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.

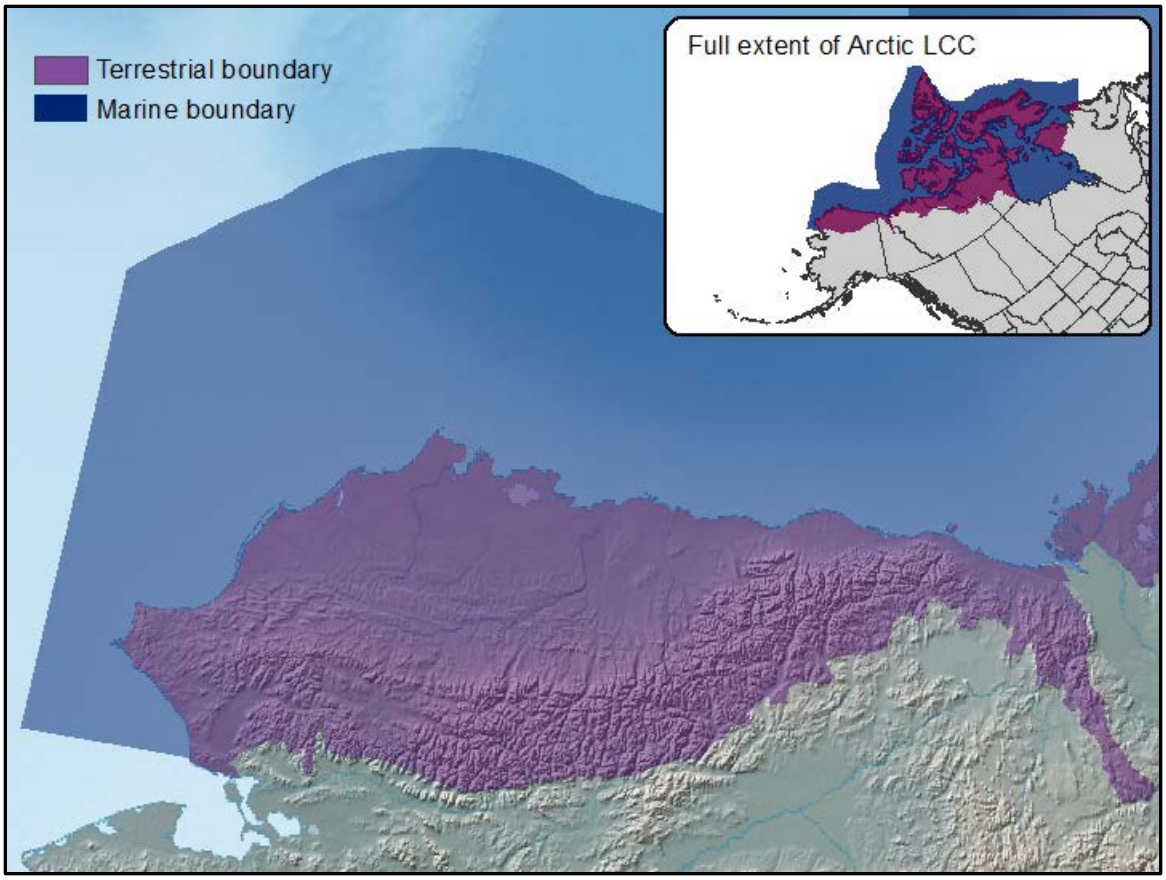

Figure 1. Spatial domain of the Arctic LCC within the United States and western Canada, with the full extent of the Arctic LCC depicted in the inset.

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.

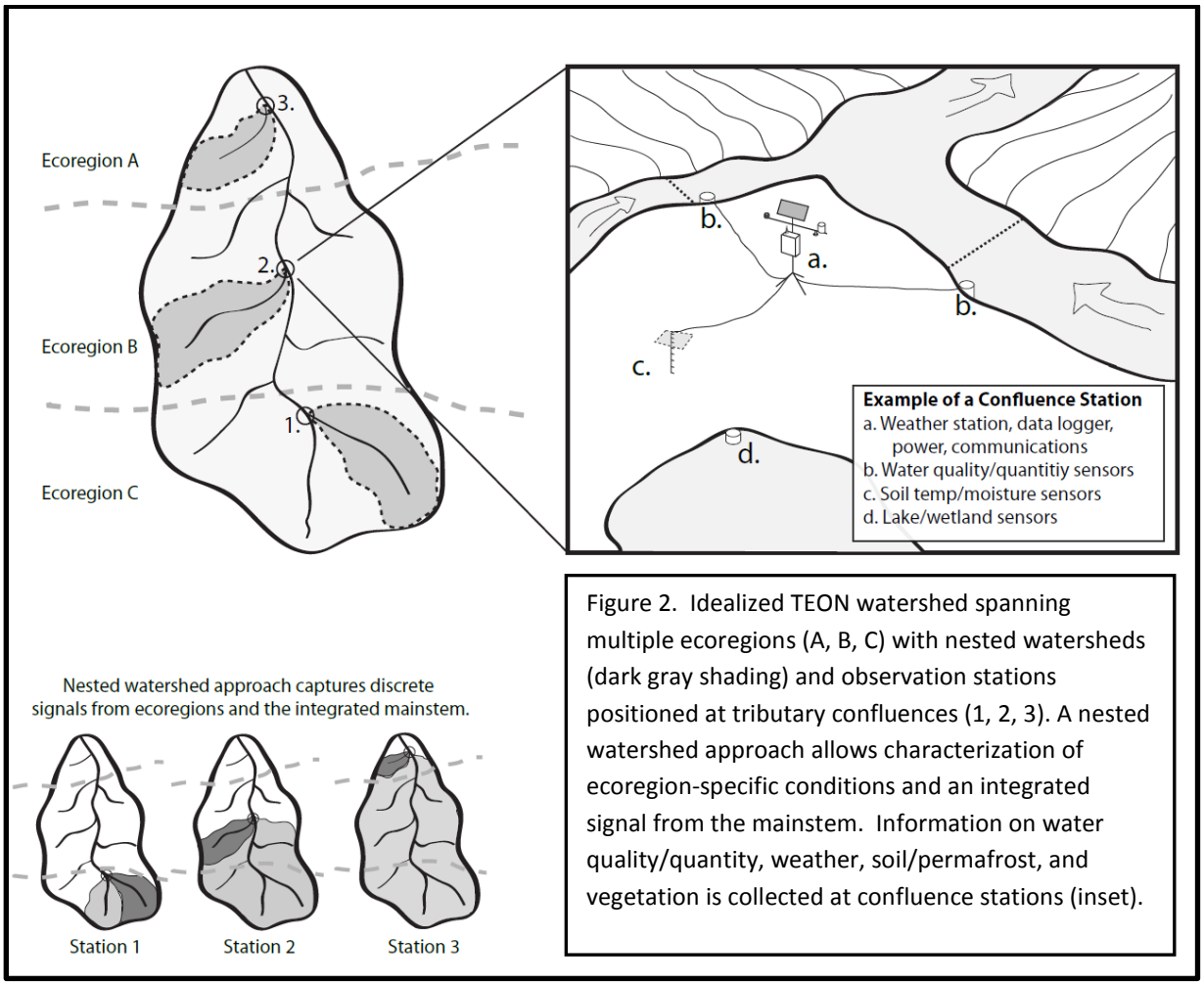

Figure 2. Idealized TEON watershed spanning multiple ecoregions (A, B, C) with nested watersheds (dark gray shading) and observation stations positioned at tributary confluences (1, 2, 3). A nested watershed approach allows characterization of ecoregion-specific conditions and an integrated signal from 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.

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)

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).

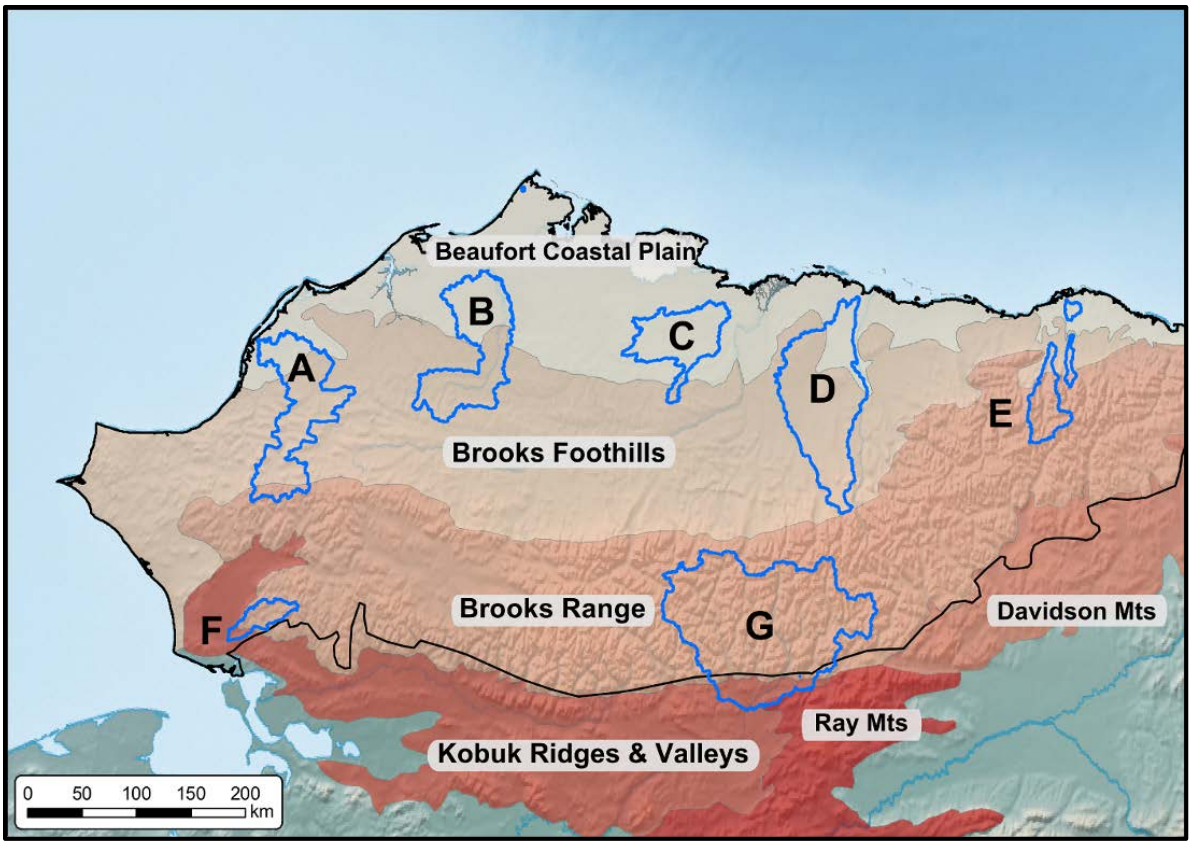

Figure 3. Candidate watersheds for TEON include A) Kokolik River, B) Barrow/Meade River, C) Fish/Judy Creek, D) Kuparuk River, E) Hulahula/Jago Rivers, F) Agashashok River and G) Upper Koyukuk. Collectively, these watersheds sample the major ecoregions and the longitudinal range represented within the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

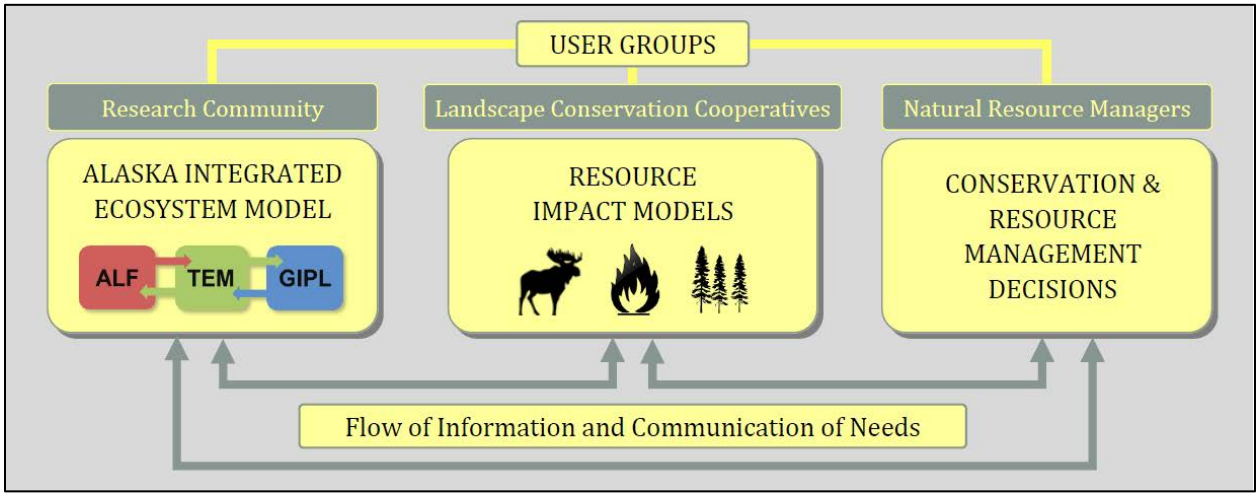

Figure 4. The Integrated Ecosystem Model will serve both the management and research communities.

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.

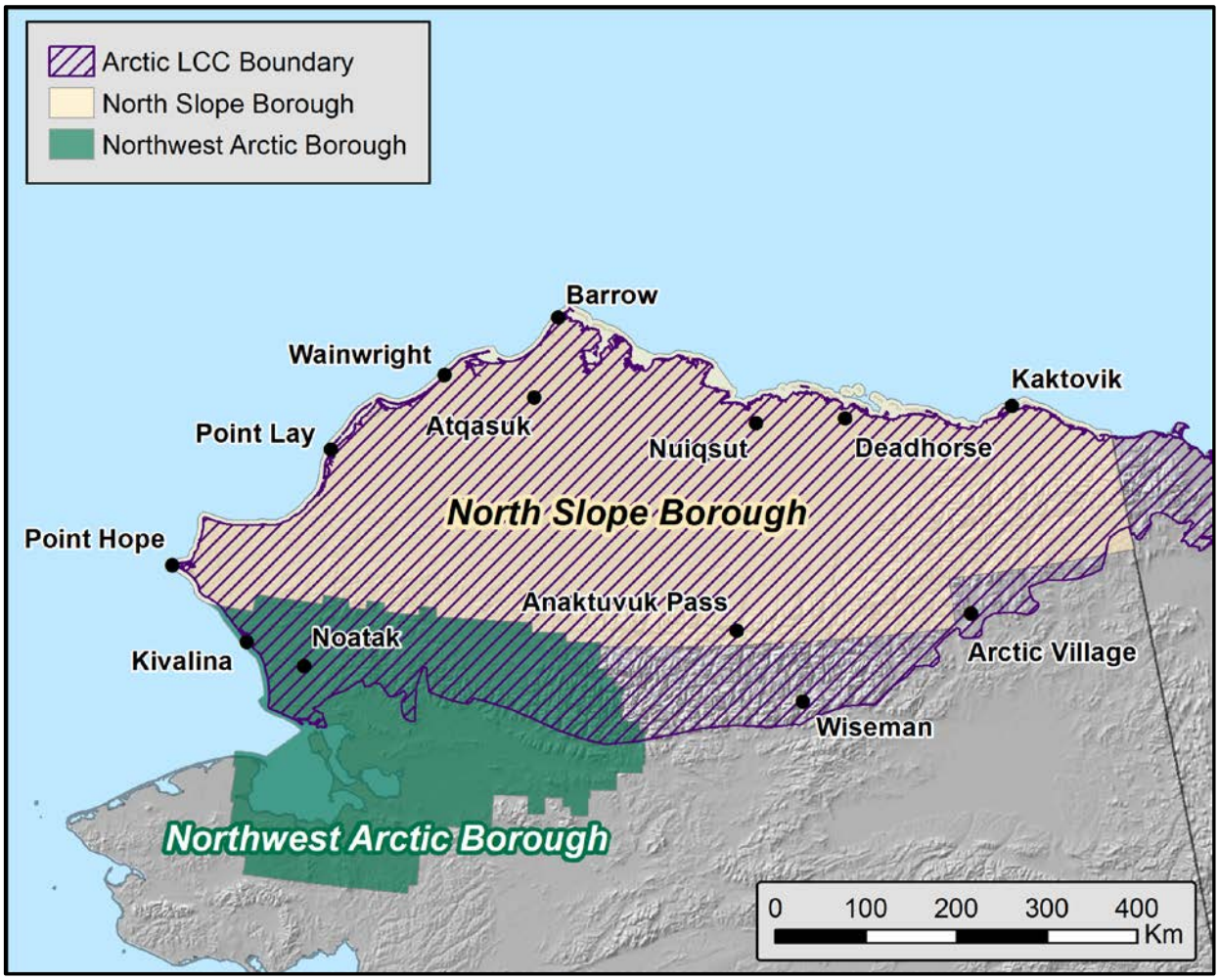

Figure 4. Communities located within the Alaska portion of the Arctic LCC. Eight communities are within the North Slope Borough, two within the Northwest Arctic Borough, and two outside of an organized borough.

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