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Vulnerability of Alaska Native Tribes in the Chugach Region to Selected Climate and Nonclimate Stressors

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Cover: Glacier by Kelsey Hawley; freshly caught fish by Nick Meganack; mushrooms and berries by Jessie Alexander; Sitka black-tailed deer by Tyler/Adobe Stock; eggs by Jessie Alexander; salmon in canning jars by Tiffany Beedle.

Abstract

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We assess the vulnerability of seven Alaska Native tribes in the Chugach region, which includes Prince William Sound (tribes in Chenega, Cordova, Qutekcak [Seward], Tatitlek, and Valdez) and the adjoining Kenai Peninsula (Nanwalek and Port Graham), to key climate and nonclimate stressors. This report supplements the interagency *Climate Change Vulnerability Assessment for the Chugach National Forest and the Kenai Peninsula* that was published in 2017. Over the next 50 years, all communities are generally expected to experience higher temperatures, with decreasing snowpack along the coast where these villages are located. However, at a finer scale, neither climate change nor natural resource distribution are uniform among communities.

Tribal community members remain dependent on wild resources, harvesting 97 kg per person annually for subsistence purposes. This harvest is composed of 42 percent salmon, 26 percent nonsalmon fish, 10 percent marine mammals, 12 percent land mammals, 5 percent marine invertebrates, 4 percent vegetation, and 1 percent birds and eggs, and represents more than 140 species. In addition to contributing to food security, wild resources provide economic opportunities in communities, where they are often limited through commercial hunting and fishing operations, the generation of tourism, and the sale of arts and crafts. Wild resources are also an important cultural and spiritual component of Alaska Native communities, with access to these foods contributing to physical and mental well-being. We selected pink salmon (*Oncorhynchus gorbuscha*), eulachon (*Thaleichthys pacificus*), harbor (common) seal (*Phoca vitulina*), Sitka black-tailed deer (*Odocoileus hemionus sitkensis*), Pacific razor clam (*Siliqua patula*), blueberry (*Vaccinium* spp.), and black oystercatcher (*Haematopus bachmani*) for assessment to represent each of the seven resource categories of subsistence harvest, respectively. Although only harbor seal and Pacific razor clam populations are decreasing currently in the assessment area, all but Sitka black-tailed deer will likely decrease in the foreseeable future. Rather than trying to directly address vulnerabilities, many of which are either unmanageable (e.g., ocean currents) or unpredictable (e.g., oil spills), we suggest the importance of focusing on resilience in traditional resources by developing both community-grown foods through agriculture, agroforestry, mariculture, or kelp farming, as well as enhancing local natural resources through habitat management and monitoring. We identify several considerations for building resilience through more collaborative resource management, building on the skills and knowledge of Alaska Native hunters who have studied, observed, and stewarded these lands and waters since time immemorial.

KEYWORDS:

Alaska Native
Chugach
Climate change
Kenai Peninsula
Prince William Sound
Subsistence
Sugpiat

Executive Summary

This report is an assessment of the vulnerability of seven Alaska Native tribes in the Chugach Region, which includes Prince William Sound (tribes in Chenega, Cordova, Qutekcak [Seward], Tatitlek, and Valdez) and the adjoining Kenai Peninsula (Nanwalek and Port Graham), to key climate and nonclimate stressors. Along with the accompanying public use assessment, this report supplements the interagency *Climate Change Vulnerability Assessment for the Chugach National Forest and the Kenai Peninsula* by Hayward et al. that was published in 2017. The 2017 report did not comprehensively evaluate the human dimensions of climate change, and specifically the exposure, sensitivities, and adaptive capacities of Alaska Native communities to these dynamics. To address this, the U.S. Department of Agriculture (USDA) Forest Service Pacific Northwest Research Station entered into a joint venture agreement with the Chugach Regional Resource Commission. This report is a product of that agreement.

Similar to the larger south-central Alaska landscape, all seven coastal communities are expected to experience higher temperatures, with decreasing snowpack over the next 50 years. However, climate change is not uniform among communities, with Valdez expected to retain a 4-month winter, while Chenega will soon have no months in which the mean temperature is below freezing. Tribal community members remain very dependent on wild resources, harvesting about 97 kg per person annually. This harvest is composed of 42 percent salmon, 26 percent nonsalmon fish, 10 percent marine mammals, 12 percent land mammals, 5 percent marine invertebrates, 4 percent vegetation, and 1 percent birds and eggs, representing more than 140 species. We selected pink salmon (*Oncorhynchus gorbuscha*), eulachon (*Thaleichthys pacificus*), harbor (common) seal (*Phoca vitulina*), Sitka black-tailed deer (*Odocoileus hemionus sitkensis*), Pacific razor clam (*Siliqua patula*), blueberry (*Vaccinium* spp.), and black oystercatcher (*Haematopus bachmani*) for assessment to represent each of the seven resource categories, respectively, not because of their importance as a food source to Alaska Natives (although some are) but because they were part of the original Chugach National Forest vulnerability assessment (Hayward et al. 2017). Although only two of these species (harbor seal and razor clam) are decreasing currently in the assessment area, all but deer are likely to decrease in the foreseeable future. Rather than trying to directly address vulnerabilities, many of which are either unmanageable (e.g., ocean currents) or unpredictable (e.g., oil spills), we suggest that focusing on ensuring resilience in the food supply makes more sense. Resilience can be built by continuing to develop community food supplies through agriculture, agroforestry, mariculture, or kelp farming, as well as by enhancing local natural resources through habitat management and monitoring. However, institutional and financial barriers exist that we suggest could be overcome by reconsidering how the USDA Forest Service and other federal agencies engage with these seven tribes in the Chugach region. We offer the following insights:

- The well-being of the Chugach National Forest and the USDA Forest Service's management decisions are intrinsically and explicitly linked to the livelihoods of tribal members.

- Inviting tribes, corporations, and tribal organizations (e.g., Chugach Regional Resources Commission, Chugachmiut, Chugach Alaska Corporation) as partners in planning efforts, including the development and implementation of policies that allow for traditional ecological knowledge in planning and management, will help build collaborative approaches to address land and resource management challenges.
- The USDA Forest Service has underused agency units and resources, such as the USDA National Agroforestry Center to help communities develop new adaptive food systems, or the USDA Rural Development program to help diversify local economies through ecotourism. Community leaders would like the USDA Forest Service to provide information about these programs and technical assistance with grant applications and implementation.
- Local-scale silvicultural actions could be conducted on USDA Forest Service lands that abut tribal and corporate lands, Native allotments, or tribal or corporate lands for which the USDA Forest Service oversees the conservation easement to enhance game habitats, ensure a sustainable supply of biofuel (wood), or otherwise manage forest lands to help ensure a more resilient wild food system.
- The USDA Forest Service is in a position to find operational efficiencies, ensure good coordination, and help tribes build technical capacity by cost- or time-sharing professional foresters, biologists, or invasive species managers with tribal organizations, such as the Chugach Regional Resources Commission or Chugachmiut.
- Opportunities exist for collaborative monitoring and research among the USDA Forest Service, tribal organizations, and tribes to better understand changes to freshwater hydrology, subsistence resources, and coastal erosion that immediately affect communities, including development of local citizen science monitoring and youth mentoring programs.

Foreword: Tribal Perspectives

Subsistence resources are not just food but are part of a holistic world view that incorporates tribal sovereignty, culture, health, spirituality, and community connection surrounding the stewardship and seasonal harvests of wild foods. In the traditional world views of the Chugach region tribes, people show respect for the land and resources, and in return, the environment provides what people need. Beyond a simple extractive relationship, spiritual and cultural connections also link the Sugpiat, or the "real people" of the Chugach and the dAXunhyuu (Eyak), or "the people," to the lands, waters, and resources of the lower Kenai Peninsula and Prince William Sound. The following two quotes reflect how nonclimate stressors originating with Western colonizers have affected this reciprocal relationship with the land:

> Our tribes in the past have been nomadic, which is an English term, but the way you explain it is exactly how our people were. We were not stuck to where we are now. We were spread out all the way from Prince William Sound to lower Cook Inlet and other places and got drawn into being in these one places during the Russian period. Then, when the canneries came around, more permanent residences were established where we are now. But even during that time, our elders were still going out and doing their traditional hunting and harvesting in the spring and summer, even though they were needed in the canneries. They maintained those traditions of going where they knew the animals and sea life were. The elders were so in tune with everything they used, they knew when to move to another area to let those resources build back up over time. That type of management of the resources that we use contradicts what we must follow now with the Western culture where it is based on the Western model based on my experiences of dealing with it. I look at it as they feel they have a need to control what we Natives are doing the same way they do with their own Western cultures. So, it is an ongoing issue on trying to get them to understand our traditional way of doing it and them not fully accepting that yeah, we did manage these resources, and accept that when we make a request under their regulations to try and move our harvesting practices back to more traditional times is hard. Trying to get those things understood has been an ongoing issue for us. If they just understand that what we are asking is our observational look at the resources and try to get the best for our people.
>
> *—First Chief Patrick Norman,*
> *Native Village of Port Graham,*
> *Chugach Regional Resources Commission Board Member*

> We, the tribes and inhabitants of the Chugach region, proclaim that our subsistence harvests are essential to our cultural, nutritional, economic, and spiritual well-being and way of life. Since time immemorial, we have served as stewards of this land, relying on detailed observation and knowledge of the environment to sustain both our people and our lands and seas. Over and over again, our way of life has been threatened, from slavery under Russian fur traders to the devastating effects of the

> 1918 flu pandemic in our region, the 1964 Good Friday Earthquake that decimated the region, and the Exxon Valdez oil spill that followed 25 years later. Today, we face the dual threats of climate change and development continuing to impact our environment and affect our livelihoods and well-being. We recognize our responsibility and authority to exercise our tribal rights as stewards to our traditional territories and resources and enter into this agreement to promote the health and well-being of our tribal members, our future generations, all Alaskans, and the plants, fish, and wildlife upon which we depend.
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> *—Preamble to the Constitution and Bylaws for the Intertribal Subsistence Alliance, an agreement between Chugach region tribes to promote education about and engagement with land managers and fish and wildlife regulatory boards on issues important to subsistence in the region*

Human-caused climate change is further disrupting these relationships, causing changes that are already having a notable impact on lives and livelihoods in the region. Like many indigenous communities, Chugach tribes are at the frontlines of climate change, witnessing unprecedented alterations to the environment, which they have both depended on, and been stewards of, since time immemorial. In our climate work, the Chugach Regional Resources Commission incorporates traditional knowledge and ways of knowing with Western science and other knowledge systems to develop and implement a vision and plan for a resilient future alongside the communities.

Contents

Scope of the Assessment

The U.S. Department of Agriculture (USDA) Forest Service Chugach National Forest and the University of Alaska Anchorage led a 2012–2015 collaborative effort to assess vulnerabilities to climate change for the Chugach National Forest and Kenai Peninsula, which included participation of 33 federal resource managers, research scientists, and economists representing 12 agencies and organizations (Hayward et al. 2017). However, it did not engage Alaska Native tribes living in the assessment area. The Forest Service agreed to supplement the initial vulnerability assessment with this document, which includes information for Alaska Native communities supported by the Chugach Regional Resources Commission (CRRC).

The CRRC is an intertribal fish and wildlife commission authorized as a tribal consortium under the Indian Self-Determination and Education Assistance Act (1975) and organized as a state and federal nonprofit organization. The CRRC represents about 3,000 members of seven Alaska Native communities. The Tatitlek Indian Reorganization Act (IRA)[1] Council, Native Village of Eyak (Cordova), Chenega IRA Council, Qutekcak Native Tribe (Seward), and Valdez Native Tribe are in Prince William Sound. The Port Graham Village Council and Nanwalek IRA Council (English Bay) are on the lower Cook Inlet on the Kenai Peninsula. Chenega, Eyak, and Tatitlek Corporations own lands within or abutting Chugach National Forest. Valdez and Qutekcak are landless and not currently recognized by the U.S. Department of Interior Bureau of Indian Affairs (BIA) as sovereign tribal governments. Of these communities, Tatitlek, Eyak, Chenega, Port Graham, and Nanwalek are remote and accessible only by sea or air, whereas Seward and Valdez are on the Alaska highway system. Chugachmiut, a 501(c)(3) nonprofit regional tribal consortium, also serves these seven communities, maintaining capacity in forest management and wildland firefighting.

The Qutekcak Native Tribe and Valdez Native Tribe continue to seek federal recognition. They currently operate as nonprofits that provide health and social services, cultural connection and activities, and advocacy for residents of Alaska Native heritage in their communities. Although these two tribes are not yet federally recognized, the other five tribes in the Chugach region recognize their tribal status and encourage their participation in regional tribal consortia. The lack of federal recognition contributes to climate vulnerability for Qutekcak and Valdez Native Tribes. Tribal sovereignty provides legal tools to enable adaptation that emphasizes cultural priorities and opens doors to financial and political resources. It is the CRRC's position that the lack of federal recognition of Qutekcak and Valdez Native Tribes is a social and climate injustice. Thus, we have chosen to use "tribe" to describe both federally and nonfederally recognized tribes in the Chugach region, with the understanding that the legal and institutional responses by the USDA Forest Service and other federal agencies to these two classes of tribes will be different. Throughout this document, tribe, village, and community can often be used interchangeably, but we generally use "tribe" in the context of sovereignty and other legal considerations, "community" in a larger socioecological context, and "village" in its formal use under the Alaska Native Claims Settlement Act (ANCSA 1971). Tribe includes all enrolled members, who may reside in locales other than their respective communities or villages, so it is not necessarily a place-based term. Community may also be obscured by the fact that although people with Alaska Native or

[1] IRA councils refer to tribes who chose to adopt the governance structure prescribed in the Indian Reorganization Act (IRA) of 1934. The IRA required tribes to adopt a U.S.-style constitution and have an elected city-council style of governance in return for additional federal benefits (U.S. National Library of Medicine, n.d.).

American Indian heritage (as identified in U.S. Census 2020) are the majority (≥68 percent) of the populations in Chenega, Nanwalek, Port Graham, and Tatitlek, they are the minority (≤19 percent) of the populations in Cordova, Seward, and Valdez. We have done our best to use these terms very deliberately to connote the appropriate meaning.

For Alaska Native communities, subsistence resources are interwoven with food security, health, and their cash economy. Subsistence is an important component of household consumption and well-being for many people. Harvest and use of wild native species represent a significant component of the culture across the Chugach region but occur within different social, economic, and cultural contexts (Hayward et al. 2017). Indeed, the fourth national climate assessment emphasized that "climate change threatens indigenous peoples' livelihoods and economies, including agriculture, hunting and gathering, fishing, forestry, energy, recreation, and tourism enterprises" (Jantarasami et al. 2018). Consequently, this document identifies the more than 146 species of fish, wildlife, and plants used for subsistence by these communities. However, because of the complexity and diversity of the list, this assessment is constrained to a selected species within each of the seven general resource categories used by the Alaska Department of Fish and Game (ADFG) Division of Subsistence: salmon, nonsalmon fish, land mammals, marine mammals, birds, marine invertebrates, and vegetation. Ultimately, this assessment points toward the salient need to build resilience in the subsistence system, which includes opportunities to both enhance wild foods and develop community-based agriculture.

Study Area

The 2.4-million-ha Kenai Peninsula juts southerly into the Gulf of Alaska, bounded by Prince William Sound to the east and Cook Inlet to the west. A 16-km-wide isthmus connects the peninsula and mainland Alaska, essentially separating these two large waterbodies at Portage (Turnagain Arm) and Whittier (Passage Canal). Prince William Sound spans about 160 km, with Hinchinbrook Entrance and Montague Strait as the primary paths for connectivity to the Gulf of Alaska. Cook Inlet spans 80 km, from Cape Douglas on the Alaska Peninsula to the southern tip of the Kenai Peninsula, defining its oceanward boundaries. The commonality that all seven coastal communities share is their traditional and current dependence on the marine environment as well as their shared geography within the northern extreme of the Sitka spruce (*Picea sitchensis*)-dominated coastal rainforest.

The traditional Chugach lands of the Sugpiat people span two climatic regions—Cook Inlet and south-central Alaska (Shulski and Wendler 2007). The south-central climatic region is under a strong maritime influence, with high annual precipitation, frequent cloud cover, and moderate temperatures, coinciding with the Sitka spruce- and hemlock (*Tsuga* spp.)-dominated coastal rainforest biome (Morton et al. 2023). Tatitlek, Eyak (Cordova), Chenega, Qutekcak (Seward), and Valdez are all located in this climatic region (fig. 1). The lands around Prince William Sound experience mean annual temperatures ranging from 4.4 °C at shoreline to 0 °C at upper elevations, and temperatures rarely exceed 26.7 °C. Mean annual precipitation ranges from 200 cm at sea level to >760 cm at some upper elevation locations. The mean maximum snowpack ranges from 150 to 400 cm depending on location and elevation. Winter snowpack, even near sea level, can extend from October through May (Littell et al. 2017).

In contrast, the Cook Inlet climatic region represents a subarctic area in transition between a maritime and continental climate, with moderate temperatures compared to

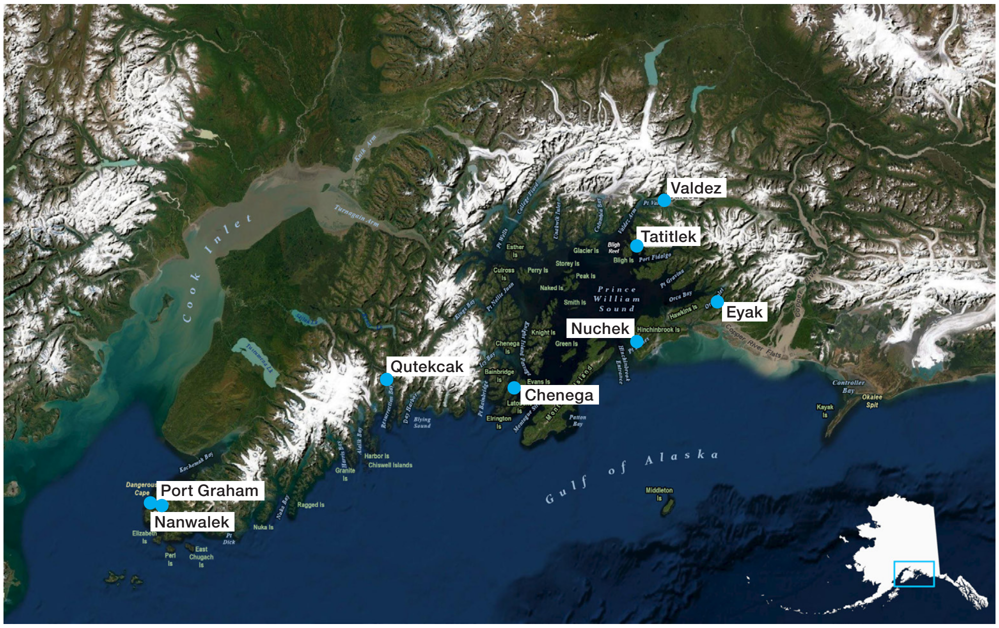

Figure 1—The locations of the seven Alaska Native communities discussed in this report. Nuchek, now abandoned, is also shown as it became an important village during the postcontact period with Europeans. Map data ©2021 Google.

regions in Alaska's interior and precipitation substantially lower than in maritime regions. This climatic region coincides with the transitional boreal biome, which is dominated by white spruce (*Picea glauca*), hybrid (Lutz) spruce (*Picea* × *lutzii* [*glauca* × *sitchensis*]), and black spruce (*Picea mariana*) on the western Kenai Peninsula (Morton et al. 2023). Port Graham and Nanwalek, located on the southwestern tip of the Kenai Peninsula, lie within the Cook Inlet climatic region (fig. 1). In the Kenai Mountains, mean annual temperatures range from 3.9 °C at low elevations to −6.7 °C at upper elevations. The annual precipitation ranges from 50 to 200 cm, with a mean maximum snowpack of 50–300 cm, depending on elevation and location. The southern and eastern coasts of the Kenai Peninsula have a maritime climate characterized by heavy precipitation falling as snow in the higher altitudes (up to 10 m on the ice fields).

Both regions experience highly variable weather across a range of years, particularly with respect to the timing and amount of precipitation and the depth of snowpack at low elevations. This variability is a consequence of variation in broad-scale ocean circulation patterns and the proximity to the Gulf of Alaska (Hayward et al. 2017). Storm tracks tend to move in a counterclockwise pattern from the Gulf of Alaska into Prince William Sound, resulting in abundant precipitation and moderate temperatures. The Kenai Mountains create a partial rain shadow on the western Kenai Peninsula (Ager 2001, Morton et al. 2023).

Methods

The *Climate Change Vulnerability Assessment for the Chugach National Forest and the Kenai Peninsula* (Hayward et al. 2017) provides the informational foundation for expected changes in the physical climate and some of their ecological effects on selected resources. We included their forecasted changes for four particularly salient variables (temperature, precipitation, snowpack, and watershed regime shift) in appendix 1. We downloaded finer grain climate forecasts for the seven tribal communities from the University of Alaska Fairbanks Scenarios

Network for Alaska and Arctic Planning website (UAF SNAP 2023). Current and forecasted changes in marine ecosystems were available in Ferriss and Zador (2020). Detailed information on the communities, their economies, and their use of subsistence resources were available as technical reports through the ADFG Division of Subsistence website (ADFG 2022). Additionally, we reviewed and cited relevant published scientific literature.

Climate and Nonclimate Stressors

Climate Stressors

We used the same climate stressors and modeling of potential future climates as in Fresco and Floyd (2017). In short, climate projections were based on downscaled outputs (771-m resolution) from five global climate models using baseline climatology grids (1971–2000) from phase 3 of the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP3)—an international effort to improve climate models by comparing multiple model simulations to observations and to each other (WCRP CMIP 2023). Temperature and precipitation values from the A2 greenhouse gas emissions scenario, which assumes high emissions driven by increasing human populations in a divided world, are expressed as monthly means for decadal time periods (current, 2020s, 2040s, and 2060s). This modeling found that temperatures are expected to increase by about 3 °C over the next 50 years. Winter temperature change is expected to be most extreme; across the region, winter temperatures are expected to increase by 3–3.5 °C. In the warmest coastal areas, average temperatures in the coldest month of the year are predicted to rise from only slightly above freezing to well above freezing, or about 4.5 °C above current temperatures. Moreover, these higher temperatures will spread inland toward Cordova, Valdez, and Seward, with above-freezing months of January dominating across all coastal regions and in some areas as much as 20 miles inland. Many rivers will shift from a below-freezing to an above-freezing temperature regime. Under each of the community descriptions, we provide local-scale UAF SNAP projections for monthly mean temperature and precipitation.

Hayward et al. (2017) also explored the potential consequences of a warmer and wetter climate on several key issues that will have cascading effects on the abundance and access to subsistence resources: snowpack, glaciers, and winter recreation; coastal landscapes and associated environments; vegetation; and salmon, caribou (*Rangifer tarandus*), moose (*Alces alces*), and Sitka black-tailed deer (*Odocoileus hemionus sitkensis*). Through at least the 2060s, directional change associated with increasing temperatures and precipitation will likely have the following consequences:

- Glaciers will continue to recede. Dramatic reductions in snow cover at low elevations will substantially change the hydrologic regime for 61 of 720 (8.5 percent) of watersheds. Warming waters are likely to increase pink salmon (*Oncorhynchus gorbuscha*) but may also decrease chum salmon (*Oncorhynchus keta*) populations.
- Apparent sea-level rise will have negligible effects over most of the study area because of interactions among isostatic rebound (from glacial loss), tectonic uplift (post-1964 earthquake), and sea conditions.
- Alpine tundra and the Prince William Sound coastline will continue to be afforested by shrubs and trees, potentially further increasing snow accumulation at higher elevations (fig. 2).

- Partially because of changing distributions of vegetation and snow, moose and deer populations will increase along Prince William Sound even as caribou will decline on the Kenai Peninsula.
- Invasive plants will continue to expand their distributions, particularly along roads, trails, and waterways.

Despite the changing climate, Prince William Sound is expected to remain a rainforest under any emissions scenario through the remainder of this century. More extreme change is forecasted for the western peninsula, where deforestation appears in some models (fig. 2), conversion to hardwoods in others, and the value of structures at risk to fire is projected to grow 66 percent on private lands by 2065. Port Graham and Nanwalek fall within a transitional area between the coastal rainforest and boreal biomes on the southern tip of the peninsula. Although neither is likely to experience the extreme warming and drying conditions forecasted farther north on the western peninsula, Nanwalek did have drinking water shortages toward the end of the 2019 drought, which also contributed to the occurrence of the Swan Lake Fire near Cooper Landing and the first lightning-caused grassland fires in spring in modern times in the Caribou Hills. This was not the first time Nanwalek had drinking water shortages; it has happened in four different years during the past decade, partially because of a changing regional climate but also because of the relatively small area drained by the 18-km-long English Bay River from which the community gets its drinking water.

Although Hayward et al. (2017) assessed the vulnerability of many key terrestrial and coastal components, the marine environment is somewhat unpredictable because of the high uncertainty associated with potential changes in ocean currents. Complicating this

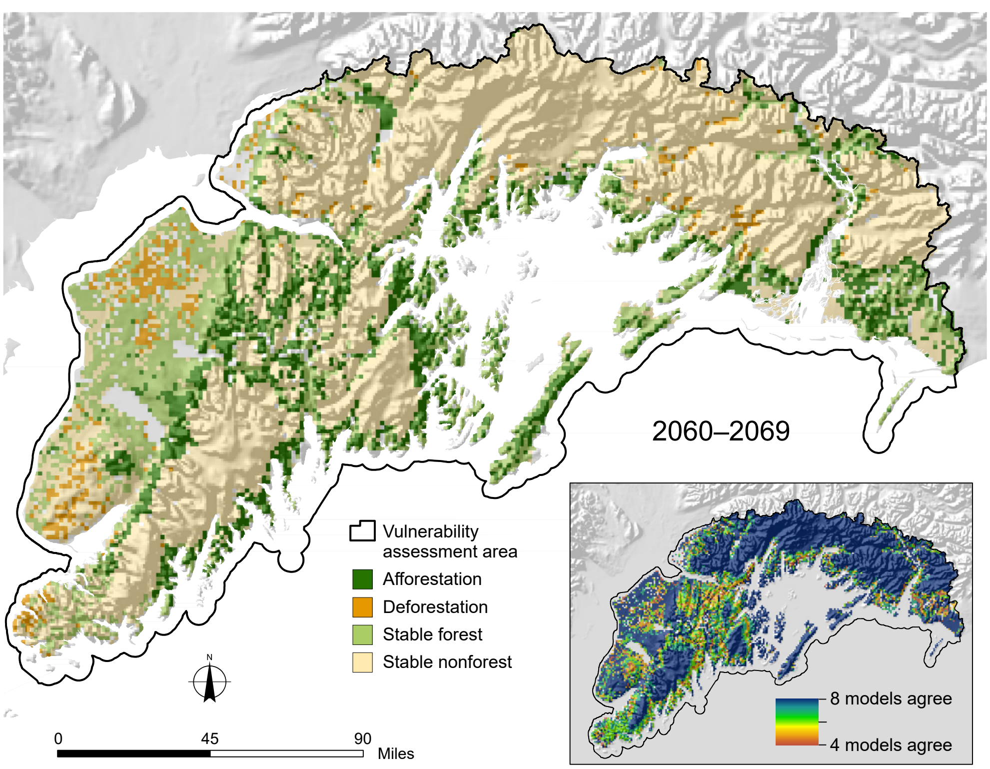

Figure 2—Deforestation and afforestation forecast in 2069 across the eight climate projections representing five global climate models (GCMs) and the five-model average GCM and three emission scenarios (Hayward et al. 2017).

uncertainty in ocean dynamics, Prince William Sound receives up to 50 percent of its freshwater discharge from glacial runoff, suggesting that changes to tidewater glaciers will have profound effects on the relative salinity and pH of coastal waters. The frequency of harmful algal blooms, extent of eelgrass beds, and abundance of prey for migrating shorebirds are all features likely to change with uncertain outcomes (Erickson et al. 2017). Furthermore, although current UAF SNAP models do not directly address the frequency and severity of storm events, both are likely increasing in the Gulf of Alaska and Bering Sea (Hayward et al. 2017).

Warming ocean water and large-scale changes in ocean currents that exacerbate more regional air temperatures affect many marine species, including marine mammals, salmon, nonsalmonids, and seabirds. The Gulf of Alaska experienced extended periods of marine heatwave conditions (also known as "The Blob") during 2014–2016 and 2019 (fig. 3). Marine heatwaves occur when sea-surface temperature exceeds a particular threshold for ≥5 days. That threshold is the 90th percentile of temperatures for a particular day of the year based on a 30-year baseline. Sea-surface temperature in central Prince William Sound has been increasing about 0.09 °C per decade for the past four decades, although there is substantial year-to-year variability. Temperatures in Prince William Sound generally track those of the Gulf of Alaska, with a lag of about 12 months, which is driven by circulation within the region (Ferris and Zador 2020).

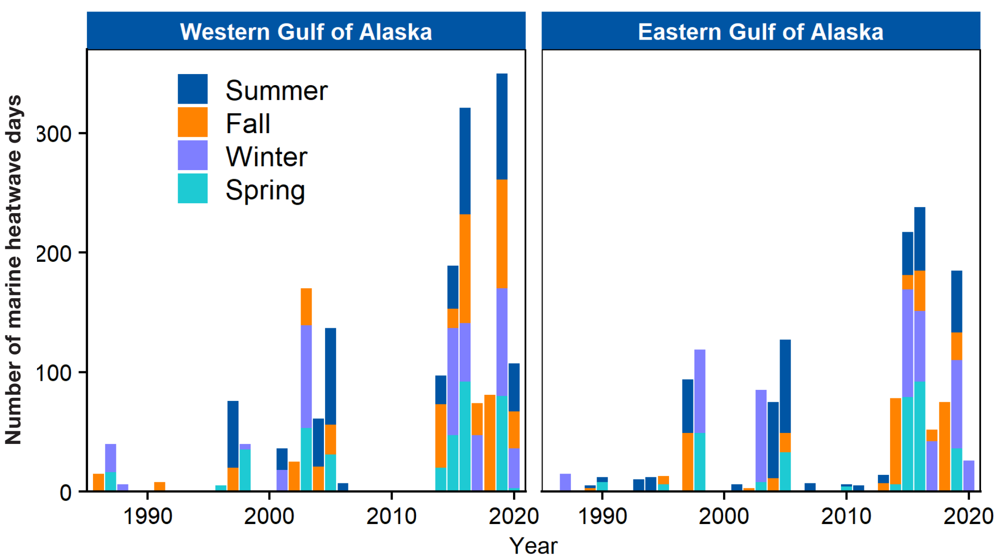

Figure 3—Number of days during which marine heatwave conditions persisted each year. Seasons are summer (June–August), fall (September–November), winter (December–February), and spring (March–June). The western Gulf of Alaska includes Cook Inlet and Prince William Sound (adapted from Ferris and Zador 2020).

The NOAA Fisheries 2020 Gulf of Alaska ecosystem status report describes the ecological effects of the two extended marine heatwaves that are still evident in the Gulf of Alaska. Deeper shelf waters (100–200 m), observed from nearshore to offshore of Seward, continue to have elevated temperatures. This has potential implications for the early survival of groundfish that use these habitats for spawning (e.g., Pacific cod [*Gadus macrocephalus*]). While conditions have been improving for some forage fish, others, such as capelin (*Mallotus villosus*), have remained at low levels since the 2014–2016 heatwave. Other significant trends attributed to these marine heatwaves include decreasing common murre (guillemot) (*Uria aalge*) population counts in Cook Inlet, abandoned nesting colonies of black-legged kittiwakes (*Rissa tridactyla*) around Kodiak, and low numbers of humpback whales (*Megaptera novaeangliae*) observed in Prince William Sound (Ferris and Zador 2020). The closures of both the Bering Sea snow crab (*Chionoecetes opilio*) and Bristol Bay red king crab (*Paralithodes camtschaticus*) fisheries in late 2022 have also been attributed to these marine heatwaves (NOAA Fisheries 2022). Marine heatwaves will almost certainly increase in duration, frequency, and intensity in the foreseeable future, causing potentially rapid and game-changing ecological effects in Prince William Sound and Cook Inlet.

In contrast to marine heatwaves, low ocean temperatures make Alaska's oceans particularly vulnerable to ocean acidification. Cold arctic waters dissolve carbon dioxide (CO_2) readily, which results in acidification. Additionally, high-latitude oceans have naturally low carbonate (CO_3^{2-}) concentrations and are thus considered more vulnerable to the impacts of ocean acidification on shorter timescales. Furthermore, additional losses of CO_3^{2-} from acidification represent a much greater proportional change to the system (Mathis et al. 2014). Unlike the vast continental shelf regions to the north, the Gulf of Alaska does not have seasonal sea ice cover. However, it receives low-alkalinity water from glacial runoff (rich in CO_2) and from deep in the gulf (undersaturated in aragonite, the more soluble form of calcium carbonate [$CaCO^3$]) (Evans et al. 2014). Most of the year, alongshore winds create a downwelling environment that keeps deeper water from penetrating onto the shelf. However, in summer, these winds relax, allowing the waters that are undersaturated in aragonite to penetrate the inner shelf, causing the saturation horizon for aragonite to become as shallow as 75 m (Evans et al. 2014). Although the narrow continental shelf of the Gulf of Alaska is more than three times as deep as the Bering and Chukchi shelves, there is still a considerable remineralization of organic matter at a depth that further drives a reduction in pH and $CaCO^3$ saturation in the bottom waters (Mathis et al. 2014).

Coastal biotic communities along the shores of Prince William Sound, the Copper River Delta, and the Kenai Peninsula may be resilient over the short term as these systems experience highly variable physical and chemical conditions because of seasonal freshwater influx (Erickson et al. 2017). Future projected conditions in Prince William Sound, in part because of warming waters, may suggest a slightly more favorable habitat overall for a variety of ecologically and economically important estuarine calcifying species (Cai et al. 2021). However, present-day conditions in the sound might already be affecting some of these species, including selected crustacean, pteropod, and echinoderm species. Under projected 2050 conditions, this could lead to heightened vulnerability in some species, such as pelagic sea snails (pteropods). Mathis et al. (2014) believe that southern rural areas in Alaska are likely at the highest risk from ocean acidification because of a confluence of factors, including subsistence fishing for nearshore species (e.g., clams, crabs, salmon), higher rates of forecasted acidification, lower industry diversity, economic dependence on fishery harvests, lower income, and higher food prices.

Currently, the CRRC's Alutiiq Pride Shellfish Hatchery in Seward is one of only two tribally-owned shellfish hatcheries in Alaska. It produces several shellfish species with early life stages known to be sensitive to low $CaCO^3$ saturation states. Monitoring of aragonite over a 10-month period in the hatchery's seawater supply indicates the largest changes are on the seasonal timescale, with extended periods of suboptimal levels in winter and autumn associated with elevated water column respiration and short-lived runoff events, respectively.

The data highlight a 5-month window (May–September) with favorable aragonite conditions in source water to the hatchery; however, this window is expected to close by 2040, a biogeochemical shift that is consistent across the coastal Gulf of Alaska (Evans et al. 2015).

Nonclimate Stressors

Catastrophic events in just the last few decades have had significant consequences for Alaska Native communities and the natural resources on which they depend. The 9.2-magnitude earthquake on Good Friday in 1964 and the tsunamis generated from it caused widespread upheaval. Port Valdez suffered a massive underwater landslide, resulting in the deaths of 32 people between the collapse of the Valdez city harbor and docks and inside a docked ship. On the other side of the sound, a roughly 10-m tsunami destroyed the community of Chenega, killing 23 of the 68 people who lived there and forcing a two-decade diaspora of those who survived. Seward and Cordova experienced massive structural damage and human loss.

Twenty-five years later, in 1989, the oil tanker Exxon Valdez ran aground on Bligh Reef less than 3 km from Tatitlek. The 10.8 million U.S. gallons (408 780 000 L) of crude oil that spilled eventually contaminated 2100 km of coastline, of which 320 km were heavily or moderately oiled. Estimates of wildlife lost included 250,000 seabirds, 3,000 sea otters (*Enhydra lutris*), 300 harbor (common) seals (*Phoca vitulina*), 250 bald eagles (*Haliaeetus leucocephalus*), and 22 orcas (*Orcinus orca*). Despite the extensive cleanup efforts, less than 10 percent of the oil was recovered. Use of subsistence resources in Prince William Sound did not return to prespill levels for several years (fig. 4) (Keating et al. 2020).

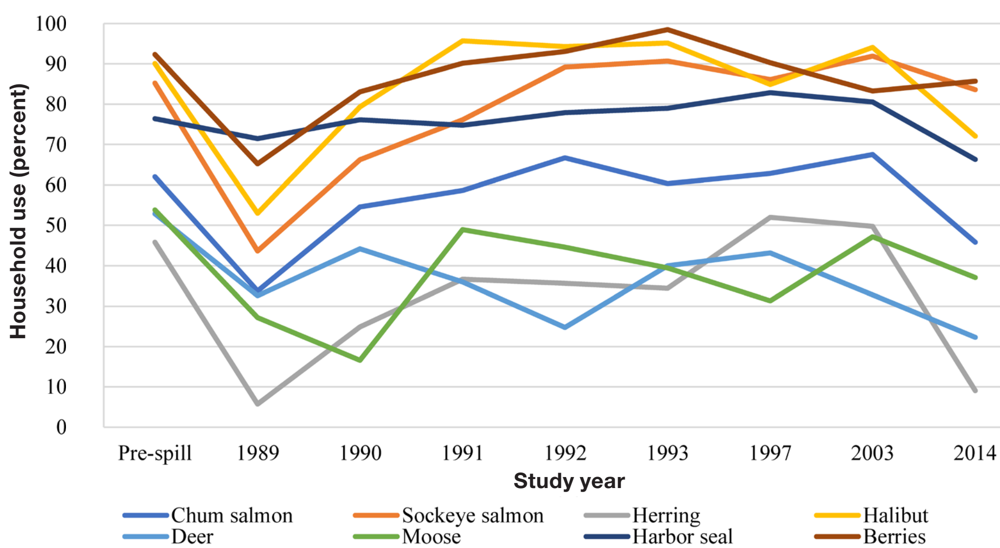

Figure 4—Household use of selected natural resources before and after the 1989 Exxon Valdez oil spill for Chenega, Nanwalek, Port Graham, and Tatitlek combined (adapted from Keating et al. 2020). "Prespill" includes Chenega in 1984–1985, Nanwalek in 1987, Port Graham in 1987, and Tatitlek in 1987–1988.

In addition to potential future earthquakes and oil spills, researchers in 2020 warned that a 1.6-km-long slope with the potential to release roughly 500 million m^3 of material into the Barry Arm Fjord in Prince William Sound would likely trigger a catastrophic tsunami within the next two decades and possibly even within the next 12 months (Dai et al. 2020).

Model simulations show a tsunami reaching 300 m in elevation along the shoreline in Barry Arm and Harriman Fjords, even breaching 10 m above the tide in Whittier. Valdez, Tatitlek, and Cordova could see noticeable but smaller waves that could produce dangerous currents at docks and in harbors; Chenega appeared largely insulated. Although glacial retreat and the subsequent landslide are clearly geological phenomena related to a rapidly warming climate, the potential tsunami is an indirect outcome that could develop in the marine waters of Prince William Sound.

Extreme biological events can also introduce vulnerability to small communities that depend on natural resources for their livelihood. For example, in 1993, the Pacific herring (*Clupea pallasii*) population in Prince William Sound collapsed for unknown reasons and still has not fully recovered (Pearson et al. 2012). The herring is a keystone species with cascading effects on the marine food web as well as a significant commercial and subsistence resource (Ward et al. 2019). The loss of this fishery cost the region millions of dollars, thousands of jobs, and a reliable subsistence food source; many communities, especially those heavily dependent on the herring fishery, went into sharp decline (Mathis et al. 2014).

In contrast, *Alexandrium catenella*, a cyst-forming dinoflagellate that causes harmful algal blooms and paralytic shellfish poisoning, is likely to become more common in warming marine waters (Anderson et al. 2021, Vandersea et al. 2018), essentially making shellfish unavailable for human consumption. Algal blooms are also associated with mortality in sea lions, seals, sea otters, dolphins, sperm (cachelot) whales (*Physeter macrocephalus*), minke whales (*Balaenoptera acutorostrata*), and many bird species, including grebes, gulls, cormorants, American avocets (*Recurvirostra americana*), loons, and sooty shearwaters (*Puffinus griseus*) (Erickson et al. 2017). Similarly, highly invasive, nonnative plants or animals can rapidly spread and endanger traditional ecosystem services. Elodea or Canadian waterweed (*Elodea canadensis*), the first submerged freshwater invasive plant to establish in Alaska, was first detected in 1982 in Eyak Lake during an aquatic plant survey. By 2015, elodea strands were topping the Eyak Lake outflow and blanketing shorelines of the Eyak River (fig. 5);

Figure 5—Strands of elodea or Canadian waterweed (*Elodea canadensis*), Alaska's first invasive aquatic plant, at the Eyak Lake outflow in 2015. Photo by John Morton, U.S. Department of the Interior, Fish and Wildlife Service.

it has spread to several other waterbodies in the Copper River watershed with uncertain impacts on salmonids. Elodea is known to become so hyperabundant that it can compromise boat travel, floatplane access, and fish habitats (Sethi et al. 2017). In these three examples, the distributions of fish, dinoflagellates, and plants are ultimately dependent on climate, but climate change may or may not mediate the mechanisms by which they insert themselves into ecosystem processes and trophic interactions.

Current Management Context

Cordova, Chenega, Tatitlek, Seward, and Valdez are within the Prince William Sound fisheries management area, while Nanwalek and Port Graham are in the Cook Inlet fisheries management area. State and federal regulations provide subsistence fishing opportunities for the five rural-designated communities, which are coincidentally the five federally-recognized tribes. Subsistence fishing for salmon, crab (*Chionoecetes bairdi*, *C. opilio*), and shrimp requires a permit from the ADFG. Residents of the five communities are also eligible for participation in the federally managed subsistence Pacific halibut (*Hippoglossus stenolepis*) fishery after obtaining a Subsistence Halibut Registration Certificate. State and federal regulations provide hunting opportunities under subsistence or general hunting regulations in Game Management Units 6 (Cordova, Chenega, Tatitlek, and Valdez), 7 (Seward), and 15C (Port Graham and Nanwalek) for moose, mountain goat (*Oreamnos americanus*), deer, black bear (*Ursus americanus*), and small game, the predominately used land animal species in these communities (Keating et al. 2020). Tribal members are also eligible to participate in spring and summer subsistence hunting for migratory waterfowl and collection of eggs under the revised Migratory Bird Treaty Act (1918). Alaska Native residents may also hunt marine mammals for subsistence uses under provisions of the Marine Mammal Protection Act (1972) (Keating et al. 2020). Tribal residents of Valdez and Seward, located in the federal nonsubsistence area, are eligible to hunt and fish under state subsistence (in Game Management Units 6 and 7, respectively), personal use, and sports rules, and to hunt for marine mammals under the provisions of the federal Marine Mammal Protection Act (1972), but they are not eligible to participate in federal subsistence harvests or the spring migratory bird harvest.

The status of land ownership and management responsibility in Alaska is complex, creating an institutional regime that contributes to food and economic insecurity in the Chugach region. Aboriginal title to Alaska's lands, including "any hunting and fishing rights that may exist," was abolished by the 1971 Alaska Native Claims Settlement Act (ANCSA 1971). The act created 13 regional corporations and around 200 village corporations, giving entitlement to 18 million ha of land and conveying about $1 billion in funding to the corporations as compensation for extinguishing aboriginal title on other lands. Under this program, the Chugach Alaska Corporation (CAC, then known as Chugach Alaska, Inc.), the regional Native corporation created under the Alaska Native Claims Settlement Act, received more than 150 000 ha of full-fee lands; i.e., CAC has full ownership with both surface and subsurface rights. Additionally, five village corporations in the region received between 28 000 and 60 700 ha of land, to which they owned the surface rights, and the CAC owned the subsurface rights, totaling about 222 500 ha of subsurface lands for the CAC. Unfortunately, the state of Alaska and federal agencies had already claimed most of the usable land in the Chugach before the corporations had a chance to make their claims. Chugach Alaska, Inc. considered only 10 percent of the land originally offered as usable, with most of it consisting of ice fields, glaciers, and inaccessible locations due to steep, impassable terrain. It took a decade of negotiation before a settlement agreement was reached in 1982 (Chugach Natives, Inc., n.d.). Soon after, in the wake of the 1989 Exxon Valdez oil spill, many village corporations in the Chugach region placed their surface lands into conservation trusts, which has had the unintentional result of limiting both regional and village corporations' abilities to manage their lands for sustainable economic development (Hickel 2022). Tribal hunting and fishing rights also remained unresolved under the Alaska Native Claims Settlement Act; leaders in Congress implicitly promised that those rights would be addressed at a later date. Subsequently, title VIII of the Alaska National Interest Lands Conservation Act (1980) created a rural, but not a tribal, priority for fish and wildlife harvesting in Alaska. It did not explicitly address the tribal hunting and fishing rights abolished under the 1971 act as tribal leaders felt had been promised during its passage (ANILCA 1980).

The Alaska National Interest Lands Conservation Act expanded the Chugach National Forest, which surrounds many Chugach region communities (ANILCA 1980: 501a), while simultaneously seeking to study and adjudicate land claims between the state of Alaska and regional and village Native corporations in Prince William Sound (ANILCA 1980: 1429–1430). The state began to implement a rural priority in its management system, but the McDowell v. State of Alaska (1989) decision determined that a rural priority violated the state of Alaska's constitution. Thus, since 1989, a dual management system has existed in Alaska, with the state of Alaska managing state and private lands without a rural priority and federal land managers implementing a rural priority on federal lands and reserved waters (Joly et al. 2015). In addition to the dual management system for fish and wildlife, several other laws and management bodies affect who, when, and how tribal members can access and harvest their traditional resources; these include the Marine Mammal Protection Act (1972) and the Migratory Bird Treaty Act (1918), both of which add a layer of bureaucratic complexity to an already confusing system. Marine mammal harvesting is further restricted by legally defining an Alaskan Native as someone with at least 25 percent Alaska Native heritage by blood (Code of Federal Regulations 1974), a minimum blood quantum requirement that is more difficult to meet in contemporary times. Because of a long history of colonization, this particularly affects the Chugach region, where many parents today are facing a situation where their children cannot legally participate in traditional practices surrounding marine mammal harvest despite being legally and culturally a member of a regional tribe.

This subsistence regulatory regime creates vulnerabilities in tribal communities as it requires significant time, expertise, and funding to participate in the public fish and wildlife management process. For small tribes, it can be difficult to find the time and build the capacity to push for regulatory changes. As climate change continues to alter growing seasons and affect when and where fish and wildlife can be found, the burdensome regulatory regime of Alaska's dual management system could hinder tribal members' abilities to get the food they need (Loring et al. 2011). In Port Graham and Nanwalek, for example, tribal members have found it increasingly difficult to harvest moose by September 30, when the hunting season usually closed. In 2023, CRRC worked with hunters from those communities to successfully change regulations in Unit 15C so the season closes November 30, reflecting climate impacts on the hunting season as the fall growth season extends longer into the year. The complex management system, combined with a lack of codified rights to traditional resources and no direct land ownership by tribes, threatens access to traditional resources and all the physical, mental, spiritual, and cultural benefits that accompany participation in traditional harvesting activities. Subsistence resources are a source of individual and community health and resilience. From a tribal perspective, loss of access to these resources is one of the gravest potential impacts of climate change, though it is not just climate change alone that threatens the continuation of subsistence ways of life.

Seven Tribal Communities, Their Natural Resource Use, and the Current and Forecasted Climate

In this section, we briefly describe the seven Chugach region tribal communities, touching on history, demographics, and community capacity, which are relevant to understanding how residents use their natural resources. Resource use is characterized with community subsistence data provided by Fall and Zimpelman (2016) and Jones and Kostick (2016). We forecasted mean monthly temperatures and precipitation through the end of this century for each community using historical Parameter-elevation Regression on Independent Slopes Model (PRISM) (1-km^2 downscaled climate data) (NACSE PRISM, n.d.) and the 5-model projected average of the representative concentration pathway (RCP) 6 (mid emissions) scenario (UAF SNAP 2023), a moderately conservative estimate. We also forecasted the growing season length for cool-weather plants (days >4.44 °C) through 2100 for each community, except Valdez, where we used light-frost plants (days >0 °C) because of a coding error in the UAF SNAP output (Fresco 2023).

Native Village of Chenega

Chenega (meaning "beneath the mountain") is a Native village on the 75-km^2 Evans Island, 67.6 km southeast of Whittier in Prince William Sound. Fifty-nine people live there, of which 63 percent are full or part Alaska Native (U.S. Census Bureau 2020), most of whom are Alutiiq. The community is accessible only by air or water, with most transportation by charter aircraft and the Alaska Marine Highway Ferry System. The community is served by the Chenega IRA Council, a federally recognized Indian tribe.

Chenega was previously on Chenega Island, which is farther north in Prince William Sound. Founded before the Russians arrived in the late 1700s, Chenega was the longest occupied village in Prince William Sound at the time of the 1964 earthquake. A tsunami resulting from the earthquake destroyed Chenega except for a single home and the community school. The earthquake killed over a third of the residents, and the survivors were relocated to Tatitlek, Cordova, and Anchorage.

With the passage of the Alaska National Interest Lands Conservation Act, the former residents of Chenega formed the Chenega Corporation, which acquired the right to select over 28 000 ha around the former Chenega village township. Chenega Corporation shareholders carefully selected the current village site on Evans Island in 1977 as the locale best able to meet the needs of their subsistence lifestyle. The Chenega Corporation and the Chenega IRA Council worked together to obtain funding for roads, a water and sewer system, electric generators, a boat and floatplane dock, and a school. The new community, named Chenega Bay (renamed Chenega in 2018), was finally occupied in 1984, following the construction of 21 U.S. Department of Housing and Urban Development homes. In 1989, the newly established community found its beaches flooded with oil when the Exxon Valdez ran aground on Bligh Reef.

Commercial fishing supports a subsistence lifestyle in Chenega; cash employment opportunities are very limited (Fay et al. 2005). In the early 2000s, residents tried oyster farming, but labors were unsuccessful. Employment is primarily with the local school, Tribal council, health clinic, and commercial fishing. Subsistence activities provide most food items, although household consumption of 24 of 25 resources used by Chenega residents has decreased in recent years (fig. 6).

In 2014, more than 65 percent of households in Chenega consumed sockeye (*Oncorhynchus nerka*), coho (*Oncorhynchus kisutch*), and chinook salmon (*Oncorhynchus tshawytscha*); Pacific halibut; and Sitka black-tailed deer (fig. 6). The Prince William Sound Aquaculture Association

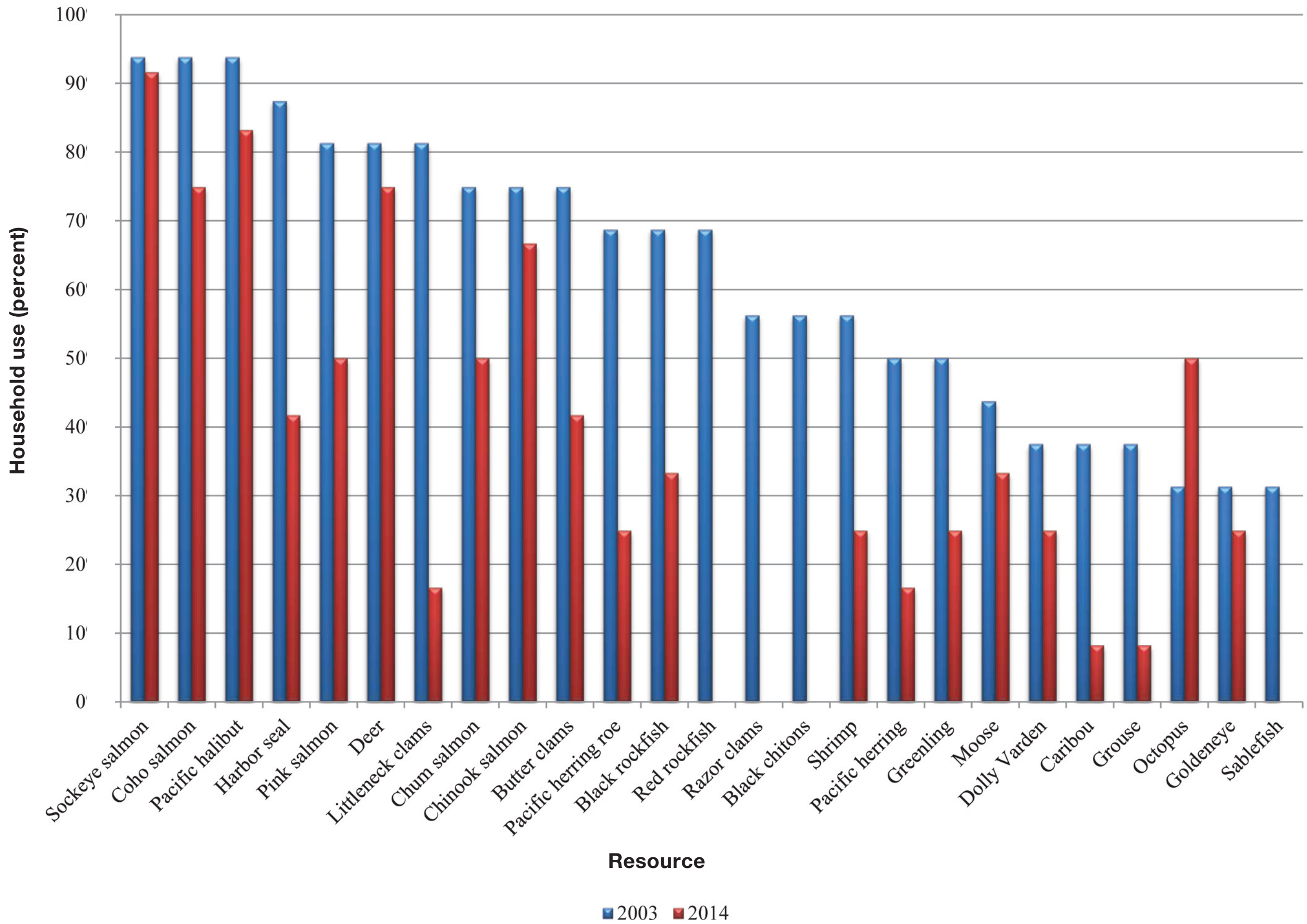

Figure 6—Household use of 25 natural resources by residents of Chenega, Alaska, in 2003 and 2014 (adapted from Fall and Zimpelman 2016).

operates the Armin F. Koernig Hatchery that is permitted to release 190 million pink salmon eggs, which provides for additional fishing opportunity for the community (Prince William Sound Aquaculture Corporation, n.d.). Chenega's fish and game processing facility is currently being retrofitted, and the CRRC has purchased about $20,000 worth of commercial fish and game processing equipment. The CRRC is currently conducting a project with the ADFG to enhance softshell clam (*Mya arenaria*) and Nuttall cockle (*Clinocardium nuttallii*) populations on traditional harvesting beaches near the community. Additionally, the CRRC piloted a project to farm bull (*Nereocystis luetkeana*), ribbon (*Alaria marginata*), and sugar (*Saccharina latissimi*) kelps in Crab Bay.

Chenega has the most benign climate of the seven communities considered in this study. Forecasted climate data for Chenega suggest that the mean monthly temperature will continue to increase in all months over the remainder of this century, exceeding 15.5 °C (59.9 °F) in July and August. Mean monthly precipitation will increase through 2050, but the forecast becomes much more variable toward the end of the century, with precipitation possibly decreasing in 3 months of the year. Winter (defined by a mean monthly temperature ≤0 °C) will decrease from 3 months (December–February) to year-round monthly temperatures averaging above freezing by 2040, if not sooner, suggesting a negligible snowpack (fig. 7). The current 5-month growing season for cool-weather plants, such as kale and peas, is expected to increase to almost 8 months by 2100, acquiring 2 more months in the spring and 3 more weeks in the fall (fig. 7).

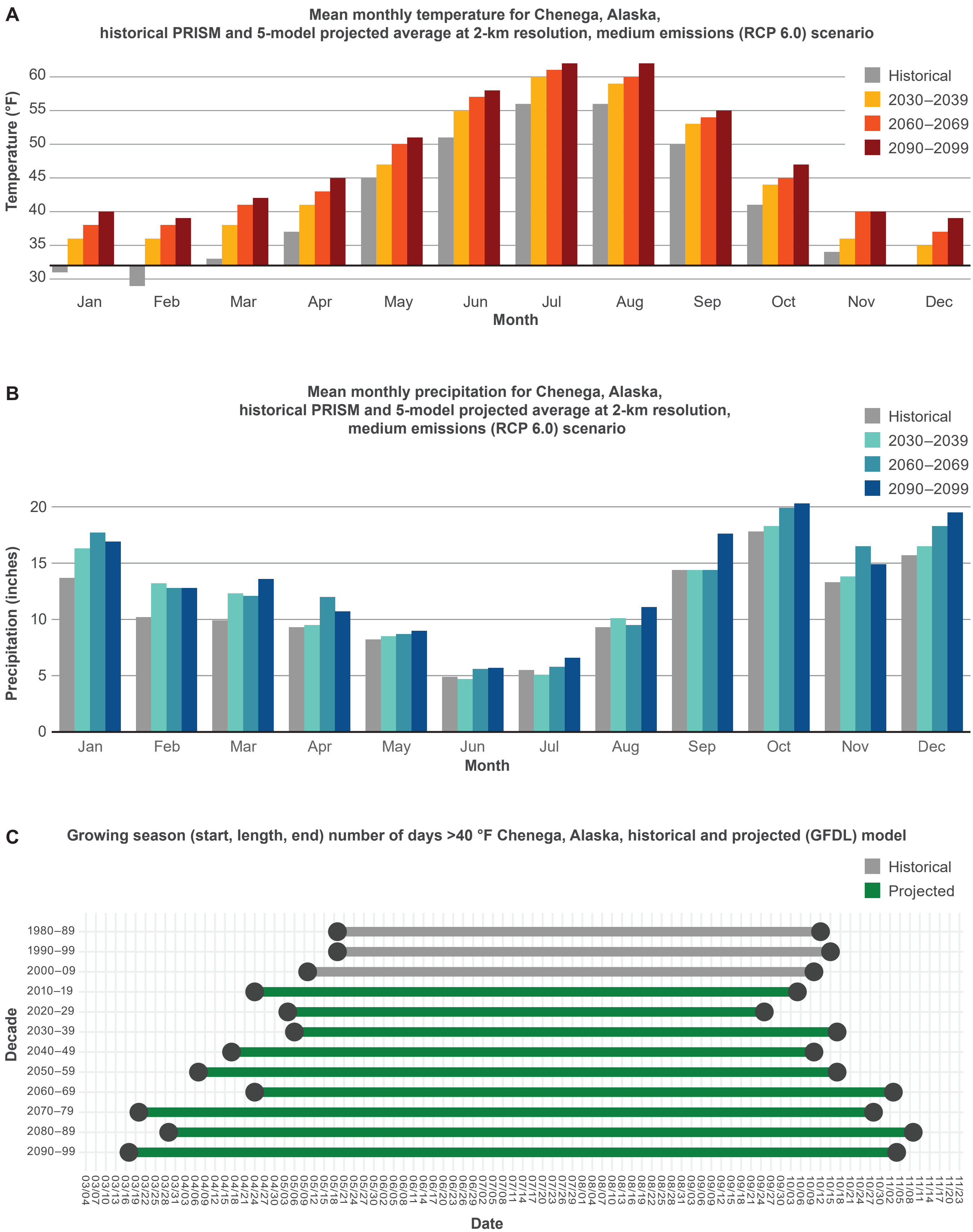

Figure 7—Mean monthly (A) temperatures and (B) precipitation, and (C) the growing season forecasted through 2100 for Chenega, Alaska (adapted from UAF SNAP 2023). Note: plots in charts A and B are useful for examining possible trends over time, not for predicting values. PRISM = Parameter-elevation Regression on Independent Slopes Model; RCP = representative concentration pathway; GFDL = Geophysical Fluid Dynamics Laboratory.

Native Village of Eyak (Cordova)

Cordova is a small fishing community of 2,609 residents, 16 percent of which are full or part Alaska Native (U.S. Census Bureau 2020). Located on the mainland in southeastern Prince William Sound, Cordova lies 84 air km southeast of Valdez and 241 km southeast of Anchorage and is accessible by plane or boat. An 80-km gravel road provides access to the Copper River Delta to the east, although the bridge (58 kilometers from Cordova) collapsed in 2011, and a boat is now needed to access much of the delta.

Cordova has a significant Eyak-Athabascan population with an active tribal council. The Native Village of Eyak is mostly comprised of four distinct Alaska Native peoples (Eyak, Sugpiat, Tlingit, and Athabascan), who are organized together as a federally recognized tribe with 515 enrolled members. The village boundaries are the external boundaries of Alaska Native Claims Settlement Act-selected lands that extend from the coastline 200 miles seaward on the outer continental shelf and encompass Middleton Island. Tribal members are shareholders in other holdings on Hinchinbrook and Hawkins Islands to the south, along Nelson Bay to the north, and in the watersheds of the Sheridan and Copper Rivers, all abutting Chugach National Forest (Native Village of Eyak, n.d.).

Cordova was built on Orca Inlet, at the base of 384-m Mount Eyak. The inlet was previously named "Puerto Cordova" by Spanish explorer Don Salvador Fidalgo in 1790. The town of Cordova was named in 1906 by Michael Heney, who was contracted to build the Copper River and Northwestern Railway. It was at this time that the City of Cordova annexed the last traditional Eyak village. Cordova became the railroad terminus and ocean shipping port for copper ore from the Kennecott Mine, located up the Copper River, which operated until 1938. One of the first producing oil fields in Alaska was discovered at Katalla, 75 km southeast of Cordova, in 1902 and produced until 1933. One of the first salmon hatcheries in Alaska operated on Eyak Lake in the early 1920s. Fishing became the economic base in the early 1940s.

Cordova still supports a large fishing fleet for Prince William Sound and several fish processing plants. Copper River sockeye (red) salmon (*Oncorhynchus nerka*), pink salmon, Pacific herring, Pacific halibut, bottom fish, and other fishes are harvested. The village links directly to the North Pacific Ocean shipping lanes through the Gulf of Alaska and to the rest of Alaska via the Alaska Marine Highway System, state-owned Merle K. "Mudhole" Smith Airport, Cordova Municipal Airport, and Lake Eyak seaplane base. Harbor facilities include a breakwater, dock, small-boat harbor with 850 berths, boat launch and haulout, ferry terminal, and marine repair services (Fay et al. 2005).

Subsistence activities provide most food items, although household consumption of 24 of 25 resources used by Cordova residents has decreased in recent years (fig. 8). In 2014, more than 65 percent of households in Cordova consumed sockeye and coho salmon, Pacific halibut, and moose (fig. 8). The Native Village of Eyak has a subsistence program with full-time staff that hunt, fish, and gather to share resources throughout its constituency but mainly with the village's elders. The subsistence program operates year-round and provides bird eggs, Pacific herring, salmon, seal, and other species. The Native Village of Eyak has a newly renovated fish and game processing facility; the CRRC was able to support the tribe with about $20,000 worth of commercial fish and game processing equipment. The Native Village of Eyak has an active natural resources management program that has been monitoring chinook salmon escapement on the Copper River since 2001. As part of an effort to reduce dependence on diesel for heat production by using a new wood processer, the Native Village of Eyak is thinning alder and spruce to provide more biofuel, while releasing willow to enhance moose browse. The Native Village of Eyak is also in the permitting stage for a kelp farm.

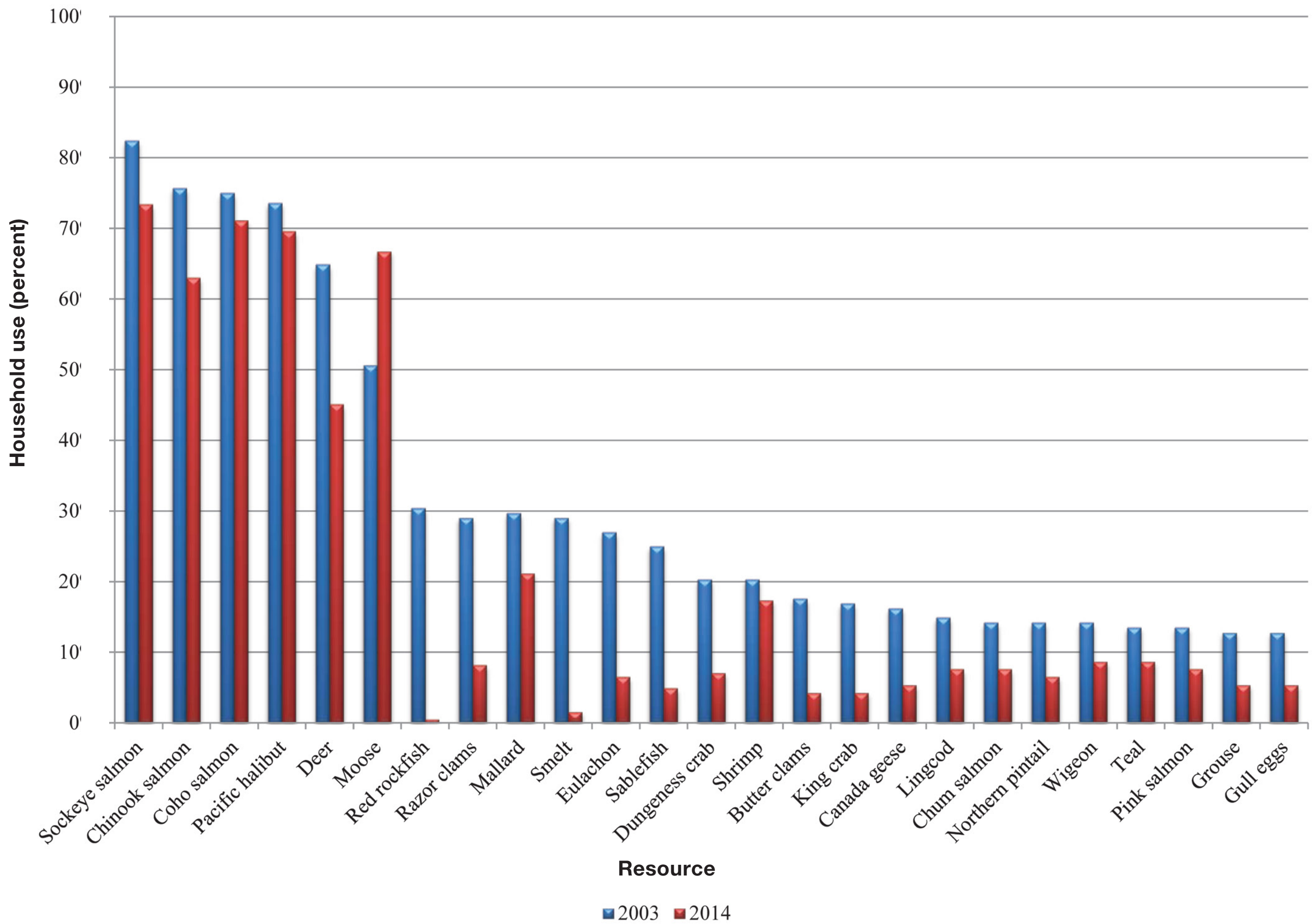

Figure 8—Household use of 25 natural resources by residents of Cordova, Alaska, in 2003 and 2014 (adapted from Fall and Zimpelman 2016).

Forecasted climate data for Eyak suggest that the mean monthly temperature will continue to increase in all months over the remainder of this century, exceeding 15.5 °C (59.9 °F) in July (fig. 9). Mean monthly precipitation will generally increase through the end of this century, but the forecast is highly variable. Winter will decrease from 5 months (November–March) to year-round monthly temperatures averaging above freezing by 2050, suggesting rapidly decreasing snowpack. The current 3.5-month growing season for cool-weather plants, such as kale and peas, is expected to increase to over 5.5 months by 2100, with most of that additional warmer weather in the spring rather than fall (fig. 9).

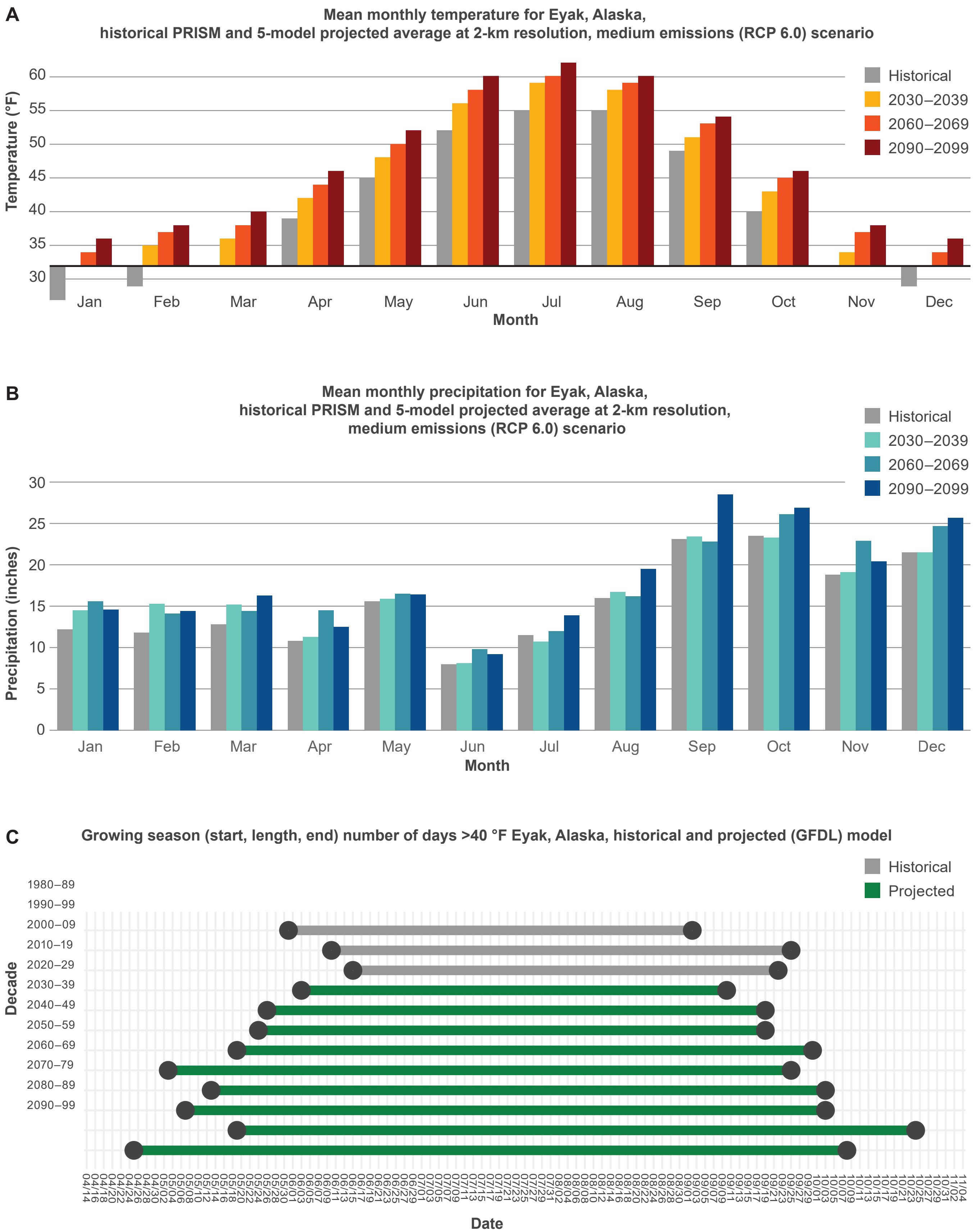

Figure 9—Mean monthly (A) temperatures and (B) precipitation, and (C) the growing season forecasted through 2100 for Eyak, Alaska (adapted from UAF SNAP 2023). PRISM = Parameter-elevation Regression on Independent Slopes Model; RCP = representative concentration pathway; GFDL = Geophysical Fluid Dynamics Laboratory.

Native Village of Nanwalek

The Nanwalek IRA Council governs the Native Village of Nanwalek. Nanwalek, which means "place with a lagoon," is located on the southwestern tip of the Kenai Peninsula on the lower Cook Inlet where the English Bay River flows into English Bay (Sugpiaq Ethnohistory, n.d.). It is 322 km from Anchorage, 56 km southwest of Homer, and 16 km southwest of Seldovia. The English Bay Corporation owns most of the land surrounding Nanwalek, with some Native allotments (land parcels for individual tribal members held in trust by the BIA) and other parcels owned by the Port Graham Corporation and Alaska Department of Natural Resources.

The community has 247 residents, of which 93 percent are full or part Alaska Native (U.S. Census Bureau 2020), mostly of Sugpiat and Russian descent. Fort Alexandrovsk was established here in 1786, which was the second permanent Russian settlement in Alaska and the last fur post on the Kenai Peninsula. During the 1880s, Russian missionaries relocated many Sugpiat from their traditional villages, in what is now Kenai Fjords National Park, to Fort Alexandrovsk (later called English Bay) and to Port Graham. With the end of the Russian period and collapse of the fur trade, commercial fishing for salmon, cod, crab, and shrimp became the dominant cash economy in the 1880s. Commercial fishing and cannery work (initially in Nanwalek but later in Port Graham) were the primary wage sources from 1910 through the 1990s until the Port Graham cannery burned down. In 1998, a new cannery was built but was not profitable and closed after 2 years. By the 2000s, the fishing economy had mostly disappeared from Nanwalek (Jones and Kostick 2016). Currently, there are about 50 houses and community buildings in the village, including a Russian Orthodox Church, a school, an Alaska Native Industries Cooperative Association, Inc. grocery and general store, a post office, a community center, Nanwalek IRA Council buildings, a health clinic, a teen center with a library, and offices for the North Pacific Rim Housing Authority. Between the lagoon and the beach, a narrow landing strip serves as the community's runway for small aircraft.

Subsistence activities provide most food items in Nanwalek, although household consumption of 25 of 25 resources used by Nanwalek residents has decreased in recent years (fig. 10). In 2014, more than 65 percent of households in Nanwalek consumed black Katy chiton (*Katharina tunicata*) (also known as bidarkis); sockeye, pink, and coho salmon; Pacific halibut; and harbor seals (fig. 10). The CRRC partners with Nanwalek, the ADFG, and Alaska Pacific University to monitor salmon returns in English Bay through the Nanwalek Salmon Enhancement Program, which informs the total allowable harvest for Nanwalek, Port Graham, and Seldovia. The CRRC, with support from the CAC, outfitted the community with a commercial fish and game processing facility and a freezer designed to withstand an unreliable power supply.

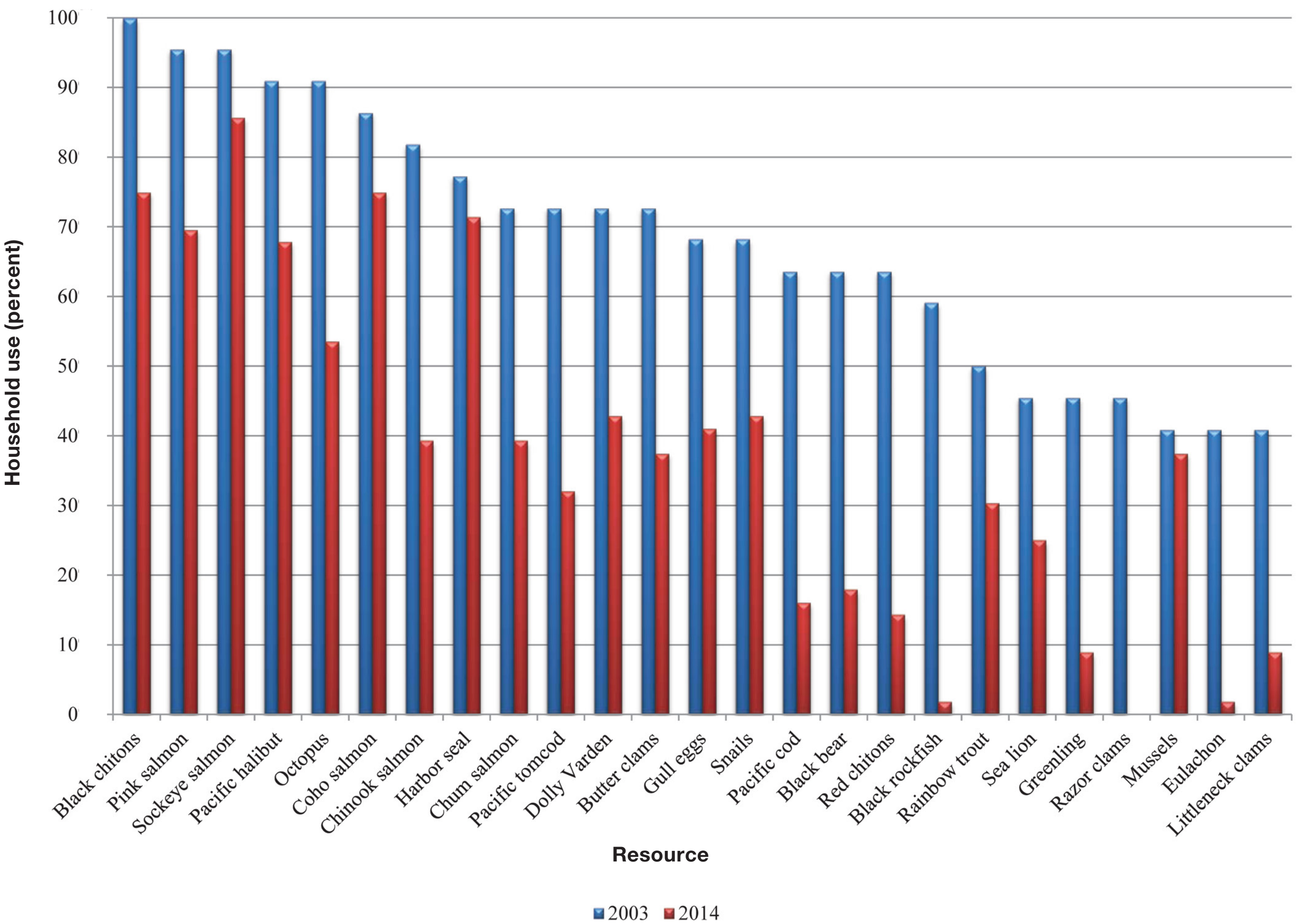

Figure 10—Household use of 25 natural resources by residents of Nanwalek, Alaska, in 2003 and 2014 (adapted from Jones and Kostick 2016).

Forecasted climate data for Nanwalek suggest that the mean monthly temperature will continue to increase in all months over the remainder of this century, exceeding 15.5 °C (59.9 °F) in July and August (fig. 11). Mean monthly precipitation is highly variable through the end of this century, with precipitation increasing in later winter (January–March), remaining essentially the same during spring and summer (April–August), and declining during fall and early winter (September–December). Winter (defined by a mean monthly temperature ≤ 0 °C) will decrease from 5 months (November–March) to 2 months (December–January) by 2060, suggesting rapidly decreasing snowpack. The current 3.5-month growing season for cool-weather plants, such as kale and peas, is expected to increase to 5.5 months by 2100, with most of that additional warmer weather occurring in the spring (fig. 11).

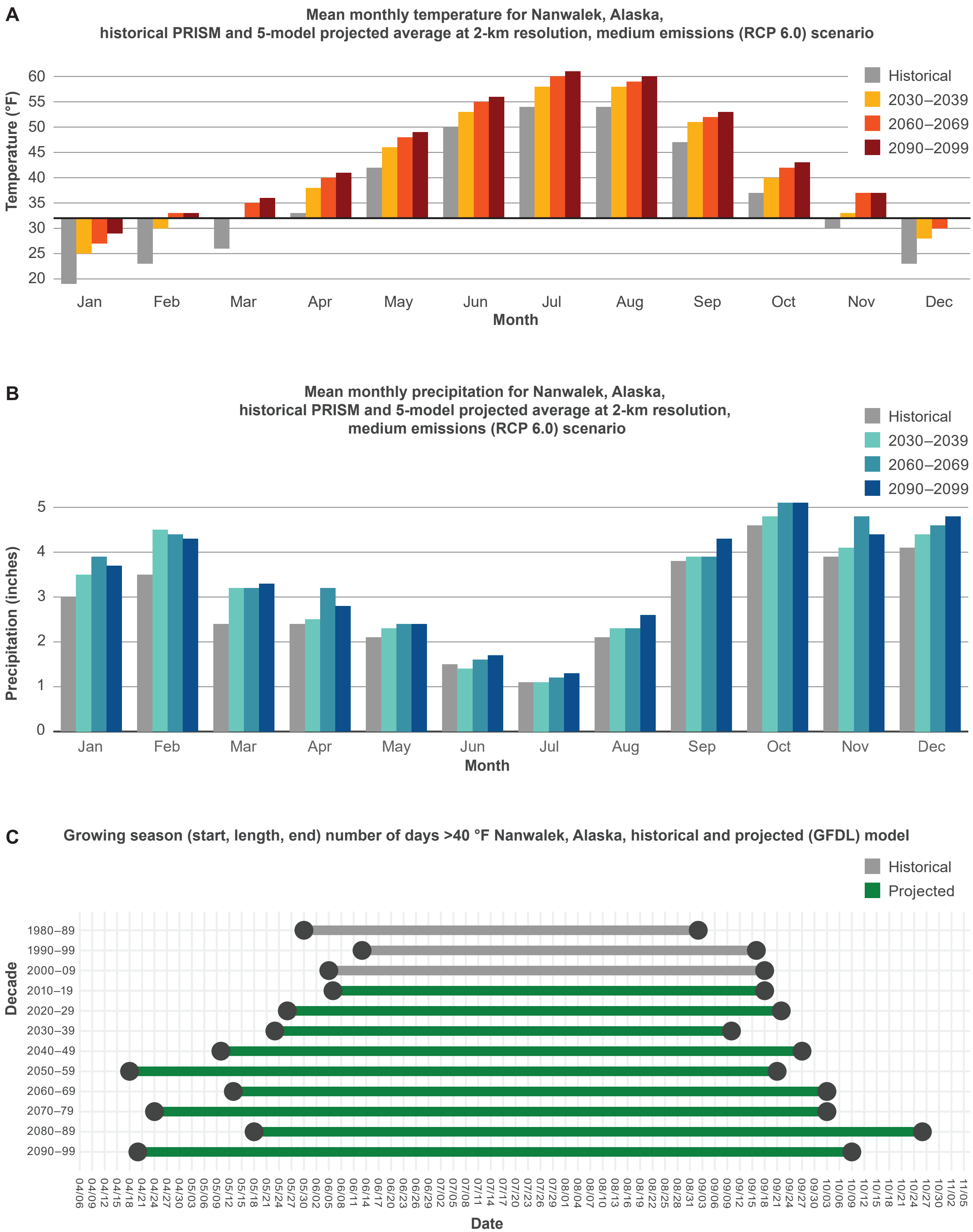

Figure 11—Mean monthly (A) temperatures and (B) precipitation, and (C) the growing season forecasted through 2100 for Nanwalek, Alaska (adapted from UAF SNAP 2023). PRISM = Parameter-elevation Regression on Independent Slopes Model; RCP = representative concentration pathway; GFDL = Geophysical Fluid Dynamics Laboratory.

Native Village of Port Graham

Port Graham (also known as Paluwik) is in Port Graham Bay on the southwestern tip of the Kenai Peninsula. It is 45 km southwest of Homer and 290 km southwest of Anchorage. The Port Graham Tribal Council is a federally recognized Indian tribe, and 93 percent of its 162 residents are full or part Alaska Native, primarily Sugpiat (U.S. Census Bureau 2020). Commuter airlines provide most of the transportation and all mail service between Port Graham and Homer. Port Graham also has a new cordwood biomass system to alleviate the dependence on fuel oil to heat the five community buildings. There is a 4-mile hiking trail between Port Graham and Nanwalek, which will soon be a road to a new airport that is currently under construction. The Port Graham Corporation owns most of the land surrounding Port Graham, with some Native allotments (identified as BIA) and other parcels owned by the English Bay Corporation and Alaska Department of Natural Resources.

Port Graham developed around a fish processing plant and dock that were built in 1910 for processing salmon and Pacific herring. The original cannery burned down in 1960 and was not rebuilt until 1968. It burned down again in 1998 and was rebuilt in 2000. The Port Graham Village Council ran a hatchery for pink and sockeye salmon from 1992–2007; in 2014, the Cook Inlet Aquaculture Association took over the facility to raise pink salmon (Jones and Kostick 2016). Following up on early pilot studies on clam enhancement in the 1990s (Brooks et al. 2001), the CRRC currently is conducting clam enhancement projects at Powder Point and Murphy Slough.

Subsistence activities remain an important component of the community's economy, while employment is primarily with the local school, the tribal council office and community center, the health clinic, the Port Graham cannery and hatchery operation, the community airstrip, and a future facility within the Port Graham Corporation building to display local crafts and history (Chugachmiut, n.d.). Subsistence activities provide most food items in Port Graham, although household consumption of 24 of 26 resources used by Port Graham residents has decreased in recent years (fig. 12). In 2014, more than 65 percent of households in Port Graham consumed black Katy chiton (bidarkis), all five salmon species, Pacific halibut, harbor seal, octopus, and moose (fig. 12). The CRRC, with support from the CAC, outfitted the community with a facility that hosts commercial fish and game processing equipment and a freezer designed to withstand an unreliable power supply. The CRRC has been conducting a project to enhance softshell clam and Nuttall cockle populations on traditional harvesting beaches near the community.

Forecasted climate data for Port Graham suggest that the mean monthly temperature will continue to increase in all months over the remainder of this century, exceeding 15.5 °C (59.9 °F) in July and August (fig. 13). Mean monthly precipitation is highly variable through the end of this century but generally increasing in all months. Winter will decrease from 5 months (November–March) to 2 months (December–January) by 2060, suggesting rapidly decreasing snowpack. The current 3.5-month growing season for cool-weather plants, such as kale and peas, is expected to increase to 5.5 months by 2100, with most of that additional warm weather occurring in the spring (fig. 13).

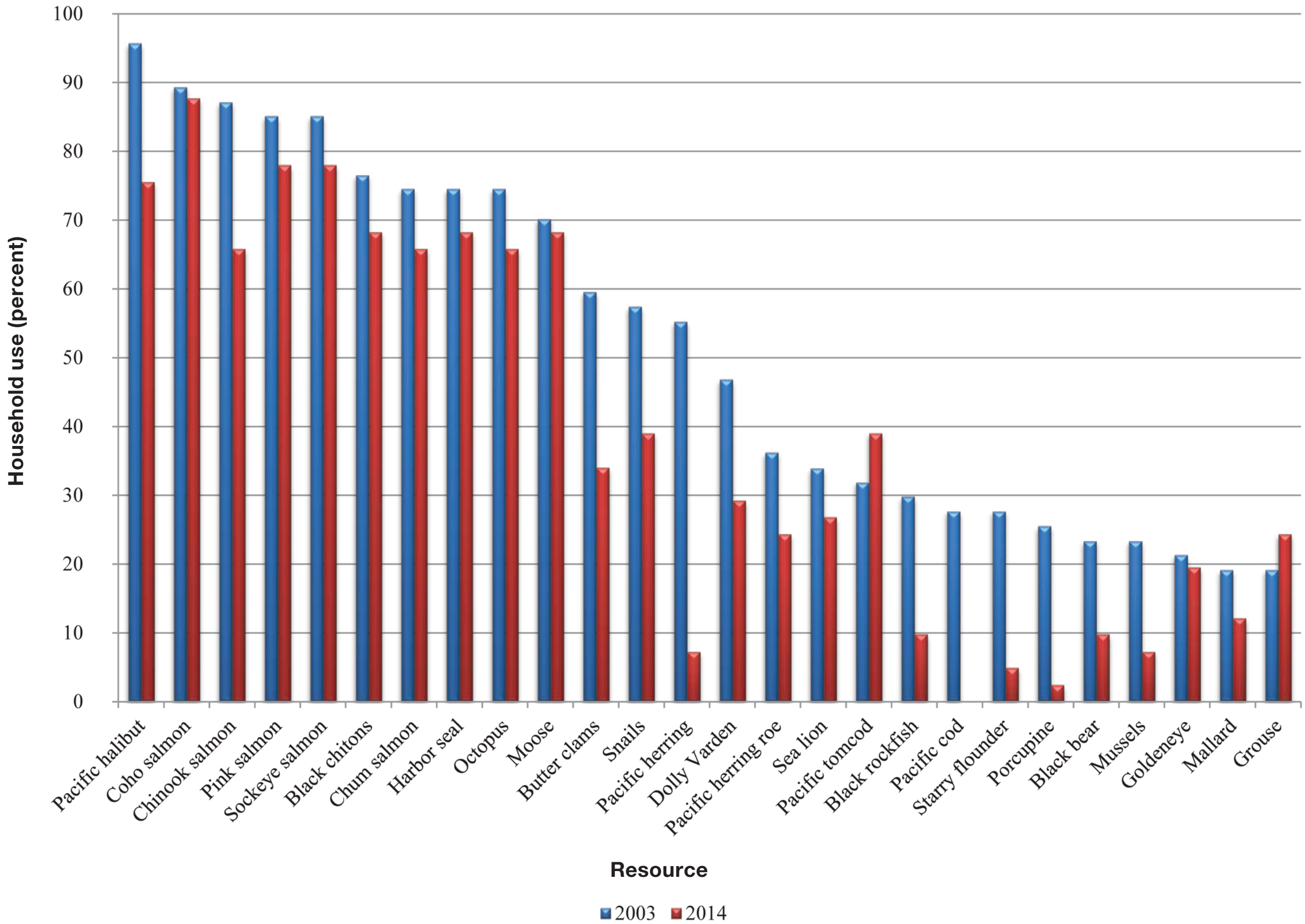

Figure 12—Household use of 26 natural resources by residents of Port Graham, Alaska, in 2003 and 2014 (Jones and Kostick 2016).

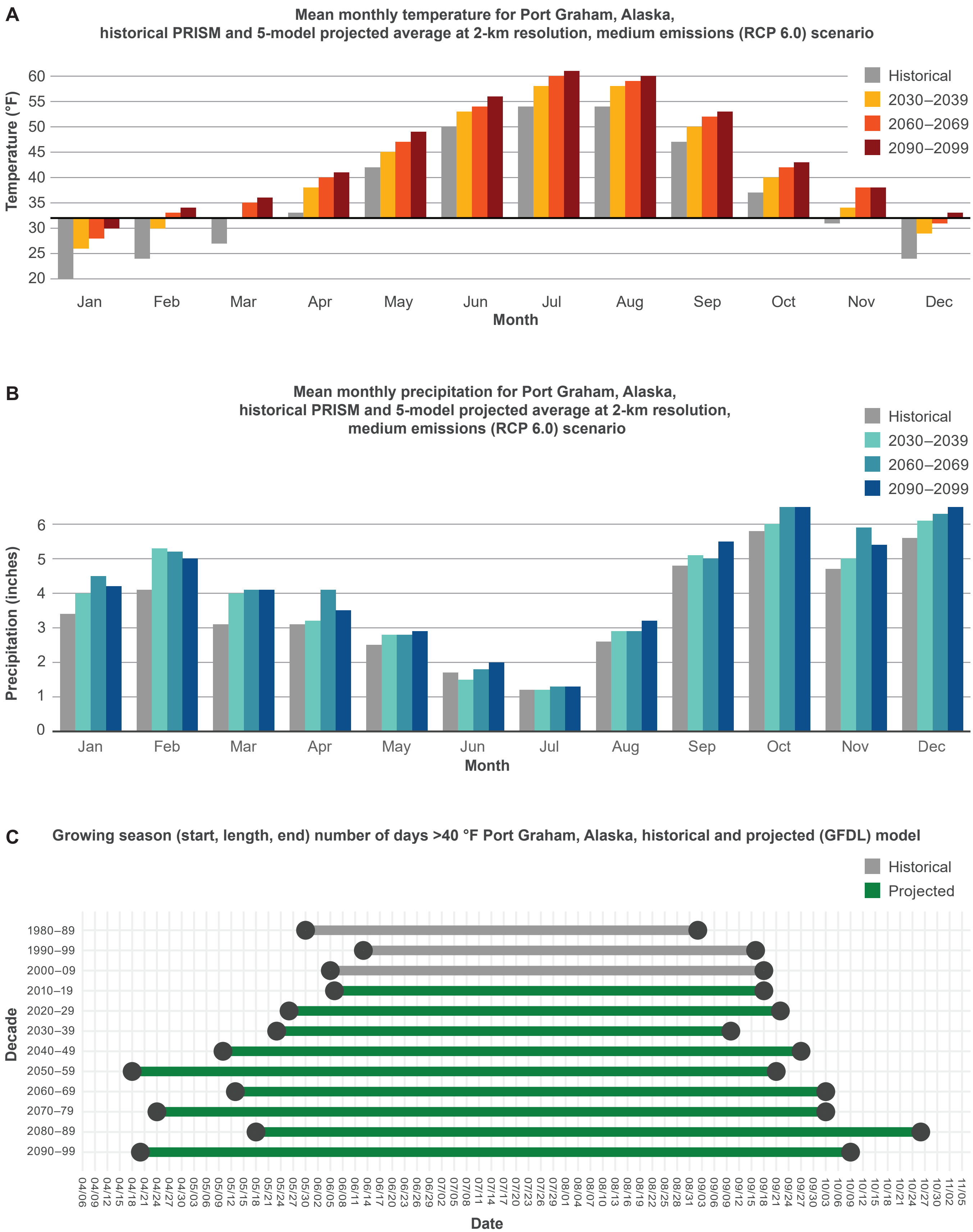

Figure 13—Mean monthly (A) temperatures and (B) precipitation, and (C) the growing season forecasted through 2100 for Port Graham, Alaska (adapted from UAF SNAP 2023). PRISM = Parameter-elevation Regression on Independent Slopes Model; RCP = representative concentration pathway; GFDL = Geophysical Fluid Dynamics Laboratory.

Qutekcak Native Tribe (Seward)

The Qutekcak Native Tribe is an incorporated, nonprofit, 501(c)(3), tribal organization. It is multiethnic and serves the Native community of the Seward area through various social, cultural and community, and economic development programs. In 1972, members of the Seward Native community began the Mount Marathon Native Association. In 1993, the name was changed to the Qutekcak Native Tribe. Nineteen percent of the 2,717 residents in Seward are at least part Alaska Native (U.S. Census Bureau 2020).

Seward is located on the eastern coast of the Kenai Peninsula at the north end of Resurrection Bay. Seward is Alaska's only deep-water, ice-free port with rail, highway, and air transportation to Alaska's interior and major urban population centers. The Seward and Sterling Highways provide paved year-round access to Anchorage, 193 km to the northwest. The Alaska Railroad runs from here to Fairbanks, and it is a major marine terminal for cruise ships. Commercial fishing and seasonal tourism largely drive the local economy.

The site that Seward sits on was known as Qutekcak, which means "big beach" in Alutiiq. At the time of European contact in the late 1700s, this area was inhabited by Alutiiq-speaking people, known as Unegkurmiut, whose descendants now live in Port Graham and Nanwalek. The territory of the Unegkurmiut comprised the entire south coast of the Kenai Peninsula, including Resurrection Bay, where three villages existed in the immediate vicinity of Seward. In 1872, Resurrection Bay became the site of a Russian trading post and shipyard. After European contact, the Unegkurmiut population declined; by 1911, no indigenous communities survived along the outer coast of the Kenai Peninsula. The history of the modern Native community in Seward begins when Frank Lowell and his wife Mary, a Native woman from Nanwalek, settled in this area in 1884. The modern Native population in Seward is composed of people from diverse cultures—Inupiat, Athabascan, Aleut, and Alutiiq. This mix of cultures was largely the result of the establishment of the Jesse Lee Home for Children in Seward in 1925. The orphanage housed children from all over Alaska; many had lost their families and, in some cases, most of their villages, to the 1918–1919 flu pandemic. Since then, residents have formed their own tribal identity based on a shared experience of the Jesse Lee Home and its legacy (Vanderpool 2018).

The BIA does not recognize the Qutekcak Native Tribe, though it has continually sought federal recognition for nearly 30 years (Vanderpool 2018). Lack of federal recognition has prevented the Qutekcak Native Tribe from engaging with surrounding land managers of the Chugach National Forest and Kenai Fjords National Park on a government-to-government basis like Chenega, Tatitlek, Eyak, and other communities that have holdings adjoining the national forest. The federally recognized tribes of the region support the Qutekcak Native Tribe's recognition and help provide tribal services to the QNT by including them as part of the intertribal health and social services compact (Chugachmiut) and intertribal natural resources commission (the CRRC) for the region. The CAC also recognizes and provides support for the Qutekcak Native Tribe and its many shareholders who belong to the tribe.

Seward is home to the Alutiiq Pride Marine Institute (APMI), a division of the CRRC, which has been operating since 1992. While mariculture is the primary focus, APMI also engages in many other facets of marine science. The services provided to tribal members have expanded from traditional shellfish hatchery production of subsistence and mariculture species. APMI now conducts numerous services to tribal citizens, including the Chugach Regional Ocean Monitoring Program, which examines climate conditions, ocean chemistry, harmful algae, and shellfish biotoxin levels to inform safe shellfish harvest and provide comprehensive data on ocean conditions in southcentral Alaska. APMI houses the Qutekcak Native Tribe's 40-foot hydroponics, fish and game processing, and freezer containers to support food sovereignty of the tribe. The Cook Inlet Aquaculture Association's Trail Lake Hatchery near Moose Pass releases sockeye (and some coho) in various places around Seward, including Bear Lake, Bear Creek, and Resurrection Bay.

Seward is in a nonrural area, so residents are not able to participate in federal subsistence hunts in the region, which are reserved for rural residents with customary and traditional use determinations. In 2022, the Federal Subsistence Board changed the designation of Moose Pass and the nearby communities of Crown Pointe and Primrose from nonrural to rural, which expanded hunting and fishing options for some Qutekcak Native Tribe members living outside of Seward proper (McDavid 2021). As a result of Seward's nonrural status, the ADFG Subsistence Division has not focused on research in the community; only one subsistence survey was conducted for Seward and Moose Pass in 2000 (Davis et al. 2003).

Forecasted climate data for Seward suggest that the mean monthly temperature will continue to increase in all months over the remainder of this century, exceeding 15.5 °C (59.9 °F) in July and August (fig. 14). Mean monthly precipitation is highly variable through the end of this century but will generally increase in the fall and winter, but not in the spring and summer (April–July). Winter will decrease from 5 months (November–March) to 2 months (December–January) by 2060, suggesting rapidly decreasing snowpack. The current 3-month growing season for cool-weather plants, such as kale and peas, is expected to increase to almost 6 months by 2100 (fig. 14).

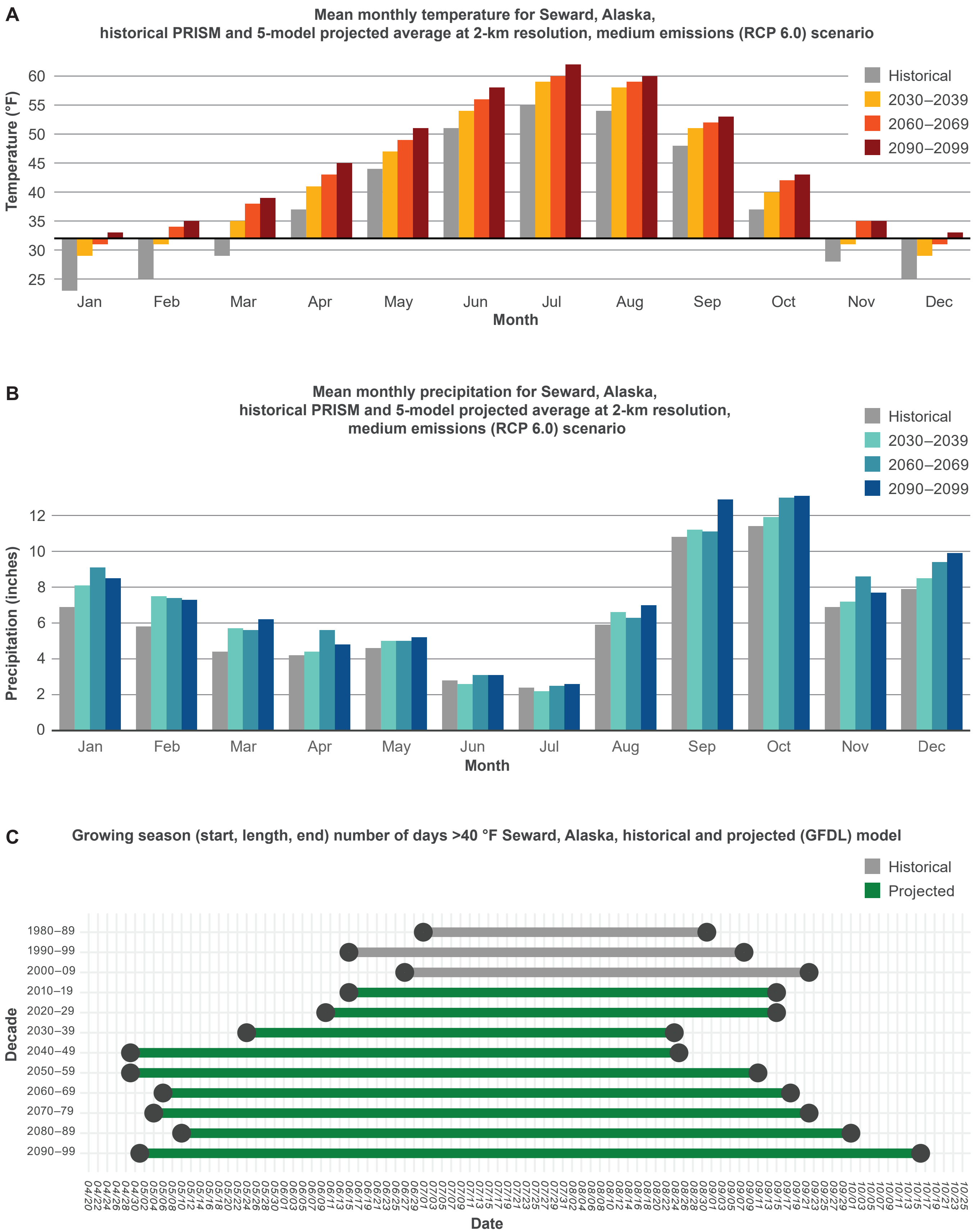

Figure 14—Mean monthly (A) temperatures and (B) precipitation, and (C) the growing season forecasted through 2100 for Seward, Alaska (adapted from UAF SNAP 2023). PRISM = Parameter-elevation Regression on Independent Slopes Model; RCP = representative concentration pathway; GFDL = Geophysical Fluid Dynamics Laboratory.

Native Village of Tatitlek

The Native Village of Tatitlek is located on the mainland in northeastern Prince William Sound, 48 km south of Valdez, Alaska, among Sitka spruce and hemlock on the northeastern shore of Tatitlek Narrows. Tatitlek means "windy place," and it sits on a relatively flat, 1-mile strip of land between Galena Bay and Boulder Bay within the Chugach National Forest. Above Tatitlek rises Ellamar Mountain (930 m elevation), part of the Chugach Mountains that form an impassable range to the north. Tatitlek has a state-owned lighted gravel airstrip and a seaplane landing area, and air charters are available from Anchorage, Cordova, and Valdez. Boats are the primary means of local transportation, and the U.S. Army Corps of Engineers recently constructed a breakwater and small boat harbor.

Tatitlek has 90 residents, 82 percent of which are full or part Alaska Native (U.S. Census Bureau 2020). The Tatitlek IRA Council, formed in 1934 and based on traditional values and beliefs, governs the Native Village of Tatitlek. The Tatitlek IRA Council owns and operates local utilities, including electricity, water, sewer, and solid waste disposal, and manages and administers all programs and projects in the community. Tatitlek is within the Tatitlek Corporation, an Alaska Native village corporation established by the Alaska Native Claims Settlement Act (ANCSA 1971). It is one of five village corporations within the geographic boundaries of the CAC (Tatitlek Corporation 2019).

The Tatitlek Corporation owns more than 62 726 ha, much of which abuts or falls within the Chugach National Forest, including two Native allotments. A land sale program resulting from the Exxon Valdez oil spill complicates the land status of the area. Tatitlek sold some of their surface estate under the Exxon Valdez oil spill program. The USDA Forest Service was deeded a conservation easement to land sold to the state; conversely, the state was deeded a conservation easement to land sold to the USDA Forest Service. Tatitlek also retained certain conservation easements and other special development easements. As a result, there are four owners of land rights on Tatitlek Corporation lands—the U.S., the state of Alaska, the Tatitlek Corporation, and the CAC. The CAC holds the subsurface estate, but they must coordinate with other land right holders of the surface estate because of certain restrictions should they choose to develop it (Smith 2021).

Russian-American Company records mention Tatitlek as early as 1847. Beginning in the 19th century, Tatitlek's residents traded sea otter pelts with Russians in the neighboring village of Nuchek. By the 1890s, they were trading with Americans at the Alaska Commercial Company store in Tatitlek. A copper mine (1898–1913) and a cannery (1940–1954) at nearby Ellamar provided income for Tatitlek residents during the previous century. In 1989, the oil tanker Exxon Valdez ran aground 2 miles from Tatitlek (Tatitlek Corporation 2019).

Today, a subsistence lifestyle continues to be an important part of Tatitlek's culture and economy. Commercial salmon and halibut fishing and fish processing are means of employment for some residents. Subsistence activities provide most food items, although household consumption of 25 of 26 resources used by Tatitlek residents has decreased in recent years (fig. 15). In 2014, more than 65 percent of households in Tatitlek consumed sockeye and coho salmon, Sitka black-tailed deer, Pacific halibut, and harbor seal (fig. 15). Tatitlek IRA Council has a multipurpose mariculture building in the community that was designed and built in the early 1990s to support the expanding mariculture industry. Efforts are underway to assess the status of the building and if and how it may support kelp efforts in Prince William Sound. Net pens for pink salmon are maintained in Boulder Bay. The CRRC received emergency funds during the COVID-19 pandemic to purchase more than $20,000 of commercial fish

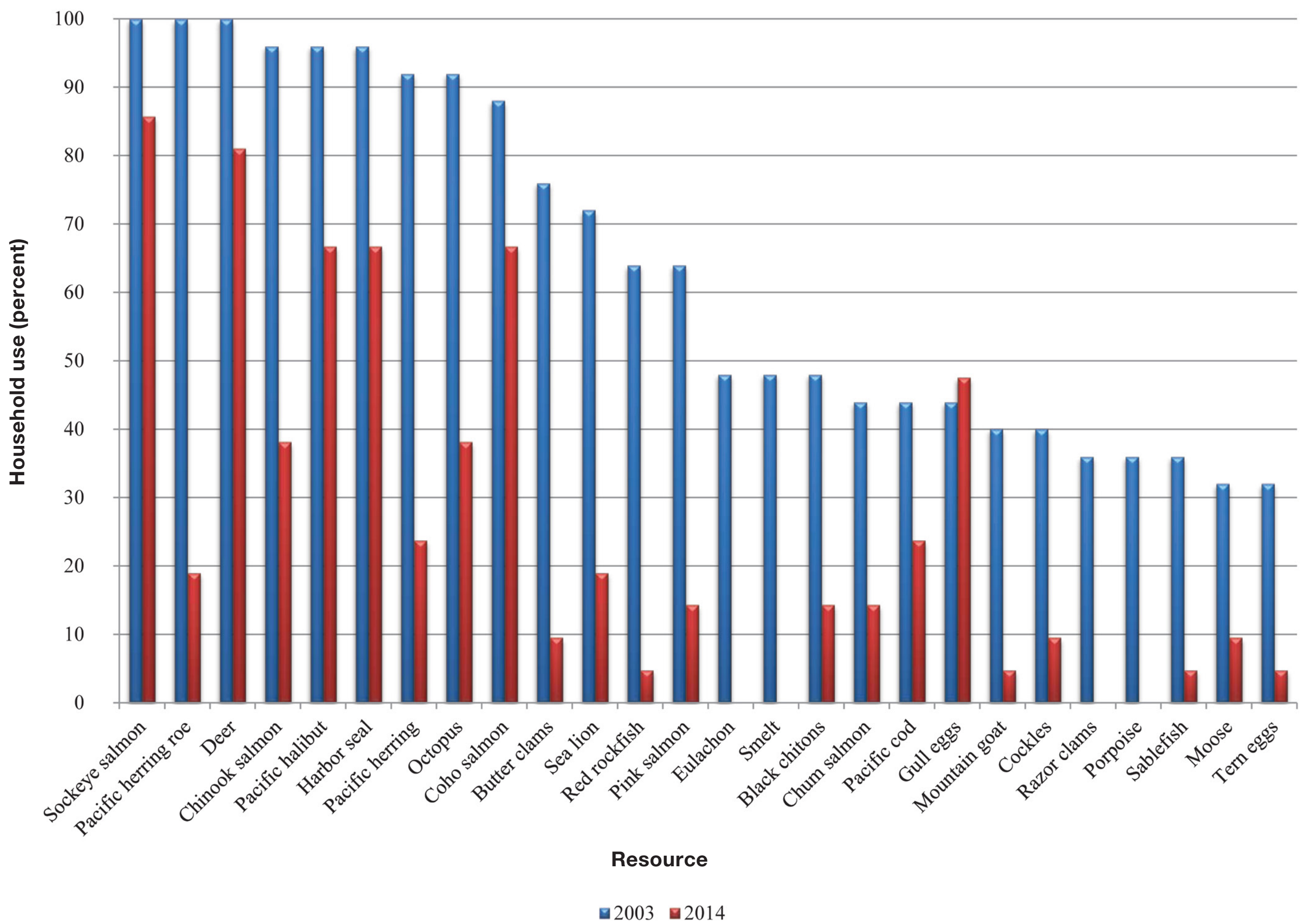

Figure 15—Household use of 26 natural resources by residents of Tatitlek, Alaska, in 2003 and 2014 (Fall and Zimpelman 2016).

and game processing equipment for the mariculture building as well as a freezer facility to keep fish and game fresher for longer.

Forecasted climate data for Tatitlek suggest that mean monthly temperature and precipitation will continue to increase in all months over the remainder of this century, exceeding 15.5 °C (59.9 °F) in July and nearing 50 cm (19 inches) of rain in September (fig. 16). Winter will decrease from 5 months (November–February) to 2 months (December–January) by 2060, suggesting a significantly reduced snowpack. The current 4-month growing season for cool-weather plants, such as kale and peas, is expected to increase by about one month in the spring over the next 50 years and a second month in the fall by 2100 (fig. 16).

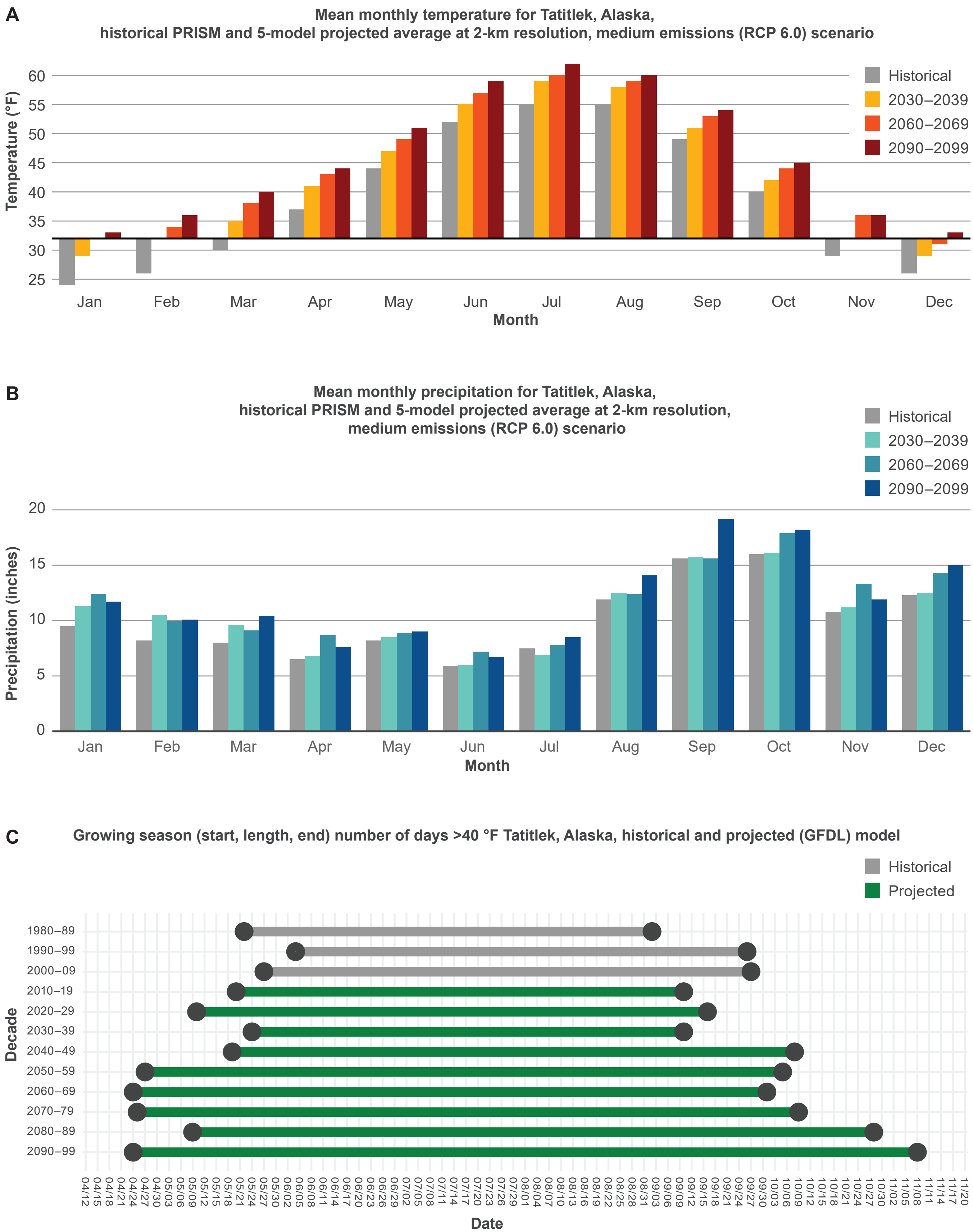

Figure 16—Mean monthly (A) temperatures, (B) precipitation, and (C) the growing season (>40 °F) forecasted through 2100 for Tatitlek, Alaska (adapted from UAF SNAP 2023). PRISM = Parameter-elevation Regression on Independent Slopes Model; RCP = representative concentration pathway; GFDL = Geophysical Fluid Dynamics Laboratory.

Valdez Native Tribe

The Valdez Native Tribe, formed in 1974, is the 501(c)(3) tribal organization representing over 700 individuals from 200 households in Valdez, Alaska (Valdez Native Tribe 2021). Of the 3,985 residents in Valdez, 14 percent are at least part Alaska Native (U.S. Census Bureau 2020).

Located at a latitude of 61°7′51″ N, Valdez is the northernmost port in North America that is ice-free year-round. Coincidentally, it is the northernmost point of the coastal temperate rainforest in North America, although it has a subarctic climate. Situated at the head of Valdez Arm, a fjord on the mainland of northern Prince William Sound, Valdez is surrounded by the Chugach Mountains (1828 m elevation) in Chugach National Forest. The town is on the delta of Mineral Creek and the glacial outwash plain from Valdez Glacier.

Valdez was named in 1790 after the Spanish Navy Minister Antonio Valdés y Fernández Bazán. The town developed during the 1898 Gold Rush as part of a scam to attract prospectors looking for an easier route to the Klondike. The port languished until the Richardson Highway was constructed to Fairbanks in 1899. In 1901, the town was formally incorporated as Valdez. Valdez suffered catastrophic damage during the 1964 earthquake and was relocated from the east side to the north side of Port Valdez in 1967. The terminal of the Trans-Alaska Pipeline that runs from Prudhoe Bay to Valdez was completed in 1977. The 1989 Exxon Valdez oil spill happened shortly after the tanker left the terminal, 40 km away on Bligh Reef. Although the oil did not reach Valdez, it devastated marine life in much of the surrounding area. Connected to Anchorage and Fairbanks by road and air, Valdez is one of the most important ports in Alaska for both freight and commercial fishing.

The federal government does not recognize the tribal status of the Valdez Native Tribe. Lack of federal recognition has prevented the Valdez Native Tribe from engaging with land managers of the Chugach National Forest on a government-to-government basis like Chenega, Tatitlek, and Eyak that have holdings within or adjoining the national forest. The federally recognized tribes of the region support the Valdez Native Tribe's sovereignty and include the Valdez Native Tribe as part of the intertribal health and social services compact (Chugachmiut) and intertribal natural resources commission (CRRC) for the region. The Valdez Native Tribe recently received two, 40-foot containers—one for fish and game processing and one for freezing—to support food sovereignty of the tribe. The CAC also recognizes and provides support for the Valdez Native Tribe and its many shareholders who belong to the tribe. One important facility in Valdez is the Solomon Gulch Hatchery, operated by the Valdez Fisheries Development Association, Inc. since 1981, which is permitted to release 270 million pink and 2 million coho salmon annually; commercial purse seines harvest most returning salmon (Valdez Fisheries Development Association 2022).

Of the seven tribal communities, Valdez is forecasted to have the least change in climate and remain the coldest (fig. 17). Mean monthly temperature will continue to increase in all months over the remainder of this century, reaching 15.5 °C (59.9 °F) in July. Mean monthly precipitation is highly variable through the end of this century, with a long-term trend not as apparent as it is with the other communities. Winter will decrease from 5 months (November–March) to 4 months (November–February) by 2060. The current 3-month growing season for light frost-hardy plants, such as barley and sunflowers, is expected to increase to almost 6 months by 2100 (fig. 17).

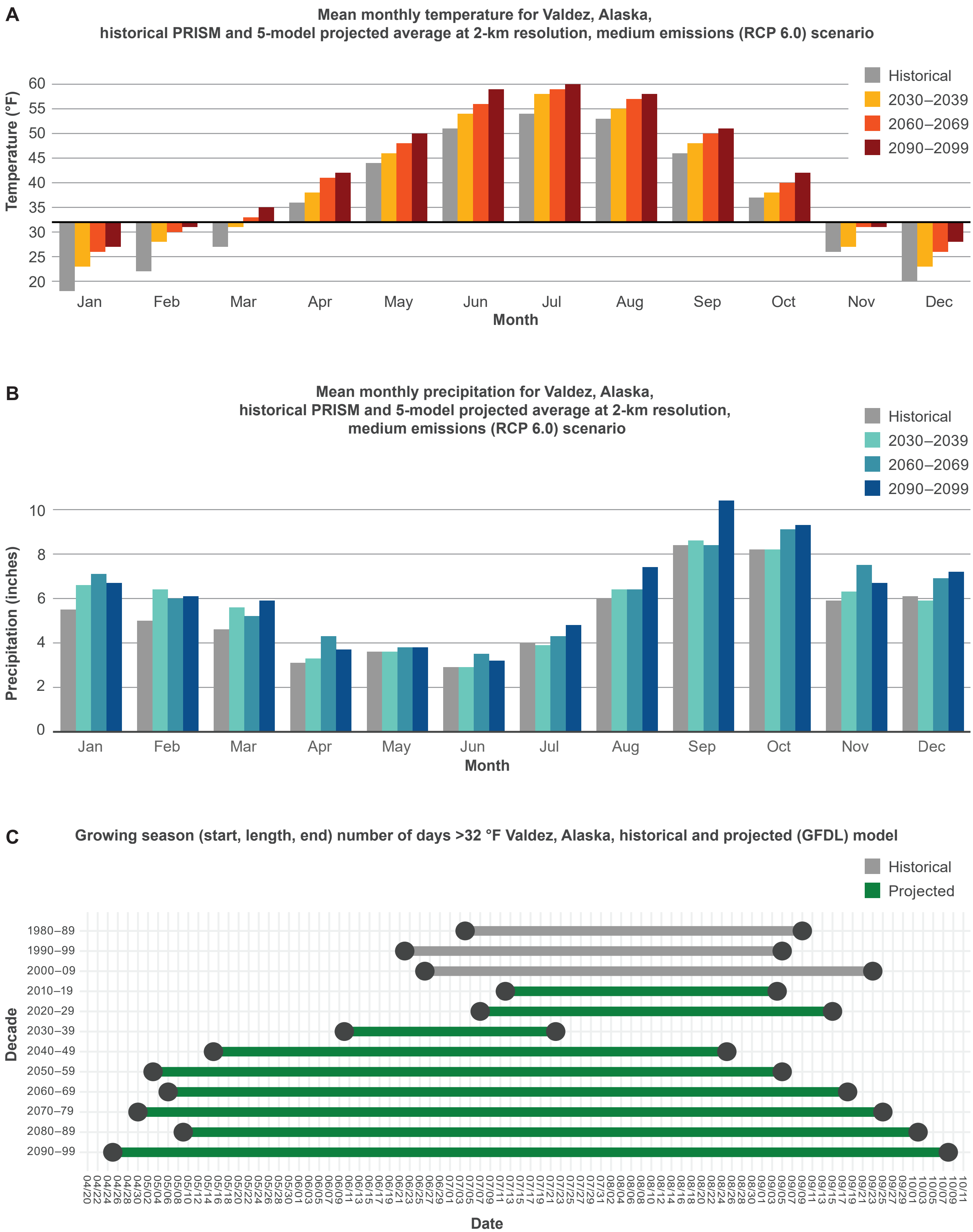

Figure 17—Mean monthly (A) temperatures and (B) precipitation, and (C) the growing season forecasted through 2100 for Valdez, Alaska (adapted from UAF SNAP 2023). PRISM = Parameter-elevation Regression on Independent Slopes Model; RCP = representative concentration pathway; GFDL = Geophysical Fluid Dynamics Laboratory.

Assessment of Vulnerabilities of Seven Representative Species to Climate and Nonclimate Stressors

Fay et al. (2005) found strong evidence of the continuing importance of subsistence harvests and uses of fish and wildlife resources in communities within Prince William Sound. Virtually every household in each community used subsistence resources, and most households engaged in harvest activities and were involved in sharing. Sharing is a critical tradition among tribal communities for coping with ecological fluctuations in species abundance (West and Ross 2012). Indeed, resource consumption within these seven tribal communities is variable because of annual variation in weather and snowpack, changing ocean currents, changing community members (i.e., those who harvest), changing technologies, and the cascading effects of changing trophic structure. In one case study, Salomon et al. (2007) illustrate how recent declines of black Katy chiton (bidarkis) populations around Port Graham and Nanwalek were preceded by the serial depletion of other benthic marine invertebrates (i.e., sea urchin, crab, clams, and cockles), starting in the 1960s. The timing of these declines coincided with changes in human behavior (from seminomadic to increasingly permanent settlement patterns, improvements in extractive technologies, commercial exploitation of regional crustaceans, and erosion of culturally based season and size restrictions) and with the reestablishment of sea otters.

Appendix 2 lists more than 140 species of animals and plants that Alaska Natives consumed for food and other uses in 2014, based on surveys conducted in Chenega, Cordova, Tatitlek (Fall and Zimpelman 2016), Port Graham, and Nanwalek (Jones and Kostick 2016). Although residents from communities in both Prince William Sound and Cook Inlet used 76 percent of species, there were some notable differences that appeared to reflect disparate species distributions and relative abundance in these two regions. At least one resident in Port Graham or Nanwalek used softshell clams, birch (*Betula* spp.) sap, chaga (*Inonotus obliquus*), and Arctic char (*Salvelinus alpinus*), all mostly restricted to the Kenai Peninsula. In contrast, bison (*Bison bison*) (presumably from the Copper River or Chitina River herds) and seven species of rockfish (*Sebastes* spp.) were uniquely harvested by at least one resident in Prince William Sound but not on the Kenai Peninsula. Reported harvest of ruffed grouse (*Bonasa umbellus*), red huckleberry (*Vaccinium parvifolium*), elk (*Cervus canadensis*), and bowhead whale (*Balaena mysticetus*) in appendix 2 suggests sharing with tribal communities elsewhere or extended trips to harvest elsewhere in Alaska. Lastly, this list includes several species that are not native to Prince William Sound or the Kenai Peninsula but have been introduced in modern times, including softshell clams (native to the Atlantic Ocean), Sitka black-tailed deer (native to southeast Alaska), common plantain (*Plantago major*) (native to Eurasia), and northern pike (*Esox lucius*) (native to the Yukon River basin). Also, although there are native dandelion species in both regions, it is likely that the dandelions harvested were *Taraxacum officinale*, the most common species, albeit not native to North America.

The importance of subsistence to food security in the Chugach region can be observed by looking at the annual per capita harvests in pounds (or kilograms) of usable weight by resource category averaged over all years (since 1985) that surveys were conducted for each of seven communities: Chenega (n = 10), Cordova (n = 8), Nanwalek (n = 9), Port Graham (n = 9), Seward (n = 2), Tatitlek (n = 9), and Valdez (n = 2) (ADFG 2022). Of the 97 kg (214 lb) of wild foods harvested annually per person, 68 percent was either salmon (41.6 kg [92 lb]) or nonsalmon fish (25.2 kg [56 lb]). Land and marine mammals (12.3 and 10.1 kg [27 and 22 lb], respectively) contributed 22 percent to total per capita harvest. The remaining 10 percent of harvested biomass comprised marine invertebrates (4.8 kg [11 lb]), vegetation (3.5 kg [8 lb]), and birds and eggs (1.0 kg [2 lb]) (figs. 18 and 19). Although fish and mammalian red meat are indeed important food resources based on weight, this crude analysis overlooks the importance of the seasonal availability of certain foods at critical times, such as bird eggs in early spring or berries in late fall. Additionally, this doesn't highlight community differences in harvest that reflect local availability. For example, in 2014, more than two-thirds of households in Nanwalek and Port Graham used black Katy chiton (bidarkis), more than three-quarters of households in Chenega and Tatitlek used deer, and two-thirds of households in Eyak used moose (figs. 6, 8, 10, 12 and 15). Households that use a resource may harvest that resource themselves or might receive that resource from another household or community.

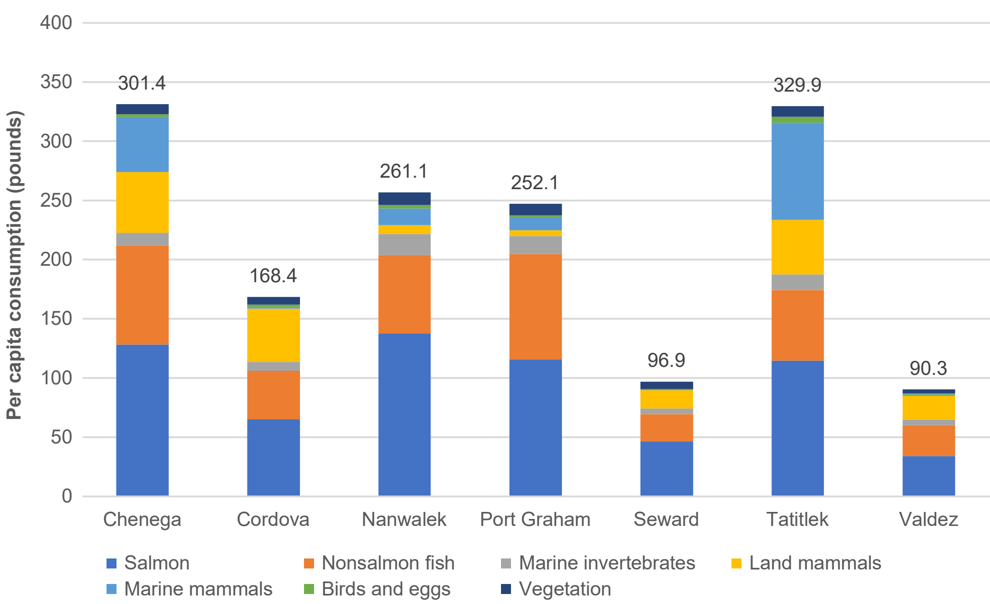

Figure 18—Mean per capita consumption of wild foods (useable weight) in seven resource categories by tribal members in seven Chugach region communities, 1985–2017 (adapted from ADFG 2022).

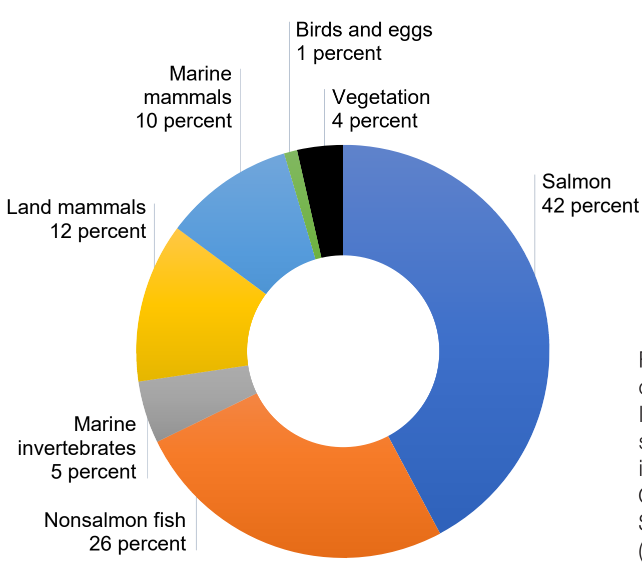

Figure 19—Composition of per capita harvest of wild foods (214 lb useable weight) averaged for seven Alaska Native communities in the Chugach region: Chenega, Cordova, Nanwalek, Port Graham, Seward, Tatitlek, and Valdez (ADFG 2022).

Assessing the vulnerability of the more than 140 fish, wildlife, and plant species is beyond the scope of this report. Instead, we selected one representative species from each of the seven resource categories for review. We chose pink salmon, black oystercatcher (*Haematopus bachmani*), and Sitka black-tailed deer to represent salmon, birds and eggs, and land mammals, respectively, because they were part of the original Chugach National Forest vulnerability assessment (Hayward et al. 2017). Shining a different light on these three species from a subsistence perspective is an opportunity to show how a different context might change the assessment of vulnerability. We selected the other species, harbor seal (marine mammal), blueberry (*Vaccinium* spp.) (vegetation), Pacific razor clam (*Siliqua patula*) (marine invertebrate) and eulachon (*Thaleichthys pacificus*) (nonsalmon fish) because they are important as traditional foods and a reasonable body of literature exists about them. Collectively, these selected species demonstrate the complexity of how climate and nonclimate stressors interact and their cascading ecological effects: harbor seals feed on eulachon and pink salmon, pink salmon feed on pelagic sea snails that are already experiencing acidification effects, the same tectonic uplift that destroyed razor clams benefited black oystercatchers, and introduced Sitka black-tailed deer browse on native blueberry plants during the winter. The Sugt'stun (the language of the Sugpiaq people) and dAXunhyuuga' (the language of the Eyak people) names for these seven species are provided below in parentheses.

Salmon: Pink Salmon (Sugt'stun: Amartuq, Amaqaayak; dAXunhyuuga': Giyah SdilahL, Kaashk')

The 2017 Chugach National Forest vulnerability assessment suggests that pink salmon in Prince William Sound and the Kenai Peninsula are likely to increase in a warming climate (Chilcote et al. 2017). Indeed, during 1986–2012, higher temperatures were associated with more fish and lower temperatures were associated with fewer fish; furthermore, wild pink salmon return closely tracked values for the Pacific Decadal Oscillation during most of that time series. Modeling of this air temperature relationship indicates that pink salmon abundance is likely to increase 26 percent (geometric mean) in Prince William Sound and the Kenai Peninsula under both A2 and A1B climate emission scenarios. A review of salmon harvest in the North Pacific shows that pink salmon production continued to increase overall since 1990 (Irvine and Fukuwaka 2011).

However, Irvine and Fukuwaka (2011) also caution that many pink salmon in the North Pacific are of hatchery origin and, moreover, parameters other than catch should be examined when assessing climate vulnerability at smaller scales. With respect to the first point, hatcheries accounted for 37 million pink salmon harvested in Prince William Sound in 2015 (PWSAC, n.d.). During 2013–2015, 55–86 percent of the 50–142 million pink salmon in the annual preharvest runs in Prince William Sound were of hatchery origin, released by the Armin F. Koernig, Wally Noerenberg, Cannery Creek, and Solomon Gulch Hatcheries (Knudsen et al. 2021). The two hatcheries in Chenega and Port Graham alone are permitted to release 274 million (combined) pink salmon eggs annually. Yet, the proportion of households reporting pink salmon use in Chenega, Cordova, Nanwalek, Port Graham, and Tatitlek declined in all five communities between 2003 and 2014 (figs. 6, 8, 10, 12 and 15). Mean annual per capita harvest of pink salmon during 1985–2014 varied from 0.23 kg in Seward to 16.3 kg in Nanwalek (ADFG 2022).

While hatcheries can help sustain high harvest levels, they can also mask more regional- and local-scale changes in spawning and survivorship of native stock (Knudsen et al. 2021).

In fact, Hilborn and Eggers (2000) suggest that the hatchery program in Prince William Sound replaced rather than augmented wild production, most likely because of the declining wild escapement associated with harvesting hatchery stocks and biological impacts of hatchery fish on wild fish. In the most comprehensive study to date in Prince William Sound, Knudsen et al. (2021) found that although commercial fisheries harvested 94–99 percent of hatchery-raised pink salmon during 2013–2015, an estimated 0.8–4.5 million hatchery pink salmon still strayed into spawning streams annually.

In the longer term, Chilcote et al. (2017) found that watersheds with pink-chum salmon systems in Prince William Sound and the Kenai Peninsula were the most vulnerable (n = 40) to climate change because of reductions in coastal snowpack over the next 60 years (although they are also the most common in the project area), and this analysis did not include the expected retreat of most glaciers. Increasing air temperatures may be favorable when pink salmon are in marine waters, but temperatures may also reach sublethal and lethal levels in nonglacial streams used for spawning. Maximum weekly water temperatures of nonglacial streams flowing into Cook Inlet, for example, have routinely exceeded established criterion for spawning and incubation (13 °C) in July, an event likely to increase in duration and frequency over the next 60 years (Mauger et al. 2016). In fact, during the 2019 drought on the western Kenai Peninsula, water temperatures in all monitored streams exceeded values not forecasted until 2069 (Mauger 2021).

Lastly, ocean acidification may negatively affect pink salmon, albeit indirectly, more than other salmon in the assessment area. Pelagic sea snails (pteropods) on the North American west coast are already displaying dissolution under current conditions (Cai et al. 2021), and pteropods make up a significant and variable fraction of juvenile pink salmon diets (Mathis et al. 2014). The CRRC's APMI is participating in the Tipping Point Project, an interagency effort to assess the effects of ocean acidification on pink salmon in Alaska. The cumulative effect of these stressors on pink salmon populations is likely to be negligible over the short term but may become increasingly negative in the foreseeable long term.

Marine Mammals: Harbor Seal (Sugt'stun: Isuwiq, dAXunhyuuga': GeeLtaaq)

Harbor seals ranked among the top 25 resources used by residents in Chenega, Nanwalek, Port Graham, and Tatitlek (figs. 6, 10, 12 and 15); up to 95 percent of households in one community (Tatitlek in 2003) used them. However, household use of harbor seals declined from 2003 to 2014 in all four communities. Mean annual per capita harvest of harbor seals during 1985–2014 varied from 0.4 kg in Valdez to 27.4 kg in Tatitlek (ADFG 2022).

Harbor seal numbers were declining in the Gulf of Alaska, including Prince William Sound, before the Exxon Valdez oil spill, in part, to prey regime shifts (Anderson and Piatt 1999). Harbor seals in eastern and central Prince William Sound declined by 63 percent between 1984 and 1997 and by about 3 percent per year since then (Frost et al. 1999, Ver Hoef and Frost 2003). Populations are estimated to be over 44,000 in Prince William Sound and 28,000 in Cook Inlet; however, the former is declining by 200 seals per year and the latter is declining by 111 seals per year (Muto et al. 2020). During roughly this same period (2007–2018), the body condition of harbor seals in the Aleutian Islands declined annually; this is attributed to declining Bering Sea ice extent and to recent rapid changes brought on by the significant Northeast Pacific marine heat wave of 2014–2016 and its lingering effects through 2018 and 2019 (Boveng et al. 2020).

The Exxon Valdez oil spill affected harbor seal habitats, including key haulout areas and adjacent waters in Prince William Sound. Estimated mortality as a direct result of the oil spill was about 320 seals in oiled parts of Prince William Sound (Frost et al. 1994). Based on 18 aerial surveys conducted at trend-count haulout sites in central Prince William Sound before (1988) and after (1989) the oil spill, seals in oiled areas declined by 43 percent compared to an 11-percent decline in unoiled areas. A study of 25 sites over 10 years in Prince William Sound indicated a 3.3 percent decrease per year over the period (Ver Hoef and Frost 2003).

Harbor seals live in coastal habitats but frequently enter freshwater rivers and inlets to forage. Although they show relatively high site fidelity, they may also move several hundred kilometers offshore to forage for days, returning to the same or nearby haulouts. Satellite tagging studies sponsored by the trustee council and genetic studies carried out by the NOAA National Marine Fisheries Service indicate that harbor seals in the sound are largely resident throughout the year and have limited movement and interbreeding with other subpopulations in the northern Gulf of Alaska. This suggests that recovery must come largely through recruitment and survival within resident populations.

Harbor seals appear to exhibit plasticity in their use of habitats during life history events (Womble et al. 2021). During the pupping season in June, harbor seals take advantage of ice in fjords that slough off from tidewater glaciers. Floating ice affords a safer and warmer environment for pups than land, but the foraging niche is narrower and more focused on pelagic prey species. In contrast, from September through April, after seals are done reproducing and molting, they are not as constrained, and fidelity to ice is reduced; seals travel much more extensively outside of tidewater glacier fjords and shift to a more diverse diet with relatively more benthic fish species (Smith et al. 2019).

Factors contributing to the decline in harbor seal abundance may involve environmental changes in the 1970s that diminished quantity and quality of prey. It is possible that the changes in the availability of high-quality forage fish, such as Pacific herring and capelin, altered the ecosystem in a way that it may now support fewer seals than it did prior to the late 1970s. Other sources of mortality that may contribute to lower seal numbers include predation, subsistence hunting, and commercial fishery interactions (e.g., entanglement and drowning in nets). Additionally, noise generated by increasing cruise ship and oil tanker traffic in Prince William Sound and seismic testing for offshore oil in Cook Inlet may physiologically damage or displace seal populations (Peng and Liu 2015). Lastly, diseases, contaminants, and their interactions in a changing climate make harbor seals vulnerable. For example, phocine distemper virus (also known as morbillivirus) was first identified in 1988 when it killed more than 18,000 harbor seals in the North Atlantic. There is mounting evidence of phocine distemper-like viruses in the North Pacific and western Arctic with serological and molecular evidence of infection in pinnipeds and sea otters (Duignan et al. 2014). Immunosuppression from chronic exposure to marine pollutants likely contributes to harbor seal susceptibility to diseases. Exposure to diseases from terrestrial carnivores, including human pets, also increases exposure risk to communicable diseases. Cumulatively, harbor seal populations have been declining and are likely to continue to decline in the foreseeable future.

Marine Invertebrates: Pacific Razor Clam (Sugt'stun: Cingtaataq; dAXunhyuuga': JiidaadAG, Uniik' Awaa qa' qiisid)

Pacific razor clams are harvested commercially and for personal use (subsistence and sport) and are a food source for sea otters, bears, and other marine animals (Bishop and Powers 2003). From the 1950s to 1963, Alaska harvested more Pacific razor clams than any other state in the U.S. (Bowen et al. 2020). Bishop and Powers (2003) present a cautionary tale of the devastation of a once hyperabundant resource in Prince William Sound from multiple stressors over three decades. During the first half of the 20th century, Cordova was known as the "razor clam capital of the world," with as much as 1587.8 tonnes harvested annually. This high harvest rate combined with a dieoff in 1958 caused a population decline in the early 1960s, which was exacerbated by tectonic uplift caused by the 1964 earthquake. In the immediate Cordova area, prime Pacific razor clam habitat in Orca Inlet uplifted 1.6–2 m, and the subsequent tsunamis eroded ≥76 cm of surface sediment from the tidal flats. During much of the 1980s, commercial Pacific razor clam harvest shifted to Kanak Island, 104 km from Cordova. Except for 1993, there has been no commercial Pacific razor clam harvest in the Cordova area including the Cooper River delta since 1988, the year preceding the Exxon Valdez oil spill.

Brooks et al. (2001) reports the following:

> "Clams were once a major subsistence resource in most of the Native communities in the Exxon Valdez oil spill region. Clam populations near most of these villages have been decreasing in recent years, and their contribution to the subsistence harvest has been greatly reduced. There are likely several reasons for this, including changes in currents and beach patterns, increasingly heavy sea otter predation, and the Exxon Valdez oil spill. The oil spill impacted the wild clam populations and their importance as a subsistence food in two ways. First, some clam beds suffered from direct oiling. Second, even though the oil did not directly impact many clams, [clams] accumulate, concentrate, and store the toxic contaminants from nonlethal amounts of oil. This has badly eroded the confidence of the villagers in the healthiness of the remaining wild clam populations as a subsistence food."

Indeed, Pacific razor clams were among the top 25 resources harvested in Chenega, Cordova, Nanwalek, and Port Graham in 2003, and 29–55 percent of households used them (figs. 6, 8, 10, and 12). By 2014, only Cordova reported household use of Pacific razor clams (<10 percent). Mean annual per capita harvest of Pacific razor clams during 1985–2014 varied from 0.1 kg in Port Graham to 1.4 kg in Cordova and Seward (ADFG 2022). This once commonly used clam highlights the vulnerability of marine benthic bivalves that filter water to contaminants, generally, and specifically to the dangers of paralytic shellfish poisoning that has plagued local Pacific razor clam populations in recent years. The dinoflagellate *Alexandrium catenella* causes paralytic shellfish poisoning; its blooms have a clear association with warming waters caused by climate change. Joe McLaughlin, an epidemiologist with the Alaska Department of Health and Social Services, stated that "the state of Alaska does not recommend that people engage in recreational or subsistence harvesting because of the potential seriousness of this disease" (Hanlon 2019).

Ocean acidification has a direct impact on shellfish, but some evidence suggests that a related razor clam, the Atlantic jackknife clam (*Ensis directus*), on the east coast may be more tolerant of low pH than other species (Preziosi 2019). The CRRC is collaborating with researchers at the University of Alaska Fairbanks to better assess the effects of acidification on razor clams (Dobbyn 2018). The nonnative softshell clam may also be competing with razor clams (and other native clams). Native to the Atlantic Ocean, the softshell clam was accidentally introduced to the San Francisco area in the 1870s. It spread rapidly northward toward Alaska and was reported first in Ketchikan in 1946, in Prince William Sound in 1964, and in Cook Inlet in 1999. Softshell clams are already a dominant bivalve in the Cook Inlet mudflats, reaching densities as high as 11 per square meter in Katmai National Park, in contrast to harvestable razor clam densities of up to 5 per square meter at Clam Gulch and Ninilchik (Bowser 2014). Softshell clams are so prevalent in Prince William Sound now that some CRRC clam enhancement projects include this species despite no evidence of use by tribal members; however, introduction of the softshell clam into diets is a form of adaptation in the region (Hetrick 2021). Cumulatively, razor clam populations have been declining and are likely to continue to decline in the foreseeable future because of multiple stressors. Its sensitivity to the environment is precisely why the razor clam has been suggested as an indicator species for monitoring nearshore ecosystem health (Bowen et al. 2020).

Birds and Eggs: Black Oystercatcher (Sugt'stun: Kiwiksaq)

Black oystercatchers and their eggs do not rank among the top 25 resources used by residents in Chenega, Nanwalek, Port Graham, or Tatitlek (figs. 6, 10, 12, and 15). However, at least some residents of communities in both Cook Inlet and Prince William Sound eat them (app. 2). Only 1 of 27 black oystercatchers and 1 of 446 black oystercatcher eggs were harvested annually in the Gulf of Alaska-Cook Inlet region compared to statewide during 1990–2015 (Naves et al. 2019), but those researchers cautioned about high annual variability and unreported take by children. In one study of several shorebird species sampled in the northern Gulf of Alaska, the eggs of black oystercatchers from Prince William Sound were found to have particularly high strontium levels, presenting a potential risk to human health if consumed in large quantities (Saalfeld et al. 2016). Unusually large amounts of strontium can affect bone growth in children (USDHHS ATSDR 2004).

The spring bird and egg hunt was once an important source of subsistence foods during a time when there were few other fresh resources available, as evidenced by midden piles discovered at archeological sites in the region (Stanek 1985). However, the Migratory Bird Treaty Act (1918) prohibited the spring harvest of birds and eggs until 2003; during this time, Chugach region tribes were forced to abandon their traditional practices or conduct them illegally. The legacy of this history is that much of the traditional knowledge about the harvest of birds and eggs has been lost and, where these traditions continue, many residents are reluctant to share their knowledge about harvest. Mean annual per capita harvest of bird eggs (all species) during 1985–2014 varied from 0.3 kg in Seward to 2.2 kg in Tatitlek (ADFG 2022).

Fewer than 11,000 black oystercatchers are estimated to remain worldwide, their range extending from the Aleutian Islands to Baja California, Mexico. More than half of these are known to nest in Alaska, particularly concentrated along the shorelines of Harriman Fjord, Montague Island, and Green Island in Prince William Sound, where at least 500 pairs nest (Tessler et al. 2010). Harriman Fjord would likely be devastated in a tsunami that could result from the forecasted landslide above Barry Arm (see "Nonclimate Stressors" above).

The black oystercatcher is a species of high concern in Alaskan, U.S., and Canadian shorebird conservation plans because of its small population size, restricted range, and threats to habitat from human and natural factors that may potentially limit its long-term viability.

Black oystercatchers exhibit strong breeding site fidelity, which makes their reproduction particularly sensitive to environmental changes and to potential disturbance of shorelines by human use (Erickson et al. 2017). Black oystercatchers nest in a restricted area between the high-tide line and coastal vegetation or on islets just above high tide. According to an Alutiiq legend, God punished the oystercatcher for laying its eggs too early one year. The birds were not supposed to reproduce until May, but they did not wait. Now, they must lay their eggs right on the beach as they have been banished from the land (Alutiiq Museum Archeological Repository 2020). Their year-round dependence on this narrow band of habitat makes these birds particularly vulnerable to natural and human disturbances. Predation by mammals, such as mink, river otters, and bears, as well as by gulls, ravens, and eagles takes a toll on oystercatchers, particularly on their eggs (2–3 per clutch) and newly hatched chicks. Because their nests typically crowd the high-tide margin, they are extremely susceptible to flooding by extreme high tides, storm surges, and large boat wakes. Campers and kayakers tend to also prefer the same gravel beaches, and they may inadvertently disturb nesting oystercatchers or even trample their highly camouflaged nests (Romanoff 2006).

After the 1989 Exxon Valdez disaster, oiling immediately killed 20 percent of black oystercatchers in the spill area, and birds not directly oiled were faced with eating oil-contaminated prey or starvation (Romanoff 2006). The life history of black oystercatchers, particularly low recruitment of young, suggests relatively long recovery periods following major mortality events. The long lifespan of the species provides a buffer against the loss of reproduction in particular years, with overall population growth most dependent on adult mortality. This large shorebird demonstrated its resilience to the major ecological disturbance following the Exxon Valdez oil spill, eventually recovering its population. Furthermore, the species demonstrated an ability to disperse into, occupy, and increase in new habitat following the development of open shore habitat on Middleton Island resulting from the 1964 earthquake (Erickson et al. 2017).

On the other hand, the diet of black oystercatchers is predominantly mollusks and bivalves that may decline in abundance if marine pH declines significantly (Erickson et al. 2017) or in response to other stressors, such as harmful algal blooms or marine heatwaves. Tessler et al. (2014) reported that black oystercatchers feed exclusively on intertidal invertebrates, particularly mussels (*Mytilus* spp.), limpets (*Diodora aspera*, *Puncturella* spp.), whelks (*Nucella* spp.), littorine snails (*Littorina* spp.), and chitons (*Katharina tunicata*, *Tonicella lineata*, *Mopalia* spp.).

Climate envelope modeling by the National Audubon Society suggests that the wintering range of black oystercatchers is likely to experience change, with a 2 °C increase, a temperature scenario likely to happen by 2050 (National Audubon Society, n.d.). Climate suitability for this species may shift as far north as Nome, but range losses are expected in western Prince William Sound and parts of Cook Inlet. Cumulatively, black oystercatchers are likely to remain stable in the near term, but they appear to be vulnerable in the longer term to both climate-driven directional change as well as nonclimate stressors.

Vegetation: Blueberry (Sugt'stun: Curaq, Cuawak; dAXunhyuuga': Ca'X.)

Berries in general represent 82–96 percent of vegetation harvested by weight (Fall and Zimpelman 2016, Jones and Kostick 2016). Although blueberries do not rank among the top 25 resources used by communities based on weight (figs. 6, 8, 10, 12, and 15), 62–76 percent of households harvested them, ranging from 1.4 kg per capita in Tatitlek to 3.6 kg per capita in Port Graham in 2014 (Fall and Zimpelman 2016, Jones and Kostick 2016). In previous years (1984–2003), annual harvest of blueberries averaged as high as 7.7 kg per capita in Tatitlek (ADFG 2022). Tribal environmental managers said that blueberries ranked second only to salmonberries in their significance among 16 communities in maritime Alaska (fig. 20) (Hupp et al. 2015). Several species occur in Prince William Sound and on the Kenai Peninsula, but the most common species are oval-leaf (early or highbush) blueberry (*Vaccinium ovalifolium*, atsaq), bog (alpine) blueberry (*V. uliginosum*, curaq) and Alaska (highbush) blueberry (*V. alaskaense*).

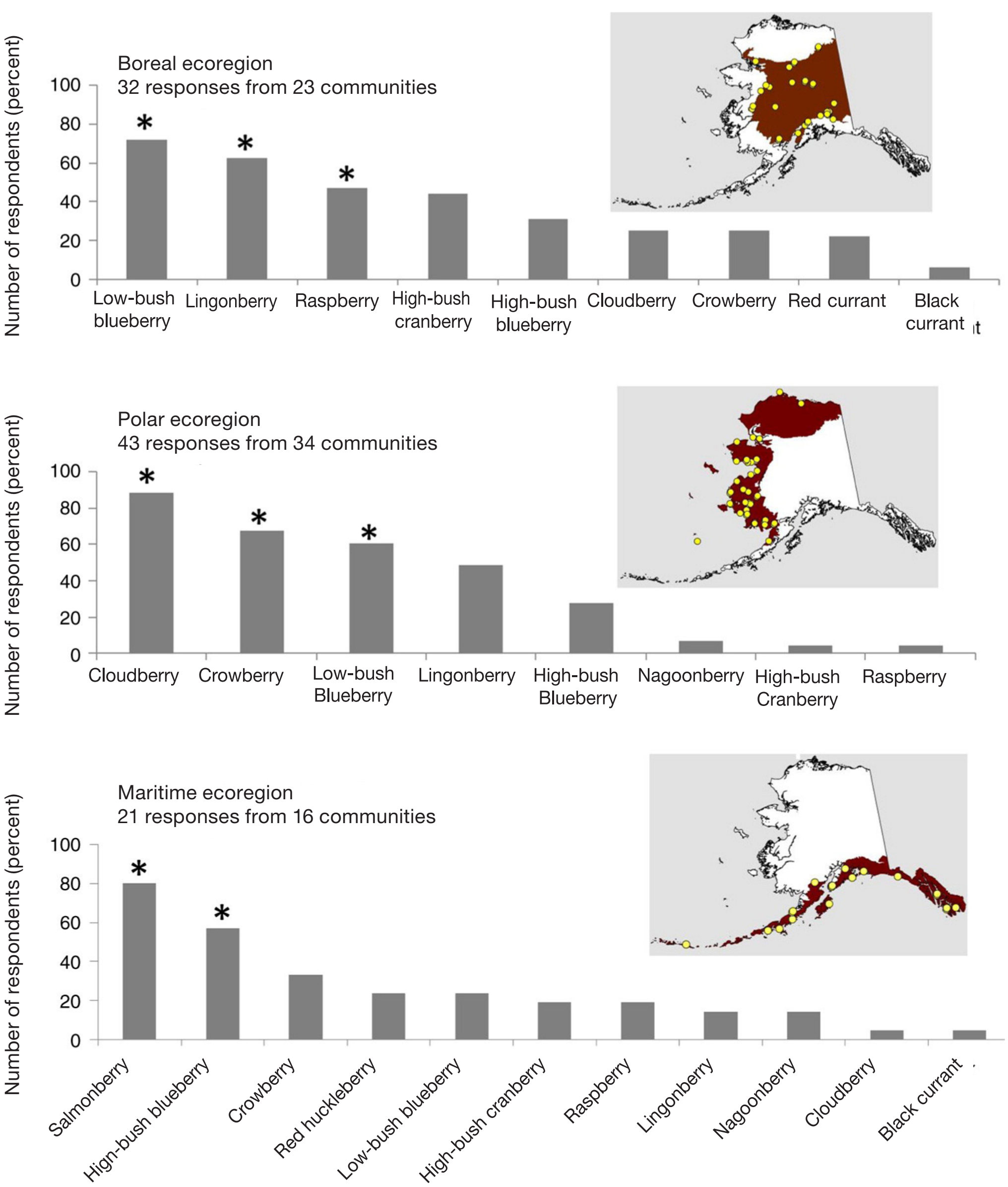

Figure 20—Ranked importance of wild berries to Alaska Native communities based on a survey of tribal environmental managers (adapted from Hupp et al. 2015). Highbush blueberry refers to *Vaccinium ovalifolium* and *V. alaskaense*. Lowbush blueberry refers to *V. uliginosum* and *V. caespitosum*. Asterisks indicate berries identified as very important by >50 percent of respondents in an ecoregion (Hupp et al. 2015).

Blueberries are a significant source of vitamin C and antioxidants (Leiner et al. 2006). Today, fresh blueberries are eaten with meat and fish or added to Eskimo ice cream—akutaq—with a variety of other ingredients. Seal oil, lard, dried fish, fish eggs, sugar, and mashed potatoes are all potential additions to this traditional dish. Blueberries are also used to make a variety of jams, jellies, and desserts (Alutiiq Museum Archeological Repository 2020). Blueberries are also an important food for many wildlife species, including songbirds, game birds, mice, chipmunks, squirrels, raccoons, and black bears. Twigs and foliage are browsed by rabbit, snowshoe hare, bear, goat, and deer. Alaska blueberry plants are important winter browse because they are often in older stands with shallow snowpack, making them more accessible to wildlife; similarly, their use as browse may also increase in early winter in open areas when lower growing vegetation becomes covered with snow (Reich et al. 2018).

In a warmer and generally wetter climate as forecasted for Prince William Sound, there is no overt reason for blueberries to be more vulnerable. Wild lowbush blueberries (*V. angustifolium*) growing in situ in an open-top chamber heated 3–5 °C produced smaller and thinner leaves; moreover, whole plant CO_2 assimilation rate also decreased 32–40 percent (Tasnim et al. 2020). Although this was an experimental situation in which temperatures were raised but not moisture, these results may be applicable to Port Graham and Nanwalek, where mean annual available water, which accounts for potential evapotranspiration, has decreased 38 percent since 1969 (Berg 2022). Indeed, 70 percent of tribal environmental managers from 16 communities in maritime Alaska said highbush blueberry (*V. ovalifolium* and *V. alaskaense*) abundance was either decreasing or had become more variable in the past decade (Hupp et al. 2015).

Beginning in 2008, an outbreak of native geometrid moths (*Epirrita undulata*, *Operophtera bruceata*) caused widespread defoliation of salmonberries and blueberries in many Native communities in the Chugach region, resulting in major berry failures (Reich et al. 2018). Chugach elders had no traditional knowledge of an outbreak on this scale in the region, even though the insects were known in Alaska. The outbreak was particularly severe in Port Graham, Nanwalek, and Seldovia on the southern Kenai Peninsula. In Seldovia, successive failure of blueberry crops put a tribal for-profit enterprise based on blueberries in jeopardy. Berry yields eventually recovered after moth populations collapsed in 2012. Although this is the first known geometrid moth outbreak in this region, in other areas of the world where closely related species are native, outbreaks return in cycles of about 10 years (Reich et al. 2018); indeed, there was a small outbreak in 2017 (Hoag 2019) with much greater defoliation of berry plants in 2022 (Lojewski 2021). Furthermore, the recent expansion of geometrid moths in the subarctic boreal has been linked to a warming climate (Jepsen et al. 2008). Cumulatively, this review suggests that blueberries may be vulnerable to a changing climate, particularly for Port Graham and Nanwalek on the Kenai Peninsula, an area that is drier and that coincidentally experienced an extended drought in 2019. Chugachmiut and the CRRC are working to obtain pesticides to combat the geometrid moths in Port Graham and Nanwalek on Native allotment lands to protect berry bushes from complete devastation.

Nonsalmon Fish: Eulachon (Sugt'stun: Qusuuk, dAXunhyuuga': Saag)

Eulachon is a species of smelt, also known as hooligan, salvation fish, and candlefish. They were traded along "grease trails" that linked interior tribes with coastal tribes along the Pacific coast, from Bristol Bay in Alaska to the Klamath River in California. High in oils, up to 20 percent of the eulachon mass is fat, and just 140 g provide half an adult human's daily energy needs. The buttery oil is produced by fermenting large quantities of whole fish and then skimming the resulting nutrient-dense oil after adding water. The oil can be added to other foods or consumed alone for medicinal purposes. The dried fish can be ignited as a light source, hence the name "candlefish." Alternatively, some tribes called them "salvation fish" because eulachon runs occur when human food supplies historically ran low in early spring (Apsens et al. 2020).

Eulachon are anadromous, spawning in fewer than 60 Alaskan rivers (Willson et. al 2006). The populations within southeast Alaska are considered genetically different than those within the Gulf of Alaska (Sutherland et al. 2020). In southcentral and western Alaska, spawning generally occurs in May. Some drainages, like the Copper River, have occasional winter runs in January and February if temperature conditions are right. Some streams can have two distinct but overlapping migrations (ADFG 2022). Eggs are fertilized in the water column, attached to river substrate, and hatch in 20–40 days. Larvae are immediately flushed to sea, where they are dispersed by estuarine and ocean currents. After 3–5 years in the ocean, eulachon return to rivers to spawn, usually in the lower tidally influenced reaches (Flannery et al. 2013). While at sea, juvenile and adult eulachon feed mainly on euphausiids, small shrimp-like crustaceans sometimes called krill (ADFG 2022). The extent that eulachon home to natal spawning sites is unknown (Flannery et al. 2013).

As a forage fish, eulachon are also prey for Alaskan wildlife predators. They are one of the first big pulses of anadromous protein to arrive at estuaries and rivers in early spring, a time of high energy demand for sea lions, river otters, harbor seals, and migrating shorebirds, all which feast on eulachon (Sigler et al. 2004). Apsens et al. (2020) report whales, dolphins, sea lions, sharks, bears, wolves, ravens, eagles, seabirds, salmon, and many other species exploit eulachon when available.

Tribal communities in Prince William Sound and on the Kenai Peninsula currently use eulachon (app. 2). Mean annual per capita harvest of eulachon during 1984–2014 varied from 45 g in Chenega, Seward, and Tatitlek to 0.5 kg in Cordova (ADFG 2022). Eulachon were reported among the top 25 resources used in Cordova, Nanwalek, and Tatitlek; however, household use declined from 27–47 percent in 2003 to ≤6 percent in 2014 (figs. 8, 10, and 15). Chenega reported 8 percent of households used eulachon in 2014 (Fall and Zimpelman 2020).

Little is known about the life history or status of eulachon in Alaska (ADFG, n.d.). Because the species is not commercially harvested, basic data are lacking for most populations, even though they fueled west coast Native cultures and trade for generations (Flannery et al. 2009). This should be alarming, as eulachon populations elsewhere have collapsed and tell a cautionary tale. Until the early 1990s, eulachon were caught in vast quantities in both subsistence and commercial fisheries in the Pacific Northwest, with commercial hauls often exceeding 1000 tonnes per year from the Columbia River (Flannery et al. 2009). However, by 2010, the National Marine Fisheries Service had listed all populations of eulachon in Washington, Oregon, and California as threatened under the U.S. Endangered Species Act. The biological review team for this listing concluded that the major threats to eulachon included climate change impacts on ocean conditions and freshwater habitat, bycatch in offshore shrimp trawl fisheries, changes in downstream flow timing and intensity due to dams or water diversions, and predation (NOAA 2016). Hayward et al. (2017) also describe forecasted changes to hydrology in the Chugach region; its potential impacts on eulachon and other forage fish need further study. Additionally, in recent laboratory experiments, exposure to both ocean acidification and nanoplastics severely reduced embryo development of krill (the primary food for eulachon) (Rowlands et al. 2021). Although there is no evidence that current eulachon populations in Prince William Sound and Cook Inlet are declining, clearly this species is vulnerable to several stressors in the longer term that could have both direct subsistence impacts and cascading effects on the food web.

Land Mammals: Sitka Black-Tailed Deer (Sugt'stun: Quak'aaq, Tuntuq; dAXunhyuuga': QuwAkaan, Xi'ts'dA'aaw q)

Sitka black-tailed deer is an example of a species that has become an important subsistence resource for communities in Prince William Sound, even though it is not native to the region. The Cordova Chamber of Commerce introduced 24 Sitka black-tailed deer from southeast Alaska to Hawkins and Hinchinbrook Islands during 1916–1923. A century later, the estimated population in Game Management Unit 6 (essentially Prince William Sound) is about 20,000 deer (Morton and Huettmann 2017). Most households in Chenega, Cordova, and Tatitlek use Sitka black-tailed deer, although the percentage of households has decreased from 65–100 percent in 2002 to 45–81 percent in 2014 (figs. 6, 8, and 15). Less than 2 percent of households in Nanwalek and none in Port Graham used Sitka black-tailed deer in 2014 (Jones and Kostick 2016). These harvests in 2014 translated to 3.5 kg per capita in Cordova, 4.7 kg per capita in Chenega, and 9.9 kg per capita in Tatitlek (ADFG 2022). In Tatitlek, 100 percent of the large mammal harvest was Sitka black-tailed deer, the first time a single species has dominated a resource category (Fall and Zimpelman 2016).

Morton and Huettmann (2017) summarized the colonization of the assessment area by Sitka black-tailed deer. After the initial introduction to Hawkins and Hinchinbrook Islands, Sitka black-tailed deer spread to the mainland and eventually to other islands in Prince William Sound. Legal hunting began in 1935 and, currently, about 2,000 Sitka black-tailed deer are harvested annually in the Prince William Sound area. Since 2002, a few Sitka black-tailed deer, including bucks and does, have been seen in Anchorage, in the Portage and Placer River drainages, and along Turnagain Arm. In more recent years, Sitka black-tailed deer have also been seen infrequently on the Kenai Peninsula near Seward. These observations are all consistent with the potential climate niche modeled by Morton and Huettmann (2017).

Snow depth and its interaction with canopy cover appear to be the ultimate driver of Sitka black-tailed deer distribution in the assessment area (Morton and Huettmann 2017). In fact, residents in Prince William Sound communities reported that record-breaking snowfalls during the winter of 2011–2012 caused a crash in the Sitka black-tailed deer population; the population is slowly recovering (Keating et al. 2020). Sitka black-tailed deer forage on evergreen forbs and arboreal lichens during winter and only switch to woody browse, such as blueberry and hemlock, when snow is deep. Woody browse alone, however, offers inadequate nutrition, and deer rapidly deplete their energy reserves when restricted to such a limited diet. Unlike grazers, such as Dall sheep (*Ovis dalli*), Sitka black-tailed deer rarely eat grass. Reductions in snow cover and expansion of snow-free periods at low elevations will generally favor improved Sitka black-tailed deer habitat, contributing to the expansion of their distribution, certainly along the eastern Kenai Peninsula. The potential (and likely) introductions of chronic wasting disease and meningeal worm to Alaska could severely reduce Sitka black-tailed deer populations despite a favorable climate forecast. In aggregate, however, Sitka black-tailed deer are expected to increase in distribution and abundance in the foreseeable future as they finish colonizing the area occupied by Sitka spruce.

Summary of Findings

This review of the vulnerability of seven key species used for subsistence by tribal communities in Prince William Sound and Cook Inlet paints a different picture than the 2017 Chugach National Forest vulnerability assessment (Hayward et al. 2017). Nonclimate stressors, the cascading trophic and other ecological interactions among species, and the enormous (albeit uncertain) impacts of the changing marine system are messy to assess and do not lend themselves to a seamless analysis of vulnerability; however, they need to be included to better reflect the complexity and reality of the immediate situation to people who rely heavily on local natural resources.

Table 1 summarizes the expected impacts of described stressors on these seven species. The two species that are known to be increasing in the assessment area are either introduced (Sitka black-tailed deer) or highly enhanced from hatchery releases (pink salmon). Pacific razor clam and harbor seal populations have been declining for several decades because of a combination of historically high (and arguably unsustainable) harvest rates, catastrophic human (oil spill) and natural (earthquake) events, and changing environmental conditions that are driven in complex ways by a warming climate. The assessments of the three species assumed to be stable (eulachon, black oystercatcher, and blueberry) are as much an outcome of poor population data and monitoring as they are of reality. Although a different selection of representative species may have had a slightly different outcome, this suite of species emphasizes the current and historic complexities of events that have led to the status of their populations in the assessment area.

Projecting ahead, only Sitka black-tailed deer is likely to increase in distribution and abundance as the species colonizes more remote Sitka spruce forests on the Kenai Peninsula. All other species reviewed here seem highly vulnerable to events that are mostly not manageable in the near term: changing ocean currents, acidification, geological events, and accidents on the marine highway. Two species, eulachon and pink salmon, are representative of migratory species (fin or feather) more generally, in that stressors completely outside local ecosystems ultimately determine their well-being. Clearly, natural resource agencies should do their best to mitigate those stressors that are within their legislative and spatial domains, but a partial fix may simply not be adequate to ensure long-term sustainability of many species, nor does it address the issue more relevant to those who depend on wild resources (i.e., ensuring place-based food security). The CRRC has focused on building opportunities for collaborative comanagement of traditional foods with current land and resource managers when considering food security, a term referred to as “food sovereignty.” Socioeconomic vulnerability resulting from climate stressors on local resources and ecosystems varies even intraregionally because food takes on different meanings for different people in different places (Chugach Regional Resources Commission, n.d.). However, Sitka black-tailed deer and softshell clams are two species that are now part of the subsistence harvest but are certainly not traditional—the former was deliberately introduced a century ago and the latter was accidentally introduced only a few decades ago. This reflects the adaptability and inherent resilience of Sugpiat culture, which values traditional foods and harvesting practices as well as adopts new technologies and adjusts to changing environmental conditions when needed (e.g., Herman-Mercer et al. 2019, Salomon et al. 2007). There are opportunities to expand food security to include mariculture, agriculture, and new hunting and fishing opportunities as the region adjusts to a changing climate.

Table 1—Current and forecasted impacts of climate and nonclimate stressors on indicator species selected for each of the seven resource categories

Resource category (indicator species)	Climate stressors					Nonclimate stressors			Trend	
	Mean annual temperature	Annual precipitation	Snowpack	Marine heat wave	Ocean acidification	Oil spill	Earthquake or tsunami	Extreme biological event	Current	Likely future
Salmon (pink salmon)	+	?	–	–	–	–	0	?	+	–
Nonsalmon fish (eulachon)	?	?	–	–	–	–	0	0	0	–
Land mammal (Sitka black-tailed deer)	+	0	+	0	0	0	0	–	+	+
Marine mammal (harbor seal)	?	?	?	–	–	–	0	–	–	–
Birds and eggs (black oystercatcher)	–	0	0	–	–	–	–	?	0	–
Marine invertebrates (Pacific razor clam)	–	0	0	–	–	–	–	–	–	–
Vegetation (blueberry)	–	0	+	0	0	0	0	–	0	–

Note: + = increase; – = decrease; 0 = no known effect; ? = uncertain effect.

Opportunities to Build Resilience in Place-Based Natural Resources

Hayward et al. (2017) identified the vulnerabilities of selected resources to a changing climate over the next five decades in a large and diverse landscape spanning the Kenai Peninsula, Prince William Sound, and Copper River Delta. However, a subsistence lifestyle is much more place-based in spatial scale and rooted in the here and now (Walch 2018). Putting food on the table or in the freezer for the winter is demanding and immediate. While the uncertainties associated with vulnerability assessments are critical for envisioning the future, they are also not pressing concerns for many of the current generations of community members trying to make a living now. For example, hunting seasons limit when tribal members can hunt on state and federal lands, and tribal members have reported that it is harder to harvest certain animals as the seasons shift toward a warmer and later fall. Traditional wisdom says to hunt when the conditions are right, but tribal members are finding themselves constrained by regulatory seasons designed for recreational hunting in much the same way that Alaska Natives were prevented from harvesting migratory birds during the spring until the Migratory Bird Treaty Act (1918) was revised (e.g., Loring et al. 2011). The well-being of fish, wildlife, and plant resources are also tied directly to the cash economy in the region, as many tribal members make their living directly or indirectly from the commercial fin and shellfish industries, with real opportunities in seaweed farming and nature-based ecotourism and wildlife viewing (Fay et al. 2005, Stekoll 2006). Rather than trying to address species-specific vulnerabilities to a warming climate and catastrophic nonclimate events, focusing on building resilience in the food system may be more efficacious. This approach can include increased use of agriculture and silviculture practices as well as enhancing wild natural resources (Kaljur 2020).

Agriculture and Silviculture

This review of the seven communities highlights some real differences in their needs and opportunities. All communities will have warmer summers, shorter winters, and reduced snowpacks, but their extent varies greatly across the two climatic regions, which span more than 5° of latitude. The climate forecast for Valdez is the most severe, with 4 months of winter continuing through the next half century. In contrast, Chenega will be almost balmy, with mean monthly temperatures staying above freezing year-round by 2040. All communities will have greatly expanded growing months, suggesting opportunities for outdoor community gardens, unheated greenhouses, and hydroponics. Indeed, the Valdez Native Tribe received a grant for greenhouses, and the CRRC recently purchased hydroponic units for Port Graham and Seward. The Chugach Regional Tribal Conservation District may be able to use the Tyonek Tribal Conservation District as a model for more agriculture development. The Tyonek Tribal Conservation District community garden has grown into a 1.5-ac operation, with two USDA Natural Resources Conservation Service-funded high tunnels, solar-powered irrigation and ventilation systems, outdoor raised beds, more than 2,000 row ft of potatoes and mixed vegetable crops, perennial fruits, and plans for expansion in coming years (Tyonek Tribal Conservation District 2022).

Although some populations and harvests used for subsistence can be managed through the Federal Subsistence Board, Board of Fish, and Board of Game, many of the opportunities to respond to a changing climate may be through habitat manipulation that the Forest Service can facilitate. Chugach National Forest abuts five of the seven communities in Prince William

Sound—Chenega, Eyak, Seward, Tatitlek, and Valdez. In other cases where parcels have mixed ownerships, the Chugach National Forest owns the conservation easement. In both situations, the Chugach National Forest could work collaboratively with the communities and other tribal organizations, such as the CRRC and Chugachmiut, to conduct silvicultural operations that specifically benefit subsistence resources. For example, Sitka black-tailed deer require both mature conifer canopy, where snow cover is reduced, and early successional growth (<20 years) for forage, an outcome that could be created by standard forestry practices near tribal communities (Hanley 1984). However, the fact that Chugach National Forest surrounds five of these seven communities may have inadvertently served as a barrier. Farrell et al. (2021) point out that proximity to federally managed lands reduces the adaptive capacity of tribes to respond to climate change because agency culture and regulations often limit movement, management, and traditional uses by indigenous people.

Tribal land managers outside of Chugach National Forest are trying other forestry applications to address a warming climate. The new biomass facilities in Port Graham and Eyak will demand wood from fast-growing tree species as local stock is harvested. For example, Alaska cedar (*Callitropsis nootkatensis*) was recently planted above Port Graham as a potential silvicultural product (Lojewski 2021). Similarly, lodgepole pine (*Pinus contorta* var. *latifolia*) was planted by the Ninilchik Native Association on the western Kenai Peninsula in the aftermath of the 1990s spruce bark beetle outbreak. Beach pine (*Pinus contorta* var. *contorta*) may be the more appropriate subspecies to consider in Prince William Sound; unlike the subspecies widely planted on the Kenai Peninsula and elsewhere in Alaska, beach pine produces mostly nonserotinous cones that do not require fire to germinate. Siberian larch (*Larix sibirica*) and lodgepole pine were planted by Seldovia Village Tribe, and the former was specifically planted recently along streams to replace Sitka spruce that was lost from spruce bark beetle and wind because it sheds snow well during the winter (as a deciduous conifer), while still providing riparian cover during the increasingly warmer summers (Higman 2021). Alaska larch or tamarack (*Larix laricina*) might have been a better choice, but that species and beach pine are unavailable through commercial nurseries.

Agroforestry is another interesting option to explore, possibly as community demonstration forests. Birch, and in particular Kenai birch (*Betula papyrifera* var. *kenaica*), can provide birch syrup and chaga (*Inonotus obliquus*), a parasitic fungus that commonly grows on birch and is used to make tea with medicinal properties. Fruit-bearing trees and shrubs, such as apple, plum, cherry, and sweetberry honeysuckle (haskap) (*Lonicera caerulea*), are commonly grown on the western Kenai Peninsula; native trees, such as serviceberry (*Amelanchier* spp.) are also viable choices. Nut-bearing trees and shrubs, such as hazelnuts (filberts) (*Corylus* spp.) are being promoted in Canada, including nearby British Columbia (Government of British Columbia 2022). Agroforestry could be piloted in fenced-in (to prevent moose and deer browsing) demonstration forests near communities. Reich et al. (2018) suggested thinning trees around Nanwalek and Port Graham could be used to increase blueberry crops by reducing shade. Similarly, biofuel harvest could be accomplished in a way that benefits berry production. However, forestry or agroforestry opportunities are currently limited by tribal capacity as well as the availability of tree species through commercial nurseries. The Forest Service could assist these efforts by providing expertise, staff, or grants. Another option is through Public Law 93-638; under the Indian Self-Determination and Education Assistance Act (ISDEAA 1975), any federal program, function, service, or activity must transfer its operations to tribes upon formal request for the benefit of the tribe. This mandate is legally structured in the form of a contract defined in ISDEAA, or a "638 contract." In some cases, tribes may compact a federal program, function, service, or activity, which can be a more favorable method for tribes to operate programs, but this requires a more extensive formal request.

Fish and Wildlife Enhancement

Prince William Sound and the Kenai Peninsula have a long history of fish and wildlife species introductions and population enhancement. During 1916–1923, the Cordova Chamber of Commerce introduced Sitka black-tailed deer from southeast Alaska and, during 1949–1958, indigenous but sparse moose populations in Prince William Sound were enhanced with translocations of calves from the Kenai Peninsula, Anchorage, and Matanuska-Susitna (Morton and Huettmann 2017). Salmon hatcheries in Chenega (operated by the Prince William Sound Aquaculture Corporation), Moose Pass and Port Graham (operated by the Cook Inlet Aquaculture Association), and Valdez (operated by the Valdez Fisheries Development Association) service areas close to the communities. The APMI (a division of CRRC), a tribally-owned shellfish hatchery and marine research facility, has a solid record of developing enhancement methods for clam populations near communities (Brooks et al. 2001) and studying ocean acidification in the local area (Evans et al. 2015). Clam enhancement is occurring in Chenega and Port Graham, and kelp farming is occurring in Chenega, Eyak, and Tatitlek. Oyster farming was tried in Tatitlek and Chenega in the early 1990s but efforts failed for various reasons (Hetrick 2021).

Conversely, management of injurious nonnative species populations will almost certainly be needed as ecosystems change and are exposed to invasion. Chenega, Tatitlek, and Cordova are badly infested with European black arion slugs (*Arion ater*). The CRRC recently received BIA funds to develop a terrestrial invasive plant strategy for Port Graham and Nanwalek. Chugach National Forest and other partners are trying to determine how best to address the spread of elodea in the Copper River basin.

Similar to the Local Environmental Observer Network, initiated to ensure that Alaska Native community observations were recorded to provide a larger collective picture of trends in a dynamic landscape, perhaps there are opportunities among the seven tribal communities to share observations. The APMI's Chugach Regional Ocean Monitoring Program examines climate conditions, ocean chemistry, harmful algae, and shellfish biotoxin levels to inform safe shellfish harvest and provide comprehensive data on ocean conditions in southcentral Alaska. Through continuous monitoring, the CRRC and APMI expect to minimize the risks to seafood harvest and enhance food security by collectively monitoring harmful algal blooms and paralytic shellfish poisoning.

Concerns Identified by the CRRC

Institutional and financial barriers exist that may prevent building resilience in place-based natural resources. However, we believe these can be overcome by reconsidering how the USDA Forest Service (and other federal agencies) engage with Alaska Native communities. Fienup-Riordan (1999) cautions that how non-Native scientists work in or with a community is as important as what they accomplish, and so we look specifically for opportunities to build capacity and understanding rather than simply provide funding as is commonly practiced. Below we offer our insights on how best to help these seven communities in the Chugach region address vulnerability to climate change and other nonclimate stressors.

1. Address tribes' lack of decision-making authority over traditional territories. The well-being of the Chugach National Forest is intrinsically and explicitly linked to the livelihood of tribal members, who have historical and cultural connections to the land and its resources, as well as a dependence on them for economic and subsistence purposes. The complexity surrounding fish, wildlife, and land management in Alaska suggests that all would benefit from shared learning and the integration of indigenous ecological knowledge with scientific knowledge. Tribes lack direct decision-making over their traditional territories, which can exacerbate vulnerabilities to climate change and other stressors by creating institutional barriers to employ traditional knowledge in building adaptive capacity. This explicit recognition of the linkage between tribal well-being and federal land management could take the more meaningful form of memorandums of understanding between the USDA Forest Service and individual tribes that detail how tribal sovereignty would be manifested in Chugach National Forest decision making and planning.
2. Include tribes as partners. There is high value in welcoming tribes or their supporting organizations (e.g., CRRC, Chugachmiut, CAC) as partners (not stakeholders) from the onset of any land management or public use planning process. As a case in point, this vulnerability assessment for tribal communities should not have been a contracted amendment to the original interagency assessment process; i.e., an afterthought. When federal land management agencies consider tribal citizens' perspectives on climate change effects on subsistence resources, it increases the likelihood of collaborative and more meaningful approaches to addressing adaptation.
3. Address the need for technical assistance. Many resources and potential partnerships exist that could be used to address shared concerns around building economic or food resilience. For example, the USDA National Agroforestry Center would be an excellent resource for communities interested in developing community demonstration forests (USDA NAC 2022). Additionally, existing programs, such as the USDA Forest Service's partnership with USDA Rural Development that promotes tourism and recreation economies, could assist communities in diversifying their economies. The USDA Forest Service could help promote these programs by providing resource portals, public workshops, or additional technical assistance to tribes or their supporting organizations (e.g., CRRC or Chugachmiut) to manage and implement grants or partnerships.
4. Manage lands for resilient wild foods systems. Chugach National Forest abuts lands owned by the regional CAC and the village corporations from Chenega, Eyak, and Tatitlek and owns conservation easements to other adjoining parcels with mixed ownership. It also surrounds the communities of Seward and Valdez, where many tribal members reside. Engaging in partnerships with tribal organizations in these communities may help to identify areas where silvicultural actions may be consistent with tribal goals to expand community resilience. There are many local-scale silvicultural actions that the Chugach National Forest could fund or even conduct to enhance habitats around communities for fish and game, help ensure a sustainable supply of biofuel (wood), or otherwise manage forests to help ensure a more resilient wild foods system. There may also be opportunities to manage nontraditional subsistence species, both native species that were once uncommon but are increasing in a changing climate (e.g., yellow cedar or birch) or nonnative species that have naturalized (e.g., softshell clam).

5. Expand technical capacity. A partnership between a federal agency and tribal organization to achieve mutual goals expands the capacities of both organizations. To help build tribal organizational capacity as well as to ensure good coordination, USDA Forest Service foresters, fisheries and wildlife biologists, or invasive species managers could be cost- or time-shared with tribal organizations, such as the CRRC or Chugachmiut, especially to help develop programs to monitor or enhance species that are important for subsistence or particularly vulnerable to climate changes.
6. Develop joint monitoring programs. Opportunities exist for collaborative monitoring and research to better understand changes to freshwater hydrology, subsistence resources (e.g., eulachon, blueberries), and coastal erosion near communities. This is another opportunity to build capacity through training and mentorship programs, perhaps through partnerships with schools for local citizen science monitoring programs as well as with the local tribal governments and regional organizations such as the CRRC and Chugachmiut. In addition to the USDA Forest Service, other federal agencies, such as the U.S. Department of the Interior (USDI) National Park Service (e.g., Kenai Fjords National Park, Southwest Alaska Inventory and Monitoring Network) and USDI Fish and Wildlife Service (e.g., Partners for Fish and Wildlife, Fisheries and Aquatic Conservation), have capacity to assist with monitoring by tribal organizations.

Common and Scientific Names

The following is a list of species mentioned in this report. Scientific names were retrieved from the Integrated Taxonomic Information System (ITIS, n.d.) for non-plant species and from USDA PLANTS (USDA, n.d.) for plant species. Common and scientific names in Fall and Zimpelman (2016) and Jones and Kostick (2016) (app. 2) that differed from valid scientific names in the ITIS and USDA PLANTS are in parentheses.

Organism	Common name	Scientific name and authority
Mammals	Moose	*Alces alces*
Mammals	Bowhead whale	*Balaena mysticetus*
Mammals	Minke whale	*Balaenoptera acutorostrata*
Mammals	Bison	*Bison bison*
Mammals	Coyote	*Canis latrans*
Mammals	Gray wolf	*Canis lupus*
Mammals	Beaver	*Castor canadensis*
Mammals	Elk	*Cervus elaphus* (*Cervus canadensis*)
Mammals	Sea otter	*Enhydra lutris*
Mammals	Porcupine	*Erethizon dorsatum*
Mammals	Steller sea lion	*Eumetopias jubatus*
Mammals	Wolverine	*Gulo gulo*
Mammals	Snowshoe hare	*Lepus americanus*
Mammals	North American river otter	*Lontra canadensis*
Mammals	Lynx	*Lynx canadensis*
Mammals	Humpback whale	*Megaptera novaeangliae*

Organism	Common name	Scientific name and authority
Mammals	American mink (mink)	*Mustela vison* (*Neovision vison*)
Mammals	Mule deer (deer)	*Odocoileus hemionus*
Mammals	Sitka black-tailed deer	*Odocoileus hemionus sitkensis*
Mammals	Muskrat	*Ondatra zibethicus*
Mammals	Mountain goat	*Oreamnos americanus*
Mammals	Orca	*Orcinus orca*
Mammals	Dall sheep	*Ovis dalli*
Mammals	Harbor seal	*Phoca vitulina*
Mammals	Sperm whale	*Physeter macrocephalus*
Mammals	Caribou	*Rangifer tarandus*
Mammals	Red squirrel	*Tamiasciurus hudsonicus*
Mammals	Arctic ground squirrel	*Urocitellus parryii* (*Spermophilus parryii*)
Mammals	Black bear	*Ursus americanus*
Mammals	Red fox	*Vulpes vulpes*
Birds	Northern pintail	*Anas acuta*
Birds	Mallard	*Anas platyrhynchos*
Birds	Greater white-fronted goose (white-fronted goose)	*Anser albifrons*
Birds	Snow goose	*Anser caerulescens* (*Chen caerulescens*)
Birds	Canvasback	*Aythya valisineria*
Birds	Ruffed grouse	*Bonasa umbellus*
Birds	Bufflehead	*Bucephala albeola*
Birds	Spruce grouse	*Canachites canadensis* (*Falcipennis canadensis*)
Birds	Long-tailed duck	*Clangula hyemalis*
Birds	Arctic loon	*Gavia arctica*
Birds	Pacific diver	*Gavia pacifica*
Birds	Sandhill crane	*Grus canadensis*
Birds	Black oystercatcher	*Haematopus bachmani*
Birds	Bald eagle	*Haliaeetus leucocephalus*
Birds	Harlequin duck	*Histrionicus histrionicus*
Birds	White-winged scoter	*Melanitta fusca*
Birds	Black scoter	*Melanitta nigra*
Birds	Surf scoter	*Melanitta perspicillata*
Birds	Sooty shearwater	*Puffinus griseus*
Birds	American avocet	*Recurvirostra americana*
Birds	Black-legged kittiwake	*Rissa tridactyla*
Birds	Northern shoveler	*Spatula clypeata* (*Anas clypeata*)
Birds	Common murre	*Uria aalge*
Fish	Sablefish	*Anoplopoma fimbria*
Fish	Arrowtooth flounder	*Atheresthes stomias*
Fish	Pacific herring	*Clupea pallasii* (*Clupea pallasi*)

Organism	Common name	Scientific name and authority
Fish	Lake whitefish	*Coregonus clupeaformis*
Fish	Northern pike	*Esox lucius*
Fish	Walleye pollock	*Gadus chalcogrammus* (*Theragra chalcogramma*)
Fish	Pacific cod	*Gadus macrocephalus*
Fish	Kelp greenling	*Hexagrammos decagrammus*
Fish	Pacific halibut	*Hippoglossus stenolepis*
Fish	Capelin	*Mallotus villosus*
Fish	Pacific tomcod	*Microgadus proximus*
Fish	Cutthroat trout	*Oncorhynchus clarkii*
Fish	Pink salmon	*Oncorhynchus gorbuscha*
Fish	Chum salmon	*Oncorhynchus keta*
Fish	Coho salmon	*Oncorhynchus kisutch*
Fish	Rainbow trout	*Oncorhynchus mykiss*
Fish	Sockeye salmon	*Oncorhynchus nerka*
Fish	Chinook salmon	*Oncorhynchus tshawytscha*
Fish	Lingcod	*Ophiodon elongatus*
Fish	Starry flounder	*Platichthys stellatus*
Fish	Arctic char	*Salvelinus alpinus*
Fish	Dolly Varden	*Salvelinus malma*
Fish	Lake trout	*Salvelinus namaycush*
Fish	Red rockfish	*Sebaste* spp.
Fish	Rougheye rockfish	*Sebastes aleutianus*
Fish	Copper rockfish	*Sebastes caurinus*
Fish	Dusky rockfish	*Sebastes ciliatus*
Fish	Quillback rockfish	*Sebastes maliger*
Fish	Black rockfish	*Sebastes melanops*
Fish	China rockfish	*Sebastes nebulosus*
Fish	Tiger rockfish	*Sebastes nigrocinctus*
Fish	Bocaccio rockfish	*Sebastes paucispinis*
Fish	Northern rockfish	*Sebastes polyspinis*
Fish	Yelloweye rockfish	*Sebastes ruberrimus*
Fish	Eulachon	*Thaleichthys pacificus*
Fish	Arctic grayling	*Thymallus arcticus*
Mollusks and crustaceans	Black arion	*Arion ater*
Mollusks and crustaceans	Waved whelk (whelk)	*Buccinum undatum*
Mollusks and crustaceans	Dungeness crab	*Cancer magister*
Mollusks and crustaceans	Tanner crab	*Chionoecetes bairdi*
Mollusks and crustaceans	Snow crab	*Chionoecetes opilio*
Mollusks and crustaceans	Nuttall cockle	*Clinocardium nuttallii*
Mollusks and crustaceans	Giant rock-scallop (rock scallop)	*Crassadoma gigantea*
Mollusks and crustaceans	Rough keyhole limpet	*Diodora aspera*

Organism	Common name	Scientific name and authority
Mollusks and crustaceans	Atlantic jackknife clam	*Ensis directus*
Mollusks and crustaceans	Black Katy	*Katharina tunicata*
Mollusks and crustaceans	Arctic surfclam (pinkneck clam)	*Mactromeris polynyma*
Mollusks and crustaceans	Softshell clam	*Mya arenaria*
Mollusks and crustaceans	Common octopus (octopus)	*Octopus vulgaris*
Mollusks and crustaceans	Red king crab	*Paralithodes camtschaticus*
Mollusks and crustaceans	Limpet	*Patella vulgata*
Mollusks and crustaceans	Weathervane scallop	*Patinopecten caurinus*
Mollusks and crustaceans	Pacific littleneck	*Protothaca staminea*
Mollusks and crustaceans	Washington butterclam (butter clam)	*Saxidomus gigantea*
Mollusks and crustaceans	Pacific razor clam	*Siliqua patula*
Mollusks and crustaceans	Flat surfclam (horse clam)	*Simomactra planulata*
Mollusks and crustaceans	Lined chiton	*Tonicella lineata*
Insects	Geometrid moth	*Epirrita undulata*
Insects	Bruce spanworm	*Operophtera bruceata*
Fungus	Chaga	*Inonotus obliquus*
Plants and algae	Ribbon kelp	*Alaria marginata* Postels and Ruprecht
Plants and algae	Wild chive	*Allium schoenoprasum* L.
Plants and algae	Seacoast angelica (wild celery)	*Angelica lucida* L.
Plants and algae	Kinnikinnick (bearberry)	*Arctostaphylos uva-ursi* (L.) Spreng.
Plants and algae	Tilesius' wormwood (stinkweed)	*Artemisia tilesii* Ledeb.
Plants and algae	Kenai birch	*Betula papyrifera* Marshall var. *kenaica* (W.H. Evans) A. Henry
Plants and algae	Alaska cedar	*Callitropsis nootkatensis* (D. Don) Oerst. ex D.P. Little
Plants and algae	Fireweed	*Chamerion angustifolium* (L.) Holub (*Epilobium angustifolium*)
Plants and algae	American hazelnut	*Corylus americana* Walter
Plants and algae	Canadian waterweed	*Elodea canadensis* Michx.
Plants and algae	Black crowberry (crowberry)	*Empetrum nigrum* L.
Plants and algae	Virginia strawberry (strawberry)	*Fragaria virginiana* Duchesne
Plants and algae	Bladder wrack	*Fucus vesiculosus* L.
Plants and algae	Seaside sandplant (beach greens)	*Honckenya peploides* (L.) Ehrh.
Plants and algae	Tamarack	*Larix laricina* (Du Roi) K. Koch
Plants and algae	Siberian larch	*Larix sibirica* Ledeb.
Plants and algae	Marsh Labrador tea (Labrador tea)	*Ledum palustre* L.
Plants and algae	Sweetberry honeysuckle	*Lonicera caerulea* L.
Plants and algae	Giant kelp	*Macrocystis pyrifera* (Linnaeus) C. Agardh.
Plants and algae	Bull kelp	*Nereocystis luetkeana* (K. Mertens) Postels and Ruprecht
Plants and algae	Devilsclub (devils club)	*Oplopanax horridus* (Sm.) Miq.

Organism	Common name	Scientific name and authority
Plants and algae	Sea ribbon	*Palmaria mollis* (Setchell and N.L. Gardner) van der Meer and C.J. Bird
Plants and algae	Dulse	*Palmaria palmata* (L.) Weber and Mohr
Plants and algae	Wild parsnip (wild parsley)	*Pastinaca sativa* L.
Plants and algae	Hybrid (Lutz) spruce	*Picea* × *lutzii* Little [*glauca* × *sitchensis*]
Plants and algae	White spruce	*Picea glauca* (Moench) Voss
Plants and algae	Black spruce	*Picea mariana* (Mill.) Britton, Sterns and Poggenb.
Plants and algae	Sitka spruce	*Picea sitchensis* (Bong.) Carrière
Plants and algae	Beach (shore) pine	*Pinus contorta* Douglas ex Loudon var. *contorta*
Plants and algae	Lodgepole pine	*Pinus contorta* Douglas ex Loudon var. *latifolia* Engelm. ex S. Watson
Plants and algae	Common plantain (plantain)	*Plantago major* L.
Plants and algae	Goose tongue	*Plantago maritima* L.
Plants and algae	Alaska wild rhubarb (wild rhubarb)	*Polygonum alaskanum* W. Wight ex Hultén
Plants and algae	Black seaweed	*Porphyra abbottae* V. Krishnamurthy
Plants and algae	Canadian gooseberry (gooseberry)	*Ribes oxyacanthoides* L.
Plants and algae	Red currant	*Ribes triste* Pall.
Plants and algae	Prickly rose (wild rose)	*Rosa acicularis* Lindl.
Plants and algae	Arctic raspberry (nagoonberry)	*Rubus arcticus* L.
Plants and algae	Cloudberry	*Rubus chamaemorus* L.
Plants and algae	American red raspberry (raspberry)	*Rubus idaeus* L.
Plants and algae	Salmonberry	*Rubus spectabilis* Pursh
Plants and algae	Western dock (sourdock)	*Rumex fenestratus* Greene
Plants and algae	Sugar kelp	*Saccharina latissimi* (Linnaeus) C.E. Lane, C. Mayes, Druehl and G.W. Saunders
Plants and algae	Virginia glasswort (beach asparagus)	*Salicornia virginica* L.
Plants and algae	Claspleaf twistedstalk (twisted stalk berry)	*Streptopus amplexifolius* (L.) DC.
Plants and algae	Common dandelion	*Taraxacum officinale* F.H. Wigg.
Plants and algae	Hemlock	*Tsuga* spp.
Plants and algae	Alaska blueberry	*Vaccinium alaskaense* Howell
Plants and algae	Lowbush blueberry	*Vaccinium angustifolium* Aiton
Plants and algae	Dwarf bilberry	*Vaccinium caespitosum* Michx.
Plants and algae	Oval-leaf blueberry	*Vaccinium ovalifolium* Sm.
Plants and algae	Red huckleberry (huckleberry)	*Vaccinium parvifolium* Sm.
Plants and algae	Bog blueberry (blueberry)	*Vaccinium uliginosum* L.
Plants and algae	Ligonberry (lowbush cranberry)	*Vaccinium vitis-idaea* L.
Plants and algae	Squashberry (highbush cranberry)	*Viburnum edule* (Michx.) Raf.

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U.S. Standard Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Kilometers (km)	0.621	Miles
Square meters (m^2)	10.76	Square feet
Square kilometers (km^2)	.386	Square mile
Hectares (ha)	2.47	Acres
Cubic meters (m^3)	35.3	Cubic feet
Liters (L)	.265	Gallons
Grams (g)	0.0022	Pounds
Kilograms (kg)	2.205	Pounds
Tonnes (t)	1.102	Tons
Degrees Celsius (°C)	1.8 °C + 32	Degrees Fahrenheit

Metrics Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters
Acres (ac)	.405	Hectares
Gallons (gal)	3.78	Liters
Pounds (lb)	.454	Kilograms
Degrees Fahrenheit	.56(°F –32)	Degrees Celsius

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APPENDIX 1

Projected Changes in Key Climate Variables in the Chugach Region

Figures A1.1–A1.4 from Taylor et al. (2017) show projected changes in key climate variables in the Chugach region into the 2060s: winter temperatures (fig. A1.1), winter snowfall (fig A1.2), snowpack (fig. A1.3), and watershed hydrology (fig. A1.4).

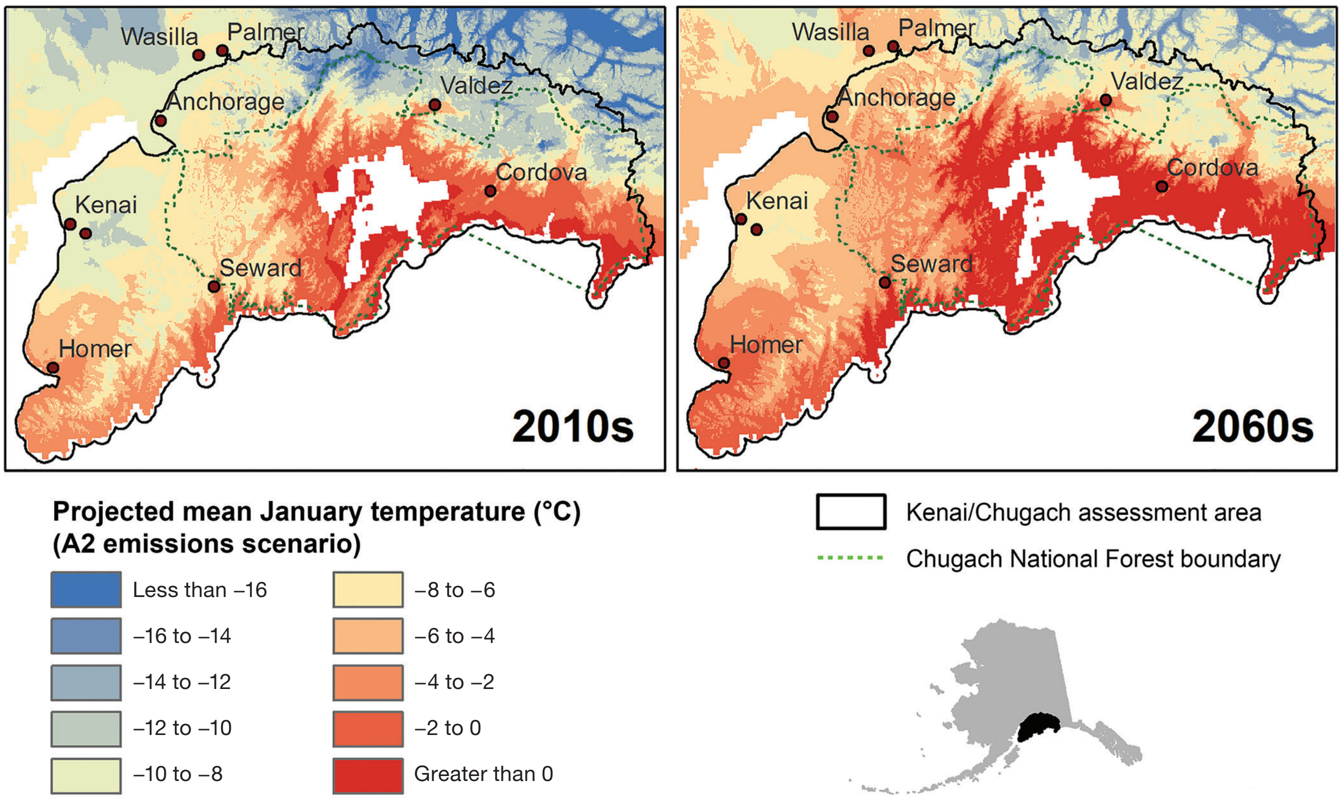

Figure A1.1—Temperature profiles for January in 2010 and 2060 (adapted from Fresco and Floyd 2017). Warming in the winter will be greater than summer (3–3.5 °C).

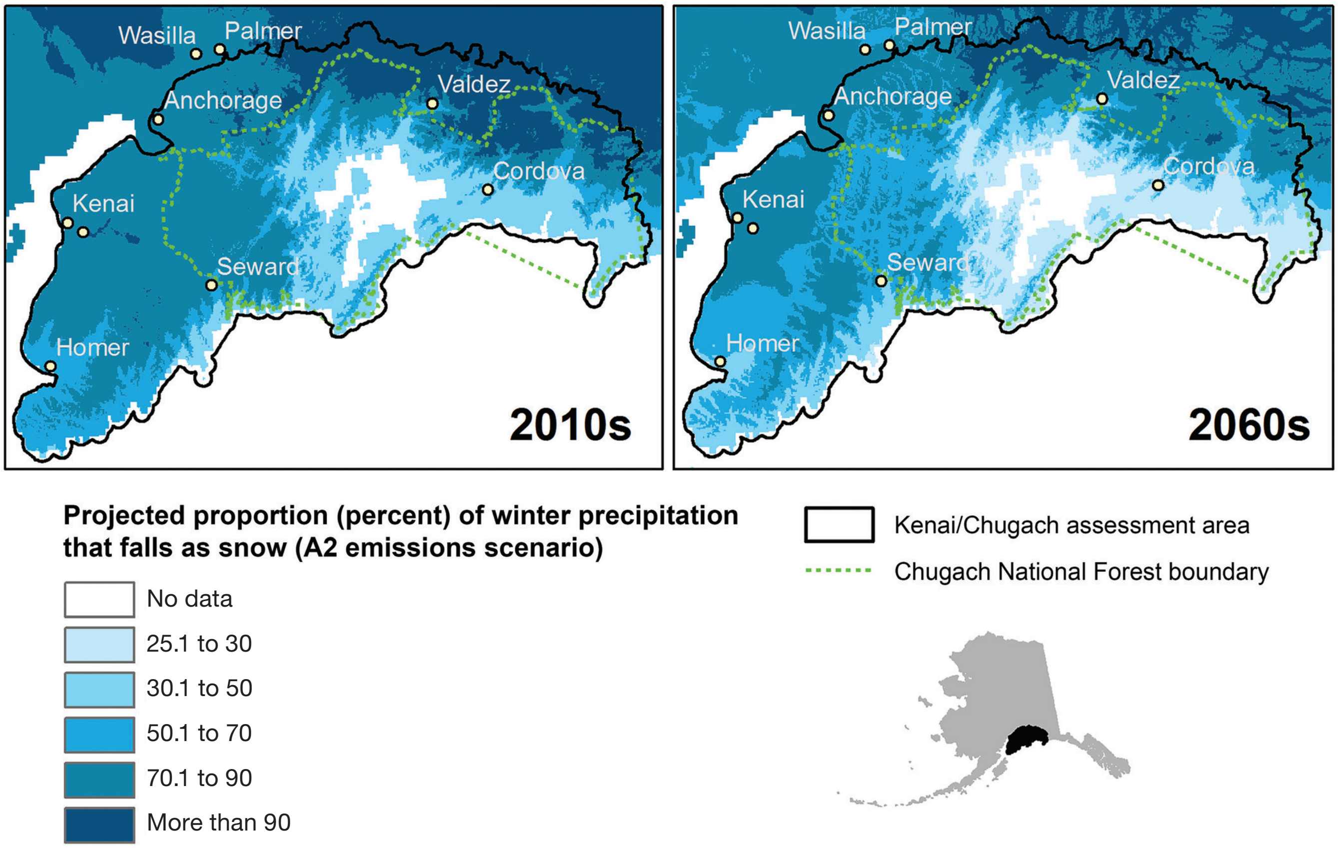

Figure A1.2—Precipitation that falls as snow in 2010 and 2060 (adapted from Fresco and Floyd 2017).

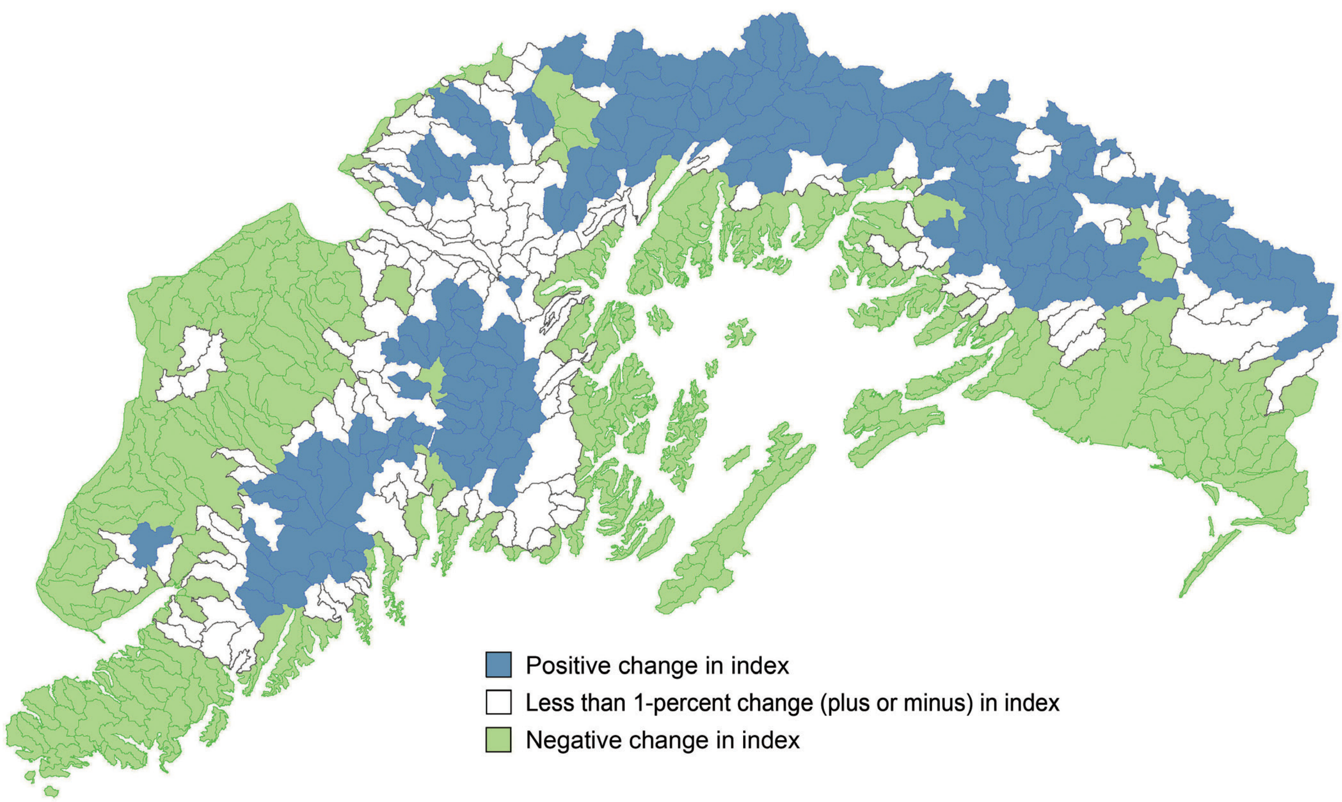

Figure A1.3—Expected snowpack changes (–20 to +10 percent) through 2069 (adapted from Chilcote et al. 2017).

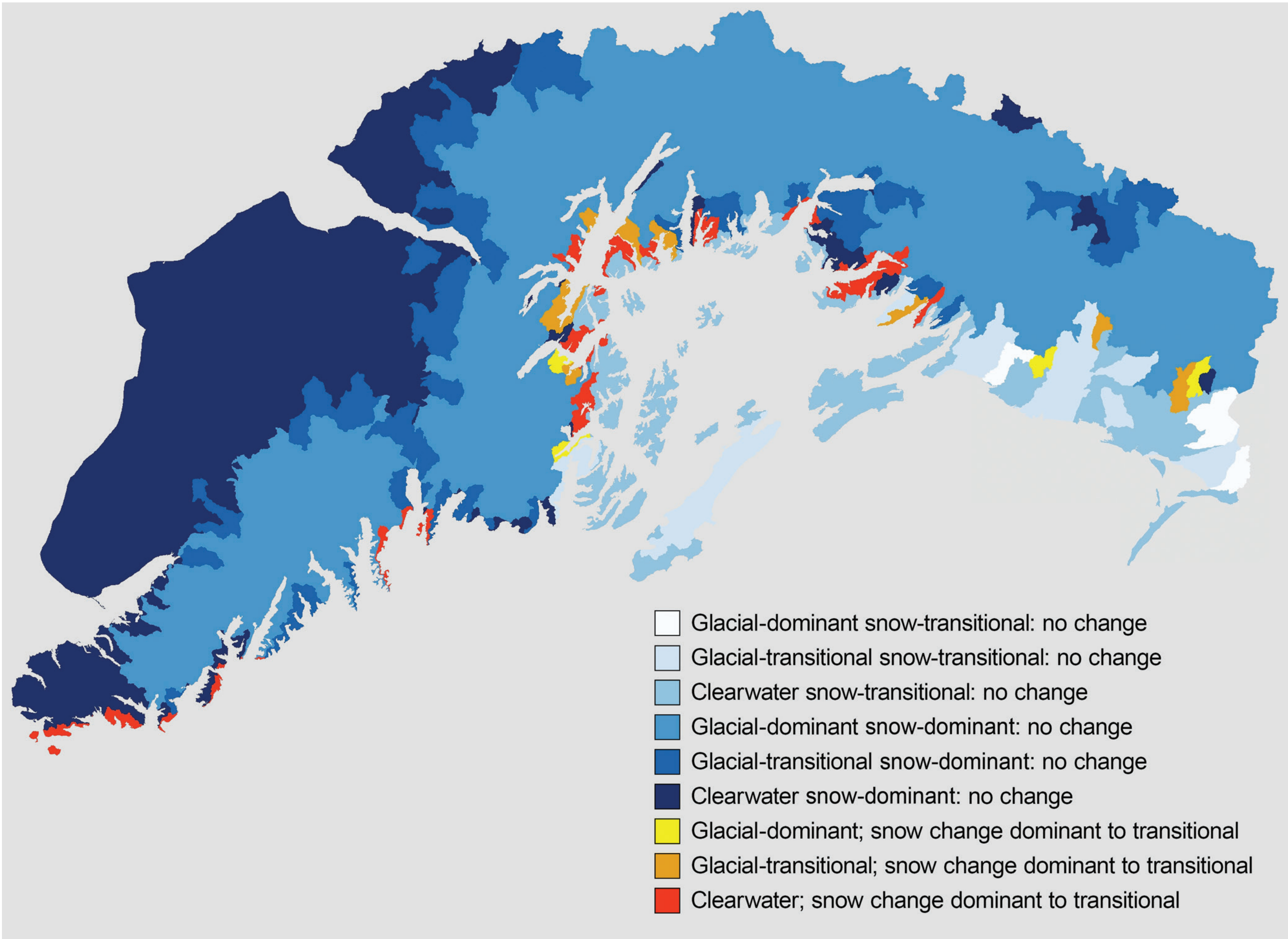

Figure A1.4—Sixty-one (colored yellow, orange, or red) of 720 watersheds are vulnerable to hydrologic shift over the next 30 years in response to changing snowpack under the A1 climate scenario. Watersheds are sixth-field hydrologic unit codes, classified into nine categories based on current and future snowpack characteristics (from Chilcote et al. 2017).

APPENDIX 2
Species Known to Be Used in the Chugach Region

Table A2.1 is a list of species known to be used in the Chugach region as reported in community surveys conducted by the Alaska Department of Fish and Game Division of Subsistence. Data are from Fall and Zimpelman (2016) and Jones and Kostick (2016).

Table A2.1—Fish, shellfish, wildlife, and plant species harvested by Alaska Native communities in Prince William Sound (PWS) (Chenega, Cordova, and Tatitlek) and Cook Inlet (CI) (Nanwalek and Port Graham) in 2014

Food category	Common name	Scientific name	PWS	CI
Salmon	Pink salmon	*Oncorhynchus gorbuscha*	1	1
Salmon	Chum salmon	*Oncorhynchus keta*	1	1
Salmon	Coho salmon	*Oncorhynchus kisutch*	1	1
Salmon	Sockeye salmon	*Oncorhynchus nerka*	1	1
Salmon	Landlocked salmon	*Oncorhynchus* spp.	1	1
Salmon	Chinook salmon	*Oncorhynchus tshawytscha*	1	1
Nonsalmon fish	Unknown sturgeon	*Acipenser* spp.	1	1
Nonsalmon fish	Wolffish	*Anarhichas* spp.	1	1
Nonsalmon fish	Sablefish (black cod)	*Anoplopoma fimbria*	1	1
Nonsalmon fish	Arrowtooth flounder (turbot)	*Atheresthes stomias*	0	1
Nonsalmon fish	Pacific herring	*Clupea pallasi*	1	1
Nonsalmon fish	Pacific herring roe	*Clupea pallasi*	1	1
Nonsalmon fish	Pacific herring sac roe	*Clupea pallasi*	1	1
Nonsalmon fish	Pacific herring spawn on kelp	*Clupea pallasi*	1	1
Nonsalmon fish	Lake whitefish	*Coregonus clupeaformis*	1	0
Nonsalmon fish	Northern pike	*Esox lucius*	1	1
Nonsalmon fish	Pacific (gray) cod	*Gadus macrocephalus*	1	1
Nonsalmon fish	Unknown Irish lord	*Hemilepidotus* spp.	1	1
Nonsalmon fish	Kelp greenling	*Hexagrammos decagrammus*	0	1
Nonsalmon fish	Pacific halibut	*Hippoglossus stenolepis*	1	1
Nonsalmon fish	Pacific tomcod	*Microgadus proximus*	1	1
Nonsalmon fish	Starry flounder	*Platichthys stellatus*	1	1
Nonsalmon fish	Cutthroat trout	*Oncorhynchus clarkii*	1	1
Nonsalmon fish	Lingcod	*Ophiodon elongatus*	1	1
Nonsalmon fish	Rainbow trout	*Oncorhynchus mykiss*	1	1
Nonsalmon fish	Steelhead	*Oncorhynchus mykiss*	1	1
Nonsalmon fish	Rougheye rockfish	*Sebastes aleutianus*	1	0
Nonsalmon fish	Dusky rockfish	*Sebastes ciliatus*	1	0
Nonsalmon fish	Copper rockfish	*Sebastes caurinus*	1	0
Nonsalmon fish	Quillback rockfish	*Sebastes maliger*	1	0
Nonsalmon fish	Black rockfish	*Sebastes melanops*	1	1
Nonsalmon fish	China rockfish	*Sebastes nebulosus*	1	1

Note: 0 = absent; 1 = present.

Food category	Common name	Scientific name	PWS	CI
Nonsalmon fish	Tiger rockfish	*Sebastes nigrocinctus*	1	0
Nonsalmon fish	Bocaccio rockfish	*Sebastes paucispinis*	1	0
Nonsalmon fish	Northern rockfish	*Sebastes polyspinis*	1	0
Nonsalmon fish	Yelloweye rockfish	*Sebastes ruberrimus*	1	1
Nonsalmon fish	Eulachon	*Thaleichthys pacificus*	1	1
Nonsalmon fish	Walleye pollock (whiting)	*Theragra chalcogramma*	1	1
Nonsalmon fish	Char	*Salvelinus* spp.	1	0
Nonsalmon fish	Arctic char	*Salvelinus alpinus*	0	1
Nonsalmon fish	Dolly Varden	*Salvelinus malma*	1	1
Nonsalmon fish	Lake trout	*Salvelinus namaycush*	1	1
Nonsalmon fish	Arctic grayling	*Thymallus arcticus*	1	1
Nonsalmon fish	Eel	—	1	1
Nonsalmon fish	Unknown sculpin	—	1	1
Nonsalmon fish	Unknown shark	—	1	1
Nonsalmon fish	Skates	—	1	1
Large land mammals	Moose	*Alces alces*	1	1
Large land mammals	Bison	*Bison bison*	1	0
Large land mammals	Elk	*Cervus canadensis*	1	0
Large land mammals	Deer	*Odocoileus hemionus*	1	1
Large land mammals	Mountain goat	*Oreamnos americanus*	1	1
Large land mammals	Dall sheep	*Ovis dalli*	1	1
Large land mammals	Caribou	*Rangifer tarandus*	1	1
Large land mammals	Black bear	*Ursus americanus*	1	1
Small land mammals	Beaver	*Castor canadensis*	1	1
Small land mammals	Coyote	*Canis latrans*	1	1
Small land mammals	Gray wolf	*Canis lupus*	1	1
Small land mammals	Porcupine	*Erethizon dorsatum*	1	1
Small land mammals	Wolverine	*Gulo gulo*	1	1
Small land mammals	Snowshoe hare	*Lepus americanus*	1	1
Small land mammals	North American river otter	*Lontra canadensis*	1	1
Small land mammals	Lynx	*Lynx canadensis*	1	1
Small land mammals	Marten	*Martes* spp.	1	1
Small land mammals	Weasel	*Mustela* spp.	1	1
Small land mammals	Mink	*Neovision vison*	1	1
Small land mammals	Muskrat	*Ondatra zibethicus*	1	1
Small land mammals	Arctic ground (parka) squirrel	*Spermophilus parryii*	1	1
Small land mammals	Red (tree) squirrel	*Tamiasciurus hudsonicus*	1	1
Small land mammals	Red fox	*Vulpes vulpes*	1	1

Note: 0 = absent; 1 = present.

Food category	Common name	Scientific name	PWS	CI
Marine mammals	Bowhead whale	*Balaena mysticetus*	0	1
Marine mammals	Sea otter	*Enhydra lutris*	1	1
Marine mammals	Steller sea lion	*Eumetopias jubatus*	1	1
Marine mammals	Harbor seal	*Phoca vitulina*	1	1
Birds and eggs	Northern pintail	*Anas acuta*	1	1
Birds and eggs	Northern shoveler	*Anas clypeata*	1	1
Birds and eggs	Mallard	*Anas platyrhynchos*	1	1
Birds and eggs	Unknown teal	*Anas* spp.	1	1
Birds and eggs	Unknown wigeon	*Anas* spp.	1	1
Birds and eggs	White-fronted goose	*Anser albifrons*	1	1
Birds and eggs	Unknown scaup	*Aythya* spp.	1	1
Birds and eggs	Canvasback	*Aythya valisineria*	1	0
Birds and eggs	Ruffed grouse	*Bonasa umbellus*	0	1
Birds and eggs	Canada/cackling goose	*Branta* spp.	1	1
Birds and eggs	Bufflehead	*Bucephala albeola*	1	1
Birds and eggs	Goldeneye	*Bucephala* spp.	1	1
Birds and eggs	Snow goose	*Chen caerulescens*	1	0
Birds and eggs	Long-tailed duck	*Clangula hyemalis*	1	1
Birds and eggs	Unknown swan	*Cygnus* spp.	0	1
Birds and eggs	Unknown puffin	*Fratercula* spp.	1	1
Birds and eggs	Spruce grouse	*Falcipennis canadensis*	1	1
Birds and eggs	Pacific diver/Arctic loon	*Gavia pacifica/G. arctica*	0	1
Birds and eggs	Sandhill crane	*Grus canadensis*	1	1
Birds and eggs	Black oystercatcher egg	*Haematopus bachmani*	1	1
Birds and eggs	Harlequin duck	*Histrionicus histrionicus*	1	1
Birds and eggs	Unknown ptarmigan	*Lagopus* spp.	1	1
Birds and eggs	White-winged scoter	*Melanitta fusca*	1	1
Birds and eggs	Black scoter	*Melanitta nigra*	1	1
Birds and eggs	Surf scoter	*Melanitta perspicillata*	1	1
Birds and eggs	Unknown merganser	*Mergus* spp.	1	1
Birds and eggs	Unknown cormorant	*Phalacrocorax* spp.	1	1
Birds and eggs	Black-legged kittiwake	*Rissa tridactyla*	1	1
Birds and eggs	Unknown murre	*Uria* spp.	1	1
Marine invertebrates	Whelk	*Buccinum undatum*	1	1
Marine invertebrates	Dungeness crab	*Cancer magister*	1	1
Marine invertebrates	Tanner crab	*Chionoecetes bairdi*	1	0
Marine invertebrates	Unknown tanner crab	*Chionoecetes* spp.	1	1
Marine invertebrates	Rock scallop	*Crassadoma gigantea*	1	0
Marine invertebrates	Pinkneck clam	*Mactromeris polynyma*	1	1
Marine invertebrates	Softshell clam	*Mya arenaria*	0	1

Note: 0 = absent; 1 = present.

Food category	Common name	Scientific name	PWS	CI
Marine invertebrates	Unknown mussel	*Mytilus* spp.	0	1
Marine invertebrates	Octopus	*Octopus vulgaris*	1	1
Marine invertebrates	Unknown king crab	*Paralithodes* spp.	1	1
Marine invertebrates	Limpet	*Patella vulgata*	1	1
Marine invertebrates	Weathervane scallop	*Patinopecten caurinus*	1	1
Marine invertebrates	Pacific littleneck clam (steamers)	*Protothaca staminea*	1	1
Marine invertebrates	Butter clam	*Saxidomus gigantea*	1	1
Marine invertebrates	Razor clam	*Siliqua* spp.	1	1
Marine invertebrates	Horse clam	*Simomactra planulata*	1	1
Marine invertebrates	Red (large) chiton	—	1	1
Marine invertebrates	Black (small) chiton	—	1	1
Vegetation and fungi	Yarrow	*Achillea* spp.	0	1
Vegetation and fungi	Alaria (ribbon kelp)	*Alaria spp.*	1	1
Vegetation and fungi	Wild chives	*Allium schoenoprasum*	0	1
Vegetation and fungi	Alder	*Alnus* spp.	1	1
Vegetation and fungi	Wild celery	*Angelica lucida*	1	1
Vegetation and fungi	Bearberry	*Arctostaphylos uva-ursi*	1	0
Vegetation and fungi	Stinkweed	*Artemisia tilesii*	1	1
Vegetation and fungi	Birch sap	*Betula* spp.	0	1
Vegetation and fungi	Crowberry	*Empetrum nigrum*	1	1
Vegetation and fungi	Fireweed	*Epilobium angustifolium*	1	1
Vegetation and fungi	Strawberry	*Fragaria virginiana*	1	1
Vegetation and fungi	Bladder wrack	*Fucus vesiculosus*	1	1
Vegetation and fungi	Beach greens	*Honckenya peploides*	0	1
Vegetation and fungi	Chaga	*Inonotus obliquus*	0	1
Vegetation and fungi	Labrador tea	*Ledum palustre*	1	1
Vegetation and fungi	Giant kelp (macrocystis)	*Macrocystis pyrifera*	1	1
Vegetation and fungi	Bull kelp	*Nereocystis luetkeana*	1	1
Vegetation and fungi	Devils club	*Oplopanax horridus*	1	1
Vegetation and fungi	Sea ribbon	*Palmaria mollis*	1	1
Vegetation and fungi	Dulse	*Palmaria palmata*	0	1
Vegetation and fungi	Wild parsley	*Pastinaca sativa*	1	1
Vegetation and fungi	Plantain	*Plantago major*	0	1
Vegetation and fungi	Goose tongue	*Plantago maritima*	1	1
Vegetation and fungi	Wild rhubarb	*Polygonum alaskanum*	1	1
Vegetation and fungi	Black seaweed	*Porphyra abbottae*	1	1
Vegetation and fungi	Gooseberry	*Ribes oxyacanthoides*	1	1
Vegetation and fungi	Currant	*Ribes* spp.	1	1
Vegetation and fungi	Wild rose hip	*Rosa acicularis*	1	1
Vegetation and fungi	Nagoonberry	*Rubus arcticus* spp.	1	1

Note: 0 = absent; 1 = present.

Food category	Common name	Scientific name	PWS	CI
Vegetation and fungi	Cloudberry	*Rubus chamaemorus*	0	1
Vegetation and fungi	Raspberry	*Rubus idaeus*	1	1
Vegetation and fungi	Salmonberry	*Rubus spectabilis*	1	1
Vegetation and fungi	Sourdock	*Rumex fenestratus*	1	1
Vegetation and fungi	Sorrel	*Rumex* spp.	1	0
Vegetation and fungi	Beach asparagus	*Salicornia virginica*	1	1
Vegetation and fungi	Willow leaf	*Salix* spp.	0	1
Vegetation and fungi	Sea chickweed	*Stellaria* spp.	0	1
Vegetation and fungi	Twisted stalk berry (watermelon berry)	*Streptopus amplexifolius*	1	1
Vegetation and fungi	Dandelion greens	*Taraxacum* spp.	1	1
Vegetation and fungi	Nettle	*Urtica* spp.	1	1
Vegetation and fungi	Huckleberry	*Vaccinium parvifolium*	1	0
Vegetation and fungi	Blueberry	*Vaccinium uliginosum*	1	1
Vegetation and fungi	Lowbush cranberry	*Vaccinium vitis-idaea*	1	1
Vegetation and fungi	Highbush cranberry	*Viburnum edule*	1	1
Vegetation and fungi	Fiddlehead fern	—	0	1
Total			**146**	**148**

Note: 0 = absent; 1 = present.

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