season for large lakes. The emphasis was on choosing focal ***processes***, not species, at the same time recognizing that the question could not be addressed in isolation of consideration of the potential effects on particular species/assemblages. The groups were asked to emphasize habitat characteristics, but because the definition of "habitat" varies by context, further guidance was provided to consider biological components at lower trophic levels only; this narrowing of scope excludes consideration of some competitive interactions among species, and some predator-prey relationships. For example, we did not consider whether warming conditions might favor increased red fox populations at the expense of arctic foxes, or fish tolerant of warm waters at the expense of cold-adapted specialists. We did consider, however, the complex of predator-prey interactions that might accompany a change in cyclicity of rodent populations.

All group meetings were facilitated by the ALCC Science Coordinator, but the groups were given latitude to follow their own individual process to address the assigned task. Each group was ultimately asked to summarize their findings in a common tabular format that identified priority biophysical processes considered most influential, species or species groups most likely to be affected, and suggestions for which related parameters to measure or model. Final edits on those products were received by the end of January, 2012.

Summary of Findings

Despite the large number of issues addressed by the individual sub-groups, they converged on a few themes that were broadly influential across taxonomic divisions, and pertinent to people's ability to access subsistence resources (Table 1, themes in bold-face). Within the general themes, the relative importance of specific indicators of environmental change varied by subgroup. Recognizing that indirect linkages are pervasive in ecosystems, the summary tables emphasize proximal relationships. For example, permafrost thaw has broad and far-reaching ecosystem implications, but its relationship with fish and wildlife habitat change is taken into account through discussions of changes to hydrology and vegetation.

All subgroups identified monitoring climate conditions as fundamental variables of interest. This highlights a widely shared need for improved downscaled climate projection products, informed by a network of observation stations sufficient to capture the spatial variation in regional temperature, precipitation, and wind fields.

Water-related topics appeared most frequently in the reports of the sub-groups. Often, the topics incorporated aspects of hydrology and other disciplines (e.g., surface storage and active layer thaw, stream discharge and sediment transport/deposition). Hydrologic-related topics identified by the fish and bird sub-groups were most similar, reflecting overlap in the habitat requirements of fish and the large proportion of arctic-breeding bird species dependent on aquatic systems. In contrast, the hydrologic topics most relevant to terrestrial mammals were related to snow conditions and indirect effects of water on vegetation phenology and plant community composition. Unlike most bird species, mammals and many fish live year-round in arctic environments where the snow season prevails for most of the year.

Birds and fish sub-groups also identified coastal processes and aquatic invertebrate phenology and abundance as being important, whereas the mammal group did not.

Changing seasonality (phenology) was identified as a separate category because the general topic was of interest to all sub-groups, even though the specific indicators varied. With the exception of insect emergence, the identified indicators can be monitored via remote sensing, and the required activities are mostly in the realm of image processing, image interpretation, and trend analysis. Correlating changing phenology with changing climate, however, requires an adequate weather monitoring network and availability of reliable interpolated gridded climate data products.

In summary, despite the complexity with which climate interacts with all components and processes of the arctic terrestrial ecosystem, the working group was able to identify a limited list of cross-cutting themes. Recommendations regarding field measurements and modeled data products most needed by biologists to address those themes are contained in the individual summaries for each sub-group. These are contained in the tables and accompanying narratives that follow.

Table 1. Cross-cutting themes (boldface) and key environmental indicators of change considered most influential to species life history and ecology and/or to people's access and use of subsistence resources.

Biophysical Process Themes and Environmental Indicators	Birds	Fish	Terrestrial Mammals	Access to Subsistence Resources
Climate and Weather				
Air temperature, precipitation	X	X	X	X
Frequency of extreme events (e.g., storms, drought)	X	X	X	X
Windiness	X			X
Water/Hydrologyic Processes				
Surface storage/soil moisture	X	X		
Streamflow/connectivity		X		
Formation of new drainage networks	X	X		
Lake volume/lake drainage	X	X		
Snow Characteristics (depth, water equivalent)		X	X	
Winter Icing Events	X		X	X
Water temperature		X		
Water chemistry		X		
Glacier input (sediments and water)	X	X		
Permafrost Warming				
Permafrost temperatures				X
Food-chain (Trophic) Relationships				
Vegetation change/shrub encroachment	X		X	X
Aquatic/semi-aquatic invertebrate abundance	X	X		
Coastal/Marine Processes				
Lagoon water chemistry/productivity	X	X		
Coastal erosion, inundation	X	X		
Sea ice and related sea state conditions				X
Sediment and freshwater input to estuaries	X	X		
Seasonal Effects				
Lake/river break-up and freeze-up	??	X		X
Snow-on/snow-off	X		X	X
Green-up/peak greenness	X		X	
Insect emergence/activity levels	X	X		

Subsistence Resources

Introduction

Landscape Conservation Cooperatives are charged with conservation of both natural and cultural resources. At the intersection of these two categories is "subsistence use," defined broadly as the taking of fish, wildlife, or other wild resources for the sustenance of families, communities, and cultures. The activities surrounding harvest of wild food have both cultural and nutritional significance. In considering the potential effects of climate change on the availability of subsistence resources, it is useful to partition "availability" into three components: resource abundance (population size), resource distribution, and human access. Access, in this context, refers to the environmental conditions necessary to allow the hunter to get to the resource when it can be legally harvested. Processing, preservation, and consumption of food are also affected by climate change, and these activities are included within this category. Adaptation to climate change by subsistence users must take all three components into account.

Use of Marine vs. Terrestrial Resources

Marine resources, particularly marine mammals, comprise a significant proportion of the harvest of subsistence resources in the communities found within the Arctic LCC (Table 2, Figure 1). For coastal communities, marine mammals may comprise greater than two-thirds of the diet, and are of great cultural significance. For others, marine mammals may constitute a minority of the diet, but are still culturally significant. For some villages on the south side of the Brooks Range, marine mammals are far less significant, nutritionally and culturally. Nevertheless, adequate consideration of climate change on subsistence resources must include consideration of marine resources, particularly marine mammals. Additional details regarding climate impacts to marine mammals are provided in Appendix A.

There is considerable variation among communities in the terrestrial and freshwater species harvested for subsistence (Table 3). There is a relatively short list, however, of species or species groups, that are frequently harvested in at least two communities: caribou, Dall's sheep, arctic fox, arctic ground squirrel, ptarmigan, greater-white fronted and Canada geese, eiders, brant, grayling, Dolly Varden, broad whitefish, arctic and least cisco, and rainbow smelt.

Climate Effects on Abundance and Distribution of Terrestrial Resources

To a large extent, the climate-related habitat changes that may be expected to affect the frequently harvested species listed in Table 3 are addressed in other sections of this report (see "Birds," "Fish," "Mammals"). Exceptions include changes in the marine environment that may affect murres and anadromous fish (e.g. arctic cisco and Dolly Varden) that are found in the open ocean. The species listed in Table 3 reflect past and current use, and exclude species uncommon in northern Alaska at present, acknowledging that future increases in abundance are possible. Examples include salmon species that may be increasing in abundance in the Chukchi and Beaufort seas, and moose, which may become more abundant as shrublands expand into tundra areas. These caveats aside, the priorities developed in the accompanying sections are broadly relevant to subsistence species. Populations may be expected to respond to climate change in an individualistic fashion, however, so work targeted at specific harvested populations may be needed to address questions of interest to managers and communities.

Effects on Access to Subsistence Resources

Physical conditions that affect subsistence access may send a clearer signal of climate-associated environmental change than observations related to abundance and distribution of fish and wildlife. Long-term trends in abundance may be detected from formal survey data or the experience and observations of life-time residents of the region (Krupnik et al. 2010). It is difficult, however, to distinguish a long-term (multi-decadal) trend against the background of short-term (annual to decadal) variation, as animal abundance and distribution varies seasonally and among years due to a multitude of environmental influences. Furthermore, distributions of resources often extend beyond the areas accessed by individual communities. Therefore, perceptions of abundance may be biased by shifts in spatial distributions. Harvest areas, however, are used on a consistent basis for long time periods: this provides an uninterrupted record of changes that influence access, passed down through human generations. Examples of environmental changes that affect access to subsistence resources are provided in Table 4. Indicators of change that are candidates for monitoring are also listed.

Recommended Priorities

Given the initial focus of the Arctic LCC on terrestrial and nearshore resources, three arenas of activity emerge with respect to subsistence resources:

1. *Biophysical processes* that broadly influence the distribution and abundance of terrestrial/freshwater species.
2. *Terrestrial-marine linkages* that affect distribution and abundance of marine resources.
3. Environmental change that affects *access* to subsistence resources.

Items in the first category are adequately addressed by the recommendations from the accompanying sections (see “Birds,” “Fish,” “Mammals”). More detailed recommendations for the other two categories are presented below.

Marine Resources

Substantial federal resources and agency capacity are available to examine issues related to climate change in the Chukchi and Beaufort Sea regions. These include, but are not limited to, research programs of the National Oceanic and Atmospheric Administration (NOAA), Bureau of Ocean Energy Management, (BOEM), and North Pacific Research Board (NPRB). The Arctic LCC can add value to these existing programs by focusing on the following:

1. Issues that involve terrestrial-marine linkages. Examples include quantifying rates of nutrient, carbon, and sediment export from the terrestrial to the marine system; changes in structural and biogeochemical characteristics of nearshore lagoons; inundation risk in the coastal terrestrial zone, changes in the propensity of marine mammals to use terrestrial habitats.

2. Develop and implement protocols to include changes in marine resources within community-based monitoring programs (e.g., Moore and Huntington 2008).
3. Monitor, model, and report on changes to the physical environment that affect human **access** to subsistence resources (see below).

Successful work in any of these arenas will most likely require partnership with organizations with a largely marine focus.

Access to Subsistence Resources

Climate effects on the physical environment directly affect access to subsistence resources, through pathways that differ from those that affect species abundance and distribution. While wildlife management agencies are concerned with resource abundance issues, climate effects on access to those resources may not be addressed. It seems particularly important for residents to understand whether observed changes are anomalous or short-term, or whether they appear to represent a pattern of change that is widespread and consistent with a predicted long-term directional shift. The Arctic LCC can help address the human dimensions of climate change by:

1. Inventory existing information that summarizes observations of changes that strongly influence access to subsistence resources (i.e., Table 4).
2. Place the observations of local residents into a larger geographic framework by incorporating these observations into a regional monitoring framework.
3. Report back the results of regional monitoring to communities and work to incorporate these results into models that forecast future conditions.

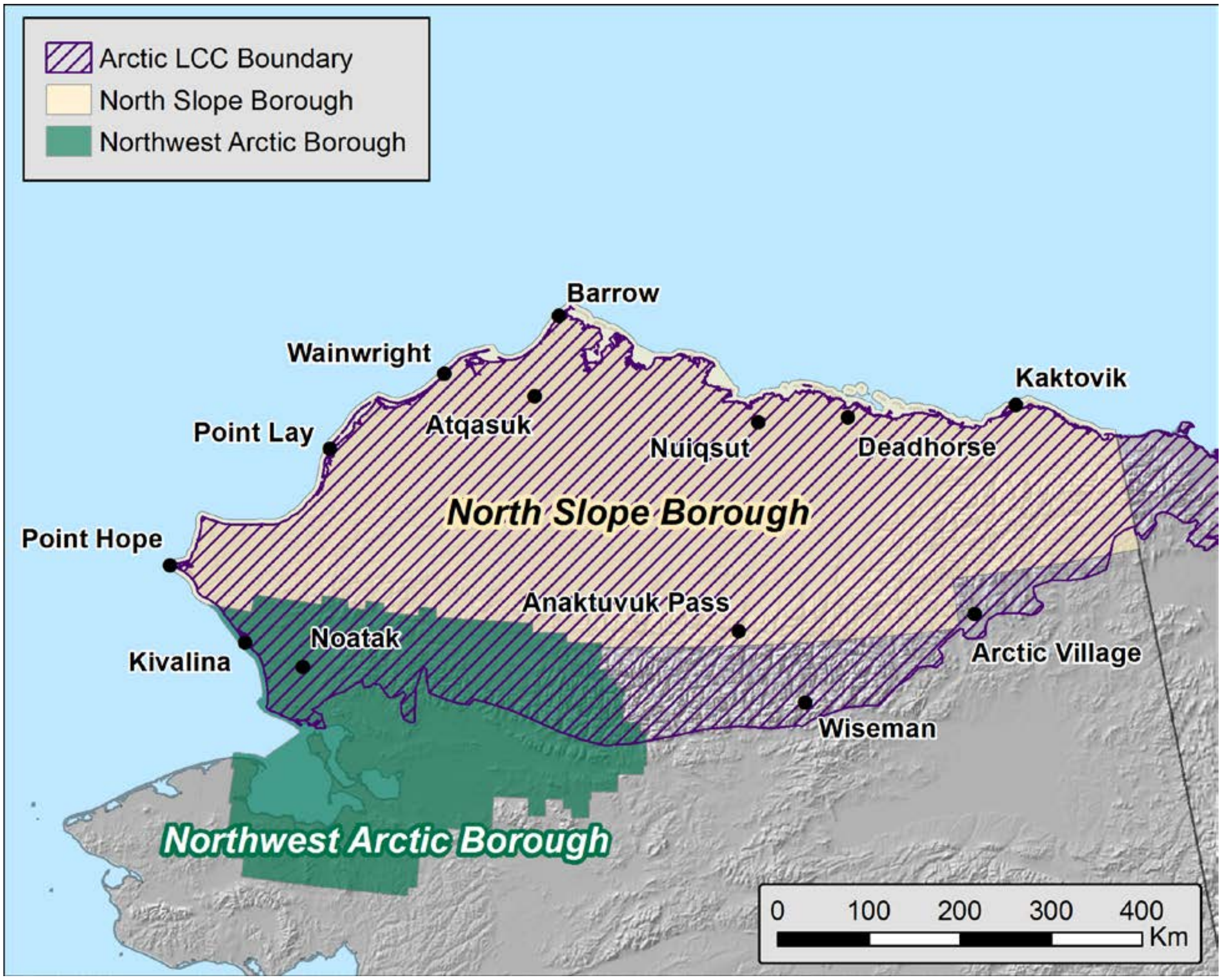

Figure 1. Communities located within the Alaska portion of the Arctic LCC. Eight communities are within the North Slope Borough, two within the Northwest Arctic Borough, and two outside of an organized borough.

Table 2. Marine mammals, as proportion of diet (by weight) at representative communities within the Alaska portion of the Arctic LCC. (ADF&G 2001, Bacon et al. 2009, Fuller 1997).

Community	% of Diet (by weight)
Anaktuvuk Pass	*
Arctic Village	NA
Barrow	58
Kaktovik	68
Kivalina	50
Point Hope	77
Point Lay	72
Noatak	18
Nuiqsut	32
Wainwright	69

*small but important part of the diet

Table 3. Most frequently harvested terrestrial and freshwater species (or species groups) by subsistence users in northern Alaska, listed by community. (ADF&G 2001, Bacon 2009, Fuller and George 1997).

Community	Mammals				Birds						Fish						
	Caribou	Arctic Fox	Arctic Ground Squirrel	Dall's Sheep	Ptarmigan spp.	Gr. White-fronted	Canada Goose	Eider spp.	Black Brant	Murre spp.	Grayling	Dolly Varden/Char	Broad Whitefish	Humpback Whitefish	Arctic Cisco	Least Cisco	Rainbow Smelt
Coastal																	
Kivalina	X						X					X					
Point Hope	X	X						X		X	X	X					
Point Lay	X		X		X	X	X	X	X		X	X					X
Wainwright	X					X		X	X		X	X				X	X
Barrow	X					X		X					X	X		X	
Nuiqsut	X	X	X		X	X	X	X					X		X	X	
Kaktovik	X		X	X	X	X	X	X	X			X			X		
Inland																	
Noatak	X					X	X					X					
Atqasuk	X		X		X	X		X					X	X			X
Anaktuvuk	X			X	X	X	X				X	X					
Arctic Village	X			X	X	X	X					X					

Table 4. Climate-related biophysical processes most influential for access to subsistence resources, and monitoring /modeling activities or products that would help develop our understanding of the relationships among climate drivers, habitat change, and species effects.

Biophysical Process – Subsistence Resources	*Consequences for access to resources or use of resources*	*What biophysical parameters to measure/model?*
Changes that affect safety and practicality of travel		
1. Earlier end , and later onset of snow season	Shorter period for snow-machine travel	• Estimated snow season onset and end for the entire domain, at 250-m to 1-km resolution. Annually updated gridded data set from remote sensing and modeling.
2. Incidence of icing events	Snow machine travel more difficult in icy conditions	• Produce gridded data sets with modeled occurrence of icing events (*retrospective and current-year*) at moderate resolution (1 –km) for entire domain; Modeled *projections* of occurrence of icing events at moderate/coarse scales dictated by the native resolution of climate models.
3. Earlier river break-up and later freeze-up	Change in timing of transition from boat to snow travel. Potential loss of safe-access during critical period (e.g., fish spawning season)	• Remote-sensing and/or modeling of open water season for rivers. • Predictive models of trends in open water season for rivers used as transportation corridors.
4. Increased incidence of high wind conditions during open-water season (marine) results in rougher seas	Fewer opportunities for safe boat travel.	• Install and maintain adequate weather station network onshore and offshore • Gridded data over entire domain at moderate spatial resolution (1-km or better) with modeled retrospective modeled wind conditions • Decadal-scale trend and forecasts of probability of occurrence of extreme wind conditions
5. Summer sea ice retreat results in rougher seas because of greater fetch	Fewer opportunities for safe boat travel.	• Monitoring of the association between sea ice extent and open water conditions.
6. Increased incidence of high wind during ice season (marine) results in larger leads opening closer to shore	Affects traditional modes and timing of access.	See #4, above.

Biophysical Process – Subsistence Resources	*Consequences for access to resources or use of resources*	*What biophysical parameters to measure/model?*
7. Less seasonally persistent and less stable landfast ice increases hazards for over-ice travel.	More dangerous travel on sea ice	• Remote sensing of sea ice dynamics (extent and thickness) within traditional hunting areas; particular attention should be given to the association between lead dynamics, sea ice thickness, and environmental variables (wind, ocean current)
8. More rapid sea ice retreat	Reduced opportunity to hunt walrus and ice seals	• See #7, above
Changes that affect safe food storage		
9. Permafrost temperatures increase	Ice cellars need to be moved or modified if they become too warm for proper storage	• Monitoring of temperatures in ice-cellars. High-resolution modeling of near-surface future permafrost temperatures in communities
10. Warmer fall temperatures	Suitable conditions for meat storage occur later in the season	• Install and maintain adequate weather station network • Gridded data over entire domain at moderate spatial resolution (1-km or better) with modeled daily temperature data (e.g. mean, median, low, high).
11. Wetter summer weather	More difficult to dry meats	• Above, and gridded precipitation products at temporal resolution of 2 weeks or better
Changes in pathogens and insect pests		
12. Warm and calm weather in summer	Changes in prevalence of biting insects	• Gridded data products with modeled “insect activity index” combining temperature and wind factors
13. Change in prevalence of fish and wildlife disease vectors	Changes in food safety and/or palatability	• Implementation of community monitoring programs. (Similar to caribou body condition programs [see http://www.carmanetwork.com/display/public/Projects])
Other Biological Indicators		
14. Change in individual size of plants used for medicinal purposes	Uncertainty regarding quantities to harvest, use	?
15. Changes in animal behavior, such as increased use of terrestrial haul-outs by walrus and seals	Change in accessibility for harvest and potential for greater disturbance to aggregations	• Aerial survey-derived maps of location and numbers of animals.

1 Sources: ACIA 2004, NSSI 2011, T. Brinkman pers. comm., ANTHC, Krupnik et al. 2010, Hajo Eicken, pers. com

Fish

Introduction

Freshwater fish in the Arctic live in a variety of habitats ranging from glacier-fed rivers to low-velocity beaded streams and ponds. The hypothesized changes to this range of habitat as a result of climate change are far-reaching. While many fish populations in Arctic Alaska may benefit at least in the near-term from increased warming, longer summer seasons, and warmer winter temperatures, cold-adapted species may be negatively impacted in the long-term, and changes in habitat use and quality, as well as movement patterns as a result of climate change, has implications for all species.

Discussion topics on fish focused primarily on the changes in water storage and transport that will affect connectivity among the important seasonal habitats used by populations, and warming water temperatures that will affect habitat characteristics. Additionally, increased melting of permafrost and decreased glacial input to glacier-fed rivers may have significant, quantifiable impacts on fish populations. The critical elements are those hydrologic changes that could negatively affect distribution and movement of fish and access to essential habitat, with particular emphasis on changes in discharge volume and flow regimes that would lead to uncoupling various life history strategies (such as migration timing and location) with the available environment. Most of the physical parameters of concern vary strongly by season in their degree of influence on fish. Spring and fall are particularly important, when habitat connectivity is critical for dispersal and migrations.

Overwintering habitat has long been considered a limiting factor for Arctic fish populations under current conditions. Expected physical changes to wintering habitat are likely to reduce the effect of this cap on populations, with the projected warmer, wetter winter environment likely having positive implications for most, if not all, fish species. In contrast, a dryer summer season with potential increased frequency of "drying events" and increasing lack of connectivity among lakes and stream systems is perceived as a greater threat to fish species than the advantages of increased availability of overwintering habitat.

Monitoring Locations

Each "physical process" ideally would be monitored at watersheds across the Arctic that represent a variety of hydrologic influences and distinct habitat types of ecological and management significance, and are feasible sites for implementing long-term, landscape-based climate change monitoring. For example, the Hulahula River watershed is a glacially-influenced stream system on the eastern Arctic Coastal Plain (ACP), the Kuparuk River watershed is a foothill stream system west of the Hulahula, and the Fish Creek/Judy Creek watershed and the Chipp River/Ikpikpuk River/Teshekpuk Lake area are both coastal plain stream systems, the former in the central portion of the ACP and the latter in the western ACP. Long-term data sets of environmental monitoring are relatively scarce in Alaska, where access to remote study areas is difficult and expensive. The afore-mentioned set of systems each has a multi-year dataset of physical and biological data that provide opportunity to address the questions of climate change effects on fish in diverse Arctic habitats.

Biological Processes Monitoring

Accurate predictions of climate change effects on fish cannot be made without sufficient information about the underlying biological processes that drive aquatic ecosystem functions. Monitoring changes in physical parameters will be most useful if conducted in conjunction with field-based observations and focused studies to clarify the mechanisms by which environmental variables influence populations. Baseline information on presence, abundance, life history traits, and genetic diversity of fish populations in representative watersheds must be collected and analyzed over time. While studies of arctic fish populations have been conducted in the past, a more complete body of knowledge is required before the true effects of climate change on habitat use and population success can be assessed. Future work with invertebrate productivity and shifts in the aquatic invertebrate community, measuring fish productivity, age and length at maturity, timing and extent of seasonal migrations and population status, as well as primary productivity within drainage systems would allow for evaluating the effects of habitat change on biological processes.

Information on spatial variation (population-level adaptive variation) would be useful in assessing adaptive potential and whether or not some populations may be more successful in responding to change. For example, fish may be able to distribute more widely and exploit more available habitat during longer summer migratory periods, but this will go unnoticed if appropriate reference baseline information is unavailable. Increased competitive interactions with species expanding their range northward may occur, if species share habitat and have similar life history, foraging and spawning behavior, although the timeline and degree of competition is highly uncertain. Understanding the response to climate-associated habitat change may be difficult if baseline distribution, habitat use, feeding strategies, or life history traits are not sufficiently documented before these changes occur. Group members acknowledged that interspecific interactions are important, but recognized that understanding these as a function of climate change adds a level of complexity requiring understanding of physical process change, as well as biotic responses, which may be highly individualistic.

Table 5. Climate-related biophysical processes most influential for fish and monitoring /modeling activities or products that would help develop our understanding of the relationships among climate drives, habitat change, and species effect. Topics are in order of priority. The 3rd column of the table identifies parameters that could be measured in order to clarify whether the hypothesized effects are operating as predicted.

BIOPHYSICAL PROCESSES – FISH	*What Species or Species Groups May Be Affected?*	*What biophysical parameters to measure/model?*
I. **Changes in Surface Storage and Stream Flows**		
Foothill streams: increased incidence of 'drying' and lack of connectivity, especially when coupled with longer, warmer summer season. • Potential negative outcomes: • possible disruption of adult migration, instream egg incubation, and juvenile dispersal	Widespread throughout fish species, especially migratory species. Genetic diversity may be affected if connectivity reduces migrations of local populations.	• In-situ measurements of all components of water balance • Test with long-term discharge record at Kuparuk River • Maintain and expand discharge monitoring on Hulahula River • Monitor drying events and document losses of connectivity due to river discharge changes • Improved observational record and hind-cast models to look for trends in incidence of "drying"

Coastal plain streams: deeper active layer results in net drying of saturated soils and shallow streams; thermokarst-related local redistribution of water and new drainage networks.
• Potential positive outcomes:
  • more available summer feeding habitat through newly formed drainage lakes
• Potential negative outcomes:
  • decreased connectivity resulting in loss of habitat, entrapment, disruption of seasonal migration patterns
	Widespread throughout fish species, especially migratory species. Genetic diversity may be affected if connectivity reduces migrations of local populations.	• *In-situ* measurements of all components of water balance
		• Measure and monitor active layer depth
		• Maintain and expand hydrologic monitoring within Fish Creek/Judy Creek and Chipp/Ikpikpuk rivers and Teshepuk Lake drainages
		• Monitor discharge and water levels in systems used during migration, especially in spring and fall
		• Remote sensing of surface water area and lake volume change (shoreline and bathymetry mapping) within and among seasons.

Increased snow depth increases insulation, resulting in thinner ice cover, • Potential Positive Outcome – Greater availability of overwintering habitat	Widespread throughout fish species.	• Winter precipitation • Snow transport and deposition models • Ice-growth models

BIOPHYSICAL PROCESSES – FISH	*What Species or Species Groups May Be Affected?*	*What biophysical parameters to measure/model?*
II. **Water Temperatures and Chemistry**		
Increased stream and lake temperatures. • Potential positive outcomes: – increased fish growth rates – increased lower trophic level productivity – lower age at maturity for some species • Potential negative outcomes: – direct physiological stresses such as reduction of individual productivity or increased susceptibility to parasite/diseases – direct mortality due to extreme temperatures – indirect stresses such as migratory pattern changes, changes in terrestrial and aquatic food availability • Outcome direction uncertain: – Change in timing of insect emergence, peak prey abundance	All freshwater species	• Monitor water physical parameters in representative watersheds throughout seasons, • Maintain existing long term datasets of water quality and characteristics, including timing and intensity of breakup, any drying events, and timing of freeze-up (Kuparuk River, Hulahula River, Judy/Fish Creek, Chipp/Ikpikpuk rivers/Teshepuk Lake) for time series analysis. • Remote sensing of spring thaw and freeze-up. • Monitor primary and secondary productivity. • Seasonal pattern of aquatic invertebrate abundance
Increased winter air temperatures. • Potential positive outcomes: • less ice cover and shorter winter season results in increased wintering habitat availability • increased overwintering survival rates • Potential negative outcomes: • increased metabolic demands	All freshwater species	• Monitor water physical parameters in representative watersheds throughout seasons • Maintain existing long term datasets water quality and characteristics, including timing and intensity of breakup, any drying events, and timing of freeze-up (Kuparuk River, Hulahula River, Judy/Fish Creek, Chipp/Ikpikpuk rivers/Teshekpuk Lake) for time series analysis. • Remote sensing and in-situ investigations of overwintering habitat available for fish. • Monitor changes in lower tropic level productivity, including aquatic invertebrates. • Document any expansion of overwintering habitat.

BIOPHYSICAL PROCESSES – FISH	*What Species or Species Groups May Be Affected?*	*What biophysical parameters to measure/model?*

Changes in water chemistry and quality, including but not limited to: pH, dissolved oxygen, dissolved carbon and nitrogen, light levels, turbidity, alkalinity, chlorophyll-a levels, and zooplankton abundance.
• Potential negative outcomes:
  • direct physiological stresses such as increased parasite load, increased metabolic demands, and increased rate of contaminant uptake
  • indirect physiological stresses such as restriction of movement and migration, especially when coupled with changes in temperature regimes and prey availability
	All freshwater species	• Monitor water chemistry in representative watersheds throughout seasons.
		• Maintain existing long term datasets of water quality and characteristics, including timing and intensity of breakup, any drying events, and timing of freeze-up (Kuparuk River, Hulahula River, Judy/Fish Creek, Chipp/Ikpikpuk rivers/Teshepuk Lake) for time series analysis.
		• Monitor changes in lower level productivity, including aquatic invertebrates.

III. **Coastal Processes and Change in Sea Level**		

Increased coastal erosion:
• Potential positive outcomes:
  • increased ease of anadromous migration and coastal migrations between feeding and overwintering habitat
• Potential negative outcomes:
  • loss of terrestrial habitat, increased lake drainage, conversion of freshwater to saline habitat, restriction of movement/migration of freshwater adults and juveniles
	Salmon species, whitefish species including ciscos, Dolly Varden, freshwater species esp. in early spring	• Remote sensing of coastal habitat
		• Monitoring of lagoon water chemistry.
		• Measure and monitor total river discharge to assess freshwater and sediment delivery to estuarine areas.

BIOPHYSICAL PROCESSES – FISH	*What Species or Species Groups May Be Affected?*	*What biophysical parameters to measure/model?*
IV. **Change in Glacial Input**		

Reduced summer flow rate and lower turbidity due to diminished glacier-derived sediment load
• Potential positive outcomes:
  • greater predatory success by sight-predators
• Potential negative outcomes:
  • changes in habitat as a result of changes in sediment transport, increased warming or cooling during summer season due to changes in turbidity
  – Changes in nutrient delivery to downstream areas and river delta as a change in glacial input may be positive or negative
	Salmon species, Dolly Varden, Arctic Grayling	• Measure and monitor total river discharge to assess freshwater and sediment delivery to estuarine areas.
		• In-situ measurements of water temperature, turbidity and other parameters within Hulahula River.

V. **Change in non-connected Lake Area**		
New connections between previously disconnected lakes and ponds may provide new habitat for fish.	Most freshwater species, including Arctic char and especially species in Western North Slope drainages	• Remote sensing and in-situ measurement and monitoring of lake surface area and lake volume changes.
Shallowing of lakes due to thermokarst-associated drainage, increased evapotranspiration, and changes in precipitation regimes may reduce habitat available to fish, and could eliminate some habitat.		

Annotation to Summary Table 5

Table 5 lists five climate-associated biophysical processes/topics, in order of priority for monitoring and research. These are:

I. Changes in surface water storage and stream flow, such as:

- Changes in flow levels, consistency and timing, particularly the magnitude and timing of summer snowmelt and fall precipitation, in order to understand the implications for fish dispersal between overwintering, spawning, and summer feeding areas.
- Changes in connectivity between lakes and streams as a result of changes in evaporation, precipitation, surface storage, or increased thermokarsting effects and thawing and subsequent lake drainage, in order to understand changes in access to available habitat, and the impacts on seasonal migrations.

II. Water temperature and chemistry, such as:

- Changes in water chemistry and quality in lakes and streams—including but not limited to pH, dissolved oxygen and carbon, alkalinity, nitrogen and phosphorous levels, and turbidity—in order to understand implications for changes in distribution, physiology, reproductive and feeding success, and timing of dispersal or seasonal migration.

III. Coastal processes and change in sea level, such as:

- Changes in mean sea level, in order to understand how these will affect the coastal areas such as lagoons, estuaries and river mouths, specifically to investigate distribution and seasonal migrations of fish.

IV. Change in glacial input, such as:

- Changes in the magnitude and timing of peak flows, as well as changes in turbidity levels, water temperature, and habitat associated with sediment transport to coastal areas as a result of decreasing glacial inputs to stream systems.

V. Change in non-connected lake area, such as:

- Shallowing of lake habitat due to increased evapotranspiration or drainage.
- Lateral expansion of lakes due to shore erosion.
- Deepening or loss of permafrost leading to lake drainage, with an overall loss of surface ponds and tundra lakes.

Within each of these topics, sub-topics are listed. These should be considered measurable indicators of climate-related change, which will have effects on fish populations. Additional detail is provided in the annotation below.

I. Changes in Surface Storage and Stream Flows

Monitoring projects should ascertain that predicted directional trends are accurate (i.e. will discharge increase or decrease over the long term) and what patterns of spatial or seasonal variation may modulate this overall trend? Projects that measure/monitor the timing and duration of peak flows as a function of spring snow melt and fall precipitation regime, and the consequences to connectivity between summer feeding areas and overwintering habitat, would have the most direct bearing on fish.

Changes in drainage connections and networks will occur differently in coastal plain and foothill watersheds, but the potential for drying or lack of connectivity exists in both ecosystems.

1) Foothills -- For foothill and glacial-fed streams, the projection that increased precipitation will lead to increased base flow potentially has positive implications for fish populations and distributions if waterbody connectivity is maintained. Validation of this projected trend for foothill streams and that the increased base flow continues throughout the season is necessary. The Kuparuk River, with its long-term dataset collected by the University of Alaska Water and Environmental Research Center (WERC) may offer an opportunity to verify “increased” base flow regimes. However, if increased base flow is only a short-term or seasonal outcome, and further warming, increased evapotranspiration and longer summer seasons results in “drying events” and a loss of connectivity, the projected impacts on fish populations may be detrimental depending on timing and extent of these stochastic events. A lack of connectivity throughout these waterbodies at critical times may prevent seasonal migrations, strand adults as they travel to overwintering areas, or disrupt juvenile dispersal.

2) Coastal Plain -- A decrease in surface flow for coastal plain streams is projected, due to creation of a deeper active layer through thawing, resulting in a downward shift of stored water, and increased surface drying. Surface drying would be further exacerbated by greater export of water through evapotranspiration, associated with a longer, warmer, summer season. Decreased surface flow throughout the summer season may lead to a loss of connectivity between lakes and streams, impeding seasonal migration especially in the fall. Fish may become stranded or unable to reach overwintering areas unless fall precipitation allows for temporary connectivity. Reduced mixing among local populations during migrations (particularly spawning) due to water body segregation can also result in a loss of genetic diversity, and increased interspecific interaction among populations utilizing the same habitat.

   The possibility of increased lake and pond connectivity developing through high water events or new drainage network creation through thermokarsting exists, but the likelihood of a net positive impact due to changes in surface water storage is low. Thermokarsting could indeed create new areas of freshwater habitat through formation of small lakes which could provide foraging habitat if these lakes remain connected to the drainage system during critical movement periods, but the certainty of this connectivity is difficult to predict.

II. Water Temperature and Chemistry

A handful of long-term aquatic monitoring datasets for Arctic watersheds already exist and should continue to be developed in order to investigate how changes in water temperature, chemistry, and quality influence fish movement patterns and population connections, as well as how primary and secondary productivity may change as a result of climate change. Investigations to monitor changes in seasonal temperature regimes and in the optimal thermal and chemical ranges for fish populations over time and space should be pursued, specifically with the intent to understand how these changes influence fish population distribution, life history and reproductive success. The magnitude of change in ecosystem productivity and biomass will likely depend on local conditions and population tolerances.

1) Higher stream and lake temperatures during a longer summer season may increase primary productivity, resulting in increased summer food availability. Increases in fish productivity, growth rates, and age at maturity will likely be a direct result. Increased productivity in nearshore areas may also aid success of anadromous species. However, for some species, increased water temperatures may result in increased physiological stress with a corresponding reduction in individual productivity or increasing susceptibility to parasites or diseases. Direct mortality as a result of extreme warm water temperatures is also possible. Temperature-related shifts in the timing of peak prey abundance will influence fish behavior and possibly production. Behavioral adaptations to increased water temperatures may include shifts in habitat use, range expansion due to changes in season length, changes in migration patterns or timing, or changes in feeding habits.

2) During winter, primary productivity is restricted, prey availability for piscivorous fish may be limited or absent, and ice formation and reduction of flow can reduce usable habitat by as much as 90%. Winter, therefore, is considered the critical period for success of freshwater Arctic fish. Warmer air temperatures are anticipated to result in earlier breakup and shorter winters, increasing overwinter survival rates. Additionally, if maximum ice thickness diminishes due to warmer winter air temperatures, more overwintering habitat may become available for fish. Deeper snow would contribute to thinner winter ice cover by because of increased insulation. Reduced winter seasons should decrease the amount of time that overwintering fish rely on stored energy reserves, leading to increased winter survival and better body condition for spring-spawning populations such as arctic grayling. Under some circumstances, warmer winters winter could have negative effects on arctic-adapted species, such as increased metabolic rate during the winter starvation period, but only if cold water (0°C) refugia become unavailable.

3) Changes in water chemistry may influence fish both directly and indirectly, especially when coupled with changes in temperature regimes and prey abundance. A variety of water chemistry and prey abundance parameters would be appropriate to monitor, including: pH, dissolved oxygen, dissolved carbon and nitrogen, light levels, turbidity, alkalinity, chlorophyll-a levels, and zooplankton abundance.

Changes in water quality and chemistry may result in direct physiological stresses such as increased rates of parasite load, increased metabolic demands, or increased uptake of contaminants. Additionally, stress may be reflected in indirect adaptations such as shifts in habitat use, changes in migration patterns or timing, or changes in feeding habits.

III. Coastal Processes and Change in Sea Level

Estuarine and marine habitat work should be conducted with the recognition that while estuarine and marine waters are important for many species distribution, feeding and migration routes, processes in the marine habitat area are very different from processes in the freshwater environment and the two require different investigation plans. Many areas of the Alaskan Beaufort Sea coast are characterized by barrier islands that form shallow lagoon systems and by river deltas, both of which provide important fish habitat. Lagoon areas may be especially important as rearing areas for juveniles and the typically high productivity in these areas are important feeding grounds for anadromous fish. High river flow during spring runoff allows freshwater species to move freely within the coastal area for a brief period of dispersal and inter-drainage exchange. Many fish in the Arctic are anadromous (such as arctic cisco, broad and humpback whitefish, Dolly Varden, ninespine stickleback and salmon species) with migration occurring seasonally between marine areas for feeding, and freshwater drainages for spawning and/or overwintering. During summer and depending on prevailing winds, topography and nearshore currents, freshwater from North Slope rivers mix with coastal waters to produce a narrow nearshore band of relatively warm, brackish water. In addition to anadromous migrations, many individuals may also utilize more than one drainage within their lifespan, and move between river systems through the nearshore or offshore environment. During winter when freshwater input is scarce, isolated nearshore waters may become hypersaline and under-ice temperatures may reach -2° C or colder, rendering the habitat unsuitable for fish.

Projects should investigate how changes in sea level and associated temperature and salinity levels affect fish distribution. For example, increased seas levels and/or frequency of storms may result in increased salinity in estuarine areas, and the salinity changes in these areas may influence migration patterns or restrict/increase distributions of anadromous and freshwater fish. Expansion of saline wedges into freshwater rivers may also restrict migrating fish, barrier islands and river delta formation may be impacted by less summer sea ice, more frequent storms, and coastal erosion while increased lagoon areas may provide more habitat for migratory fish.

IV. Change in Glacial Input

Although glacial-fed systems are a minority of drainages across the North Slope, reduced glacial input is one of the more high-probability consequences of warming on stream flow regimes. Projects should look forward to predict how diminished glacier meltwater input will affect flow regimes, specifically with regard to connectivity of streams and deeper overwintering channels for seasonal distribution in the spring and fall months.

1) Reduced summer flow rates may affect summer freshwater resident species, especially when coupled with warmer water temperatures.
2) Decreased turbidity and sedimentation transport as a result of decreased glacial input may also affect fish populations adapted to glacier-fed rivers, especially distribution and feeding by visual predators.

V. Change in non-connected Lake Area

Changes in drainage and discharge may affect lake storage area. Warmer temperatures may result in more rapid shoreline erosion, draining nearshore lakes. Deepening or loss of permafrost may increase lake drainage rates, with an overall loss of surface ponds and tundra lakes. Although individual lake size is expected to increase through the process of lateral expansion, on a landscape scale, overall lake area may be reduced if there is also an increase in the frequency of lake drainage events. Overall, this is likely not as important to fish populations as other changes in hydrology and lake habitat. While erosion at lake edges may have a neutral or positive effect on fish habitat availability, it is not expected that these impacts will be as significant as the ability of fish to disperse into and out of lakes seasonally.

Terrestrial Mammals

Four seasons in the annual cycle of arctic mammals are: breakup, growing season, plant senescence, and snow season. In Arctic Alaska, conditions of snow and sub-0^0 C temperatures dominate the year (Fig. 3). Although snow can fall in any month, the snow season generally lasts for 8-9 months from September through May. Depth and distribution of snow is affected by local terrain (both micro and macro features), slope and aspect, and exposure to wind and vegetation type. For example, topographic breaks and riparian willows act as snow traps. Breakup is only a few short weeks, but is a time of rapid change. Snow melt and breakup of rivers and streams generally occurs in mid to late May. The growing season in arctic Alaska is short, but this is the critical time of year when mammals must regain body resources lost during pregnancy, lactation and the long snow season. High quality green vegetation available during the growing season provide resources needed for herbivores to fatten before the onset of another snow season. Senescence occurs after the peak of green up and maximum plant biomass in July and lasts until the return of snow. Plants generally lose their leaves by early to mid -August. Ponds, lakes and rivers freeze in September. The coldest temperatures of the year occur in January and February and maximum snow depth for the year occurs in April. The onset and length of snow and growing seasons are variable from year to year and also differ by geographic, terrain, and landcover.

Most mammals living in the Alaskan arctic remain in the region year-round, and therefore are greatly influenced by changes during the 8-9 month snow season. Climate projections from General Circulation Models (IPCC 2007) indicate that average annual air temperatures and precipitation are projected to rise in arctic Alaska. Most of the projected warming and increased precipitation is expected to occur during the snow season (Martin et al. 2009, p 21). Arctic mammals use several strategies to survive the long snow season: dormancy in winter dens, living under insulating snow, migrating to more hospitable habitats, or remaining active on the snow-covered ground.

Figures 4 A-D show examples of how biophysical processes are important to some mammals with various life history strategies, categorized by season. The positive or negative effects of climate related changes in biophysical variables on biological systems accumulate across season to yield the net annual effect of climate on particular species of interest. Climate effects on biophysical variables and the implications for species of interest may be additive or compensatory among seasons. Net effects of climate may be evaluated only by considering the cumulative effects across all seasons. The cyclical form of the diagrams (Figures 3, 4A-D) is intended to illustrate the interdependencies of seasonal effects. The diagrams do not, however, purport to represent the complex web of interacting influences on habitat attributes important to mammals. For example, both temperature and snow can affect season lengths, soil characteristics, and plant growth; plant growth can directly affect reproduction of herbivores that in turn affects the availability of prey to predators. A comprehensive set of conceptual models representing all such relationships and feedbacks was beyond the scope of this effort.

Understanding changes in biophysical processes that may affect arctic mammals is essential to understand how these mammals are likely to be affected by climate change. To prioritize which of the biophysical processes shown in Fig. 3 should be measured, we qualitatively evaluated possible effects of changing processes on food, shelter, reproduction, risk of death, and energy balance for 26 species of terrestrial arctic mammals including 5 shrews, 8 rodents, 1 hare, 6 weasels/foxes/wolves, 2 bears, and 4 ungulates in different seasons. Effects were judged to be positive, negative, or in an unknown direction, or no effect was expected. The highest priority was given to those processes that were likely to affect the *most life history elements for the most species*.

Results of this evaluation are shown in Table 6. The length of the snow season and changes in snow characteristics are likely to affect two or more life history elements of all 26 arctic mammals. The implications of warmer temperatures on growing season length and vegetation biomass are also likely to affect two or more life history elements of all arctic mammals but polar bears.

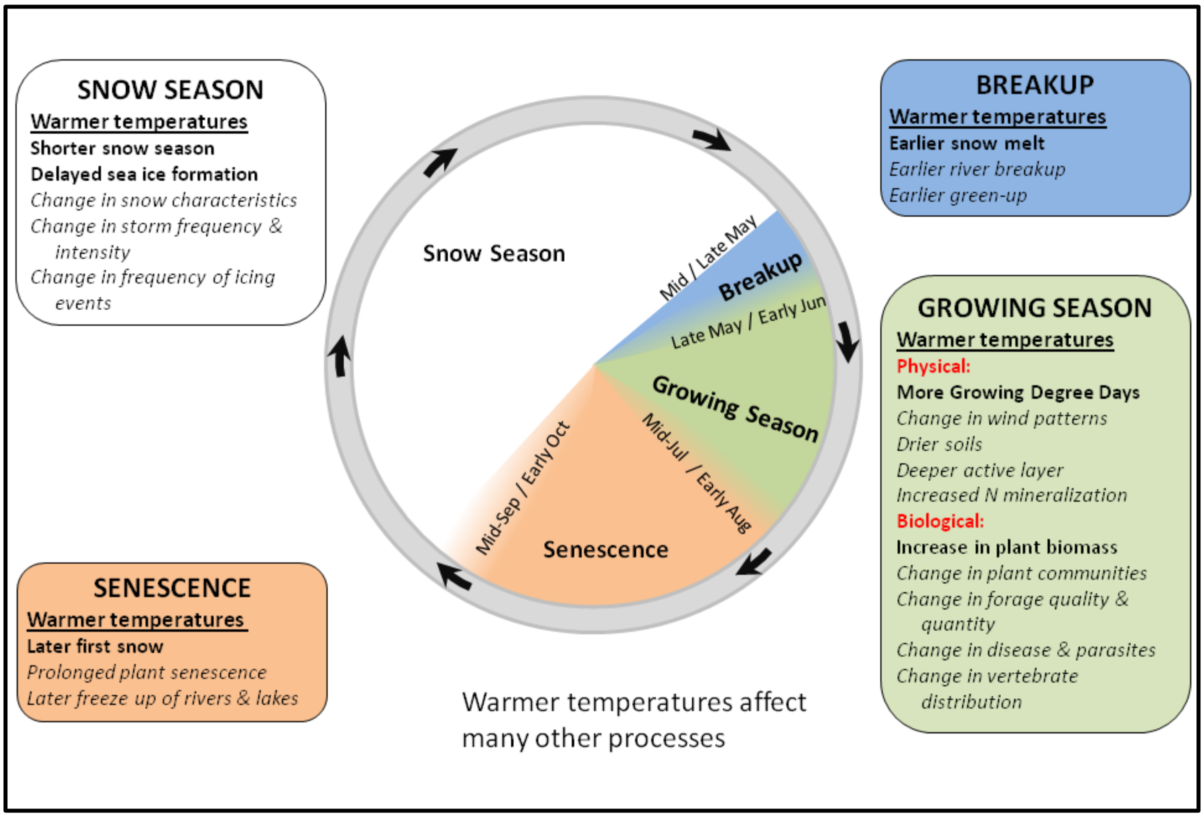

Figure 3. Possible effects of climate change on biophysical processes seasonally important to arctic mammals. Season definitions: end of Snow Season and onset of Breakup = first date in spring that median snow cover falls below 50% which typically corresponds to the date when median Normalized Difference Vegetation Index (NDVI) first exceeds zero; end of Breakup and onset of Growing Season = first date that median NDVI >0.10, using Global Inventory Modeling + Mapping Studies (GIMMS) data (about 0.08 for Moderate Resolution Imaging Spectroradiometer (MODIS) data) , typically corresponding to 0% snow cover; end of Growing Season and onset of Senescence = date when NDVI reaches the maximum value for the year; end of Senescence and onset of Snow Season = first date in fall that median snow cover exceeds 50%, which typically corresponds to the date when median NDVI first falls to zero.

Figures 4A-D depict some examples of possible effects on arctic mammals due to climate change on seasonally important processes. Main topics in **Boldface** type refer to the biophysical process identified in Fig. 1. First subtopics, numbered, are possible effects of biophysical processes. Second subtopics are possible effects on life history elements, such as reproduction and energy balance. Each second subtopic is associated with a sign: "- " signifies a negative effect, "+" signifies a positive effect, "**?**" signifies an effect with direction unknown. Topics/subtopics in *italics* refer to effects that are conjectured; topics in non-italics refer to effects documented in scientific literature. Season duration proportional to size of "pie slices," with colors corresponding to the accompanying sidebar boxes.

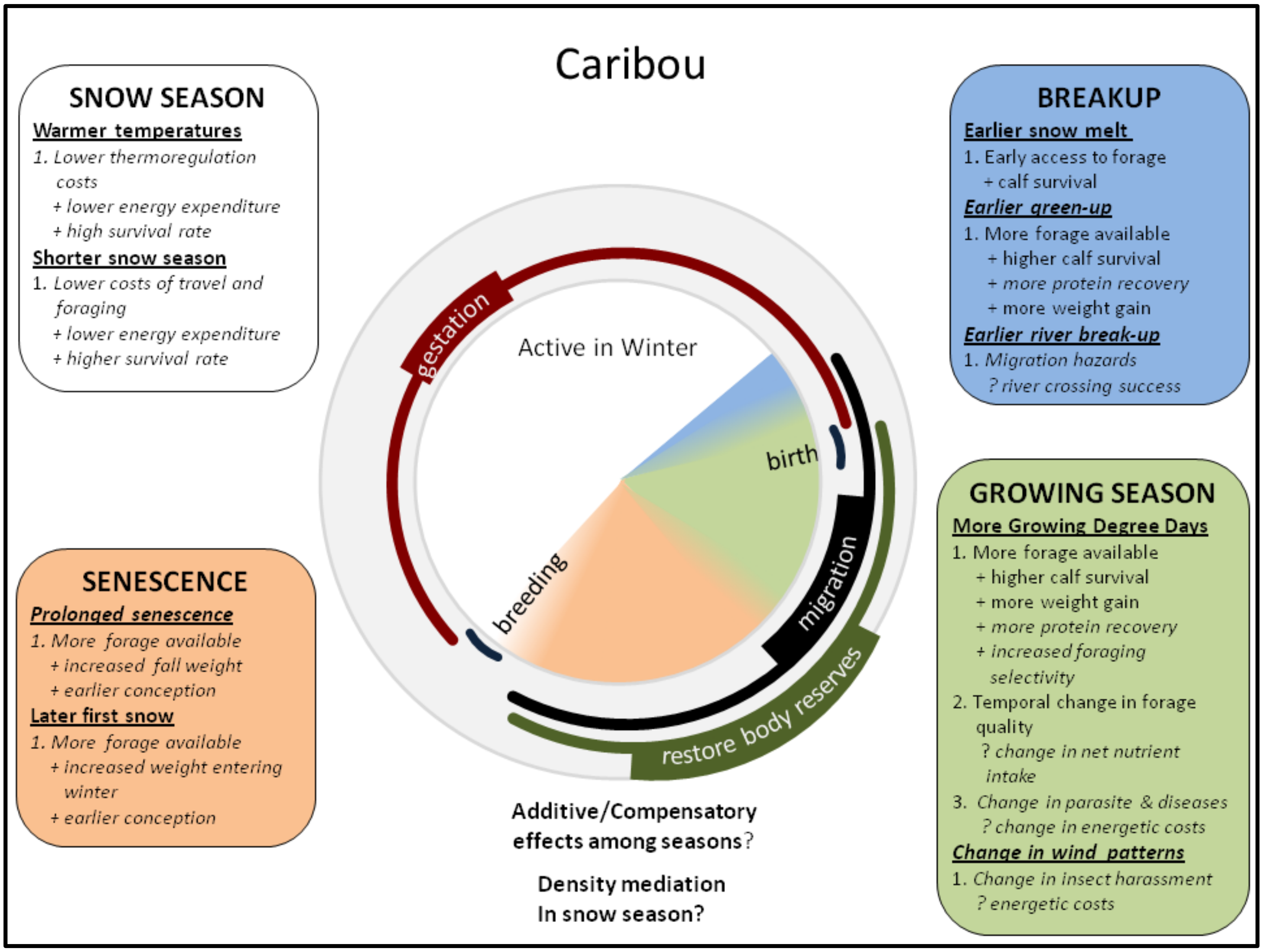

Figure 4A. Caribou: large plant-eating ungulate, active in the snow season, migrates between calving, summer and winter areas, breeds in late October or early November, gives birth in early June after 7 month gestation, regains body reserves during the growing season, weans its single calf before the snow season .

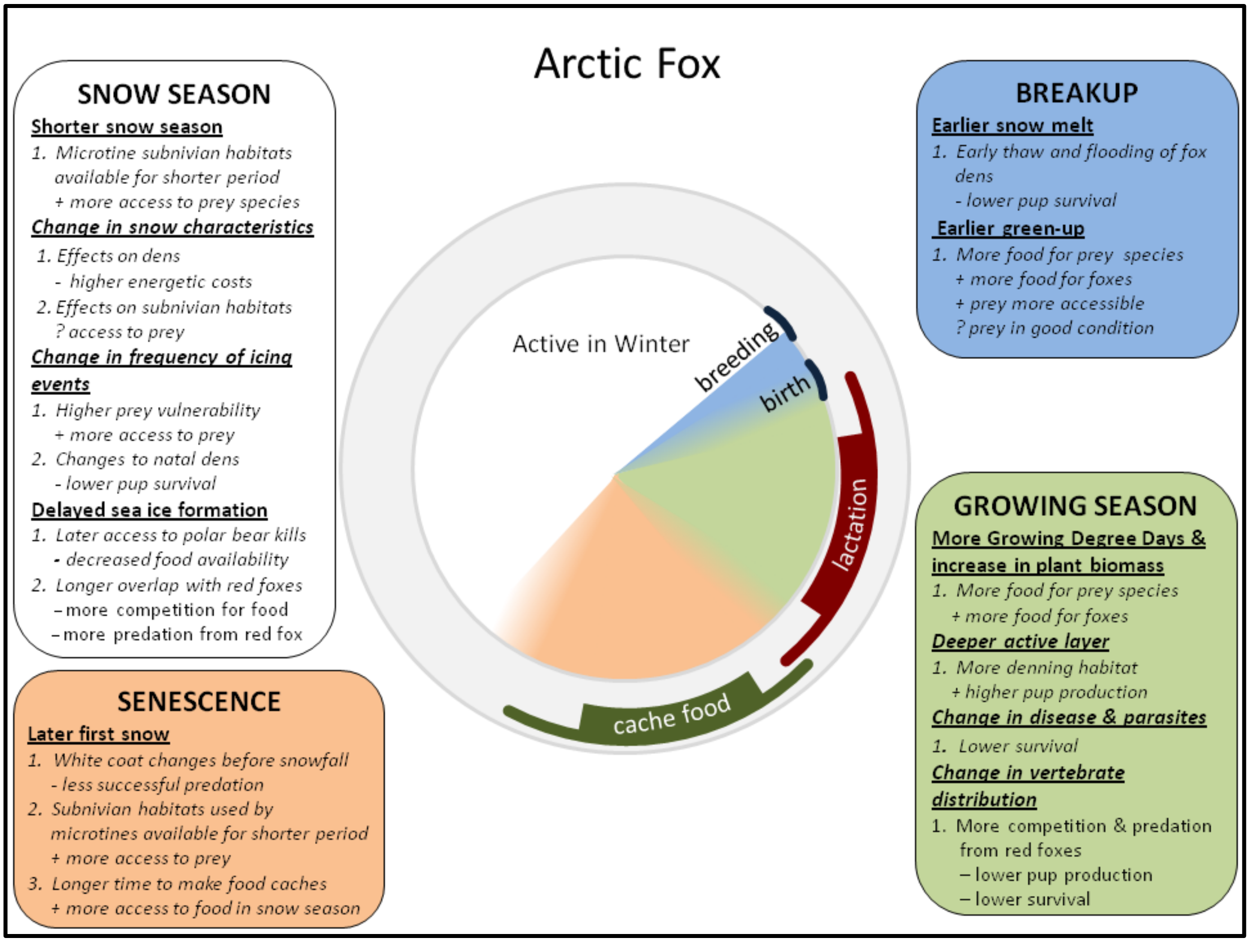

Figure 4B. Arctic fox: medium-sized carnivore, active in the snow season, breeds in March, gives birth in May after a gestation about 7 weeks, weans pups in 8-10 weeks, makes food caches, turns white by the onset of the snow season.

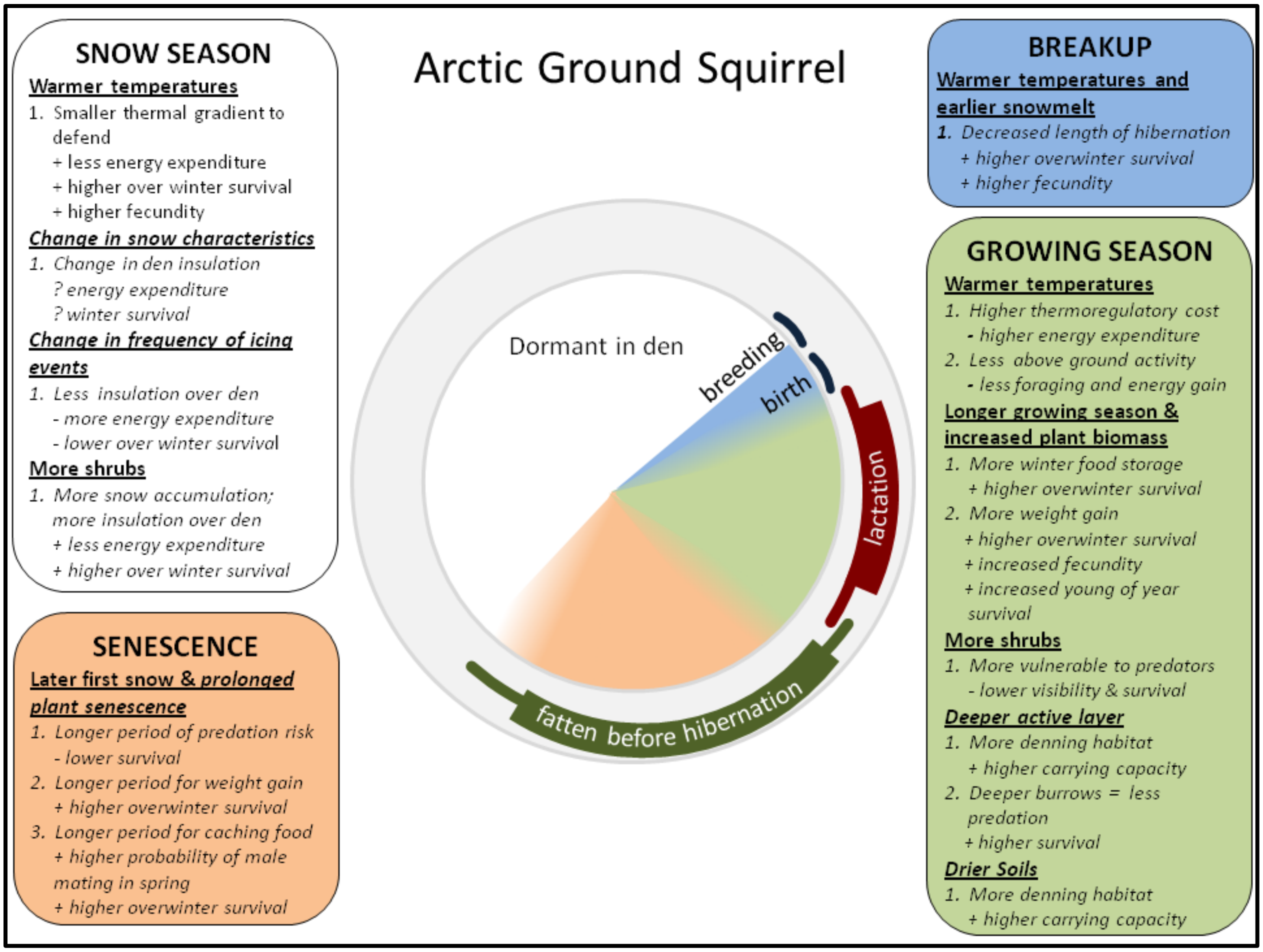

Figure 4C. Arctic ground squirrel: medium sized plant-eating rodent, hibernates during snow season, dormant in den for 7 months, reproduce once per year in late May-early June after gestation of about 3 weeks, weans pups at 6-8 weeks, increases body mass during the growing and senescence seasons, store food used in the den during pregnancy and early lactation.

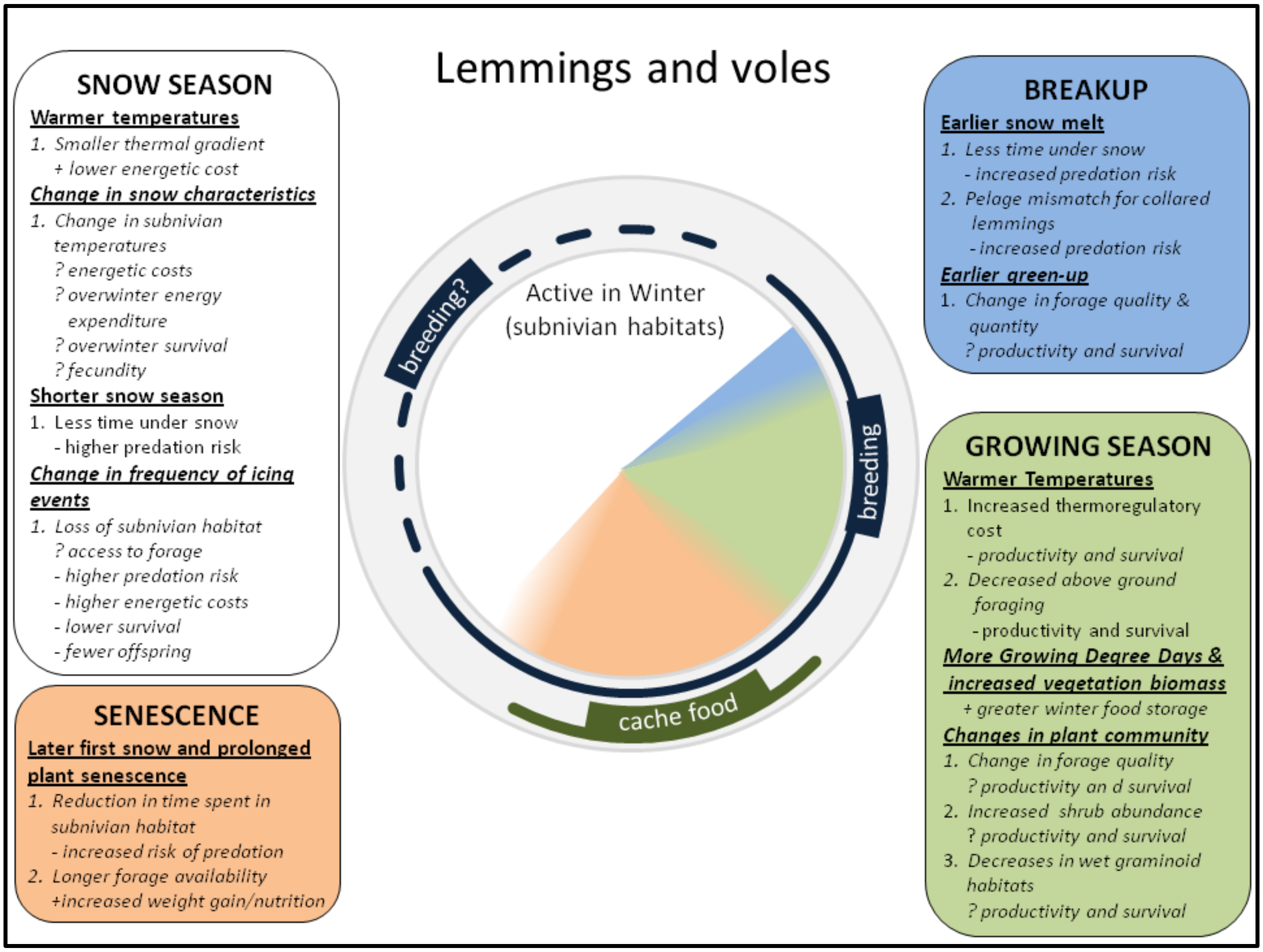

Figure 4D. Lemmings and voles: small plant-eating rodents, active in snow season, beneath the snow (subnivian), can reproduce 2 -3 times per year after gestation of about 3 weeks, wean at 2-3 weeks. Most species store food used during the snow season. Collared lemmings increase body mass and turns white before onset of snow season.

Table 6. Climate-related biophysical processes most influential mammals and monitoring /modeling activities or products that would help develop our understanding of the relationships among climate drives, habitat change, and species effects.

BIOPHYSICAL PROCESSES – MAMMALS	*What Species or Species Groups May Be Affected?*	*What biophysical parameters to measure/model?*
Shorter Snow Duration		
Earlier end of snow season	lemmings + voles, shrews, squirrels, bears, ungulates, hares, porcupines; weasels, foxes + wolves	• Estimated snow season onset and end for the entire domain, at 250-m to 1-km resolution. Retrospecitve analysis and annually updated gridded data set from remote sensing and modeling.
Later onset of snow season		
Change in Snow Pack Characteristics		
Snow depth	ungulates, foxes + wolves, weasels, hares, porcupines; lemmings + voles shrews	• Install and maintain adequate weather station network. • Strategic *in-situ* snow transect data collection to verify snow models and as source for assimilation into models. • Produce gridded data sets with modeled snow pack characteristics (*retrospective and current-year*) at moderate resolution (1 –km) for entire domain; higher resolutions data sets for intensive study sites. • Modeled *projections* of snow pack characteristics at moderate/coarse scales dictated by the native resolution of climate models. • Develop logical and data-based criteria for identifying minimum amount of rain-on-snow that can be reliably detected and/or relevant to wildlife species.
Snow density		
Incidence of icing events		
Warmer air temperatures		
Direct physiological influence	ungulates, lemmings+ voles, squirrels, hares, porcupines, grizzly bears, weasels, foxes + wolves	• Install and maintain adequate weather station network • Gridded data over entire domain at moderate spatial resolution (1-km or better) with modeled daily temperature data (e.g. mean, median, low, high). • Gridded data at moderate spatial resolution representing modeled growing degree days.
Indirect effect on availability of food and cover		

BIOPHYSICAL PROCESSES – MAMMALS	*What Species or Species Groups May Be Affected?*	*What biophysical parameters to measure/model?*
Longer Growing Season		
Earlier green-up	ungulates, lemmings + voles, squirrels, hares, porcupines, grizzly bears, weasels, foxes + wolves	• Assemble retrospective NDVI data with date-stamped pixel values at finest spatial and temporal scale practical for the entire LCC domain. • Develop retrospective datasets of greenness onset and progression at finest spatial and temporal scales practical. • Ongoing updates and dissemination of gridded NDVI data. • Establish calibration algorithms among AVHRR platforms and MODIS at 1-km resolution to facilitate transition to the newer MODIS technology. • Review literature and extract, or explicitly project, future changes in growing season length and validate with ongoing data collections. • Develop/compile a uniform Arctic LCC wide landcover class map with quantitatively estimated accuracy; • Establish relationships among existing landcover maps (i.e. pixel-level correspondence and proportional composition of land blocks of relevant size. • Develop/evaluate the ability to upscale 30m landcover class pixels to larger remote sensing pixels. • Establish relationships between landcover classes and NDVI dynamics at finest spatial and temporal scales practical.
Prolonged plant senescence		
Vegetation Change		
Increased Vegetation Biomass	ungulates, lemmings +voles, squirrels, hares, porcupines, grizzly bears, weasels, foxes + wolves	• All items in Section III relevant to this issue. • Test for trends in date of maximum NDVI at the finest spatial and temporal scales practical, by landcover class.

BIRDS

Introduction

The Bird Sub-group began its discussion by considering the conceptual models developed in the WildREACH report (WildREACH Figures 5.3 - 5.6), describing potential climate change effects on bird habitat. These models focused on water surface availability, coastal processes, vegetation, and invertebrates as mediators of climate impacts. After identifying changes to the models, and correcting omissions, group members selected and ranked the most significant (no greater than ten) biophysical processes thought to affect broad assemblages of arctic birds. From that list, the group came to consensus on six broad categories of effects, as outlined in Table 7.

Conceptual Models of Habitat Change

Four revised models are presented (Figures 1 - 4) depicting hypothesized effects of increased temperature and altered precipitation regimes on bird habitat, and groups of birds. Almost two-thirds of the species regularly found within the Alaska portion of the Arctic LCC are associated with freshwater or coastal aquatic and wetland habitats, and this is reflected in the focus of the first two (Figures 1 and 2) models. Food resources and habitat structure are addressed in the remaining two models, which deal with invertebrate prey and vegetation. The reasoning that informs each model is described below each figure, in brief (text is keyed to numbered tags embedded in the figures).

Other Climate Effects

Some potentially influential climate-related effects were not captured by the conceptual models of habitat change. These include some direct effects of temperature and weather, and indirect effects mediated through interspecific interactions.

- Warmer air temperatures are expected to advance snow melt. Snow cover that is present when migratory birds arrive is thought to influence density and distribution, and persistent snow cover during the nesting season is thought to limit reproductive effort and success. Earlier snow melt could have a mitigating effect on these current constraints.
- Inclement weather during the breeding season can negatively affect nest success, juvenile growth, and/or juvenile survival. The potential for increased "storminess" during the Arctic summer is highly uncertain.
- Increased competitive interactions with bird species expanding their range northward are anticipated, although the timeline and degree of competition is highly uncertain.
- Predation pressure may change with changes in relative abundance of predators. For example, it has been hypothesized that red foxes may be expanding their range at the expense of arctic foxes. Also, rodent population cycles may become less pronounced, which could have far-reaching effects on inter-annual variation in the intensity of predation on birds, as well as the abundance of predators.

- Prevalence of pathogens, including invertebrates, viruses, and bacteria, would change along with changes in distribution and abundance of host species, and relaxation of any constraints on parasites imposed by cold temperatures.

These topics are included in the summary table. The complex of interactions between birds, lemmings, and their predators fell outside the guidelines to include only those biotic habitat components in lower trophic levels, but an exception was made because of the importance of lemmings as a keystone species, and current literature to suggest that climate change may be influencing rodent population cycles in the artic.

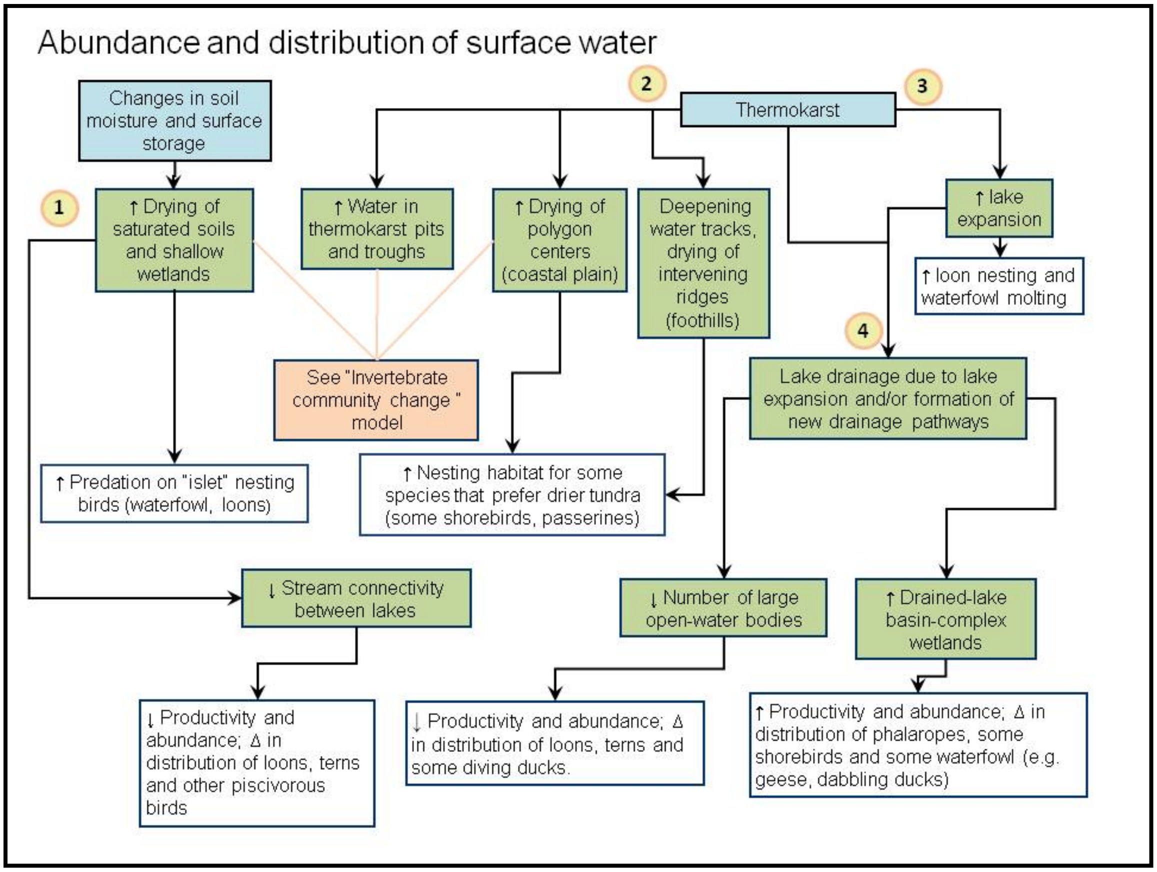

Figure 1. Influence of changing surface water availability and distribution on birds. Blue boxes indicate physical drivers, green indicates habitat response, and white indicates bird response.

Abundance and Distribution of Surface Water – Warming is hypothesized, (1), to affect soil moisture and surface storage, *via* deepening of the active layer and increasingly negative water balance whereby summer precipitation is insufficient to counteract increased evapotranspiration resulting from longer, warmer, summers. This could result in drying of shallow, precipitation-dominated wetlands (e.g., basins of low-center polygons). If a drying regime affects the connectivity of lakes and streams, piscivorous birds may be indirectly affected (see "Fish"). Thermokarst processes may result in a fine-scaled redistribution of surface water, increasing the moisture gradient between wet troughs and drier intervening ground, (2), and potentially basin-scale drying. Thermokarst can increase individual lake area (3) through the process of lateral expansion, but this could ultimately increase the rate of lake drainage (4) and decrease lake area on the landscape scale. Lake drainage could also increase if drainage networks are created and/or deepened by melting ice wedges. Although a summer drying regime is not a certainty, should it occur it would affect both plant and invertebrate communities (see below).

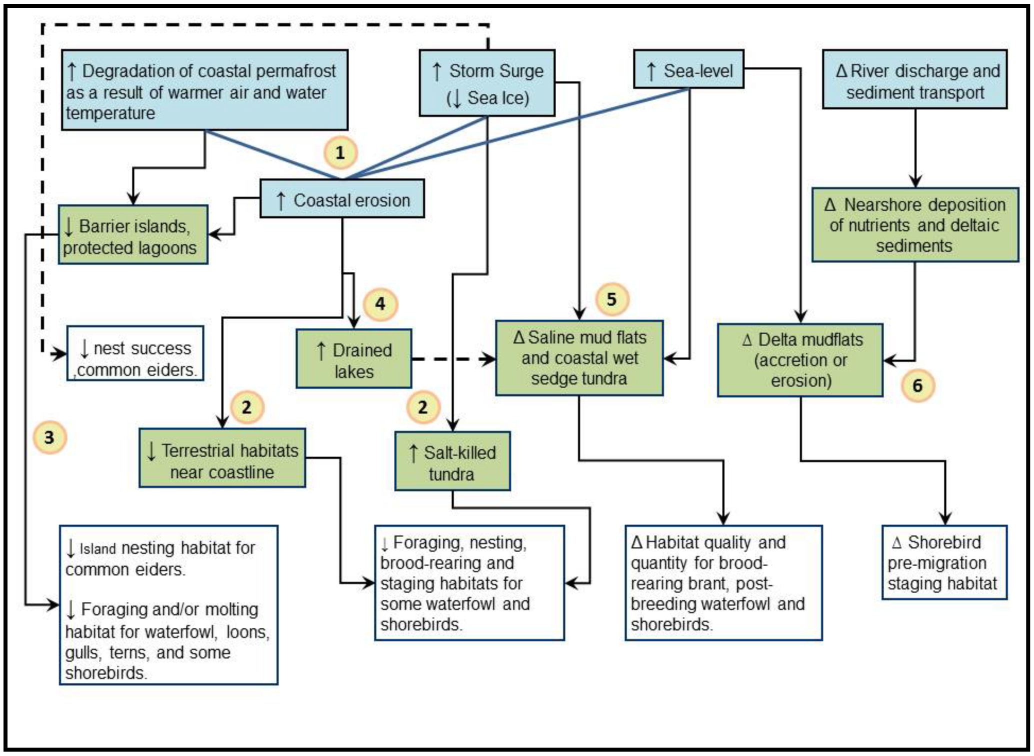

Figure 2. Influence of climate-related changes in coastal processes on birds. Color codes as in Figure 1.

Coastal Processes – Increasing numbers of high-energy storms during the lengthening summer ice-free period results in higher rates of coastal erosion and inundation of low-lying coastal areas, (1). One outcome is outright loss of terrestrial habitat and reduction in productivity in "salt-killed" zones, (2). Of greater potential significance to birds, though speculative, would be degradation of the barrier island/lagoon systems, (3). Coastal erosion will increase the incidence of lake drainage, for those lakes breached by a retreating coast line, (4). Availability of coastal wet sedge tundra, a rare habitat preferred by brant and used by many water birds, will be affected by coastal erosion and inundation, (5). Delta mud flat systems may be impaired by rising sea levels and erosion, (6). In some river systems, sediment transport may increase as a result of permafrost degradation, compensating for sea level rise; in glacial-dominated systems, however, reduced peak flows may result in diminished deposition rates on deltas.

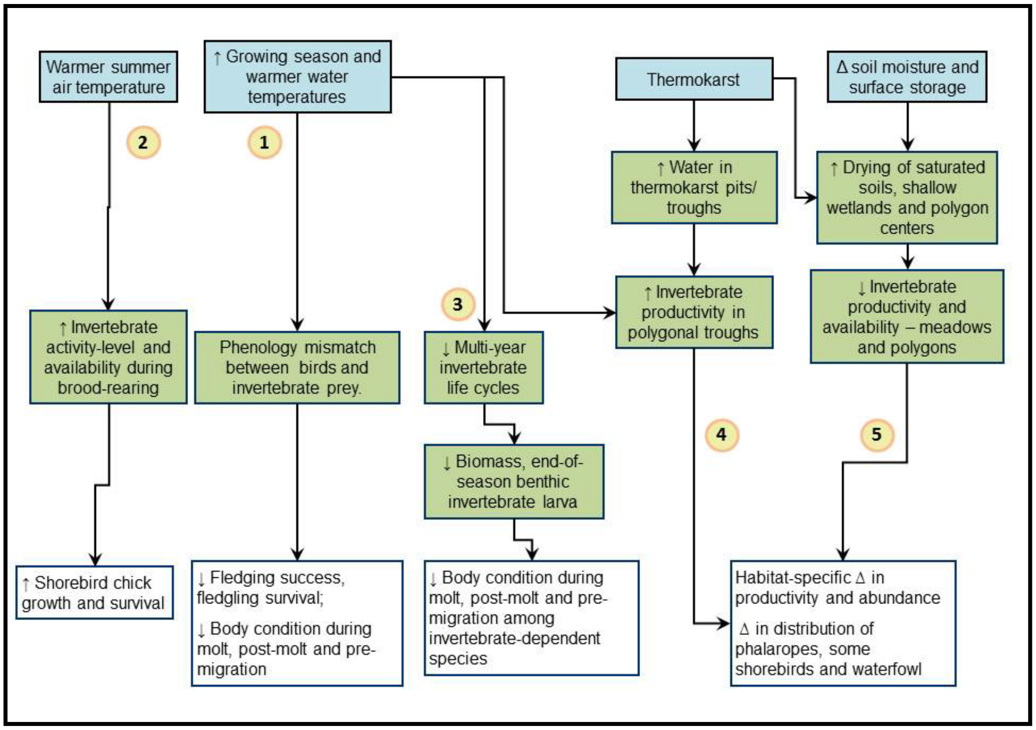

Figure 3. Influence of changing invertebrate prey availability on birds. Color codes as in Figure 1.

Invertebrate prey – The majority of bird species (> 75%) in northern Alaska are at least partially dependent on invertebrate prey. Warming soil and water temperatures could benefit birds through increased secondary productivity, but the temporal and spatial occurrence of invertebrate prey could also change in ways that are detrimental to birds. Earlier snow melt and green-up could result in asynchronies in peak availability of prey items and peak demand, especially critical during the rearing period for juveniles. The severity of this effect may depend on the ability of birds to adjust their migration and breeding schedules to match phenology on the breeding grounds, (1). On the other hand, there is evidence to suggest that slower chick growth rates are related primarily to cold weather events that result in short-term reductions in invertebrate activity and availability, rather than the absolute abundance of prey, and such events may occur less frequently under a warmer climate regime (2). Over the longer term, a shift from the predominant insect multi-year life cycles toward single-year life cycles could reduce end-of-season standing biomass despite high productivity, (3). Redistribution of surface water and changes in soil moisture will presumably influence invertebrate community composition and abundance. Wetter microsites should maintain high levels of productivity, (4), while drying microsites may experience reductions (5). The net effect is highly uncertain, both with respect to the nature of hydrologic change and invertebrate community response.

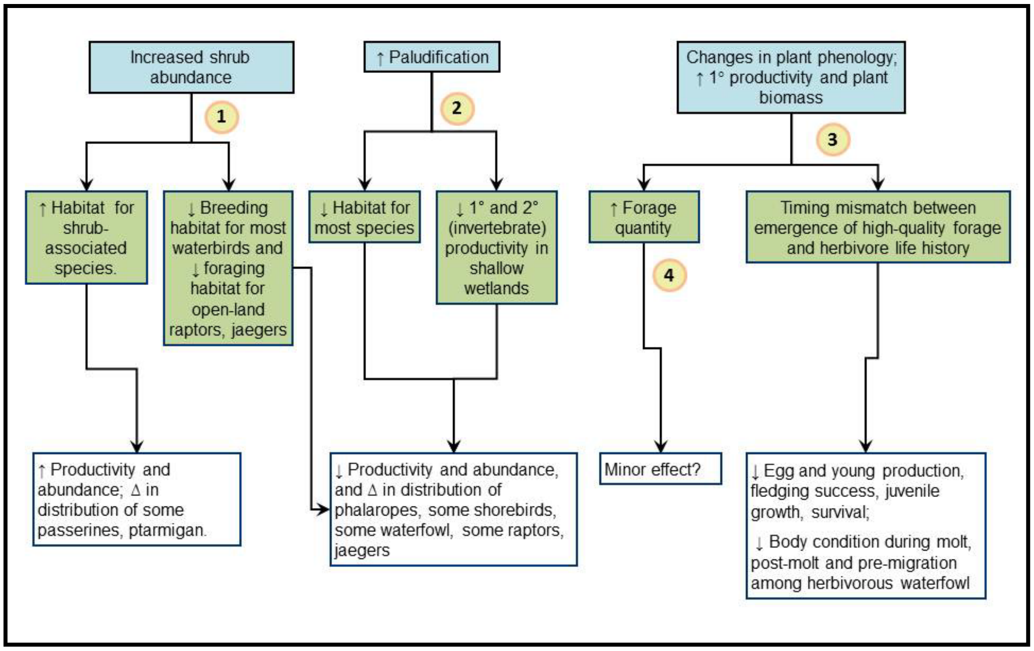

Figure 4. Influence of changing vegetation structure, community composition, and phenology on birds. Color codes as in Figure 1.

Vegetation – Vegetation change is important from multiple perspectives: nutrition for herbivorous species, influence of vegetation structure on bird habitat selection, and the role of plants in trophic systems. A decadal-scale trend of increased shrubbiness, (1), is documented in some landscape settings in northern Alaska, and the expectation that warming will promote future shrub increase is supported by experimental evidence. Forecasting the effect on birds, however, depends on developing accurate forecasts of spatially-varying rates of change. The hypothesis that sedge-dominated wetlands may become increasingly dominated by *Sphagnum* moss (paludification), (2), with an associated drop in ecosystem productivity, is based on “space-for-time” substitution comparing the vegetation of northern Alaska with that of western and interior Alaska wetlands, rather than longitudinal observations of vegetation change. If widespread paludification occurs, it will likely progress slowly over a period of centuries or longer. Seasonal abundance of high-quality forage, relative to the breeding schedules of herbivorous species (e.g., geese) could result in reduced fecundity, juvenile growth, and survival (3). The association between warmer temperatures and increased primary productivity could result in greater food abundance for some species (4), such as willow browse for ptarmigan.

Summary Table

Table 7 lists six climate-associated biophysical processes/topics, considered to be of top priority for monitoring and research. These, listed in order of priority, are:

I. Changes in surface water storage and soil moisture on the Arctic Coastal Plain
II. Changes in phenology and composition of plant and invertebrate communities
III. Changes in coastal zone habitat quantity and quality
IV. Changes in the frequency of extreme weather events
V. Interspecific interactions
VI. Changes in stream flow regime, nutrient flux, sediment transport/deposition

Within each of these topics, sub-topics are listed, along with a description of the species or species groups likely to be affected. These should be considered testable hypotheses of climate-related effects. The 3rd column lists, with vary degrees of specificity, parameters that could be measured in order to clarify whether the hypothesized effects are operating as predicted. Group members acknowledged that interspecific interactions are extremely important, but recognized that understanding these as a function of climate change adds a level of complexity requiring understanding of both physical process change and biotic responses. Our current understanding of interspecific interactions may not be adequate to formulate hypotheses and devise monitoring to assess effects of climate change on aspects such as predator-prey dynamics, pathogen-host relationships, and interspecific competition.

It was noted that in many cases, the putative relationships between bird populations, distribution, or habitat use are poorly known. Among the topics that require further study are:

- Breeding bird community composition as a function of moisture gradient
- Influence of inclement weather on breeding success
- Bird use of lagoons and estuarine areas as a function of prey distribution
- Abundance and distribution as a function of varying soil and water salinity

A full exposition of bird –related data needed to test the conceptual models was beyond the scope of this exercise.

Table 7. Climate-related biophysical processes most influential for birds and monitoring /modeling activities or products that would help develop our understanding of the relationships among climate drives, habitat change, and species effects.

BIOPHYSICAL PROCESSES – BIRDS	*What Species or Species Groups Will Be Affected?*	*What biophysical parameters to measure/model?*
I. Changes in surface water storage and soil moisture on the Arctic Coastal Plain		
Longer/warmer summers and deeper active layer may result in net drying of saturated soils and shallow wetlands.	Widespread -- most species associated with wetlands. Particularly relevant to shorebirds, waterfowl, and some other waterbirds Species nesting in wet/emergent tundra (phalaropes, long-billed dowitcher) would lose nesting habitat, but species that utilize drier tundra may gain habitat	• In-situ measurements of soil moisture, and all components of water balance (precipitation, evapotranspiration, storage, runoff) • Remotely sensed surface water cover within and among seasons. • Active layer depth
New drainage networks may result in accelerated lake drainage and conversion to drained basins; may result in increased number, depth, and connectivity of polygon troughs, and drying of intervening terrain.	Widespread -- most species associated with wetlands. Particularly relevant to shorebirds and waterfowl – some species would benefit while others would be negatively impacted e.g. Loons would be lose habitat via lake drainage while other bird (shorebirds, waterfowl) would gain new nesting/forage habitat.	• Remotely sensed monitoring of lake change, ecoregion-wide or select areas • Remotely sensed monitoring of ice-wedge degradation in select areas • In-situ measurement of tundra drying during the nesting season & pond water level / temperature monitoring
II. Phenology and species composition		
Changes in phenology and composition of plant and invertebrate communities	Widespread – all migratory species potentially affected by trophic mismatch. Most species feed on invertebrates; geese and ptarmigan are herbivores and important to harvest.	

BIOPHYSICAL PROCESSES – BIRDS	*What Species or Species Groups Will Be Affected?*	*What biophysical parameters to measure/model?*
Earlier spring melt, and green-up changes timing of quantity/quality of forage plants.	Waterfowl, frugivorous shorebirds, ptarmigan, some passerines	• Estimated snow season onset and end for the entire domain, at highest practical resolution. Annually updated gridded data set from remote sensing and modeling. • Develop retrospective datasets of greenness onset and progression at finest spatial and temporal scales practical. • Arrival of migratory birds onto breeding grounds • Monitoring of river breakup • Measure snowmelt / snow cover recession on ground at select sites.
Earlier spring melt, changes timing of insect emergence/ arthropod activity levels	Shorebirds, passerines, waterfowl, waterbirds,	• Insect emergence (field measurement) & activity levels • Change in invertebrate annual and inter-annual life cycle • Nest initiation and date of hatch for nesting birds
Warmer and longer growing seasons result in changes to plant communities, including shrub encroachment	Shorebirds, passerines, ptarmigan, raptors	• Ground-based vegetation plots, remote sensing and classification of vegetation communities • Establish relationships between landcover classes and NDVI dynamics at finest spatial and temporal scales practical
Warmer and longer summers result in shifts in abundance/biomass/size distribution of aquatic and semi-aquatic invertebrate prey	Shorebirds, passerines, waterbirds	• Numbers and biomass of aquatic invertebrates, stratified sampling by habitat.

BIOPHYSICAL PROCESSES – BIRDS	*What Species or Species Groups Will Be Affected?*	*What biophysical parameters to measure/model?*
III. Changes in coastal zone habitat availability and quality.		
Increased coastal erosion leads to loss of terrestrial habitat and lake drainage and conversion to saline habitat.	Yellow-billed and Pacific loons, tundra swans, long-tailed ducks, and other species that nest and molt on coastal thaw lakes. Spectacled eiders, northern pintail, red-throated loons, and other species that nest and rear young in ponds and emergent wetlands in coastal areas. Brant and snow geese that used coastal sedge meadows for brood rearing and molting. Phalarope spp., semipalmated sandpipers, dunlin, ruddy turnstone, and other shorebirds that nest and year young in coastal wet and moist sedge tundra.	• Aerial and satellite imagery, and ground measurement of rates of coastal erosion. Correlation between erosion rates, shoreline aspect and exposure, and occurrence of storm surges. • Rate at which coastal thaw lakes and emergent wetlands are drained due to coastal erosion, as well as associated hydrologic shifts. • Changes in salinity of coastal thaw lakes and wetlands due to marine inundation during storm surges. • Change in plant species composition and salinity of coastal sedge meadows, especially in low-lying areas of special importance to birds such as Teshekpuk Lake and Colville River Delta
More frequent inundation of terrestrial habitat accompanied by salinization	Black brant and snow geese that use coastal areas as nesting, brood rearing, or molting sites. Ruddy turnstones, semipalmated sandpipers, dunlin, phalarope spp., other shorebirds, and Lapland longspur that nest and rear young in coastal wet and moist sedge tundra	• High resolution digital elevation data for coastal areas and accompanying measures of sea level and tidal range, tied to a common datum. • Frequency, timing, and inland extent of storm surges. • Measures of sediment accretion and shallow subsidence in coastal deltas to assess whether change in surface elevation will keep pace with sea level rise. • Change in salinity of coastal wetlands and substrates, and accompanying change in plant communities, including increased area of salt-tolerant communities and increased "salt-kill" within intolerant communities

BIOPHYSICAL PROCESSES – BIRDS	*What Species or Species Groups Will Be Affected?*	*What biophysical parameters to measure/model?*
Degradation of barrier islands leads to change in temperature and salinity of coastal lagoons	Black brant, semipalmated sandpipers, phalarope spp., loon spp. that use lagoons and beaches as migration habitat. Long-tailed ducks, scoter spp., and greater scaup that molt in lagoons. Red-throated loons that use coastal lagoons as breeding season feeding areas, and all loon spp. that use lagoons for post-breeding habitat. Common eiders, black guillemots, arctic terns, glaucous gulls, and other species that nest on barrier islands.	• Change in areal extent of barrier islands, their shorelines, and distribution. • Rate of new sediment deposition versus sediment removal from barrier islands. Origin of sediments (marine vs. riverine) that are deposited on islands. • Correlation between storm surge events and changes in barrier island extent or distribution. • Examine relationships among temperature, salinity, and net primary productivity of lagoon waters. Determine if salinity, temperature, and productivity of near shore waters influences important forage species for birds (marine algae, marine grasses, benthic invertebrates, forage fish). • Changes in duration and timing of the ice-free period in coastal lagoons. • Assessment of how barrier islands influence near-shore currents to create areas of open water in spring, or affect nutrient and freshwater flux.

BIOPHYSICAL PROCESSES – BIRDS	*What Species or Species Groups Will Be Affected?*	*What biophysical parameters to measure/model?*
IV. Changes in the frequency of extreme weather events.		
Cold snaps and/or extreme precipitation events during nest initiation or brood-rearing result in increased egg/chick mortality	Widespread – all migratory species potentially affected	• Install and maintain adequate year-round weather station network • Gridded data over entire domain at moderate spatial resolution (1-km or better) with modeled daily temperature data (e.g. mean, median, low, high), wind, and precipitation. • Daily temperature, wind, and precipitation measurements over wide-scale (stratified by habitat and/or distance from coast)
Major storm surge results in egg/chick mortality for species nesting on barrier islands, other coastal lowlands.	Coastal species such as Common Eiders, Ruddy Turnstones, etc.	• Tidal stage monitoring on barrier islands and select coastal areas to measure high tide/flood events; use for model development. • Modeled inundation history for barrier islands and lowland coastal areas. • remote sensing measurements of coastal erosion
Winter icing events	Ptarmigan	• Gridded data depicting modeled freeze-thaw and rain-on-snow events
V. Interspecific interactions.		
Lemming population cycles and abundance change, affecting predation pressure on birds	Species that depend on lemmings as a primary food source (pomarine and long-tailed jaegers, snowy owl, other raptors?) Nesting bird species that cannot defend against predation (shorebirds, some waterfowl).	• Estimate lemming population trends (live trapping and winter nest counts) • Predator monitoring (see above).
Changes in exposure to pathogens	Resident, arctic-specialists likely most susceptible including ptarmigan and gyrfalcons; all birds likely susceptible to generalist pathogens like West Nile.	• Surveillance via tissue sampling and/or specimen collection and necropsy in likely highly susceptible species and secondarily, in broad sample of other bird groups. (field measurement)

BIOPHYSICAL PROCESSES – BIRDS	*What Species or Species Groups Will Be Affected?*	*What biophysical parameters to measure/model?*
Invasive or novel plant, invertebrate, and vertebrate species may degrade current systems	Uncertain, but potentially widespread across taxa.	• Regular monitoring of expected invasives and routes, including: ship ballast as shipping/harbors expand, highway corridors for plants, and presence/absence of vertebrate species.
VI. Changes in stream flow regime, nutrient flux, and sediment transport/deposition.		
If discharge increases, nearshore lagoons may become fresher and warmer, with indirect effects on nearshore food webs	Black brant, semipalmated sandpipers, phalarope spp, loon spp. that use lagoons and beaches as migration habitat. Long-tailed ducks, scoter spp, and greater scaup that molt in lagoons. Red-throated loons that use coastal lagoons as breeding season feeding areas, and all loon spp. that use lagoons for post-breeding habitat.	• Continue monitoring stream flow at existing stream gage stations on the North Slope. • Measure seasonal variation in inputs of freshwater and riverine sediments to lagoon systems. Measure effects of snow water equivalent on freshwater inputs to lagoons during breakup. • Examine effects of freshwater and sediment inputs, salinity, and temperature on nutrient levels and net primary productivity of lagoon waters.
If discharge increases, sediment delivery will also increase, perhaps enriching nearshore food webs, and changing structural characteristics of delta mud flats	Waterfowl, shorebirds, and passerines that nest and rear young on coastal deltas and use deltas as migration habitat.	• Measure rates of sediment accretion in coastal deltas. Assess relationships among timing of breakup, snow water equivalent, flooding extent, and sediment deposition in spring. Assess sediment accretion resulting from storm surges. • Assess seasonal and annual variation in sediment loads of rivers that also have stream gages. Assess relationships among stream flow, rainfall, glacial inputs, and sediment loads.

Appendix A. Climate Change and Marine Mammals

Observed and anticipated impacts of climate change in the Arctic, and in particular on the marine environment, are described in ACIA (2004). The anticipated impacts from climate change on Arctic marine ecosystems and their predicted impacts on marine mammals have been discussed and summarized in several key sources (Bluhm and Gradinger 2008, Hopcraft et al. 2008, Huntington and Moore 2008, Laidre et al. 2008, NSSI 2009, Holland-Bartels and Pierce 2011,). Key climate-related changes to the Arctic marine environment, both observed and hypothesized trends, are summarized in Table A-1.

Many of the biological repercussions from a changing marine environment may not seem immediately apparent or are subject to debate (Parry et al. 2007). Nevertheless, we may surmise some of the direct and indirect effects that climate may have on Arctic marine mammals based on their general habitat requirements and associations. The generalized habitat associations of Arctic marine mammals (Table A-2) were summarized by Laidre et al. (2008). Physical habitat characteristics include features, which vary in importance by species, such as shorefast ice, polynyas (persistent areas of open water), and multi-year pack ice. For example shorefast ice that freezes and abuts up to the coastline is important to and has been utilized during the winter months by both denning polar bears and ringed seals that carve out lairs (snow caves) over breathing holes, so any physical factor impacting this habitat may impact these species. The other component in the marine environment that influences habitat use is prey availability. Existing information on prey types and trophic levels are summarized by Bluhm and Gradinger (2008). Despite gaps, our knowledge of food webs is sufficient to form reasonable hypotheses regarding climate-related effects. For instance, walrus tend to feed on the shallow benthic invertebrates present on the Chukchi Sea floor, made easily accessible from resting platforms with the waning and drifting seasonal sea ice. These benthic communities benefit from nutrient input derived from the primary productivity of ice-associated algal and plankton communities that flourish in response to lengthening spring days. Change in seasonal ice cover could disrupt these relationships and result in diminished food resources for walrus.

Reduced sea ice cover is of particular importance to Arctic marine mammals. The trend of diminishing sea ice is projected to continue, with the possibility of a seasonally ice-free Arctic by the middle/end of this century (Stroeve et al. 2007, Stroeve et al. 2008, Perovich and Richter-Menge 2009, Wang and Overland 2009). It is expected that delayed freeze-up that extends the open-water season by one month by the end of the century. Other changes associated with reduced ice cover include increased wave amplitude, increased light presence in the water column, and warmer surface waters due to lengthened periods of open water. These types of persistent changes could have significant long-term effects. Arctic marine mammal species will most likely be affected both directly and indirectly by the changes associated with the loss of sea ice. Moore and Huntington (2008) suggest a conceptual model that describes negative effects for those species that rely on sea ice as a platform for hunting, resting, or rearing their young (e.g., polar bear, ringed seal), as well as positive effects for seasonally migrant species, e.g., gray whales or harbor seals (Figure A-1). Moore and Huntington (2008) differentiate anticipated changes among ice-obligate, ice-associated, and seasonally migrant species, and propose practical approaches to monitoring change (Table A-3).

Hopcraft et al. (2008) reviewed observed and expected impacts of climate change and recommended work on a wide range of research topics. Top priorities relevant to marine subsistence resources included:

- How will the dramatic change in ice (i.e., thick multi-year to thin first-year and reduced summer sea ice extent) impact the ecological components of the Beaufort and Chukchi Seas?
- How will increased anthropogenic activity such as increased vessel traffic and increased industrial activity due to longer periods of open water influence marine mammals? And, how will these changes be discernible from those changes caused by climate change?
- How will ocean acidification affect food webs?
- How will broad-scale circulation patterns change, and how will this affect local and overall productivity and physical chemistry?

Most of these questions are outside the current scope of the Arctic LCC, but some aspects could be the subject of collaboration between the Arctic LCC and marine-focused science initiatives.

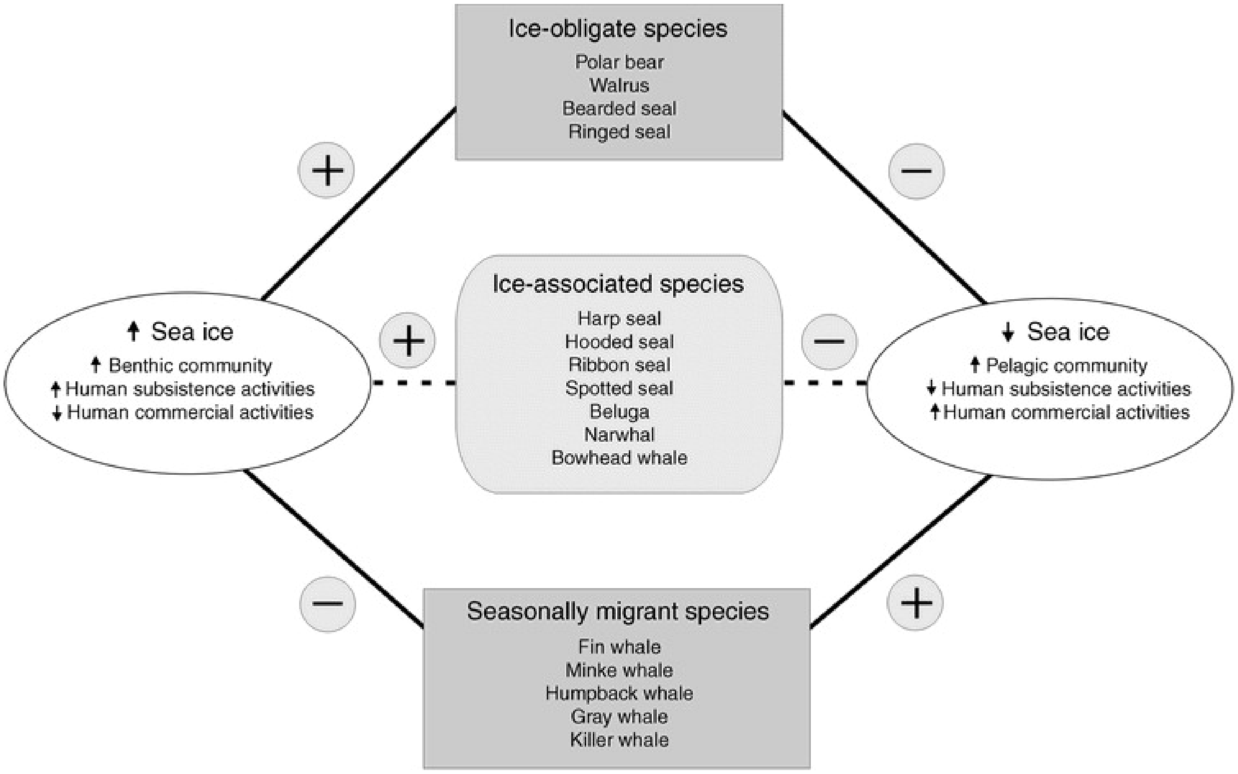

Figure A-1. A conceptual model of sea ice impacts on ice-obligate, ice-associated, and seasonally migrant marine mammal species: positive impacts are indicated by circled plus signs; negative impacts by circled minus signs. Dashed lines indicate uncertainty regarding potential impact of sea ice gain or loss for ice-associated species. Anticipated changes in benthic and pelagic community productivity are as presented in Bluhm and Gradinger (2008); anticipated change in human subsistence and commercial activities are as presented in Hovelsrud et al. (2008). Source: Moore and Huntington 2008.

Table A-1. Projected climate change impacts on marine mammal of the Beaufort and Chukchi seas.

Increased temperatures	increased temperatures, particularly in fall/winter warmer surface waters reduced sea ice cover reduced sea ice thickness
Increased precipitation	increased rain events in fall/winter - when sea ice forms reduced salinity of surface waters increased river run-off
Increased clouds/fog	less radiation available for photosynthesis
Storm occurrence	more wave action increased occurrence of fall/winter storms likely summer storminess - uncertain
Reduced sea ice	complete freeze-up delayed ~ 1 month mid century increased light in water column warmer surface waters more wave action changes in circulation
Sea level rise	Barrier Islands degrade?
Ocean circulation	changes in availability of nutrients changes in distribution of nutrients
Ocean acidification	increased CO2; lowers concentration of carbonate ions used by calcifying organisms, increasing their energy demands cold water absorbs more CO2 than warmer waters, resulting in undersaturation of buffering aragonite in the Arctic sooner than other ocean basins food web impacts - difficult to predict

Sources: Bluhm and Gradinger 2008, Hopcraft et al. 2008, Laidre et al. 2008, Moore and Huntington 2008, Holland-Bartels and Pierce 2011

Table A-2. Importance of physical and biotic Arctic habitat features for primary Arctic marine mammal species (X= used; XX= important, XXX =Critical). Source: Laidre et al. 2008.

Habitat	Beluga	Narwhal	Bowhead whale	Ringed seal	Bearded seal	Walrus	Polar bear	Harp seal	Hooded seal	Spotted seal	Ribbon seal
Physical features											
Shore-fast ice				XXX	X		XXX				
Loose annual pack ice	XXX	X	X	XX	XX	XX	XX	XX	XX	XX	XXX
Dense annual pack ice		XXX	XX	XX	XXX	XXX	XXX	XXX	XX	X	X
Multiyear pack ice	X			X	X	X	XX				
Shear zones/leads	XX	XXX	XX	X	XX	X	XX				
Polynyas	XXX		XX	X		XX					
Open water	XX	XX	XX	X		XX		XXX	XXX	XX	XX
Shallow water/ continental shelf	XXX		XXX	X	XX	XXX		XX		XX	XX
Shelf break	XX	XXX	X	X				X	XX		X
Deep ocean basins		XXX		X					XXX		X
Estuaries/lagoons/fjords	XXX	XXX		X						XXX	
Land haul-outs				X	X	XXX				XX	
Land denning areas							XXX				
Biotic features											
Macroplankton/nekton			XXX	XX						X	X
Macrobenthos	X		XX	X	XXX	XXX		X		X	X
Midwater fish (polar/ Arctic cod)	XXX	X		XXX	X			XXX	XX	XXX	XX
Benthic fish	X	XXX		X	XX				XXX	X	XX
Marine mammals as prey						X	XXX				
Interactions											
Pack ice × open water (ice edge)	XX	XX	XX							XX	XX
Pack ice × continental shelf				X	XX	XX		XXX	XX	XX	XX
Polynya × shallow water	XXX					X					

Table A-3. Anticipated climate-related changes for ice-obligate, ice-associated, and seasonally migrant marine mammal species. Source: Moore and Huntington 2008.

Species category	Anticipated change	Indicator	Monitoring approach	What we learn
Ice-obligate				
Polar bear†‡§ Walrus§ Bearded seals Ringed seals	declines in recruitment and body condition	blubber thickness; tissue and stomach samples	measurements and biopsy during harvest; biochemical analyses; documentation of local knowledge	the level of energetic challenge posed by sea ice reduction; exposure of subsistence communities to toxins
Ice-associated				
Bowhead whale†§ Beluga†‡§ Narwhal‡§	migration alteration and occupation of new feeding areas	harvest timing; tissue and stomach samples	documentation of local harvest and knowledge; visual and acoustic surveys; satellite tracking	changes in migration timing and trophic dynamics; exposure of subsistence communities to toxins
Seasonally migrant				
Gray whale†‡§ Harbor seal†‡§	novel occupation of Arctic latitudes and longer residence times	harvest or detection of novel species	documentation of local harvest and knowledge; visual and acoustic surveys; satellite tracking	evidence of sympatry and potential for competition between arctic and temperate species; changes in trophic dynamics and availability of novel species to local hunters

Notes: Indicators and monitoring approach lead to what we learn. Suggested sentinel species listed are those with strong baseline data, for at least some populations, from census (indicated by a dagger, †) satellite tracking (indicated by a double dagger, ‡) and/or harvest monitoring (indicated by a section symbol, §).

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Data Sharing Policy for the Arctic LCC

Data sharing is an essential component of rapid adaptation and response to changing environmental conditions. All LCCs are committed to acquisition, synthesis, and distribution of information needed by managers and scientists to make informed decisions in the face of a changing landscape. This document sets forth the Arctic LCC (LCC) policy for the sharing of data[1,2] by collaborators funded entirely or in part by the Arctic LCC. These policies are considered to be a binding condition upon all Arctic LCC-supported projects. Deviations from this policy may be obtained, but must be requested in writing by the Principal Investigator (PI), and agreed to by the Arctic LCC Coordinator or Science Coordinator, prior to the implementation of the project. Within the proposal review process, compliance with this policy will be considered in the Steering Committee's evaluation of the proposal.

1. Proposals and scopes of work submitted after March 15, 2011 to the LCC for funding must include a written data management plan that:
    - Addresses all aspects of the data life cycle;
    - Describes how data will be collected;
    - Articulates quality assurance/quality control procedures;
    - Defines the metadata standard for the data;
    - Identifies anticipated data formats;
    - Specifies how and when the data will be transferred to LCC custody; and
    - If applicable, describes archiving, data exposure, data delivery, and long-term maintenance measures.

2. Principal Investigators (PIs) are expected to submit to the LCC the raw data, data[1], derived data products, and other supporting materials created or gathered in the course of work under LCC-supported research. Release of these materials at the conclusion of LCC-funded projects[3] into the public domain will be the de facto policy of the LCC.
    a. PIs shall be responsible for the quality, completeness, and description of the data, metadata and associated products prior to submitting to the LCC.
    b. Raw data shall be turned over for archive by the LCC as soon as possible after its collection. The purpose of the LCC raw data archive is to protect against data loss and the archive will not be accessible by other researchers or the public.

[1] Data may include "textual information, numeric information, instrumental readouts, equations, statistics, images (whether fixed or moving), diagrams, and audio recordings. It includes raw data, processed data, derived data, published data, physical samples, and archived data. It includes the data generated by experiments, by models and simulations, and by observations of natural phenomena at specific times and locations. It includes data gathered specifically for research as well as information gathered for other purposes that is then used in research."

[2] Ensuring the Integrity, Accessibility, and Stewardship of Research Data in the Digital Age. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine 2009, page 22.

[3] Conclusion of the project is defined as the date upon which final deliverables are due for submission to the Arctic LCC as defined in the project's contract.

Upon transfer of raw data from investigators to the LCC, the LCC becomes responsible for maintaining the raw data archive.

c. All data is due to be submitted to the LCC at the conclusion of the project. Conclusion of the project is defined as the date upon the project contract ends. Final payment may be withheld until all data and proper documentation have been turned over to the LCC.

d. For those projects in which PIs have been granted initial periods of exclusive data use, data should be made publically available as soon as possible, but no later than two years after the conclusion of the project.

e. The period of exclusive use may be extended to three years for projects supporting work of a PI or Co-PI who is a matriculated student in a master's degree program. The period of exclusive use may not be extended past the student's graduation date.

f. The period of exclusive use is extended to five years for projects supporting work of a PI or Co-PI who is a matriculated student in a doctoral degree program. The period of exclusive use may not be extended past the student's graduation date.

g. For projects producing observation sets greater than 5 years in duration and for long-term (>5 years duration) projects, data are to be made public as follows: data collected from January 1 to September 30 of a given year will be made publicly available by March 31 of the following year. Data collected from October 1 to December 31 of a given year will be made publicly available by June 30 of the following year.

h. Upon transfer of data from investigators to the LCC, the LCC becomes responsible for providing the long-term maintenance and public access to this data.

i. For data which has constraints such as file sizes or data types not supported by the capacity of the LCC, an alternative information clearinghouse may be arranged. In such cases the PI should arrange for data to be made available through a public web site, an institutional archive that is standard to a particular discipline or university, or through other approved repositories. If an alternative information clearinghouse is used, the PIs remain responsible for providing long-term maintenance and support for the data. In all cases, the PIs are still responsible for delivering a copy of all data, appropriate metadata and other supporting information to the LCC for archiving (ensuring that the LCC retains access to the information in the event of insolvency of the alternative information clearinghouse chosen by the PI to serve project data. Intention to use this alternative approach to making data public and discoverable must be indicated in the project pre-proposal, proposal, and scope of work.

3. Principal Investigators are responsible for depositing any samples and physical collections associated with their research in a recognized repository or collection within their discipline. A sample or physical collection preservation plan must be defined in the project's data management plan.

4. Principal Investigators that will use or create proprietary data such that the terms of information release or types of data use are affected must clearly state this in their

proposal documents. The requirements of data restriction must be documented in the pre-proposal, proposal, and scope of work, and must clearly state what information, data, and conclusions cannot be released to the public upon conclusion of the project.

a. All data deemed sensitive, privileged, or subject to restricted access must be identified and appropriately labeled by the PIs upon submission to the LCC. Policies for access to these data must be negotiated between the PIs and the LCC Coordinator or Science Coordinator, and documented in writing, prior to project implementation.

b. This policy does not supersede the legal requirements imposed upon organizations to restrict public access to data. However, such legal requirements restricting information and data access must be clearly stated in the project pre-proposal, proposal and scope of work.

5. Metadata will be required of all data sets. Metadata content and format will be determined on a project by project basis, and must be FGDC or NBII compliant.

6. Data that rely on licensed software for access, evaluation, or use should be identified in the project pre-proposal, proposal, and scope of work. Proprietary formats and software should be documented in the project metadata. Project data shall also be submitted in a non-proprietary format as agreed upon by the PI and the Arctic LCC Coordinator or Science Coordinator prior to project implementation.