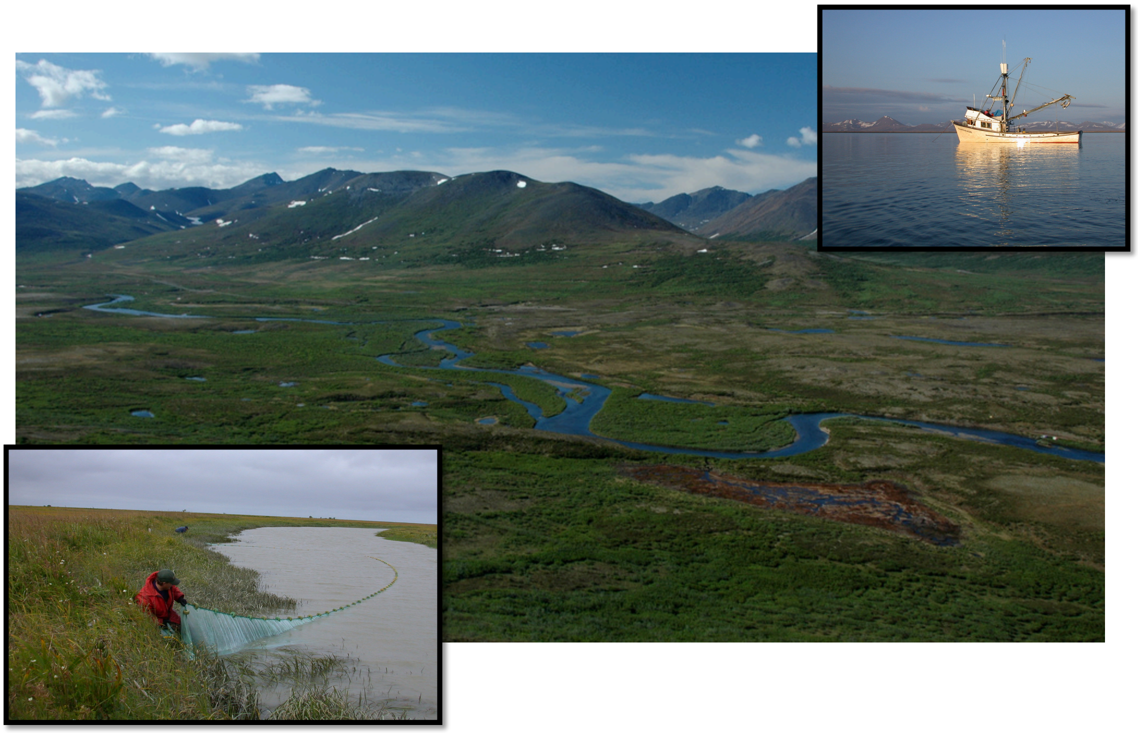
U.S. Geological Survey
Alaska Science Center



Fish and Aquatic Ecology Program

Strategic Research Plan FY2014 – FY2024

May 5, 2014

Table of Contents

Foreword 3

Introduction 3

Approach 5

Identification of Research Needs 6

Theme I: Biocomplexity, Resilience, and Function of Aquatic Systems 7

Theme II: Environmental Control and Future Predictions of Fish and Aquatic Ecosystems 9

References 17

Appendix A. Information and research needs identified by Landscape Conservation Cooperatives (LCCs). 18

Foreword

The current USGS Science Strategy (USGS 2007) provides a broad overview of the agency's fundamental mission in areas of societal impact for energy and minerals, climate and land use change, ecosystems, natural hazards, environmental health and water. At the local level, USGS scientists interact with management partners to shape research programs that meet their highest priorities within the bureau's broad goals. In our initial assessment of research priorities, we relied heavily on research needs expressed by the five Landscape Conservation Cooperatives in Alaska. A draft strategic plan that included priority research themes that we think will be useful to address during the next 10 years, FY2014-2024, was distributed to Department of the Interior (DOI) agencies for comment and suggestions. In January 2014, we held a workshop with representatives from each of the DOI agencies to further solicit comments and suggestions based on information needs of each agency. This document is based on those comments and suggestions. The purpose of this document is to identify priority research needs developed through this collaborative process and will be used to guide our approach to research of Fish and Aquatic Ecosystems over the next ten years. If you have questions or comments, please contact:

Christian Zimmerman, Research Fish Biologist
Fish and Aquatic Ecology Program Leader
USGS Alaska Science Center
907-786-7071
czimmerman@usgs.gov
http://alaska.usgs.gov/staff/staffbio.php?employeeid=211
http://alaska.usgs.gov/science/biology/fish/index.php

Introduction

Aquatic and marine habitats used by fish are ubiquitous features of Alaska. According to the Alaska Fish Distribution Database, maintained by the Alaska Department of Fish and Game, the state contains more than 16,000 bodies of water, including streams, rivers, and lakes that are used by fishes such as salmon, char, and whitefish for spawning, rearing, or migration (Johnson and Weiss 2006). Further, coastal and shelf waters of the Gulf of Alaska and Bering, Chukchi and Beaufort Seas provide habitat important to many commercial, subsistence, and sport fisheries. Agencies within the Department of Interior that have specific management responsibilities for aquatic habitats and resident fish, bird and mammal populations include U.S. Fish and Wildlife Service, National Park Service, Bureau of Land Management, and Bureau of Ocean Energy Management. Other Federal agencies, including U.S. Forest Service and National Oceanic and Atmospheric Administration, also have land and resource management responsibilities within Alaska.

The Alaska Science Center (ASC) is an important component of the U.S. Geological Survey (USGS), the organization responsible for providing the Nation with high-quality objective scientific information needed to manage natural resources and prevent losses due to natural hazards. The ASC is a leader in providing biologic, geologic, hydrologic, and geographic data, information and related research in arctic regions to meet the broad requirements of Federal, State, and local governments for issues such as conservation of land and natural resources, offshore petroleum exploration, allocation of water resources, disaster response and mitigation, land and resource development, pollution abatement, transportation planning, and urban development and recreational use. Moreover, as one of the Survey's most significant initiatives in scientific integration, the ASC is uniquely capable of providing managers and policy-makers at all levels with comprehensive and incisive scientific information on difficult natural resource policy issues.

As part of its Ecosystem Missions Area, the USGS Alaska Science Center conducts research on fish and aquatic ecology for the U.S. Department of the Interior. Fish research at what is now the ASC began in the mid-1980s with work on salmon populations on the Kenai Peninsula. Over the ~25 years since its creation, the program has conducted a range of fish and aquatic research with an emphasis on population genetics, movement and migration, the physiological effects of sport fishing, application of electronic tags, descriptions of spawning habitats throughout the state, and marine ecology of forage fishes important to seabirds. The program is increasingly involved in studies with an ecosystem focus. Results of these studies have been used to guide conservation, protection, and management of fish and fish habitats throughout the North Pacific Rim and Alaska. A list of all publications resulting from past ASC fish research is available at: http://alaska.usgs.gov/science/biology/fish/pubs/index.php

The ASC Fish and Aquatic Ecology Program is part of the USGS Ecosystems Mission Area (http://www.usgs.gov/ecosystems/index.html), which includes a Fisheries Program (http://www.usgs.gov/ecosystems/fisheries/index.html). The long-term goals of the Ecosystem Mission Area are (Williams et al. 2012):

1. Improve understanding of ecosystem structure, function, and processes
2. Advance understanding of how drivers influence ecosystem change
3. Improve understanding of the services that ecosystems provide to society
4. Develop tools, technologies, and capacities to inform decision-making about ecosystems
5. Apply science to enhance strategies for management, conservation, and restoration of ecosystems

The purpose of this strategic plan for the ASC Fish and Aquatic Ecology Program (FAEP) is to identify strategies and activities to achieve the objectives of the USGS Ecosystems Mission Area and Fisheries Program while addressing information needs concerning fish and aquatic systems of importance to DOI and key partners in Alaska. Management and conservation of fish and aquatic habitats in Alaska is hindered by lack of data, difficulty in predicting future performance of fish populations, lack of understanding of environmental forcing factors, and impending changes in temperature, length of growing seasons, and hydrology caused by global climate change. Predicting the effects of global climate change on aquatic communities requires a better understanding of the ecology of aquatic organisms in the circumpolar North (Reist et al. 2006). While we frequently understand the general impacts of changing flow or temperature regimes (i.e., growth is coupled to temperature, or survival can be positively or negatively impacted by flood or drought conditions), we are frequently unable to model the specific responses of individual fish or populations to changes in mean temperature or changing hydrographs. The fish and aquatic ecology team seeks to better understand the role of ecological processes in shaping fish distribution and population characteristics, habitat requirements of fish, and evolutionary adaptations of aquatic organisms in response to environmental gradients. Results of these studies will help to predict impacts of changing climate, define habitat use and requirements to guide restoration and conservation actions, and improve our basic understanding of the life history and evolution of fish species and populations.

Approach

This plan is based on a review of research/information needs identified in strategic science plans or lists of prioritized information needs developed by agencies or cooperative initiatives with direct application to DOI resource management responsibilities in Alaska. The most current of these are plans and documents developed by Landscape Conservation Cooperatives (LCCs). Landscape Conservation Cooperatives are a network of public-private partnerships that provide shared science to ensure sustainability of America's land, water, wildlife, and cultural resources (Department of Interior Secretarial Order No. 3289). Developed in 2009, the LCC network includes 22 Cooperatives based on geographic boundaries that encompass common biomes. Within Alaska there are five LCCs: Arctic LCC, Aleutian and Bering

Sea Islands LCC, North Pacific LCC, Northwest Boreal LCC, and Western Alaska LCC. Because the LCCs are partnerships with Federal, State, university, and private representation, research plans and identification of information needs developed by the LCCs are inherently inclusive and comprehensive. As such, in developing this plan, we have relied heavily on the research needs identified by the LCCs.

To identify research needs that could be addressed by the Fish and Aquatic Ecology Program we reviewed draft research plans from the Western Alaska LCC, Arctic LCC, Aleutian and Bering Sea Islands LCC and North Pacific LCC and a list of prioritized information needs developed by the Northwest Boreal LCC (which, will hold a workshop in 2014 to develop a research plan). In addition, we reviewed other cooperative research plans or identified information needs developed by the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative (AYKSSI), Pacific Coast Sustainable Salmon Fund, North Pacific Research Board, and action plans from National Fish Habitat Partnerships in Alaska. From each plan, we identified all stated research or information needs that pertain to fish and aquatic habitats and, from these, we identified specific needs to be addressed by the Fish and Aquatic Ecology Program. Using these lists, we organized our research into themes and provided short descriptions of objectives for current and proposed future work to frame further discussion with partners. In January 2014, we held a one-day workshop with representatives from DOI partner agencies to review and discuss a draft strategic plan. Partners presented research needs and provided input that informed preparation of this strategic plan. This plan will be used to guide development of annual work plans, study plans targeting highest priority information needs, and external funding opportunities that match program goals.

Identification of Research Needs

Common themes identified in the LCC research plans and information needs focus on four themes: Baseline, Monitoring, Understanding Relationships, and Predicting Future System Status. Nearly all research plans identified important monitoring needs. For example, the need for systematic and standardized monitoring of long-term hydrological data (including discharge and water temperature) was commonly identified as a high priority. To identify appropriate information and research needs to be addressed by FAEP, we selected information needs that concern ecological processes, elucidating relationships between environmental variables and biotic response, and developing predictive models to better understand how climate change will affect fish and aquatic communities. Specific information and research needs identified by LCC plans are presented in Appendix A.

Research Themes and Integration

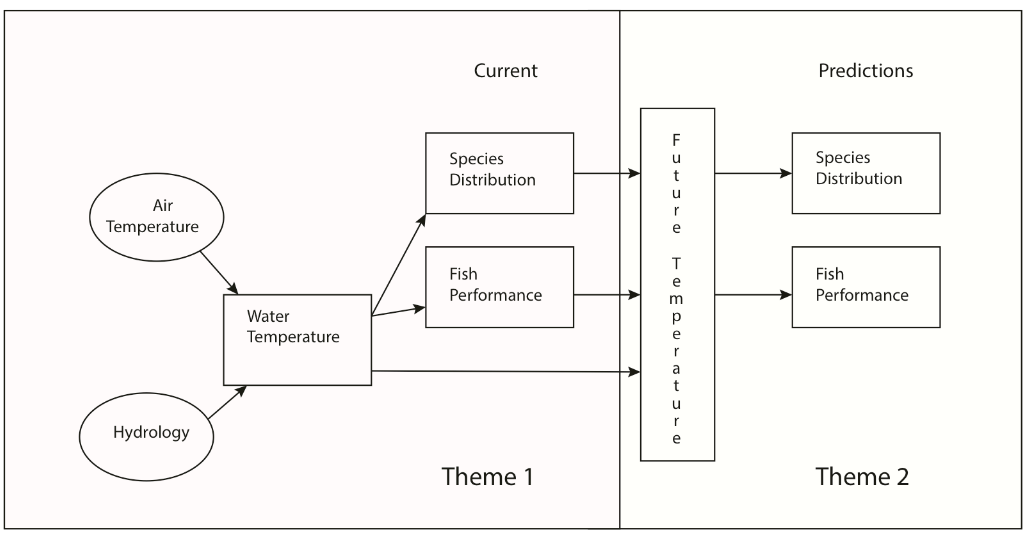
To address the priority information needs, FAEP research is characterized by two interrelated research themes:

1. *Biocomplexity, Resilience, and Function of Aquatic Ecosystems* and

2. *Environmental Control and Future Predictions of Fish and Aquatic Ecosystems*.

FAEP research strives to determine how physical and ecological processes build, sustain, and influence life history and productivity of fishes and aquatic systems to guide land and resource management conducted by DOI. To do so, FAEP research works across a broad range of latitudes, environmental gradients, and among habitats to better understand the range of biotic response. By understanding the range and diversity of response, we can better predict the potential range of future response to climate change, development, and land use management. See Box 1 for an example of how the two research themes are integrated to answer questions about long-term climate warming. In the following section, we describe ongoing work within each theme, and highlight potential new lines of research that we propose to pursue in building our research portfolio over the next 10 years, identified with an asterisk (*).

Box 1. Integration of Research Themes to Address Forecast Effects of Climate Change on Fish and Aquatic Systems



Thermal Ecology and Future Scenarios

FAEP research themes are complementary. For example, prediction of fish response to climate change requires research within each theme. A research goal of Theme 1 is to examine how thermal regimes drive fish performance and distribution in Arctic and Subarctic systems. The impacts of changing temperatures can be difficult to predict due to a lack of basic biological information and incomplete understanding of how temperature alters population dynamics and ultimately community interactions and ecosystem processes. With a better understanding of how temperature determines fish performance in Theme 1, the next step is to predict fish responses to future conditions - the main goal of Theme 2. Temperature changes in freshwater lakes and rivers due to climate change have the potential to alter fish populations and this is especially true in Arctic and Subarctic systems. Thus, Theme 2 is exploring the effect of a changing thermal regime on freshwater and anadromous fish in Arctic and Subarctic regions of Alaska.

Theme I: Biocomplexity, Resilience, and Function of Aquatic Systems

Aquatic ecosystems are the product of a complex suite of physical and biotic drivers. As a result, conservation and management of aquatic ecosystems is complicated and crosses many disciplines. The FAEP conducts aquatic ecosystem research with a focus on fish and indicators of ecosystem health and productivity. Fish species have multiple predators, multiple prey, and may express multiple life history types in response to and with cascading influences on aquatic systems. These general fish attributes lead to complex and evolving dynamics that are unparalleled by other taxa and places aquatic systems among the highest levels of biocomplexity. Biocomplexity is the complex behavioral, biological, social, and physical interactions of living organisms with their environment and encompasses biodiversity and ecology. As fish develop from eggs to juveniles and adults their energy pathways and food web structure change dramatically and in some cases result in two species being simultaneous predators and prey of the other according to life stage. Even within a life stage, multiple predators and prey are common and variability in food webs and energy pathways are anticipated over space and time. In some cases, a fish species may express distinct life history types such as anadromous and freshwater residents. When anadromy is expressed, freshwater and marine systems exchange nutrients and energy, increasing connectivity and complexity among systems. Biocomplexity ultimately promotes species and system resilience when maintained. For example, recent research indicates that the broad range of life history diversity among sockeye salmon populations in Bristol Bay results in stability of salmon productivity at a regional scale (Hilborn et al. 2003; Schindler et al. 2010) despite major changes in climatic conditions affecting the freshwater and marine environments during the last century.

Describing the interactions among species within ecosystems is central to understanding ecosystem function. Comparative studies among systems, species, or life history types can address the causes and consequences of changing interactions and expression. As biocomplexity and connections among species diminish, species and systems become vulnerable to changes from climate and development. The Fish and Aquatic Ecology Program conducts research to better understand diversity and function of aquatic systems to support land and resource managers in the Department of the Interior.

Biocomplexity Overarching Goal: Determine how physical and ecological processes build, sustain, and influence life history and productivity of fishes and aquatic systems to guide land and resource management conducted by Department of the Interior in Arctic and sub-arctic North America and in nearshore regions of the North Pacific and Arctic Oceans.

Objectives:

1. ***Evaluate critical thresholds at which aquatic ecosystem change can result in large reductions in aquatic ecosystem services (fish for subsistence and commercial fisheries)**. An ecosystem service approach provides a means to integrate ecological processes with socio-economic values. By monitoring how human activities change the structure and function of natural systems we can determine the change in value of ecosystem services derived from those systems. We will seek opportunities to collaborate with managers or social scientists to better evaluate biotic response to climate change as it relates to ecosystem services to human communities and assess the interrelationships among multiple ecosystem services.

2. **Develop tools, technologies, and standards to observe, map, analyze, and model biological diversity and complexity in aquatic ecosystems**

    a. **Continue development of otolith-based technologies**, such as geochemical markers, as tools to map the movement and provenance of freshwater and marine fishes
        i. Complete strontium isoscape for Alaska in collaboration with UAF
        ii. Complete development of multi-elemental markers used to evaluate movement and duration of residence in lakes affected by climate change (Black and Chignik lakes) in collaboration with UW

    b. **Continue development of tools based on Barium in otoliths to reconstruct movements and productivity histories** (or upwelling and freshwater inputs to nearshore) in collaboration with US Fish and Wildlife Service, University of Waterloo, and University of New Mexico

    c. ***Build collaborations with scientists from other disciplines to better map and examine the role of watershed-level physical and hydrologic drivers of biological diversity and resilience.**

3. **Impacts of anthropogenic development on aquatic communities –** Identify pending threats to aquatic communities from human development. Future impacts to arctic and sub-arctic aquatic systems include invasive species, energy development, and urban expansion. To understand the anthropogenic impacts on fish and fishery resources, we will move beyond a single-species approach to gain a better understanding of aquatic systems at the community level. Resource management often focuses on single species, and a more comprehensive examination of the entire community may provide a better guide for management decisions by encompassing the complex interactions that ultimately determine ecosystem processes.

    a. **USGS Technical training in Support of Native American Relations (TESNAR) Program**: Researchers from the National Research Program (NRP) partnering with researchers from the Alaska Science Center (AKSC) to conduct water-quality sampling and invasive species monitoring training at the request of the Kuskokwim River Watershed Council (KRWC).

b. ***Potential impacts of emerging invasive species on ecosystem function:** Invasions by exotic species can cause economic and ecological harm as invasive species disrupt communities through many mechanisms, including competition, predation, parasitism, hybridization, nutrient cycling, and habitat alteration. Ultimately, invasive species may disrupt the relationship between native biodiversity and ecosystem function (Carey and Wahl 2010). Freshwater systems in Alaska have not been overwhelmed with invasive species as in other locations around the world (e.g., Carey et al. 2011). Yet, invasive species are spreading through freshwater systems in Alaska include plants (i.e., elodea), invertebrates (i.e., New Zealand mudsnails) and vertebrates (i.e., Northern pike – invasive to south central Alaska). We plan to collaborate with US Fish & Wildlife Service to document and monitor the spread of invasive species, and understand the functional consequences of invading species to Arctic and subarctic systems.

4. **Describe community structure, habitat use, and energy pathways in nearshore habitats of the North Pacific to better understand physical and ecological processes affecting commercially important fishes and the energy sources that sustain healthy nearshore fishery ecosystems**

    a. **Determine energy pathways of nearshore marine fish in the northeast Pacific Ocean.** Nearshore systems are characterized by submerged vegetation, which may provide an energy subsidy to consumers. Estimating the relative energy contributions from submerged vegetation (e.g., kelp and eelgrass) and phytoplankton to fish consumers will quantify an ecosystem service of aquatic vegetation (North Pacific LCC Priority).
        i. Contrast benthic and pelagic energy pathways
        ii. Examine consistency in energy pathways across a latitudinal gradient
        iii. Compare how energy pathways differ between fish in the Alaska Coastal Current and the California Current
    b. **Understand juvenile salmon use of nearshore habitats.** Early marine life history is a critical survival window for Pacific salmon and a period when lifetime survival rates can be largely determined. Kelp and eelgrass beds are likely preferred habitats for some salmon species during nearshore residency and these habitats are vulnerable to oil spills and other human disturbances. Understanding the potential use of nearshore habitats is urgently needed due to new oil and gas lease sales under consideration in Cook Inlet and Shelikof Strait. This work addresses the North Pacific LCC Plan priority to quantify ecosystem values and services of kelp and eelgrass habitat.
        i. Identify differences in nearshore occurrence by habitat and species
        ii. Quantify the use of primary production from kelp and eelgrass

iii. Examine differences in growth rate and energy density among fish captured in different habitats

5. **Determine watershed level controls of life history expression and biological diversity of fish**

    a. **Watershed-level controls of life-history variability in steelhead and rainbow trout.** Previous studies suggest that discharge is a significant control in the distribution of migratory and non-migratory rainbow trout (Zimmerman and Reeves 2002; Mills et al. 2012) but other factors, such as thermal and productivity gradients within watersheds are likely to also play a role. In this collaborative study with USFS and FRESC, the distribution of life history types (steelhead v. resident rainbow trout) will be related to watershed scale factors to identify associations between life history and potential landscape controls in the Eel River, California.
    b. **Watershed characteristics and age structure and life history variability of coho salmon**. In collaboration with USFS Tongass National Forest and Pacific Northwest Research Station, examine variability in age at migration in coho salmon of Prince of Wales Island.
    c. ***Watershed-level controls of distribution, growth, age at maturity, demographics, and life-history expression in fishes of headwater streams of Arctic and NW Alaska.** In collaboration with USGS Water, we will develop a study (Changing Arctic Ecosystems) to examine how fish and aquatic systems respond to watershed level patterns of flow, temperature, and nutrient dynamics to better understand how changes in hydrology associated with permafrost degradation will affect freshwater habitats.

Theme II: Environmental Control and Future Predictions of Fish and Aquatic Ecosystems

Warmer temperatures, increased precipitation, and changes in phenology are anticipated across Alaska. Models linking these anticipated scenarios with biological outcomes are needed for effective resource management by the Department of the Interior.Multiple landscape characteristics and processes shape aquatic systems, but a few tend to limit and control a substantial number of outcomes. Identifying these key characteristics and processes is a necessary step toward predicting future outcomes due to climate change and other stressors. Simple models can predict distribution, abundance, growth, recruitment or any other characteristic of a species or system. A major challenge to identifying key landscape processes is the ability to accumulate data from a range of likely scenarios. FAEP research addresses this problem with three solutions: 1) Use natural long-term data archives in hard parts of aquatic animals (principally otoliths), 2) Examine environments with high natural variation over short time periods, and 3) Substitute space for time so past and future conditions are represented across a geographic range.

Known landscape controls in aquatic systems include habitat connectivity, nutrient availability, light, and temperature. Control can be exerted directly or indirectly through species interactions. Direct influences on fish include reduced visual foraging success due to low light conditions from turbidity and increased metabolic demands due to warmer temperatures. Indirect influences include stronger stratification due to increased temperatures and increased primary production due to a longer ice-free season.

Predictive Modeling Overarching goal: Determine how fish and aquatic ecosystems are affected by physical and biological controls and develop predictive models to better understand the potential impacts of climate change.

Objectives:

1. **Determine what environmental drivers affect fish growth and performance.**

    a. Describe long-term trends in freshwater growth of sockeye salmon and determine the relation between growth and environmental controls such as temperature, length of growing season, and turbidity. Climate change effects on freshwater ecosystems include changes to the annual hydrograph, increased temperature, and increased sedimentation, among others. Understanding how these changes affect growth and productivity of sockeye salmon is a critical information need in southwest Alaska (Western Alaska LCC)

        i. Develop long-term growth histories of sockeye salmon in Lake Clark
        ii. Using satellite imagery, develop a long-term record of the extent and intensity of turbidity (resulting from increased glacial runoff) in Lake Clark

iii. Determine the relation between growth and environmental controls such as temperature, turbidity, and growing season
iv. Develop predictive models of fish growth based on bioenergetics and future temperature and hydrologic model predictions

b. Complete biochronology study of lake trout captured from lakes within Lake Clark National Park and Preserve to determine how environmental drivers and sockeye salmon abundance affect growth of lake trout
c. *Expand collections of lake trout (from current captures and archival collections) otoliths to compare environmental drivers of growth across a latitudinal and climatic gradient in Arctic Alaska and Canada
d. *Develop studies in focus watersheds of NW and Arctic Alaska to examine fish response to flow, temperature, and nutrients to inform studies of fish response to permafrost degradation

2. **Thermal ecology – determine how temperature influences fish and aquatic systems in Alaska**. Temperature controls fish production and aquatic food web dynamics. Temperature changes in freshwater lakes and rivers due to climate change have the potential to alter fish populations and this is especially true in arctic and subarctic systems.

   a. **Determine how temperature influences migrating fish in thermally stressed systems** - Particularly susceptible to changes in river conditions are anadromous salmon due to the physiological challenge of migrating upriver to spawn and complete their life cycle.
      a. *Determine energetic response of sockeye salmon in Pilgrim River:* Recently, low numbers of sockeye salmon have returned to the Pilgrim River (Nome, AK) coinciding with warm river temperatures. We hypothesize that higher river temperatures have increased the energetic demands on sockeye salmon causing more en route and pre-spawn mortality. This mortality reduces spawning escapement and eventually contributes to the low number of returning adults. Determining if the higher temperatures are an energetic cost to migrating salmon will help identify a mechanism influencing spawning escapement and population dynamics. Exploring the influence of temperature on sockeye salmon in the Pilgrim River will be insightful as we are likely to see a large effect of temperature at the northern end of the distribution of salmon. This work addresses the high priority hypothesis from AYK SSI Research & Restoration Plan that "Spawning escapement and subsequent egg deposition are important determinants of the abundance of the next generation of salmon."
      b. *Predict future fish performance in a warming climate:* Using a bioenergetics approach, we will determine energetic costs of migration relative to water temperature under past conditions and future climate scenarios.

c. **Expanded to other systems and anadromous species:* We propose to use Pilgrim River sockeye salmon as a model of salmon response to water temperatures in the Arctic-Yukon-Kuskokwim (AYK) region. Exploring the influence of temperature will help generalize the impact of in-river temperature to northern salmon that are increasingly at risk of experiencing higher river temperatures due to climate change. Developing collaborations with other researchers (hydrologists, geomorphologists, landscape ecologists) will increase our capacity to look at temperature effects at a landscape level.

b. ***Develop gene expression as tool for detecting thermal stress**: The impact of climate warming on fish communities and aquatic food webs is expected to become more severe in the future. In anticipation of these continued effects, we will work with the ASC Molecular Ecology Lab and other labs to develop tools for detecting thermal stress. By determining the genetic markers of thermal stress, we will have another tool to explore the impact of climate change for application to other species and systems throughout Alaska.

c. ***Determine how temperature alters energy flow and contaminants in aquatic systems of the Arctic** - Temperature is a primary control for many ecosystem processes in Arctic lakes. These effects are difficult to predict due to lack of basic biological information, and incomplete understanding of how climate drives aquatic systems. The implications of higher lake temperatures on fish growth and bioenergetics have not, however, been thoroughly studied for fish populations in small lakes on the Arctic coastal plain; at this point, many of our predictions are based on research conducted in more temperate systems, or in larger and deeper lakes. Our research will include both collection of empirical data and modeling, and our overall aim is to enable better predictions of broad-scale ecological and ecotoxicological consequences of climate change in shallow Arctic lakes.

d. **Biological responses to increasing water temperatures in lakes of the Barrow/Atqasuk focus watershed:** Data will be collected in lakes in the Barrow/Atqasuk watershed to better understand how and to what extent continued changes in thermal regimes will affect fish growth, food web structure, and bioaccumulation of mercury. This work addresses a research priority of the Arctic LCC.

    a. *Climate warming increases fish production in freshwater ecosystems of the arctic*: Understanding the effect of climate-induced changes on fish populations will provide insight into how arctic food webs are responding to climate drivers. Climate change effects on temperature could result in different water temperatures, length of ice-free season, and energy flow through the food web, all of which have consequences relevant to food webs on the arctic coastal plain. To explore these consequences, we are using bioenergetics models to simulate changes in fish growth under different climate scenarios. Bioenergetic models provide a framework to test hypotheses about climate change by linking physiological and ecological factors. This work addresses a research priority of the Arctic LCC.

3. ***Predicting the colonization of Alaskan Arctic rivers by Pacific salmon.** Develop a study plan to characterize rivers and streams of the North Slope of Alaska in order to predict the successful colonization of Pacific salmon using downscaled climate change models, predicted hydrology, and improved understanding of salmon populations at the current northern range extent. We will continue collaborative work with Department of Fisheries and Oceans and University of Manitoba to examine characteristics of salmon captured in Arctic rivers of Alaska and Canada (with an emphasis on the Mackenzie River).

4. **Understand oceanographic and terrestrial influences on production and estimating energy transfer to higher trophic levels in nearshore marine systems across the northeast Pacific Ocean, Chukchi Sea, and Beaufort Sea.** Nearshore systems are transitions between marine and terrestrial environments that can be influenced by changes that occur at sea or on land. Some of these nearshore areas are probably healthier than others based on differences in the population growth or decline of sea otters (*Enhydra lutris*), an apex predator. Ecosystem health may differ if some areas are less productive than other areas. Fish living in nearshore systems carry growth records in their otoliths that can be used to identify differences in the energy transferred from primary producers to higher trophic level consumers across years and locations. Portions of this research are components in the USGS Pacific Nearshore Project.
   a. Develop biochronologies from resident black rockfish and kelp greenling across a latitudinal gradient in the northeast Pacific Ocean
   b. Assess the response of fish growth to oceanographic and terrestrial influences
   c. Use fish growth indices to represent energy transfer to higher trophic level in Bayesian models of sea otter abundance
   d. *Develop biochronologies for benthic infauna of the Chukchi and Beaufort seas to examine how changing sea ice may alter food web dynamics. When sea ice is present, ice algae and early-season primary production sinks rapidly and is incorporated in benthic food webs. With diminishing sea ice and increased warming, anticipated increases in zooplankton may intercept this production, resulting in energy shifts to pelagic fishes such as Arctic cod.

5. **Bayesian Network Models** – Bayesian Network Models (BNM) are a decision support tool that structure knowledge in a transparent way and can be used for research planning and to inform management decisions. For example, Peterson et al. (2013) used a BNM to elucidate climate change impacts in freshwater ecosystems in the Pacific Northwest. We are currently developing a BNM to examine climate impacts on food webs in lake ecosystems on the arctic coastal plain. This large interdisciplinary project is part of the USGS Changing Arctic

Ecosystems Initiative and is examining changes in hydrology, energy flow, species composition, and food web dynamics to predict climate changes and identify information gaps.

a. Develop Bayesian Network Model describing the relationship between hydrology, invertebrates, and fish populations to loon (*Gavia spp.*) performance on the arctic coastal plain (ongoing).
b. Use future scenarios of climate change to predict changes to ecosystems on the arctic coastal plain (ongoing).
c. *Develop new models as needed to guide development of hypotheses and exploration of potential future conditions

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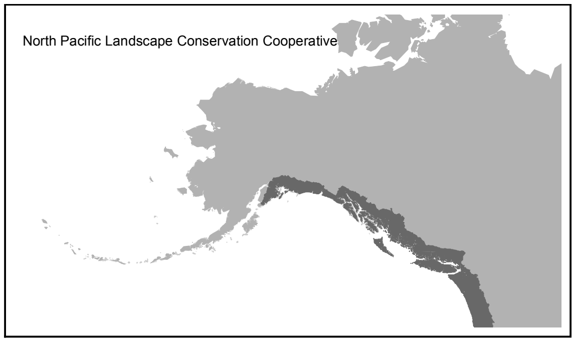
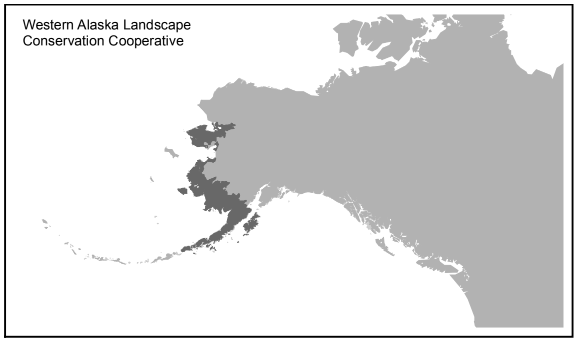
Appendix A. Information and research needs identified by Landscape Conservation Cooperatives (LCCs).



North Pacific Landscape Conservation Cooperative

- Models linking hydrologic changes to species (especially fish) and habitat responses from watershed headwaters to nearshore areas
- Monitor and evaluate water quality in freshwater and nearshore habitats with an emphasis on studies linking water quality to long-lived nearshore species
- Assess the integrated environmental impacts of climate change, hydropower, and associated hydropower infrastructure with reference to fish passage
- Characterize and track climate change effects on physical, chemical, and ecological processes in the marine nearshore and estuarine environment
- Map and characterize the marine nearshore and estuarine environment and associated habitats. Include species occurrence, distribution, and dynamics
- Assess vulnerability and compare management options
- Coastal Ecosystems and Habitats: Address potential changes in phenology and food webs due to acidified and low-oxygen ocean conditions
- Coastal Ecosystems and Habitats: Characterize eelgrass and kelp habitats and identify priority areas. Quantify ecosystem values and services including value to fish
- Rare, endemic, vulnerable, and keystone species: Assess the vulnerability of Pacific salmon and other anadromous fish, and their habitats to climate change effects
    - Study and monitor the effects of climate change on Pacific salmon life stages
    - Examine the importance of estuarine interface for juvenile fish
    - Impact of increasing salinity due to sea level rise on the riparian habitat used by juvenile salmon
    - Assess the vulnerability of Pacific salmon to climate change effects
        - What life stages are most vulnerable to climate change?
        - Relative vulnerability of Alaska vs Pacific NW/California salmon
        - Study salmon population response to environment stressors
        - Identify future salmon habitat
        - Assess current and future salmon productivity
    - Map current and projected Pacific salmon habitat
- Rare, endemic, vulnerable, and keystone species: Generate research and models for forage fishes
- Rare, endemic, vulnerable, and keystone species: Develop maps and models to address climate change effects on other key fish species
    - Develop downscaled data to address climate change effects on key fish species
    - Develop models and vulnerability maps for changes in fish habitat
- Invasive Species, Pests, Pathogens, and Disease: Support efforts to identify the dispersal corridors invasive species, pests, pathogens, and diseases are likely to use in response to changes in climate
    - Develop research partnerships to study fish and bird disease



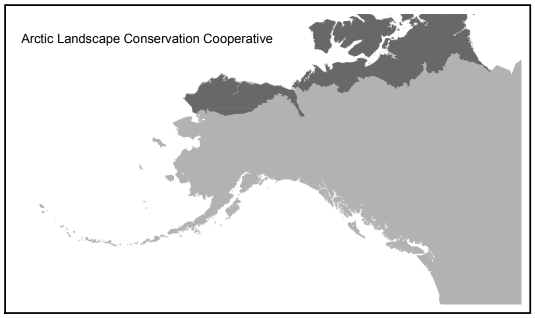
Western Alaska Landscape Conservation Cooperative

Priority Information Needs:

- Estimate forage fish population size, distribution, and response to changing food base to better understand prey availability to coastal mammals
- Conduct data harvest/synthesis and analysis for taxa that have been studied over a period of years and for which population data are available (e.g., salmon escapement, caribou, etc…)
- Monitor prey availability for birds. Prey could include any species groups from aquatic or terrestrial invertebrates to small mammals and birds. The desire to understand the predator–prey links and how they could be affected by climate change is implicit in this data need
- Changes in water temperature and chemistry in lakes, rivers, and streams.
  - understand the thermal tolerances of species at different life stages throughout the region
  - collect baseline conditions of water chemistry and temperature in different freshwater habitats
  - evaluate contaminants (e.g., methylmercury, PCBs) sources and transport through different trophic pathways and how that may be altered by climate change
- Develop fish habitat maps
- Analyze long-term population data (pop. dynamics), migration data, and distributions across landscapes
- Gap analysis for data on important species and/or physical and climate data
- Understand how aquatic temperature and chemistry is affected by air temperature and local conditions of geology for lakes, rivers, and streams (e.g., vulnerability analysis of fish habitat to climate changes)
- Develop decision-support tools

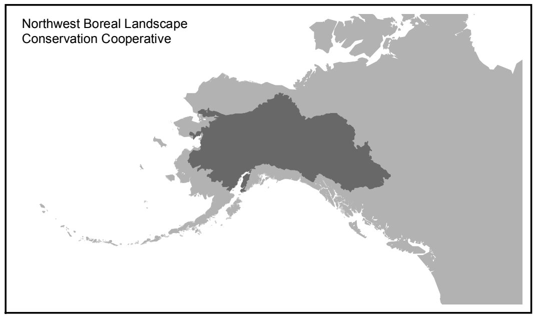
Secondary Information Needs:

- Change in fish migration patterns
- Loss of fish habitat and changing connectivity
  - Changing connectivity with oxbow lakes (for fish spawning and rearing) (
  - Partial drainage can lead to conversion of deep lakes to shallow lakes, causing a loss of overwintering habitat for fish
  - Effect of erosion of ice-bearing permafrost on fish habitat
  - Effect of changes in sedimentation due to glaciers on freshwater ecosystems and availability of fish habitat, and thus timing and availability of subsistence resources. Large glacially affected lakes include Lake Clark, Illiamna, Becharof, Naknek, and Karluk lakes and are prominent features of the glaciated region along the Alaska Peninsula, Ahklun Mountains, and Kodiak Island
- Importance of lakes to terrestrial systems.
  - Large and deep lakes support a wide diversity of fish and are particularly important to the long-term productivity of many salmon fisheries and, therefore, brown bear populations and the surrounding terrestrial ecosystems
- Importance of salmon and forage fish to marine mammals
- Importance of kelp forests to marine mammals
- Important fish species: salmon, whitefish, sheefish, Dolly Varden, Arctic char, northern pike, Arctic grayling, rainbow smelt, rainbow trout, steelhead
- Important process changes for fish: Water balance, timing of discharge, magnitude of flood events, winter base flow, sediment transport and rates, water quality, and vegetation change



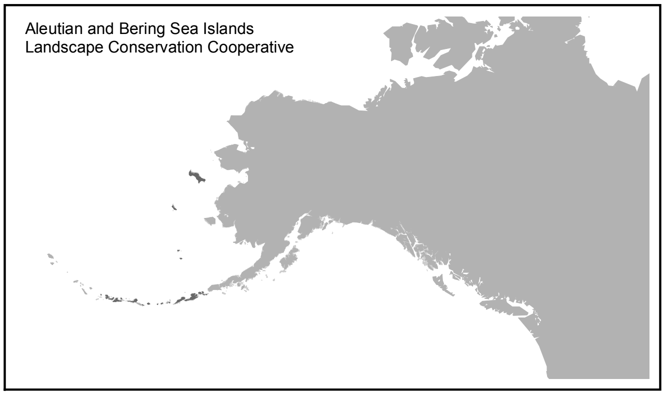
Arctic Landscape Conservation Cooperative

- Subsistence Resources
  - *Biophysical processes* that broadly influence the distribution and abundance of terrestrial/freshwater species
  - *Terrestrial-marine linkages* that affect distribution and abundance of marine resources
  - Environmental change that affects *access* to subsistence resources
- Fish
  - Changes in surface storage and stream flows that affect fish
    - Document losses of connectivity due to changes in discharge
    - Understand the implications for fish dispersal between overwintering, spawning, and summer feeding areas
    - Understand changes in access to fish habitat
  - Water temperatures and chemistry that affect fish
    - Understand implications for changes in distribution, physiology, reproductive, and feeding success, and timing of dispersal or seasonal migration
    - Higher temperatures and longer summers may increase fish productivity, growth rates, and influence age at maturity in freshwater and nearshore systems. Potential negative effects include physiological stress and increased parasites/diseases. Possible behavioral mitigation
    - Potential for increased and decreased overwinter survival rates depending on species
  - Coastal processes and changes in sea level that affect salmon and whitefish
    - Investigate distribution and seasonal migrations of fish
  - Changes in glacial input that affect salmon, Dolly Varden, and Arctic Grayling
    - Reduced summer flows affect summer FW residents
    - Decreased turbidity and sedimentation transport affect the distribution and feed by visual predators
  - Changes in non-connected lake area that affect freshwater fish
- Marine Mammals
  - Availability of midwater fish (Arctic cod/polar cod)
  - Availability of benthic fish



Northwest Boreal Landscape Conservation Cooperative

- **Baseline** -- These are information needs that support or enhance the LCC's understanding of current system states. Fundamentally, this bin includes information needs that define "Where we are, today."
    - In the face of changing land uses, obtain baseline data on life histories, species habitat associations and suitability models for plant and animal species of concern (e.g., identify critical anadromous and freshwater habitat, migratory routes, spawning areas, and overwintering habitats).
- **Monitoring** -- These information needs tell us "How systems are performing" and provide an essential feedback loop for landscape conservation.
    - Monitor changes in plant and animal species distribution, abundance/density, productivity and survivorship, including invasives, as a result of growing-season length changes
- **Understanding Relationships** -- This information is necessary to project future states (based on anticipated changes). This bin also includes information needs that explain "How or why systems function."
    - Assess the vulnerability of forest species and communities to climate change, including vulnerability of species throughout food webs
    - Impact of climate change on vegetation composition and on subsistence resources (e.g., harvested vegetation, ungulates, freshwater fish, etc…)
- **Projecting Future System States** -- Fundamentally, this bin includes information needs that predict "Where we are headed" given various future scenarios.
    - Predict and map the impacts of changing permafrost dynamics on the following: Hydrology-surface and subsurface, Wetlands, Lakes, rivers, streams (including connectivity), Biochemistry, Land use management, Species habitat and populations, Water quality and quantity, Terrestrial plants (forests), and Human use; public safety/health
    - Project changes in plant species, community composition/biomes, and ecosystem processes as a result of climate change
- **Adaptation Planning and Best Management Practices** -- The information needs in this bin pertain to the conception or implementation of local to regional adaptation strategies. This includes the creation of Best Management Practices or alternative management scenarios, and decision support to identify "Where do we want to go, and how do we get there."
    - Best management practices for protecting/informing landscape scale conservation, ecosystem function (e.g., wildlife corridors, road placement, buffers)
    - Develop management protocols for potential future invasive species



Aleutian and Bering Sea Islands Landscape Conservation Cooperative

- **The ABSI LCC is primarily interested in natural and cultural resources** and their associated marine and terrestrial ecosystems, with special interest in effects of climate change and other landscape scale stressors.
- **The geographic scope of the ABSI LCC** includes the islands of the Aleutian archipelago, the Pribilof Islands, St. Matthew and Hall Islands, and St. Lawrence Island. It also includes their surrounding marine waters out to the 200 nautical mile Exclusive Economic Zone in the northeast Pacific and Bering Sea and is bounded in the north by the Bering Strait
- **The ABSI-LCC has identified six landscape-scale stressors** of greatest concern to the natural and cultural resources of the region:
    - Climate Variability and Change
    - Commercial Fishing
    - Contaminants and Pollutants
    - Invasive and Introduced Species
    - Marine Vessel Traffic
    - Ocean Acidification
- **Priority natural resources include a number of iconic species** from the region including federal agency trust species and species vital to social and economic well-being of humans. The rather short list includes the dominant marine fauna of the Bering Sea islands:
    - Seabirds
    - Marine Mammals
    - Fishes (commercial and forage fish important to seabirds and marine mammals)
    - Coldwater Corals
    - Invertebrates/Shellfish
- **Primary focus of ABSI-LCC support will be on the stressor "Climate Variability and Change".** Research efforts will focus o**n** understanding how climate change will affect key marine mammal, seabird and fish species and regional food webs**.**
- **A secondary focus of ABSI-LCC support will be on contaminants,** where impacts are observed through bio-accumulation for top-level predators like marine mammals, fishes and seabirds, and where it can be passed on to human communities through subsistence lifestyles. This trophic cascade of contaminants is of key concern for our partnership community