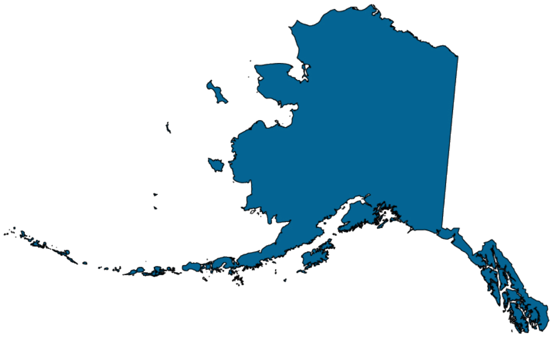
Fifth National Climate Assessment: Chapter 29

Alaska



Chapter 29. Alaska

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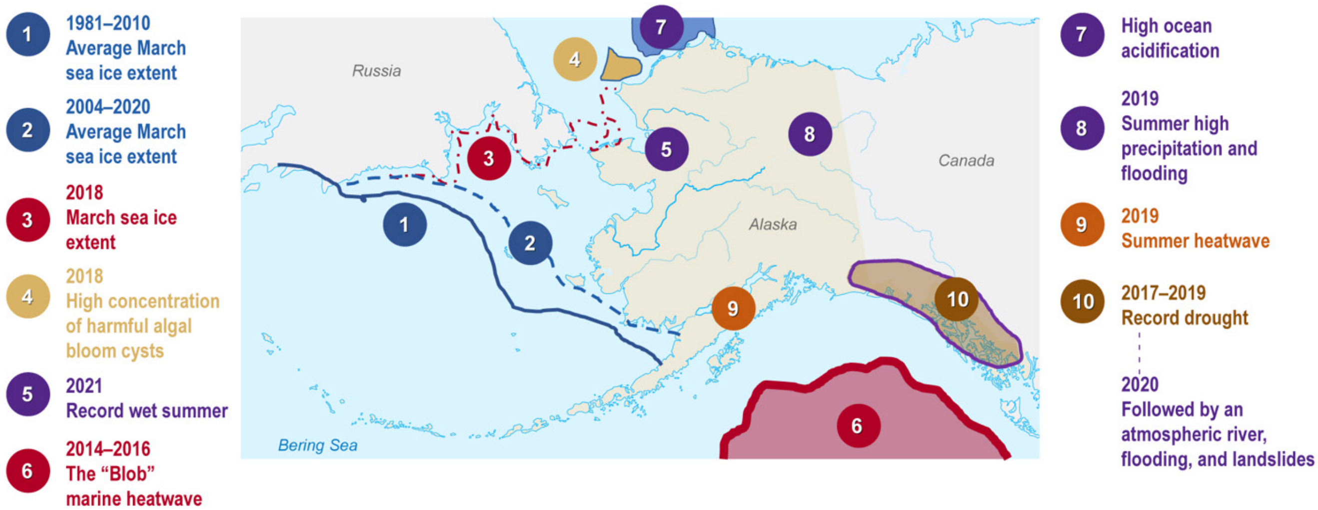
Introduction

Alaska is warming two to three times faster than the global average.[1,2] The physical and ecological effects of warming are evident around the state (Figures 29.1, 29.11). Glaciers are shrinking, permafrost is thawing, and sea ice is diminishing. The growing season is longer, and fish, mammals, birds, and insects have increased in numbers in some areas and dropped sharply in others. This combination of environmental effects has far-reaching consequences for people statewide. Following a brief description of distinctive characteristics of Alaska and an overview of recent climatology in this Introduction, the chapter emphasizes the societal implications of climate change for Alaska to a greater degree than in the corresponding chapters of previous National Climate Assessments (NCAs), with illustrative examples and recurring themes, such as salmon, governance, and adaptation.

Recent Climate-Driven Extremes and Notable Events



Climate-driven extreme events continue throughout Alaska.

Figure 29.1. Climate-driven extremes and notable events have recently affected different regions of Alaska. These events have redefined expectations of regional extremes and challenged preparedness (Focus on Compound Events). March sea ice extent in 2018 was far below recent low averages (Figure A4.6).[3] High concentrations of harmful algal bloom cysts were discovered in the Chukchi Sea (KM 29.1).[4] A record wet summer occurred in northwest Alaska in 2021, and 2019 brought uncharacteristic precipitation and flooding on the North Slope. The effects of the 2014–2016 North Pacific marine heatwave (the "Blob")[5] have become clear (Figures 29.11, A4.11; Box 10.1). Ongoing ocean acidification in Arctic Alaska has contributed to fundamental changes in marine water quality (KM 3.4).[6] In summer 2019, a record and persistent heatwave occurred in southern Alaska. A multiyear drought (2017–2019)[7,8] in Southeast Alaska's rainforest was followed by intense rain and destructive landslides.[9] Figure credit: USGS, NOAA Fisheries, and Ocean Conservancy.

Climatologically, Alaska is notable for frozen water in the forms of permafrost, sea ice, land ice, and snow. Culturally, Alaska is home to 21 distinct Indigenous Peoples, comprising about one-fifth of the population. Alaska's lands and communities are governed by a complex system of federal, state, and local agencies and 229 Tribal governments, as well as Alaska Native regional and village corporations. More than 200 communities are located off the road system. Most of these have year-round access by only small aircraft and summer access by ferry, cargo barge, or river vessel. Economically, Alaska is dominated by the public sector and by natural resource industries, with fisheries being the largest private-sector industry in terms of employment and oil and gas the largest in terms of revenue.[10] These characteristics shape the ways that climate change affects society in Alaska (see also KM 29.2).

Responses to climate change in Alaska's communities occur in the context of the governance systems divided among federal, state, regional, local, and Tribal agencies, with various and often overlapping responsibilities. About two-thirds of Alaska's land is under federal jurisdiction, with another quarter owned by the State of Alaska and a tenth owned by Alaska Native corporations. Tribal governments, with few exceptions, do not have geographical jurisdiction but are responsible for many programs affecting Tribal members. Because climate change affects society in many ways, fragmented governance can frustrate a coordinated response or the ability of communities to address climate change in a holistic fashion (Figure 29.16). Some precedents, such as the Denali Commission (an independent federal agency designed to provide Alaska with critical utilities, infrastructure, and economic support), demonstrate the potential for greater coordination of government support to better address community needs, if adequate resources and direction are provided.

Since NCA4 was published in 2018, Alaska has continued to experience rapid, widespread, and extreme climate-related changes in the form of ocean warming, record low sea ice,[3,11,12] the world's highest rates of ocean acidification,[6,13] an increasing frequency of extreme events such as marine heatwaves (KM 10.1),[5,12,14,15] and extreme snow and rain storms in winter (App. 4.2; Box 29.2).[16,17] These changes have reduced biological productivity, shifted seasonal timing of productivity, altered food web dynamics, and caused steep declines in prey.[18,19,20,21] In many freshwater environments, these changes result in a combination of reduced summer streamflows, increased summer water temperatures, hypoxia, and decreased prey abundance, which are lethal to many aquatic species.[7,19,22,23] There is no indication that these trends will slow or reverse in the near future (KM 2.2).[19,24,25,26,27,28,29]

Climate change in Alaska is driven by global trends (KM 2.1), but regional impacts are evident. The state is experiencing warming air temperatures,[1] record-breaking droughts,[7] reduced snowpack,[1] shrinking glaciers,[30,31] continued permafrost thaw,[32] relative sea level change,[33] record numbers of pollen outbreaks, increasingly destructive wildfires,[34] changing snowfall amounts and seasons,[1] and changing patterns of windstorms.[35] Although year-to-year variability is and will be a feature of Alaska's climate,[36] it is apparent that detectable warming trends started in the 1970s.[1,2] Annual average temperatures have increased across the state since 1971, with increases ranging from 2.4°F in Southeast Alaska to 6.2°F in northern Alaska,[1] up to 2.6 times the rate of change in the Lower 48. Of the annual average Alaska warming for 1950–2017, 75% is explained by greenhouse gas warming.[37] Heatwaves are increasing in the Arctic.[38] A 2019 summer heatwave brought record-high temperatures to southern and Interior Alaska,[39] with daily high temperatures exceeding normal by more than 20°F. This event had important community impacts such as wildfire smoke and fish kills, as well as uncharacteristically severe and expensive disturbances such as the Swan Lake Fire on the Kenai Peninsula.[40] Alaska's statewide annual average surface air temperature is projected to increase by 8.1°F (4.5°C) by the end of the century under an intermediate scenario (SSP2-4.5) and 14.2°F (7.9°C) under a very high scenario (SSP5-8.5), for 2081–2100 relative to 1981–2010.[41,42] This projection is 2.5°F (1.4°C) greater than comparable regional projections in NCA4.[43]

Annual and seasonal precipitation totals are generally increasing, but the size and significance of the changes vary with dataset and location,[1,44] with the most consistent increasing trends in northern Alaska, particularly on the North Slope (over 2.5% per decade).[1] One- and five-day maximum precipitation is increasing in most Alaska climate divisions, but changes are statistically significant since 1957 on the North Slope (over 2% per decade) and in the southeastern part of the Interior (over 1.4% per decade). Recent unprecedented extreme rainfall and seasonal precipitation events have presented challenges in multiple parts of Alaska. For example, an atmospheric river (an atmospheric flow that causes extreme precipitation) in December 2020 broke all-time extreme 24-hour precipitation records in 11 Southeast Alaska communities and caused two fatalities and more than $33.5 million (in 2022 dollars) in public property damage due to rain-on-snow and storm runoff as well as wind and landslides. Alaska's statewide average annual total precipitation is projected to increase by 20.6% by the end of the century under an intermediate scenario

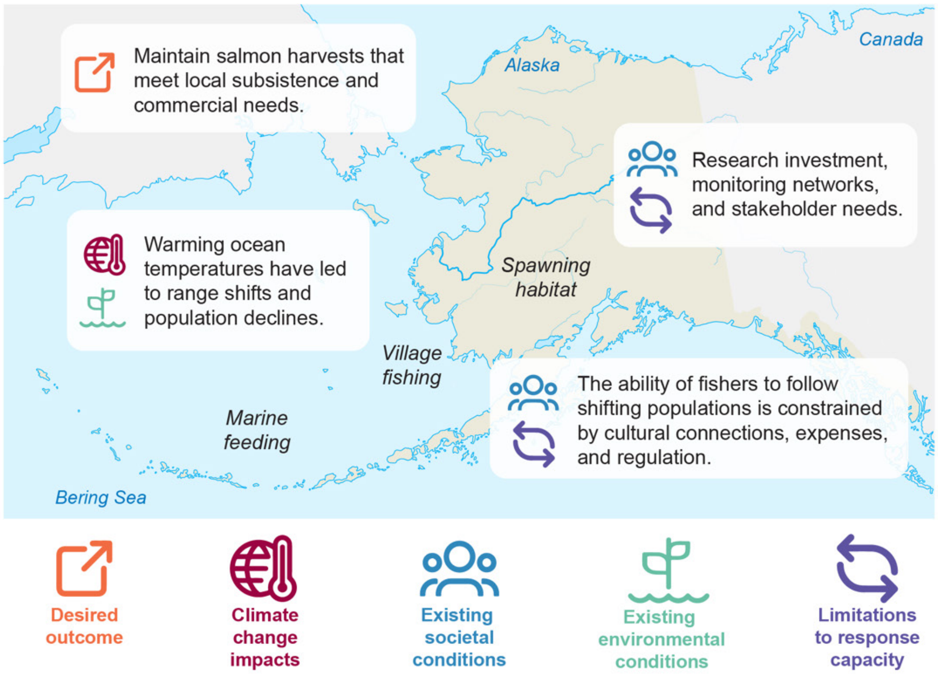
(SSP2-4.5) and 35.8% by the end of the century under a very high scenario (SSP5-8.5), for 2081–2100 relative to 1981–2010.[41,42]

Some of the most direct impacts of rising temperatures are on the cryosphere—snow, ice, and permafrost (KM 3.4),[45] with substantial, consequential impacts on hydrology, ecosystem function, infrastructure, and human health and livelihoods. Across the Arctic, temperature increases are driving a shortened snow cover season, melting glaciers, thawing permafrost, and less predictable sea ice extent (App. 4.3).[1,45] Snowfall has decreased in autumn and spring but increased in parts of Alaska in the midwinter snow season.[1] The Alaska snowfall season is projected to decrease across the state,[46,47] and water entrained in snowpack is projected to decrease between 20% and 60% by the 2050s (2040–2069, moderate emissions) and between 40% and 90% by the 2080s (2070–2099, higher emissions) in most of the southern and western parts of the state. The highest elevations and coldest parts of Alaska, however, could see no net loss or even increases up to 35% (such as in the Brooks Range) in snowfall during the midwinter snow season.[46] For March, historically the month of maximum sea ice extent, the Bering Sea ice extent has decreased by about 20,000 square miles per decade since 1957,[1] and record minimums in 2018 and 2019 were associated with warm ocean temperatures.[48] For September, historically the month of minimum sea ice extent, the Chukchi and Beaufort ice extents have decreased by about 27,000 square miles per decade and 31,000 square miles per decade, respectively.[1] These sea ice losses accelerated in the mid-1990s. Permafrost degradation and thaw described in previous NCAs continues and may be accelerating due to recent warm winters and, for 2018, increased snow cover (e.g., Douglas et al. 2021[49]), which insulates the surface from cold air above.[50] Previously reported projections of permafrost degradation may underestimate permafrost thaw rates.[51]

These extensive changes affect Alaska's society in many ways—in the context of Alaska's existing geography, governance, economics, demographics, cultures, and social services (Figure 29.2 provides two examples). By disrupting familiar patterns and conditions, climate change exacerbates existing tensions and conflicts across the state. As coastlines and riverbanks erode, and as fish and wildlife distributions shift, potential responses include relocating communities or using new areas for hunting, fishing, and other uses. However, current societal systems can constrain the options available for responding to change (KM 20.2). Land and resource management policies and practices, for example, may prevent or restrict the movements of people and their activities.[52] At the same time, the strong ties that Alaska Native Peoples have to their lands and waters are a vital consideration in any equitable responses to change.

The Context of Climate Change Response

Alaska Salmon Fishing



Denali Park Road

The response to climate change depends on the desired societal outcome and is shaped by existing societal and environmental conditions.

Figure 29.2. Two examples illustrate the interactions between climate change and societal and environmental factors for an activity important throughout much of the state and for a place that attracts many residents and visitors alike. Successful salmon fishing in rural Alaska villages is threatened by ecological changes affecting salmon spawning and survival (top; Boxes 29.3, 29.5). The $600 million annual tourism economy of Denali National Park is threatened by a thawing rock glacier that has damaged the access road (bottom; Box 29.4). Figure credit: (top) Ocean Conservancy; (bottom) adapted from NPS. Photo credit: NPS

Although Alaskans cannot stop global warming alone, they can choose to take actions that contribute to global efforts to limit climate change and be leaders in effective planning and adaptation (KM 31.3). From Alaska Native culture camps teaching climate and cultural resilience to courses on residential solar installation for homeowners and workers, Alaskans working together can accomplish a great deal. The effectiveness of cooperation, together with careful preparation and planning, was seen in the rapid and effective response to the November 2018 earthquake in Southcentral Alaska.[53] If Alaska's response to climate change remains fragmented, climate change will be intertwined with nearly all of the other persistent problems facing Alaska. If Alaska's society pulls together, much can be done to create lasting benefits for today and for future generations, contributing to a prosperous and just society in the state (Table 29.1).

Table 29.1. The Intersection of Climate Change and Societal Context

Climate change exacerbates existing societal tensions, but responding effectively to climate change can yield many societal benefits, as shown in the examples here for each of the chapter's Key Messages.

Key Message	Examples of Challenges That Intersect with Climate Change	Examples of Opportunities for Climate Responses with Multiple Benefits
29.1 Our Health and Healthcare Are at Risk	Inequitable access to basic nutrition and physical and mental healthcare services	Strong public health services
29.2 Our Communities Are Navigating Compounding Stressors	Food insecurity	Increasing community capacity and agency
29.3 Our Livelihoods Are Vulnerable Without Diversification	High prices and scarce jobs, especially in rural Alaska	Renewable energy and value-added industries
29.4 Our Built Environment Will Become More Costly	High needs, high costs, and barriers to implementation	Cross-community learning, priority setting by communities themselves
29.5 Our Natural Environment Is Transforming Rapidly	Allocation conflicts and cumulative effects of human activities	Ecosystem-based management and equitable participation
29.6 Our Security Faces Greater Threats	Conflict at many scales and competition for limited resources	Recognizing and supporting widespread contributions to security
29.7 Our Just and Prosperous Future Starts with Adaptation	The societal needs listed above present challenges to climate change adaptation	Cross-scale learning and cooperation to improve justice and equity

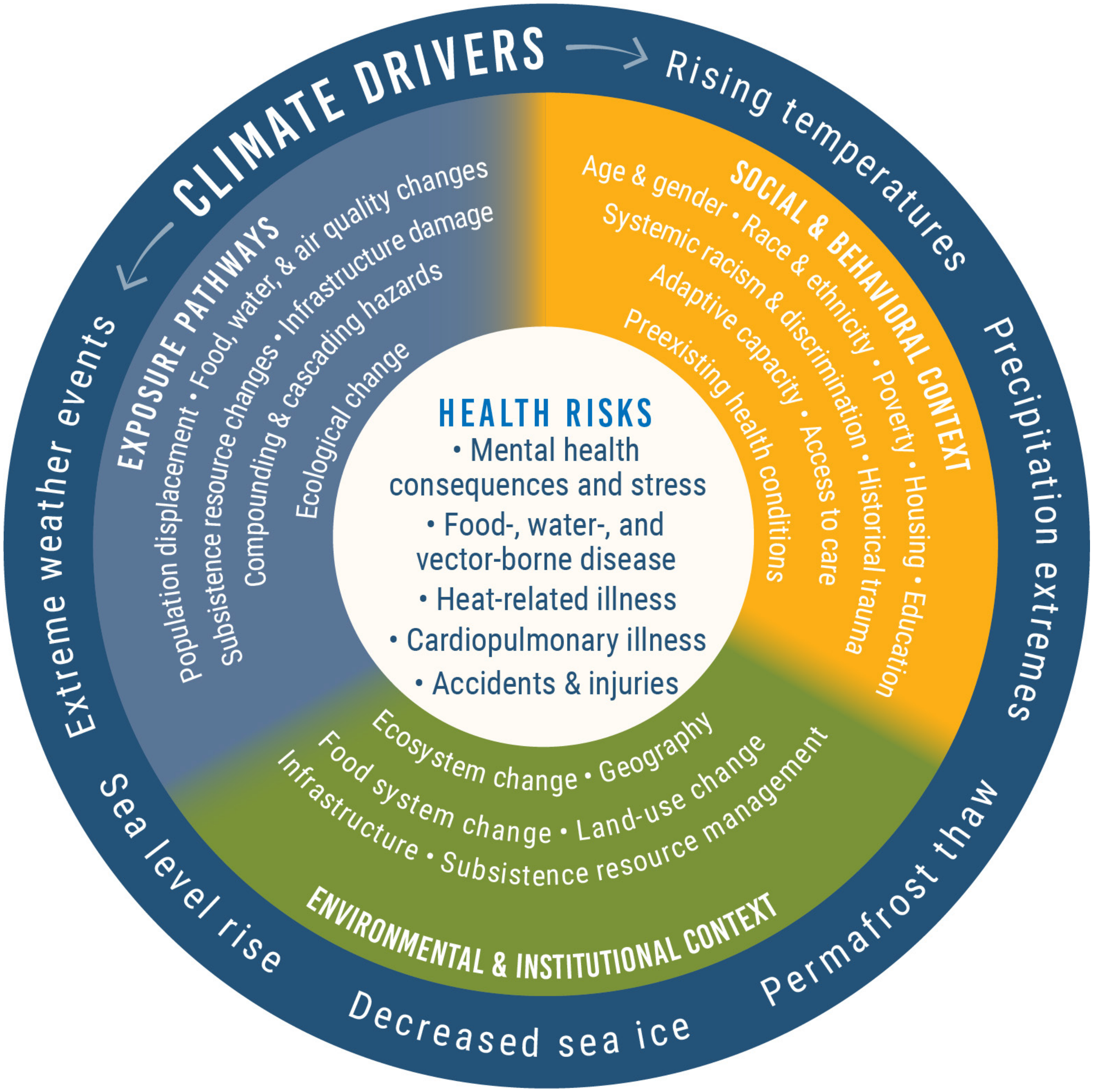
Key Message 29.1

Our Health and Healthcare Are at Risk

Health disparities in Alaska, including access to healthcare and health outcomes, are exacerbated by climate change (*high confidence*). The well-being of Alaska residents will be further challenged by climate-driven threats and by emerging diseases (*medium confidence*). Improving health surveillance and healthcare access statewide can increase resilience to events that threaten public health (*medium confidence*).

Many Alaskans, particularly Alaska Native Peoples, have a distinct connection to and understanding of the natural environment (KM 29.5) and depend on the land, sea, and natural resources for their economic activities, food security, health, culture, and overall well-being. This close connection to local ecosystems, combined with the geographical isolation of many communities and their resulting distance from healthcare and other services, creates a population particularly vulnerable to health impacts from the local effects of a changing climate (Figure 29.3) yet also fosters self-reliance and resilience.

Climate, Health, and Well-Being in Communities



The impacts of climate change on health and well-being depend on many social and environmental factors.

Figure 29.3. Well-being includes physical, mental, and spiritual health outcomes, all of which are shaped by many contextual factors, including environmental change and governance, social and behavioral characteristics and systems, and the exposure pathways that connect the changing environment to human health. All of these contextual factors are affected by climate change and occur simultaneously. Adapted from Balbus et al. 2016.[54]

Climate change in Alaska highlights existing inequities confronting many racial and ethnic groups, including discrimination, lack of access to healthcare, lack of indoor plumbing, and poverty.[55,56,57] In rural Alaska especially, underserved communities often face food and water insecurity, inadequate sanitation, overcrowding in homes, limited transportation options, limited medical access, and significant geographical isolation.[58,59,60] People living in such settings are disproportionately impacted by climate change (KMs 15.2, 20.1),[61] and have limited options to respond to additional disturbances.

The lack of basic household sanitation facilities (Figure 4.16) contributes to health disparities, especially in rural Alaska. The lack of indoor plumbing was a key factor contributing to the high incidence of COVID-19 cases among Tribal communities (Focus on COVID-19 and Climate Change).[62,63,64] More than 3,300 households in more than 30 Alaska communities lack in-home piped water and sewer services.[65,66] In Alaska, the lack of water and sewer services is associated with multiple adverse health outcomes.[67,68,69] Environmental factors such as permafrost thaw, river erosion, and flooding exacerbate inequitable health-related infrastructure, and climate change has created new challenges to building and supporting sanitation systems. The Portable Arctic Sanitation System, developed by the Alaska Native Tribal Health Consortium and tested in five communities to date, provides households with treated water for drinking and a handwashing sink, in addition to a waterless toilet system. These systems allow households to meet basic water and sanitation needs in situations such as damage to existing water and sewer infrastructure or community relocation.[66] While not a replacement for a piped water system, these systems are a successful example of responding to climate hazards in Alaska (KM 16.3).

Climate change in Alaska is related to a range of environmental catastrophes, which can directly impact health in significant ways that may not be well known (KM 15.1). Flooding, for example, negatively impacts physical and mental well-being, with special and persistent implications for certain populations, such as pregnant people and children.[70,71] In Alaska, these effects are compounded by preexisting disparities, such as limited access to healthcare (e.g., pregnant people in rural Alaska typically travel to urban areas for childbirth) and the lack of alternative housing options. In the aftermath of ex-Typhoon Merbok in September 2022, which resulted in widespread flooding of a thousand miles of Alaska's coastline, people experienced loss of air travel service, multiday power outages, and damaged housing (often resulting in a subsequent need to move to a different community).[72]

Environmental disruption due to climate change can lead to increased rates of suicidality, among other negative mental health effects (KM 15.1).[73] These effects, including a profound loss of connection to a landscape altered by climate change, can increase instances of mental illness and spiritual grief in affected populations and subsequent generations.[74,75,76] Forced displacement inland due to rising sea levels, coastal erosion, flooding, and permafrost thaw disrupt social networks and increase instances of homelessness.[77,78,79] Alaska Native populations already experience significantly elevated rates of suicide, especially among youth.[80] Based on research with Inuit in Labrador, Canada, Alaska Native populations whose ways of life and culture depend on subsistence activities may be particularly vulnerable to negative mental health impacts related to climate change because of their deep connection to the land, exacerbated by existing disparities in mental health services (KM 16.1).[81]

Various health concerns connected to climate change have been raised by Alaska residents and public health officials (KM 15.1). For example, wildfire smoke exposure is associated with an increased risk of adverse health outcomes among Alaska Natives and rural residents.[82] This increased risk is thought to be due, in part, to underlying differences in rates of chronic disease, as well as access to healthcare and resources for exposure reduction (e.g., air filters).[82] Common exposure-reduction strategies may not be an option for many households. For example, few homes in Alaska have air-conditioning. During a wildfire smoke event that occurs at the same time as a heatwave, people must weigh the risks of opening a window to decrease the heat versus keeping windows closed to minimize smoke exposure. When developing adaptation strategies for climate hazards, it is critical to consider existing health disparities within communities, the relative capacity of individuals to adapt, and the potential to exacerbate existing inequities (KMs 15.3, 20.3).

The expanding geographic ranges of tick species and the potential implications for human health are another concern (KM 8.2). The blacklegged tick and western blacklegged tick, carriers of the bacteria that cause Lyme disease, are not established in Alaska, although the western blacklegged tick has been found on humans and domestic animals that have not reported recent travel out of the state.[83,84] Current conditions in

Southeast Alaska and some portions of Southcentral Alaska are suitable for the establishment of the western blacklegged tick, and models predict an increase in the suitability of tick habitat in many areas.[84] While there have been no known locally acquired human cases of Lyme disease in Alaska, the risk of occurrence is expected to increase, especially for those who spend a lot of time outdoors.[57]

Rabies is another disease that can be transmitted from animals to people, with potential connections to changing climate conditions due to shifting ranges of host species. In Alaska, rabies is found in populations of Arctic and red fox populations along the northern and western coasts. During the 2020/21 winter, there was a widespread outbreak of rabies in western Alaska, with more than 35 confirmed cases in animals, compared with an average of four to five cases each year. Changes in sea ice and prey availability may have played a role by increasing exposure of red foxes to rabid Arctic foxes and thus spreading rabies to inland areas as well as along the coast.[85,86]

Climate change is also affecting the ability to dry and store food in traditional ways[87] and increasing the potential for adverse health effects from processing and consuming fish and wildlife.[57] Wetter weather inhibits drying of fish and meat, and permafrost thaw and flooding damage ice cellars.[88] Additionally, human, marine mammal, and seabird health are increasingly threatened by harmful algal blooms (HABs), which produce a toxin that can cause severe illness or death when consumed (KM 10.1).[89,90,91,92] The largest bed of resting cysts of HAB species in the world has been discovered in the Chukchi Sea.[4] Warming ocean temperatures make these cysts more apt to hatch into massive and recurring toxic blooms.[4]

In general, there are limited conventional disease surveillance systems in Alaska for identifying, detecting, and monitoring climate-related hazards and conditions, as well as limited information on broader health impacts, such as the degree to which climate-related factors have impacted mental health. The development and sustainability of robust surveillance systems is hampered by many factors, including the state's small population and large geographic scale, limited in-state locations with adequate laboratory and diagnostic testing, and other healthcare limitations, such as access to healthcare and disconnected health databases. To fill these gaps, several local and Tribal programs have been implemented, such the Local Environmental Observer Network, Southeast Alaska Tribal Ocean Research, and Indigenous Sentinels Network, which facilitate integration of community observations.

In addition to limited health surveillance systems for climate-related risks, there are also large disparities in healthcare access and services in Alaska. The COVID-19 pandemic highlighted some of these gaps,[93,94] although some responses to the pandemic created or strengthened health partnerships and surveillance, which may support longer-term action to improve healthcare and health outcomes around the state. Because more immediate crises, such as a disease outbreak, can reduce the capacity for responding to longer-term healthcare challenges, such as those posed by climate change, continued investment in these types of improvements in the healthcare system statewide may increase resilience to climate-driven health impacts.

Box 29.1. “I’ve Been Called to Pray”

Tragedies related to climate change, such as deaths associated with changing ice conditions, impact more than just those who are directly affected. Alaska Native communities, although often geographically spread out, remain intimately connected via cultural and family ties, social media, and other networks, such as churches (KM 16.2).

Iñupiaq Elder Gladys I’yiiqpak Pungowiyi, of Kotzebue, a predominantly Inupiaq town in northwestern Alaska, states:

> *I’ve been called to pray.*
>
> *On Facebook, there are mothers, grandmothers requesting prayer for their lost loved ones who fall through the ice and their families who are going through a hard time. Especially when they’re not found.*
>
> *I’ve been called to pray for people that are affected mentally. What’s happened over the years is that a number of skilled hunters were lost when they went out hunting. Either they fall through the ice or just disappear. It seems like every springtime people start saying “Our men are going out hunting. Please pray for them.” It’s hard.*[95]

Gladys I’yiiqpak Pungowiyi

Strong connections between individuals and communities are vital in rural Alaska.

Figure 29.4. Iñupiaq Elder Gladys I’yiiqpak Pungowiyi is shown here using a laptop computer in Kotzebue, Alaska, August 19, 2022. Photo credit: ©Cana Uluaq Itchuaqiyaq.

Key Message 29.2

Our Communities Are Navigating Compounding Stressors

Climate change amplifies the social and economic challenges facing Alaska communities (*high confidence*). Resource shifts, coastal and riverbank erosion, and disproportionate access to services will continue to threaten the physical and social integrity of these communities (*high confidence*). Increased adaptation capacity and equitable support have the potential to help rural and urban communities address Alaska's regionally varied climate-driven threats (*high confidence*).

Climate change affects all Alaska communities but in regionally distinct ways for urban areas compared with rural, predominantly Alaska Native, places. Lacking road connections, Alaska's rural areas are more remote than rural areas in the Lower 48. About 79% of Alaskans live in urban areas.[96] This concentration creates challenges for the development and maintenance of infrastructure in rural areas where economies of scale do not exist (KM 12.2). For example, there are large disparities in exposure to the effects of climate change and inequities in access to resources and capacity for responding to those effects.[97]

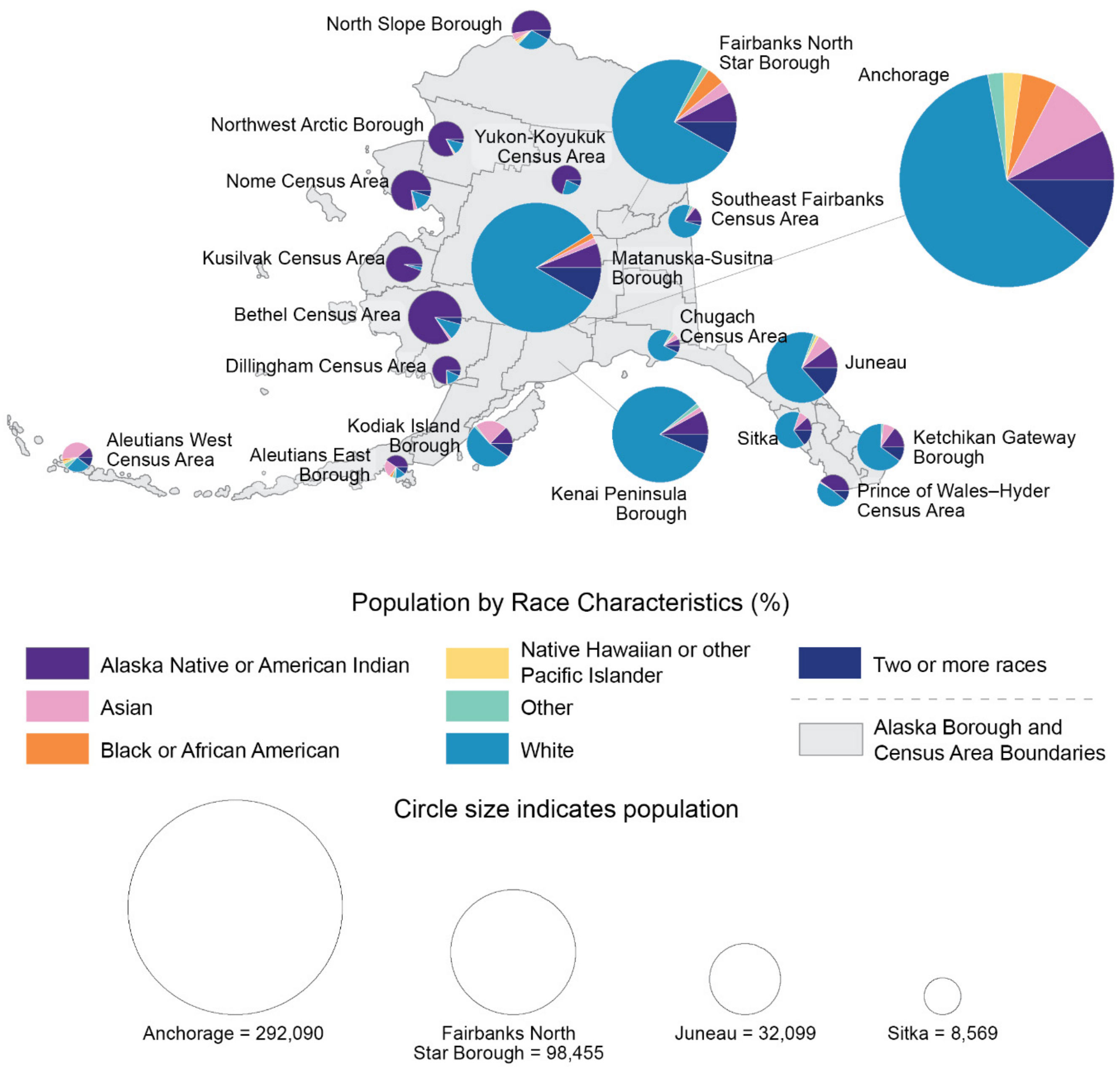
The limited reach of broadband internet access in the state is testament to this challenge.[98] As of 2023, 46% of Alaska communities remain unserved according to the National Telecommunications and Information Administration's minimum broadband standards.[99] An additional 3% are considered "underserved," lacking internet that meets the new baseline for functional service. Many fewer communities have access to affordable internet, with some paying as much as $500 per month with usage caps. Lack of broadband and cell reception diminishes access to healthcare (via telemedicine), educational opportunities, emergency response capability, and resilience to shocks from environmental hazards and extreme weather events,[100] which are expected to increase with climate change.

As another example, the frequency of wildfire seasons in which more than 1 million acres are burned is increasing throughout much of western and Interior Alaska (KM 7.1; Focus on Western Wildfires). In addition to health concerns (KMs 14.2, 29.1), smoke can limit visibility and interfere with air travel. This disproportionately affects rural areas accessible only by plane, leaving Alaska Native Elders, other older adults, and those with existing respiratory ailments without a means to escape environmental stressors.[34]

Both urban and rural communities face significant infrastructure and access challenges related to permafrost thaw and erosion (KM 29.4). Rural communities facing relocation are among the hardest hit, as are low-income populations in urban areas. In the Fairbanks North Star Borough (FNSB), a comparison shows that the average value of residential land[101] with shallow permafrost soil[102] is about 40% the average value of residential land borough-wide. Low-income populations in FNSB disproportionately reside in homes on or near permafrost-affected soils and are thus disproportionately impacted by damage resulting from permafrost thaw.

Alaska's population is gradually becoming more diverse (Figure 29.5). The percentage of White residents dropped 2% from 2010 to 2020.[103] The Alaska Native population increased nearly 10%, and the Black population increased 2%, but the largest growth was among residents with Asian heritage, whose population increased 32%. Much of the non-White population growth occurred in urban areas where, as in other parts of the United States, BIPOC (Black, Indigenous, and People of Color) populations historically were subject to discrimination and exclusionary housing practices. Such discrimination continues to shape the character of Alaska's urban neighborhoods today.[104] More research could illuminate the disproportionate impacts of climate change experienced by BIPOC communities in urban Alaska, which, if consistent with national trends, are expected to be substantial. Increased knowledge of the current and historic inequities in relation to climate change and other environmental factors would help inform adaptation and mitigation measures that protect and uplift vulnerable populations.

Racial and Geographic Distribution of Alaska's Population



The racial makeup and population density of Alaska's communities vary greatly by region, creating the potential for varied exposures and disparate impacts across subpopulations

Figure 29.5. The total Alaska population estimate in 2021 was 734,323.[105] Urban areas account for the majority of Alaska's population. Racial and ethnic characteristics throughout the state vary greatly by region, as do the impacts of climate change. Alaska's urban areas are particularly diverse, and given a legacy of historic discrimination, there is still much to learn about the unique ways racial and ethnic subpopulations are impacted by climate change in Alaska and how these vary around the state. Circle sizes are proportional to population for each region. Figure credit: Northern Social-Environmental Research, Ocean Conservancy, and University of Alaska Fairbanks.

Food security is a major priority for the state of Alaska (Box 11.2).[106] Food prices may be more than twice as high in rural versus urban communities, with considerably less variety.[107] Alaska Supplemental Nutrition Assistance Program (SNAP) recipients receive the third-highest benefit per person in the United States, behind only Hawaiʻi and Guam. The number of households receiving SNAP benefits in Alaska increased 8% between 2019 and 2020.[108] The vast majority of food Alaskans purchase is grown elsewhere, arriving via long supply chains (Focus on Supply Chains). COVID-19 highlighted the fragility of the state's food supply and serves as an analog for the potential impacts of climate-related environmental shocks. During the pandemic, backlogged ports and restrictions on overland trucking through Canada made food and other essentials difficult to obtain. Remote regions of Alaska were among the hardest hit by supply chain disruptions after a primary air carrier in rural Alaska declared bankruptcy in April 2020 (Focus on COVID-19 and Climate Change). This left many rural off-road-system communities without a commercial airline to deliver mail and freight, including medications and food supplies.

Given the high cost of food and the vulnerability of rural transportation networks, subsistence activities (including hunting, fishing, and sharing) are critical in rural Alaska. This is especially true for Alaska Native communities, as well as for many non-Native and urban residents. About 45.4 million pounds of wild food were harvested in Alaska statewide in 2017, with an estimated replacement value of $262–$523 million (in 2022 dollars),[109] not counting their cultural and spiritual value. Yet the success of subsistence harvests is influenced by numerous external and climate-driven factors. These include shifting distribution, abundance, and migratory patterns of fish, birds, and mammals that affect availability to hunters and fishers; rising fuel costs that increase the cost of hunting, fishing, and gathering activities; and changing weather, flooding, and dangerous ice that increase risks to those engaged in these practices (KMs 8.1, 29.3).[87,109]

Climate change will have some positive impacts on Alaska food security, particularly in the agricultural sector. A longer growing season, increased number of growing degree days, and increased yields are expected to enhance the share of locally grown foods consumed by Alaskans.[110,111,112] On the other hand, pests, flooding, and ground collapse resulting from permafrost thaw will pose challenges.

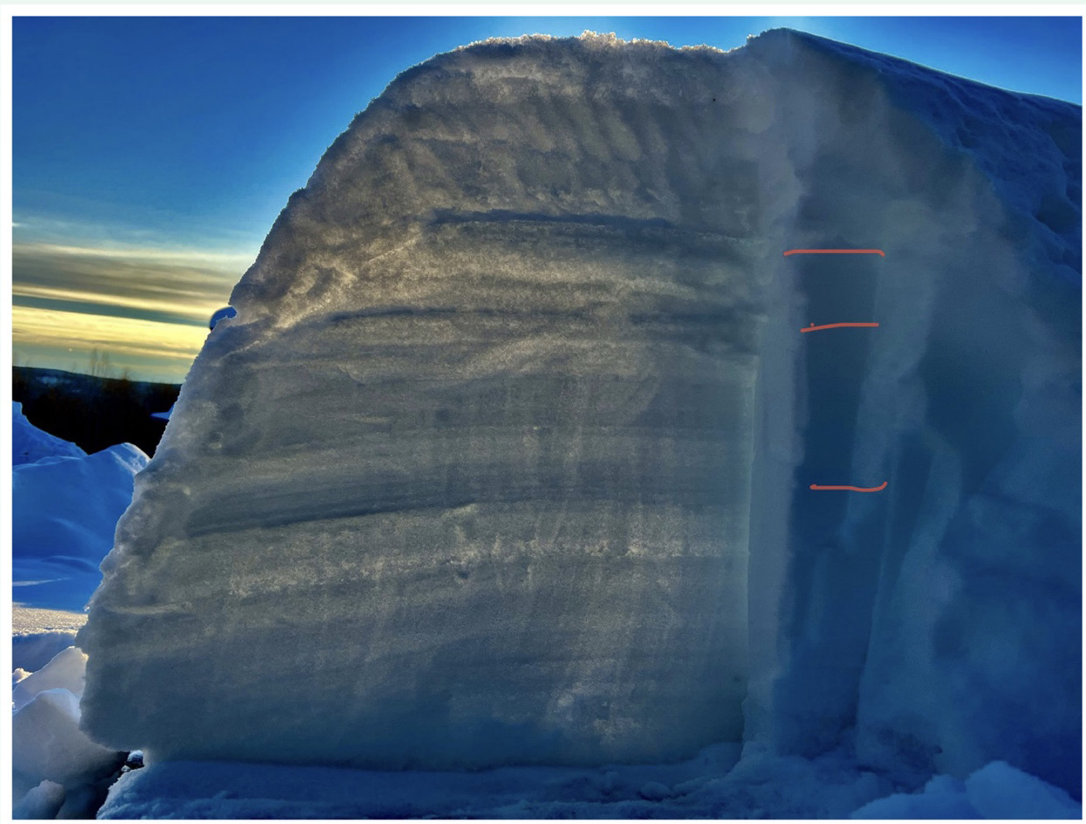
Box 29.2. “We Had to Dig In and Out of Our House”

Snow and cold are expected in Fairbanks and Interior Alaska in winter. Rain is not. More than an inch of rain fell on top of feet of snow during the 2021 holidays. The resulting ice made roads impassable, caused power outages, delayed emergency services, damaged homes, and was linked to at least one highway fatality months later as roads remained dangerously icy into spring.[113,114] State and federal disaster declarations were issued as well.[115,116] More extreme weather events are expected in a warming Alaska.

Fairbanks resident and tax preparer Marjorie Casort recalls, “I shoveled my driveway seven times in five days. In April we are still feeling the effects, with an inch of ice stubbornly clinging to roads. Many of my elderly clients are housebound, unable to even cross the road to check their mailbox because of the dangerous ice conditions”.[117]

Social relationships are an essential component of resilience. Denali resident Erica Watson explained, “I trust my friends and neighbors to know what they need to do to stay warm, to check in on each other, to care for each other’s homes the way we would our own.”[118]

Cross-Section of Snowpack After the December 2021 Storm



A rain-on-snow event in December 2021 blocked roads and caused other damages.

Figure 29.6. Shown here is a 20-inch-high cross-section of the snowpack near Fairbanks, Alaska, taken on January 23, 2022. Red lines indicate ice layers from rain-on-snow events. The ice persisted through the winter, impeding travel for humans and moose. Photo credit: ©Bill Witte.

Key Message 29.3

Our Livelihoods Are Vulnerable Without Diversification

Livelihoods, especially those dependent on natural resources, are at risk around Alaska. While advancing climate change has contributed to the collapse of major fisheries and is undermining many existing jobs and ways of life (*high confidence*), it may also create some opportunities related to adaptation and response (*medium confidence*). Economic diversification, especially expansion of value-added industries, can help increase overall livelihood options (*medium confidence*).

Many jobs in Alaska are affected directly or indirectly by climate change—through alterations in abundance and distribution of fish species, through changes in access to lands and waters dominated by permafrost and ice, and through the cascading effects of a changing economy (Figure 29.7). Sustaining healthy livelihoods and ways of life in Alaska involves more than wages and salaries. Traditional cultural practices outside the cash economy include the harvest and sharing of fish, wildlife, and berries. Climate-driven changes to lands and waters, along with societal trends such as greater adoption of mainstream food practices, can reduce opportunities for subsistence harvests and thus affect cultural, nutritional, and spiritual well-being, especially for Alaska Native communities (KM 16.1).

Climate-Sensitive Employment in Alaska

Climate change is expected to have wide-ranging effects on key economic sectors in Alaska.

Figure 29.7. The figure shows examples of key sectors of Alaska's economy that are expected to be affected in various ways by climate change. Many, but not all, of the changes are negative. Data sources: Oil and Gas;[96,119] Agriculture;[120] Tourism;[121] Fishing;[122] Subsistence.[87,109] Figure credit: Northern Social-Environmental Research, University of Alaska Fairbanks, and Ocean Conservancy.

Climate impacts have severe socioeconomic consequences for Indigenous Peoples, small rural communities, and industries throughout Alaska.[123,124,125,126] For example, the Yukon River king salmon subsistence fishery has been closed river-wide since 2020, with no expected opening date in the foreseeable future. This is the first occurrence of a year-round Yukon River subsistence king salmon closure. King salmon contribute 64% of all protein to rural Yukon River communities. A multiyear closure of the subsistence king salmon fishery due to climate change (Box 29.5) and the overharvesting of ocean king salmon via bycatch is disastrous to Indigenous Peoples' physical, mental, cultural, and spiritual well-being.

Alaska's commercial fisheries have also been impacted. Alaska's seafood industry generates $6.1 billion (in 2022 dollars) in economic outputs,[122] accounting for 60% of the volume and 31% of the value of the US fishery catch.[127] A number of fisheries have been closed or dramatically reduced due to fewer fish (KM 10.2).[128,129,130,131] In January 2022, the US Department of Commerce declared several fishery disasters because of the extreme economic impact of their decline.[132] Climate change has had a large role in these fishery disasters.[133]

Climate change has negatively impacted the condition, growth, survival, reproduction, population biomass, and harvest of marine fishes,[134,135,136] salmon,[29,126,137,138,139,140] and crab.[131,141] In addition, groundfish and crab distributions have shifted northward or offshore,[142,143] following colder water, and the timing of groundfish spawning[144] and salmon spawning migration[145] has been altered (KM 8.1). Salmon are in double jeopardy because climate affects both their freshwater and marine habitats (Box 29.5). Changes in spawn timing will require changes in survey timing and stock assessments.[146,147] Changes in fish and crab distribution will require adjusting survey locations and area-based management measures.[148,149] Fishers will need to adjust the timing of harvest or switch to other harvest targets.[150] Local economies can be resilient through income diversification such as participating in several different fisheries.[151] Proactive adaptive management can help in the face of rapid climate change. One recent example is the management of Prince William Sound pink salmon during the extreme 2019 drought. After detecting high mortality early in the fishing season, managers limited harvest at critical times so that fish could successfully migrate and spawn.[23]

Warmer temperatures and changes in precipitation patterns also affect the distribution of and access to terrestrial and marine mammals (KM 8.3).[152,153] Increasingly volatile storms and changing ice and water levels are of immediate concern because they threaten the availability of wild foods, as well as safe access to these subsistence resources by boat, snowmobile, or all-terrain vehicle.[153,154] Shorter durations of suitable conditions for spring marine mammal subsistence hunting in the Arctic due to loss of sea ice will require adaptation of traditional hunting practices.[155] On land, more frequent rain-on-snow events can increase stress and mortality for wildlife,[156] reducing availability. Migratory patterns for caribou and other species are also changing,[157] again affecting access for hunters.

Berries are of high nutritional and cultural importance to Indigenous and rural communities.[158] A recent survey indicated that, statewide, berry harvests have become less reliable due to declining abundance or increased variability.[159] Changes in precipitation and temperature are expected to continue to affect berry production,[160] and they may also impact pollinators.[159]

The intersecting demands of the climate crisis and the high cost of living in Alaska have forced Alaskans to creatively address interrelated challenges related to energy and heat, crisis response, and food equity and access (KM 19.3). Union electricians and laborers, private contractors and installers, and utility inspectors are training a growing workforce in clean energy industries.[161,162] Farmers and artisans are providing local goods, training aspiring agriculturalists, and creating new employment opportunities in mariculture.[163,164] In Fairbanks, community members are working with local healthcare providers to create crisis response teams and centers that focus on harm reduction and community care, needs made greater by climate change.[165]

Box 29.3. What It Means to Lose Salmon

Prior to the recent period of unusually warm water temperatures in the Gulf of Alaska, the Chignik fishery typically supported returns of more than one million sockeye worth nearly $10.2 million (in 2022 dollars) a year to the fishermen. In 2021, in part due to the effects of ocean warming, returns were so poor that some residents chose not to subsistence fish out of fear of harming the fragile run.[166] Resident George Anderson explained how that felt: "We had something that we took for granted—that the fish were just always going to be there for smoking, salting, freezer, whatever. And to have that not be there for you is just something we were never prepared for."[166]

Some nonprofit and industry organizations have tried to help by donating fish. But for the predominantly Alutiiq community, subsistence is not just about food, it is also a connection to place and family.

"It's our lifeblood. Chignik's going to go away if we can't get this run back up to where it used to be," said Al Anderson, another Chignik fisherman.[166]

Unloading Salmon Sent to Chignik in Response to the Fishery Disaster

Donations of salmon provided much-needed food to Chignik and other small communities.

Figure 29.8. Boxes of salmon are unloaded from a small plane in response to the fishery disaster in Chignik, Alaska, July 11, 2022. Photo credit: ©Miranda Lind.

Key Message 29.4

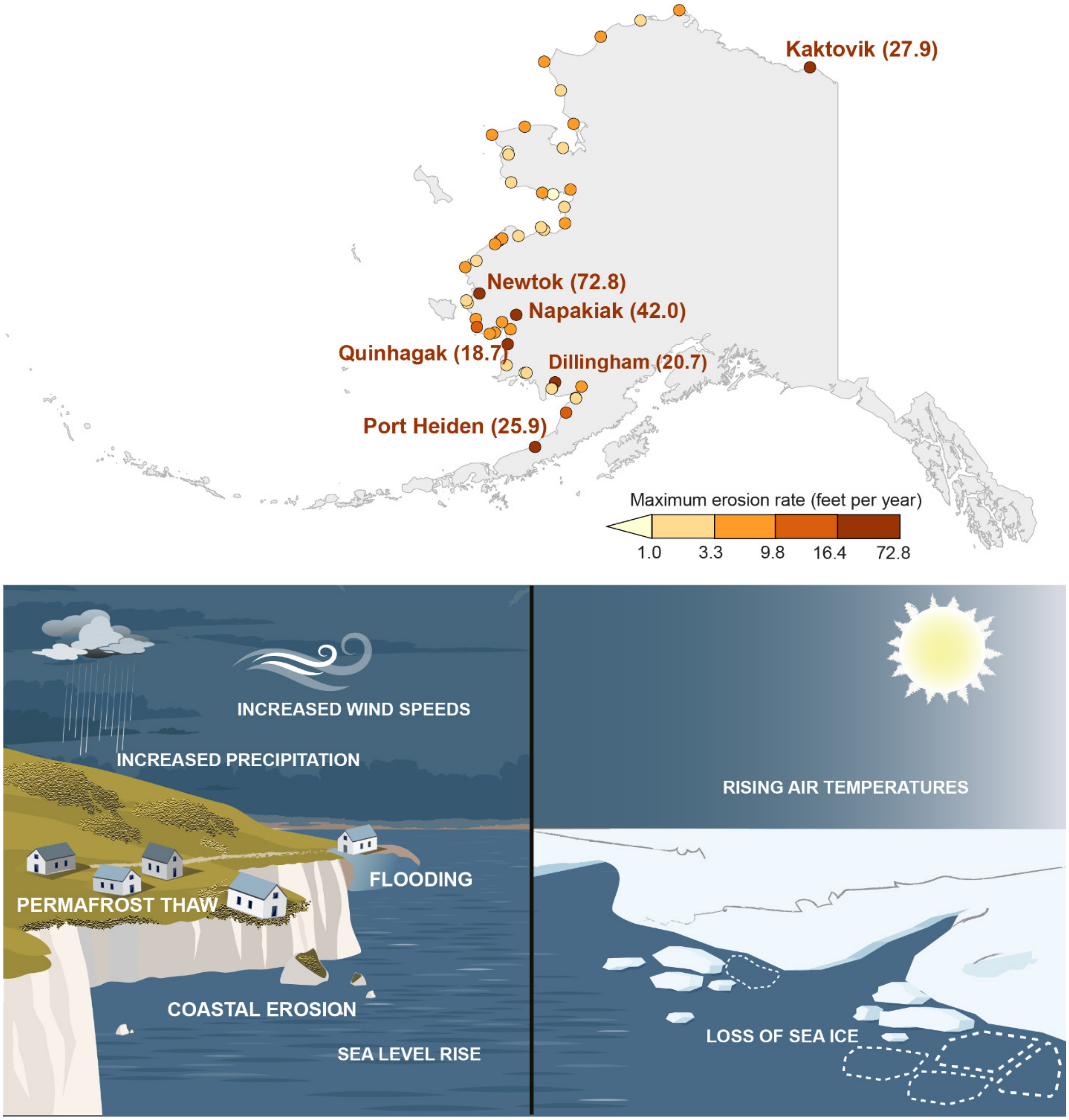
Our Built Environment Will Become More Costly

Much of Alaska's infrastructure was built for a stable climate, and changes in permafrost, ocean conditions, sea ice, air temperature, and precipitation patterns place that infrastructure at risk (*high confidence*). Further warming is expected to lead to greater needs and costs for maintenance or replacement of buildings, roads, airports, and other facilities (*high confidence*). Planning for further change and greater attention to climate trends and changes in extremes can help improve infrastructure resilience around Alaska (*high confidence*).

Power, water, and transportation infrastructure in Alaska varies from large-scale and modern in urban areas to small-scale and even rudimentary in some villages. Air transport depends on suitable weather for flying and adequate runways in the destination community. Transport by water, delivering fuel and other heavy goods to many communities, requires rivers or coastal waters deep enough for barges and adequate offloading sites or facilities. Most communities lack backup systems for water, sewer, and electricity, leaving them vulnerable to disruption. Emergency housing may be limited to the school gymnasium as the largest indoor space in the community. Many Alaskans, especially in rural areas, also depend on remote camps for hunting and fishing to produce food. These camps are vulnerable to climate-driven damage and disruption.

Buildings and other infrastructure throughout Alaska are at risk from flooding, erosion, and permafrost degradation (Table 13.1; Figure 29.9).[167,168,169,170] More than half of Alaska's communities are at the highest threatened level according to the most recent statewide report.[171] For example, on Alaska's northern and western coastlines, communities face between 1 and 72.8 feet of erosion per year (KM 9.2).[172,173] Recent progress has been made to understand local flood and erosion vulnerability for Alaska communities by determining erosion rates [173] and historical flood heights (Figure 29.15); however, these reports are not available for all communities. Given that 80% of Alaska is underlain by permafrost (Figure 8.5),[174,175] regional infrastructure damages are projected to be high.[176] Modeling erosion's dependence on permafrost integrity and persistence has been an emphasis of recent research.[177] However, the widespread lack of permafrost presence assessments, and the degree to which local erosion depends on permafrost responses, is a key source of uncertainty in forecasts for specific Alaska communities.[178] Extensive coastal and riverbank erosion has also exposed old gravesites in western Alaska,[179,180] and permafrost is integral for cold storage in many Alaska Native communities and camps.

Coastal Erosion Rates and Processes in Alaska



Coastal erosion is a major threat around Alaska.

Figure 29.9. The figure shows rates of coastal erosion in selected communities (**top**) and coastal erosion processes in Alaska (**bottom**). Data are unavailable for many parts of Alaska's extensive coastline, but erosion risk is high in much of the state (Figure 29.14). Coastal erosion processes are affected by many aspects of climate change (bottom), exacerbating the problem. (top) Adapted with permission from Overbeck et al. 2020;[173] (bottom) adapted with permission from the University of Alaska Fairbanks, Alaska Arctic Observatory and Knowledge Hub.

Alaska Native communities face an estimated $4.8 billion (in 2022 dollars) in costs to infrastructure from environmental threats over the next 50 years.[181] These costs may be significantly underestimated due to limitations in current model-based approaches[182], as well as to the omission of dispersed but culturally vital infrastructure such as fish camps. Various assessments have been completed to try to determine the cost of environmental changes to communities.[178,181] The costs of responding to climate change are unevenly distributed, with rural areas facing greater costs and few benefits, in contrast to urban areas that will realize some benefits such as reduced heating expenses and where the costs of infrastructure maintenance will be spread over a much larger population base (KMs 11.3, 12.2).[97]

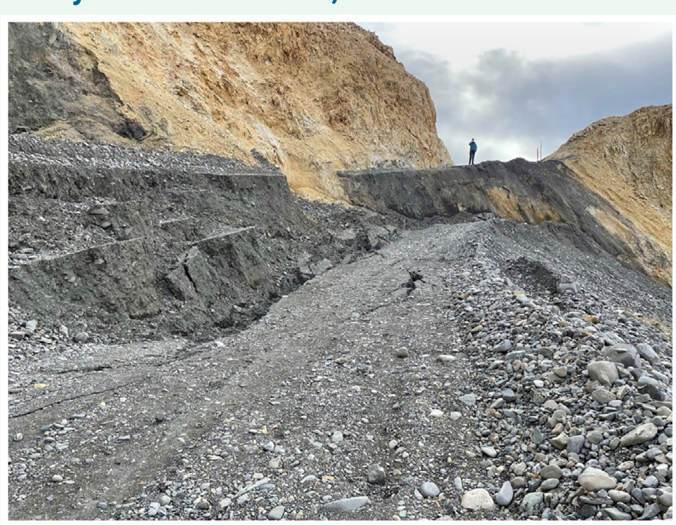
Communities dealing with flooding, erosion, and permafrost degradation are responding immediately as well as planning long-term adaptations, which generally include a combination of protection of infrastructure in place, raising buildings out of the floodplain or moving them out of vulnerable areas, and entire community relocation (which has been the case for Newtok moving to the new site of Metarvik) (KM 9.3; Figure 9.5).[183] As mentioned earlier, however, relocation options may be limited by the availability of land that is culturally, economically, politically, and environmentally suitable. An additional complication is that no single agency has financial responsibility for the costs of relocation.[52]

Box 29.4. The Cost of Thawing Ground for Alaska Industries

The oil development and production industry on Alaska's North Slope also faces challenges from thawing permafrost. Intensive efforts are now required to keep the ground cold and solid to support roads, pipelines, and buildings (KM 5.3),[184,185] and these are short-term solutions. Thawing permafrost will drive up the costs of North Slope operations.[184] Similar problems are expected with infrastructure elsewhere in the state, potentially reducing the viability of some industries.

Thawing ground can damage infrastructure, affecting many economic sectors around Alaska. In 2021, a landslide from a thawing rock glacier in Denali National Park cut off a section of the 92-mile road that takes visitors deep into the park (Figure 29.2).[186,187] The rate of ground slumping and damage to the road had accelerated by summer 2022.[188] A bridge over the damaged section of the road is estimated by the National Park Service to cost $102 million (in 2022 dollars). Other sections of the road are also at risk. Access to the park, which generates some $680 million (in 2022 dollars) in tourist spending each year, will be hampered at least through the 2024 season.

Pretty Rocks Landslide, Denali Park Road



Thawing permafrost limited access to Denali National Park.

Figure 29.10. A slump in the Denali Park Road at the Pretty Rocks location was caused by movement of the rock glacier beneath the road, September 16, 2021. Photo credit: NPS.

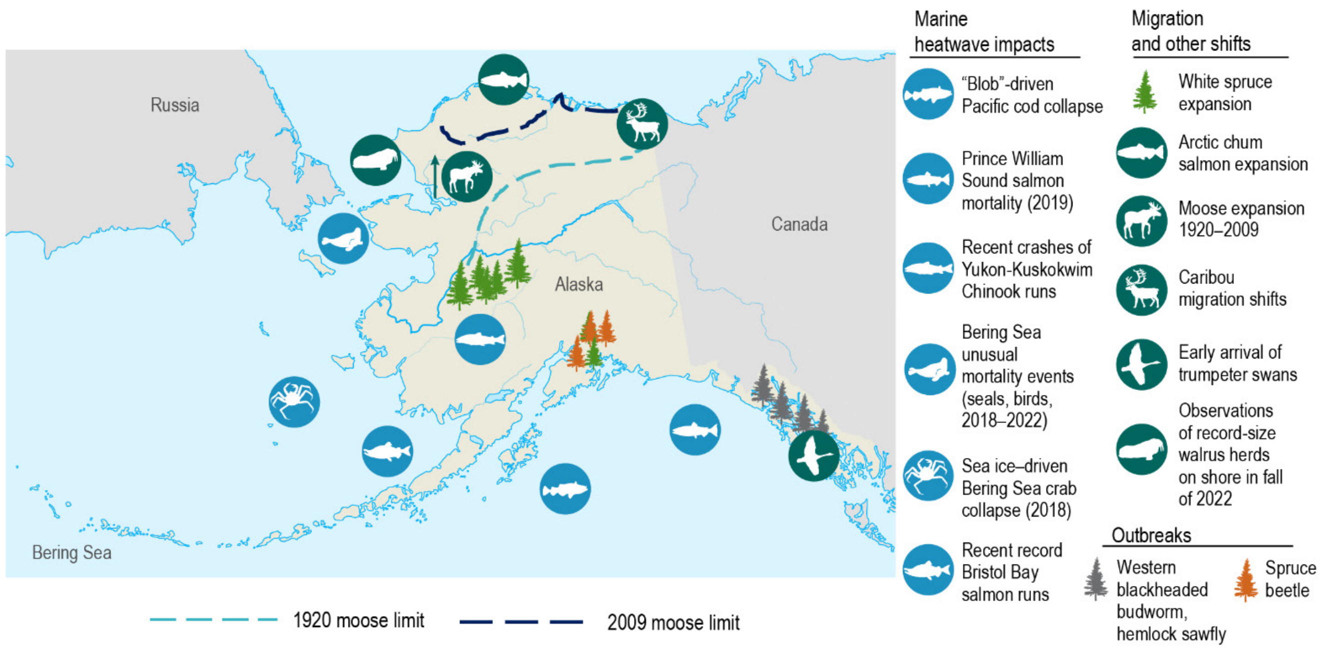
Key Message 29.5

Our Natural Environment Is Transforming Rapidly

Alaska's ecosystems are changing rapidly due to climate change (*high confidence*). Many of the ecosystem goods and services that Alaskans rely on are expected to be diminished by further change (*medium confidence*). Careful management of Alaska's natural resources to avoid additional stresses on fish, wildlife, and habitats can help avoid compounding effects on our ecosystems (*medium confidence*).

Alaska enjoys large, unfragmented marine and terrestrial ecosystems. This abundance makes possible hunting and fishing for subsistence use, cultural well-being, recreation, and commercial activities. At the same time, there are conflicts over land use and the allocation of hunting and fishing opportunities due to different land management regimes or distribution of harvest opportunities, with competing claims from traditional, commercial, and recreational constituencies.[189] Climate change is expected to exacerbate existing challenges by shifting the distribution and abundance of fish and wildlife and by increasing disturbance to lands and waters (Figure 29.11; KMs 8.1, 8.2). Climate-conscious management efforts can help individuals and communities adjust but cannot by themselves address the underlying changes that will continue to occur.

Major Recent Ecological Changes



Climate change has caused or contributed to extensive ecological effects throughout Alaska in recent years.

Figure 29.11. Warming ocean waters, extreme heat events, and other changes, including the events shown in Figure 29.1, are affecting ecosystems across Alaska. Some species' ranges are expanding, including chum salmon in Arctic rivers,[190] moose[191], and beaver[192] in the Arctic (not shown), and white spruce in western Alaska (KM 8.2).[193] Migration timings or patterns are changing, for example trumpeter swans in Southeast Alaska[194] and caribou in the eastern Arctic. Marine heatwaves and reduced sea ice cover are affecting seabird, fish, and seal populations: the North Pacific "Blob" (Figure 29.1) contributed to Pacific cod collapse, the 2019 Southcentral heatwave affected Prince William Sound king salmon survival,[139] and low sea ice caused or contributed to the collapse of crab fisheries and unusual mortality events for seabirds and ice seals in the Bering Sea region (2018–2022) (KM 10.2; Figure 10.1). In 2022, Pacific walrus hauled out in record numbers in the Bering Strait area,[195] suggesting that the minimum population estimate may be higher than previously thought, even if the range may be shrinking. Insect distributions and outbreaks have also changed.[196,197] In Southeast Alaska, outbreaks of western blackheaded budworm and hemlock sawfly have damaged forests in the wake of the 2017–2019 drought.[198] The 2019 heatwave in Southcentral Alaska contributed to spruce beetle expansion in that region and extreme fire activity on the Kenai peninsula (KM 7.1; Box 7.1). Salmon runs responded variably: Yukon–Kuskokwim River king salmon runs have been decimated,[139] while Bristol Bay has had record sockeye salmon returns. Figure credit: USGS, NOAA Fisheries, and Ocean Conservancy.

Climate change has negatively impacted nearly all aspects of the life history of commercial groundfish, salmon, and crab (KMs 10.2, 29.3). Arctic seabirds and marine mammals have also experienced reproductive failure, unprecedented mortality, and changes in migratory behavior. Extreme ocean warming and record low sea ice in the Chukchi Sea are affecting the entire food web[199,200,201] and possibly transforming the ecosystem.[143,202] For example, the lowest abundance of marine zooplankton in a decade was observed in recent warm years (2017 and 2019), combined with a decline in large, fatty Arctic species of zooplankton and an increase in smaller, less calorie-dense sub-Arctic species.[203,204] In turn, fish such as Arctic cod and saffron cod, which feed on zooplankton, were not as robust.[205] Subsequently, seabirds and marine mammals preying on these less nutritious fish experienced increasingly frequent reproductive failures and mortality. Emaciated seabird carcasses were found on beaches during extreme mortality events in the Bering and Chukchi Seas,[201] and the body condition of ice seals has declined.[206] In addition, the ranges of ice-dependent species such as polar bears[207] and walrus[208] are shrinking.

Ocean acidification is harmful to some Arctic phytoplankton and zooplankton.[209,210] Laboratory studies have shown that the early life stages of commercial fishes such as northern rock sole,[211,212] walleye pollock, Pacific cod,[213,214,215] and salmon[140,216] are sensitive to more acidic waters and to resulting food web changes.[135,211] Laboratory experiments suggest that Alaska commercial crab species are also highly vulnerable.[141,217,218,219,220,221] Although no studies of the impacts of ocean acidification on crabs in Alaska have been conducted, a study of Dungeness crab off California showed that shell dissolution was observed in areas of high acidification, reducing growth.[210] Finally, seals, walrus, and marine birds may be affected by the vulnerability of their prey.[222]

Climate changes and extreme events are also contributing to terrestrial changes, affecting species distributions, habitats, resource availability, and human access (KMs 2.2, 29.4; Focus on Compound Events). Moose and beaver are colonizing previously inhospitable Arctic areas,[191,192] in part due to temperature-driven increases in shrubs, and there is evidence salmon are colonizing streams where they were previously rare or absent,[190] presumably due to warmer waters. Ongoing warming is also associated with rapid changes in vegetation. Alaska residents are also noting unusual plants.[223] Decreases in berry production have been noted by communities in Alaska, related to multiple climatic drivers (e.g., Herman-Mercer et al. 2020[160]). Exceptionally high midsummer tundra productivity ("greening") has been observed on the North Slope of Alaska, but lower productivity ("browning") has continued in Southwest Alaska due to drying.[224] In 2019, the rapid expansion of a spruce beetle outbreak in the Susitna Valley (ongoing since 2016) caused extensive spruce mortality over 1.6 million acres (Box 7.1),[198] due in part to warmer temperatures increasing beetle development rates. In Southeast Alaska, hemlock sawfly outbreaks caused defoliation and mortality on more than 500,000 acres of forest, and a developing western blackheaded budworm outbreak is affecting Sitka spruce.[198] Both are plausibly[225] related to the unprecedented 2017–2019 drought in the region.

Landscape changes due to fires, permafrost, and their effects on other processes are climatically driven and increasing. Projected fire-driven transitions from conifer- to deciduous-dominated boreal forest[226] appear to be manifesting at regional scales. Wildfires in 2019 (Southcentral Alaska)[39] and 2022 (Southwest Alaska)[227] burned large areas in places where fire was rare or with atypical severity, as has been seen in other parts of the western US (Focus on Western Wildfires).[40] Overwintering fires, or "zombie" fires, which occur when uncharacteristically severe burning in hot, dry summers results in burning the following fire season, may also be increasing in the Arctic[228] and Alaska.[40] Permafrost thaw, including thermokarst (ground slumps or cave-ins)[229,230] and lake drainage,[231,232,233,234] is accelerating due to warming (e.g., Douglas et al. 2021[49]), particularly with recent wildfires[235,236] and uncharacteristically warm precipitation events.[237] These changes are projected to affect Arctic ecosystems and hydrology in important ways.[238] Across central and northern Alaska, changes in disturbance, vegetation productivity, and permafrost will affect the region's role in the global carbon cycle.[239,240] Current evidence suggests that carbon emissions from thawing permafrost[241] will exceed the carbon captured by increased vegetation productivity.

Box 29.5. A New Era for Pacific Salmon Research in Alaska

When aquatic ecologist Vanessa von Biela's career started in 2007, it was still a "warmer is better" era for Alaska's salmon in their cooler northern range extent. Over the last decade, however, she has been among a group of scientists and local people who have found that salmon are reaching climate-driven tipping points. Stressful conditions for salmon include warm years with poor marine feeding,[21,242] heat stress or drought during freshwater spawning migrations,[23,139] and heavy fall rains during egg incubation.[243] Stressors are minimized in oceans and deep lakes where mixing maintains cooler waters, high nutrients, and productive feeding, as well as in places where glaciers and groundwater keep lakes and rivers cold.[29,244] Positive changes include new salmon habitat with retreat of glaciers and sea ice,[143,245] although Arctic winters still limit major northward shifts.[246] Salmon may be able to tolerate and adapt to stressful habitats, or they could move to find a better habitat patch. These options have important implications for people who depend on salmon. Investment in research by Vanessa, her colleagues, and local residents concerning new and emerging stressors can help inform climate-responsive management strategies that aim to improve outcomes for people.

Chinook Salmon Research

Research on the effects of heat on salmon can help scientists understand the effects of continued warming.

Figure 29.12. Shown here is a chinook (king) salmon caught for non-lethal research on heat stress in a fish wheel on the Yukon River, July 2017. Photo credit: Shannon Waters-Dynes, USGS.

Key Message 29.6

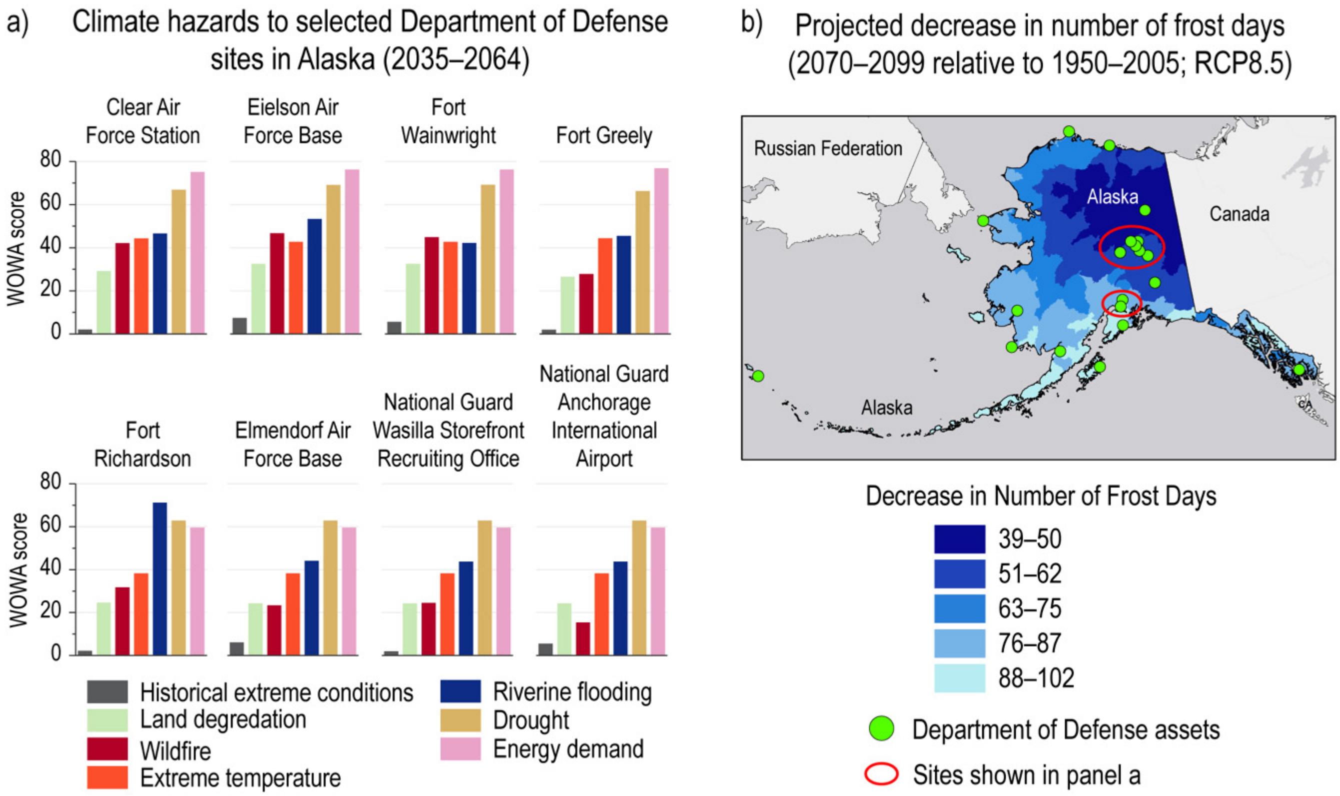
Our Security Faces Greater Threats

Rapid climate-driven change in Alaska undermines many of the assumptions of predictability on which community, state, and national security are based (*high confidence*). Further change, especially in the marine environment with loss of sea ice, will create new vulnerabilities and requirements for security from multiple perspectives and at multiple scales (*high confidence*). Greater capacity for identifying and responding to threats has the potential to help reduce security risks in the Alaska region (*medium confidence*).

Security entails a sense of well-being and safety that is protected from or resilient to disruption. It is a combination of many interests and perspectives and reflects values such as a nation's sovereignty and integrity (KM 17.1) or a community's reliance on livelihoods and food sources that enable its people to thrive (KM 29.3; Box 11.1). Different interests are prioritized at the national/homeland, state, and community levels. Security actors at the national, state, and community level may face increasing demands for security services while also confronting the additional costs of climate change on physical infrastructure and operations, creating a double burden and making decisions even more challenging.

The Department of Defense (DoD) and Department of Homeland Security are impacted by climate change.[247] For example, coastal erosion, degrading permafrost, wildfire, and other climate effects will continue to impact DoD installations in Alaska (Figure 29.13).[248,249] At the state level, increasing wildfire risk and climate impacts to infrastructure increase management costs to the state.[176] Coastal erosion and thawing permafrost are affecting many coastal villages, reducing community security (KMs 9.2, 16.1, 21.3, 22.1, 29.4). Beyond Alaska, national policy responses to climate change, such as reducing dependence on fossil fuels, may impact energy sources, prices, and industry in Alaska, with potential effects on employment, household budgets, and environment.

Climate Change Risks to Military Installations



Climate change poses risks to military assets in Alaska.

Figure 29.13. (**a**) The bar charts display climate risk for selected Department of Defense (DoD) sites in Alaska, based on the higher emission scenario for 2035–2064 data from the DoD Climate Assessment Tool. The y-axis is the weighted order–weighted average (WOWA) score of each site's exposure to aggregated climate hazards. For the Interior and Southcentral Alaska sites, drought and energy demand are the top climate hazards. At Fort Richardson, there is notably higher exposure to the riverine flooding climate hazard. In general, the scores are lower for the Southcentral region, indicating lower exposure to climate hazards. (**b**) Selected DoD sites in Alaska and projected reduction in frost days, illustrating the scale of the risk statewide (frost days are defined here as days with a minimum temperature at or below 32°F). The average annual number of frost days over the modeled baseline (1950–2005) ranges from 140–180 days in the Aleutian Islands to 260–290 days in the Brooks Range. In a higher greenhouse gas emissions scenario (RCP8.5), this will be reduced by about 20% in the Brooks Range and by over half in the Aleutians in 2070–2099. This will result in a longer ice-free season on the coast, leaving coastal communities vulnerable to storm surge more of the year. Portions of this figure include intellectual property of Esri and its licensors and are used under license. Copyright © 2020 Esri and its licensors. All rights reserved. Figure credit: USACE and DoD.

At the national level, DoD installations face a range of climate-associated hazards. For example, wildfire is a constant concern for military installations. Climate-driven drought, wind, and fire can affect operations, training, assets, and wildfire-suppression activities for DoD installations in a variety of ways.[248] The Alaska Fire Service and the US Army have recently been partnering to conduct springtime prescribed burns on military training lands in Alaska to reduce fire danger around military training targets.[250]

Climate impacts also generate national security concerns by altering maritime traffic in Alaska. Reductions in sea ice in Alaska waters enable more maritime activity. Changing and difficult-to-predict ice conditions, however, may require search-and-rescue activities that affect US Coast Guard presence and missions, as well as DoD civil support and military missions. Increasing maritime traffic in the Arctic[251] intersects with the broader geopolitical context of competition with the People's Republic of China (PRC) and tension with Russia. The Russian government has been building (and rebuilding) military capability and capacity across its northern border, including sites near Alaska such as Wrangel Island.[252] The PRC has expressed interest in Arctic governance, resources, shipping lanes, and climate science.[253] In Alaska, recent concerns include PRC and Russian naval operations in the US exclusive economic zone; illegal, unreported, and unregulated fishing especially in the Bering Sea; and marine debris.[254]

Rising concern about climate change and increased geopolitical competition in the Arctic are reflected in recent Arctic-specific military strategy documents (e.g., DHS 2019;[255] DOD 2019;[248] USAF 2020[256]). In Alaska, the DoD is developing new capabilities and capacities in response to these changes. For example, as of spring 2022, Eielson Air Force Base has 54 F-35 aircraft, the largest concentration of the most technologically advanced airpower in the world.[257]

The state of Alaska faces direct and indirect climate change impacts to security with regard to crime, economic impacts (KMs 19.1, 19.3, 29.3), environmental impacts (KM 29.5), and state capacity to respond to such security challenges. Climate change is also increasing costs for the state, from firefighting to infrastructure maintenance (KM 29.4), with potential adverse ramifications for the state's ability to balance its budget and meet the needs of its citizens.[170]

At the community level, concerns center on food and environmental security (KM 29.2), as well as the safety of small boat operators and hunters navigating increasingly unpredictable and crowded marine and riverine environments (KM 15.1).[87] Changing sea and river ice conditions are increasing the physical risks for hunters and travelers. Climate change may also drive intensification of human offshore activities, such as increased commercial shipping, that generate additional risks such as accidents or spills.[258] Cultural practices are vital to well-being and security throughout Alaska (Box 29.3) but are often overlooked or minimized in fisheries management and in research on climate change and ecosystems.[75]

Box 29.6. Tribal Perspectives on “Security”

For Tribes in Alaska, climate change is yet another reason to exercise leadership and sovereignty on their own behalf (KM 16.3). In Bristol Bay, for example, the Native Village of Port Heiden has created Meshik Farm to improve food security and would like to build a fish processing facility too. Says Jaclyn Christensen, Brownfield Coordinator for the Tribe, “I worry about my husband making long trips in dangerous waters when he’s fishing, and we need an economic base for the community.”[259]

The Knik Tribe in Southcentral Alaska is deeply involved in land management. As Theo Garcia, the Tribe’s Environment and Natural Resources Director, explains, “We grow potatoes to provide food, we are cultivating native plants to support streambank restoration, and we are exploring ways to use waste heat to grow cheaper fodder for livestock.”[260]

As conditions continue to change, being able to adjust is essential to security, through Tribes’ own efforts and in partnership with others.

Canned Red Salmon in Port Heiden

Salmon is vital for food security in much of Alaska.

Figure 29.14. A locally processed jar of red salmon sits in the sunshine in Port Heiden, Alaska, July 28, 2022. Photo credit: ©Jaclyn Christensen.

Key Message 29.7

Our Just and Prosperous Future Starts with Adaptation

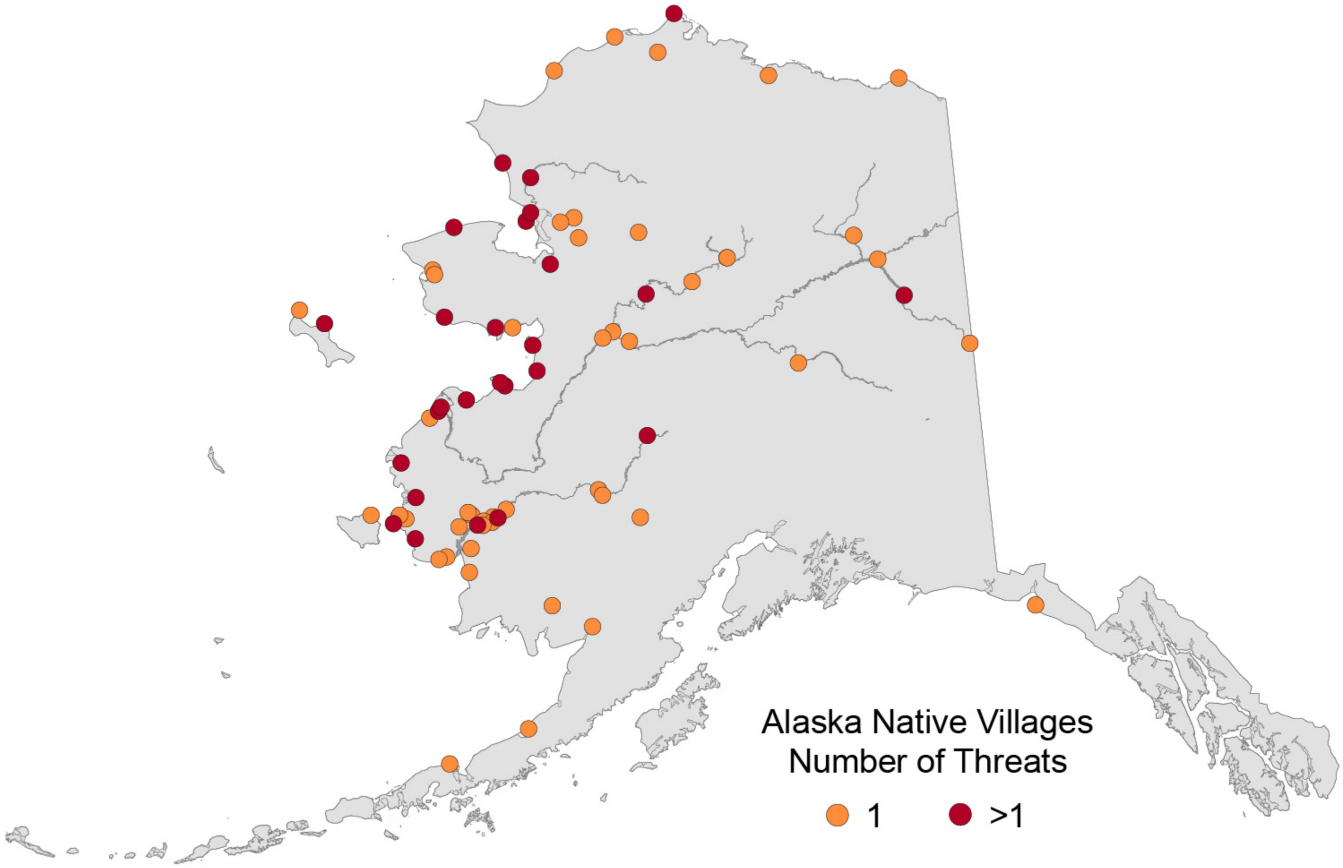
Local and regional efforts are underway around Alaska to prepare for and adapt to a changing climate (*high confidence*). The breadth of adaptation needed around the state will require substantial investment of financial resources and close coordination among agencies, including Tribal governments (*high confidence*). The effectiveness of adaptation planning and activities can be strengthened by addressing intersecting non-climate stressors, prioritizing the needs of the communities and populations experiencing the greatest impacts, building local capacity, and connecting adaptation efforts to economic and workforce development (*medium confidence*).

In recent years, Alaska has emerged as a leader of climate adaptation initiatives in the Arctic,[261] many of which have been implemented by regional entities and municipal, community, and Tribal governments.[262,263] Together, these efforts address climate change and intersecting societal challenges in ways that begin to lay a foundation for a just and prosperous Alaska. A wide variety of adaptation efforts has been undertaken statewide, from trainings and workshops to the implementation of hazard mitigation and climate action plans.[262,263,264] Despite widespread impacts (Figure 29.15), support for climate adaptation varies among communities,[263,265,266] and adaptation has not been a consistent priority for the state government (KM 31.1).[263,267,268] For many Alaskans, the ability to adapt to current and projected climate impacts is shaped by social and political factors such as food and water security, economic opportunity, and the capacity of governance systems (KM 31.4).[45,269,270,271]

Many of Alaska's Tribes have completed or are currently engaged in efforts that increase their ability to adapt to a changing climate (KM 16.3). These include applying for federal funding for climate resilience,[272] conducting risk assessments,[273] collaborating with researchers to bridge Western climate science and Indigenous Knowledge,[274] and developing and implementing community- and regional-level adaptation plans.[76,275,276] These activities are bolstered by the accumulated knowledge that has enabled Indigenous Peoples of Alaska and the Arctic to innovate and adapt to their changing environment for millennia.[270,277,278] The traditional values and practices of Alaska Native cultures focus on well-being, cultural continuity, and a holistic, integrated worldview (Figure 16.3).[75,270,279] They are often tied to components of adaptive capacity, such as environmental stewardship, communal pooling of subsistence resources, and mobility.[280,281,282,283,284] It is important to emphasize, however, that Alaska Native Peoples' ability to adapt does not mitigate the impacts of unprecedented environmental hazards or reduce the need to address the causes of climate change.

To achieve widely needed climate adaptation, communities must navigate a complex system of siloed federal agencies (Figure 29.16).[285,286,287] Overlapping local, borough, state, and federal jurisdictions can create confusing or conflicting policy directives and impede local adaptation efforts (KM 31.4).[277,288] Complex governance and resource management systems, many of which are imposed on Tribes through colonization, create challenges to adaptation efforts, which are most effective if they are timely, equitable, and community led. Also, the high adaptive capacity and self-reliance of Indigenous Peoples continues to be eroded by the ongoing impacts of colonization, including barriers to social networks and the transfer of Indigenous Knowledge.[277,279,289,290] Tribes are sovereign nations that require government-to-government consultation. Communities with strong collaboration among governing entities, including through coproduction of knowledge (research based on equitable and respectful partnerships), may be better able to respond to the adverse impacts of climate change through partnership and flexible management of natural resources.[279,281,285] Targeted coordination among and between federal, state, and Tribal entities would help build resilience to environmental threats.[286]

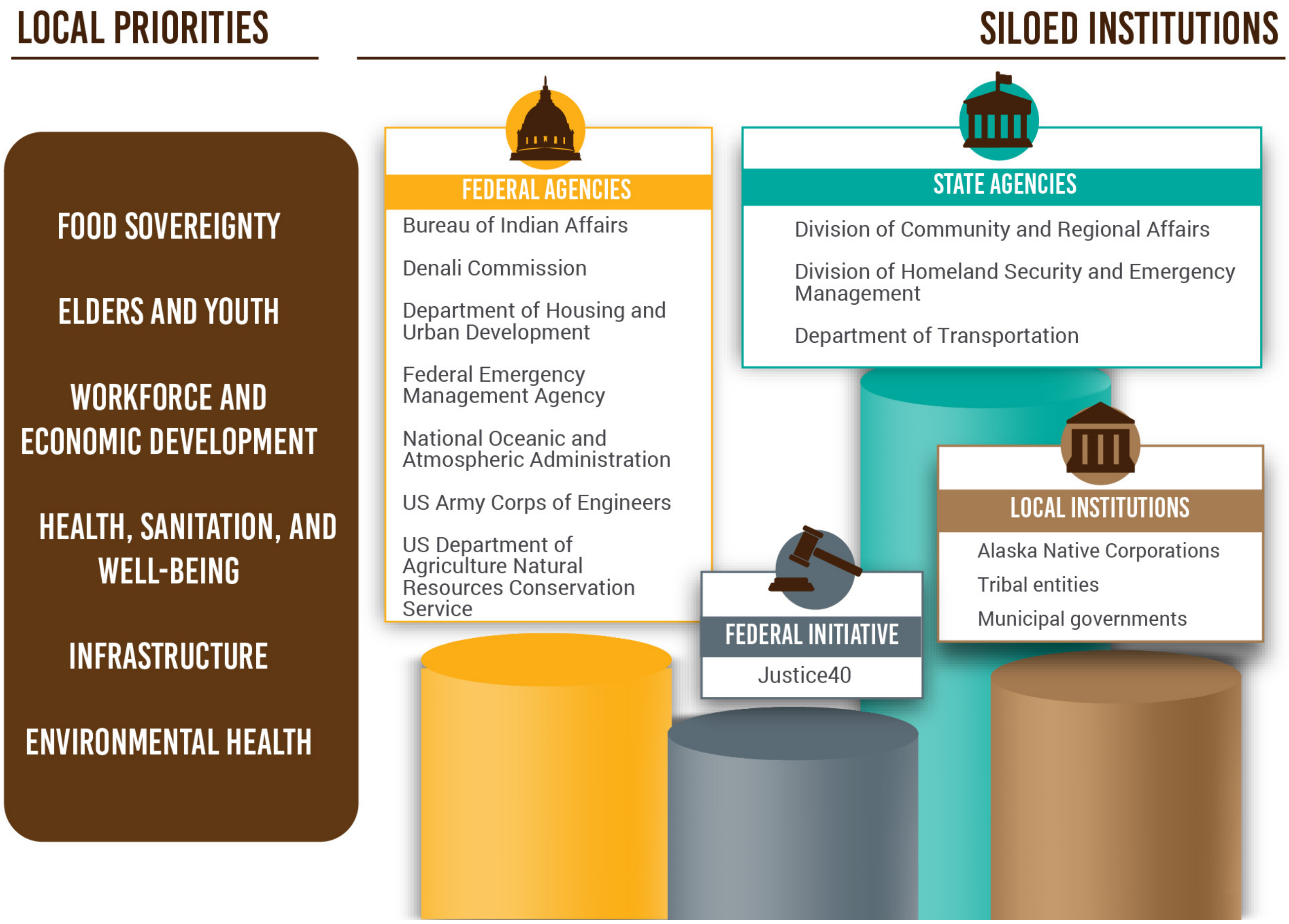
Climate Threats Across Alaska



Statewide assessments show extensive climate-related threats throughout Alaska.

Figure 29.15. The map shows threats to Alaska Native villages from permafrost thaw, flooding, and erosion. Many communities face multiple threats, compounding the challenges they face. Adapted from GAO 2022.[286]

Navigating Diverse Institutions to Meet Local and Regional Priorities



Adaptation is a complex process, requiring expertise and engagement with multiple entities.

Figure 29.16. Climate adaptation typically requires a wide range of expertise as well as engagement of those who are affected together with other entities, including but not limited to those listed in this figure.[286] Alaska Native corporations were created by the Alaska Native Claims Settlement Act of 1971.[291] Local priorities are holistic, involving integrated environmental and social issues. However, institutions on multiple levels are often siloed with specific priorities, which can lead to duplication of efforts and hamper local efforts. Figure credit: University of Alaska Fairbanks and Ocean Conservancy.

Although there are various sources of state and federal funding and technical assistance available to support municipal and Tribal climate adaptation in Alaska, the effectiveness of such efforts is hindered by institutional barriers and limited capacity across various levels of government (KMs 31.4, 31.6).[261,292] In both rural and non-rural communities, some residents have reported that climate adaptation has been impeded by a lack of local leadership or political will.[265,266,293] Many communities and organizations have stepped up to lead mitigation efforts and address the inequities compounded by climate change in the absence of consistent municipal and state action. At least four municipalities (Anchorage, Homer, Sitka, and Juneau) have adopted climate action plans,[264] with Fairbanks also currently at work on theirs. Seven Tribal governments from the Nome Eskimo Community to the Central Council of T'lingit and Haida have adopted climate action or adaptation plans.[264]

Community renewable energy initiatives like Thermalize Juneau and the Solarize initiatives in Anchorage, Fairbanks, Kenai, Mat-Su, and Palmer help residential and commercial property owners install solar capacity.[294,295,296] Local utilities such as Golden Valley Electric Association, Alaska Energy Light and Power, and Chugach Electric Association have worked on several renewable energy projects.[297,298,299] Juneau Electric Vehicle Association specifically has worked to electrify public and personal transport in the region.[300] Many communities around the state are building local community-supported agriculture markets, shared gardens, and supply boxes to supplement neighborhoods farther away from urban grocery stores.[301] Tribal governments in Interior and Southwest Alaska delivered salmon to residents impacted by the Yukon–Kuskokwim salmon crash.[302]

Climate change can lead to divergent goals. While there are potential economic opportunities of a warming Arctic, such as increased marine traffic, growth in tourism, and resource extraction, considerations of relevant climate-related risks are not consistently incorporated into regulatory and planning processes.[266,269] For example, across coastal Alaska, communities are increasingly reliant on hard structures, such as seawalls and shoreline reinforcement. These structural adaptations can provide a sense of security, but they lack the flexibility, long-term sustainability, and cost effectiveness of regulatory and ecosystem-based approaches.[303]

Climate impacts are being experienced within the larger context of social, political, and economic change in the Arctic (KM 20.2).[281] Non-climate stressors such as food insecurity (KMs 29.1, 29.3, 29.5), limited employment (KM 29.3), substandard housing (KM 29.1), aging infrastructure (KM 29.4), limited access to healthcare (KM 29.1), the high cost of living in remote areas (KM 29.2), and limited search-and-rescue capability (KM 29.6) can affect a community's capacity and ability to pursue climate adaptation.[269,304,305] By identifying and addressing the intersections of climate risk and social and economic vulnerability, decision-makers can develop and implement adaptation initiatives that are scalable, innovative, and/or transformational.[266]

The need to center adaptation actions around and support Indigenous and local values, knowledge, and priorities has been widely identified as a critical component of community-based adaptation (KM 16.2).[45,269,270,285,289,306,307,308] In addition to integrating multiple knowledge systems and building workforce development and Tribal capacity for climate resilience,[309] climate adaptation efforts can be strengthened by fostering partnerships among diverse groups and supporting community-based leadership and monitoring.[45,267,285] This need is recognized in White House guidance to federal agencies.[310]

Education for many audiences has long been an essential component of adaptation in Alaska. Numerous educational efforts in Alaska are bringing climate change information and understanding to K–12 students, undergraduate and graduate students, educators, and community members. The Global Learning and Observations to Benefit the Environment (GLOBE) program has engaged more than 1,400 rural and urban Alaska teachers and over 20,000 students in climate change learning and citizen science in a culturally sustaining way since 1996.[311,312,313] Scientists have used Alaska students' GLOBE data.[314,315] The Arctic and Earth STEM Integrating GLOBE and NASA project braids Indigenous and Western science to engage formal and informal educators, community members, and youth in projects relevant to their communities[316], in partnership with the Association of Interior Native Educators. Other community/citizen science projects related to climate change focus on Alaska berries, freshwater ice, snow depth, and coastal community observations and knowledge.[317] Climate education efforts for adults include an online course exploring climate change in Arctic environments, community training in the Alaska Tribal Resilience Learning Network through the Alaska Climate Adaptation Science Center, and peer-to-peer learning and knowledge exchange in the community-led relocation, managed retreat, and protect-in-place coordinator cohort. The Scenarios Network for Alaska and Arctic Planning provides downscaled climate data, while the Alaska Center for Climate Assessment and Policy provides climate and weather webinars, graphics, and tools. New initiatives are also being developed.[318]

Box 29.7. Tribal Adaptation to Climate Change

Threats to traditional foods are existential concerns for Tribal communities:

> *We're at a tipping point that people need to learn how to spell food sovereignty. — Dune Lankard, Eyak Athabascan, Copper River Delta (interview with Willow Hetrick, December 16, 2020).*[319]

Food sovereignty includes the ability of communities to determine the quantity and quality of food that they consume by controlling how their food is produced and distributed. To meet this need, Chugach Regional Resources Commission (CRRC) and one of its divisions, the Alutiiq Pride Marine Institute (APMI), incorporate Indigenous Knowledge, Tribal perspectives, and Western scientific methods. To address health concerns, the harmful algal bloom program analyzes weekly water samples and warns Tribal governments of any health concerns. To bolster regionally important food sources, they place young clams on beaches with dwindling clam populations and are extending that effort to bidarkis (the local name for black leather chitons, *Katharina tunicata*). To help reduce the effects of carbon dioxide emissions, CRRC and APMI are developing kelp farming as a mitigator of ocean acidification effects, a carbon sink, and a potential source of income. These efforts show what can be accomplished with dedication and collaboration.

Harvesting Kelp in Prince William Sound

Kelp farming is an adaptation action that can reduce the impacts of ocean acidification, take up carbon dioxide, and provide income.

Figure 29.17. Kelp is being harvested on a boat in Prince William Sound, Alaska, May 15, 2022. Photo credit: ©Emily Mailman.

Traceable Accounts

Process Description

The author team reviewed the Alaska chapters in previous National Climate Assessments (NCAs) and considered the guidance from NCA leadership to make NCA5 "people-centered." The team recognized three broad topics: rapid biophysical change, compounding societal effects, and adaptation efforts. From these, the team developed seven areas for Key Messages and identified a number of themes to emphasize throughout the chapter, tying together the material in each Key Message. The team then reviewed the available information (as detailed below for each Key Message) to write the chapter. Where necessary, the team has cited reports and other non-peer-reviewed sources for specific information that is not available elsewhere. The author team agreed that the sources were credible and appropriate for the purposes for which they were cited. The team has not included likelihood statements (*very likely*, *unlikely*, etc.) because there was not a quantitative basis for doing so (Guide to the Report).

Key Messages from previous NCAs, and the overall guidance from NCA leadership, helped identify major areas where expertise would be needed. Diversity of age, race, gender, discipline, and perspective were also considered in selecting the author team, along with the ability to think broadly about connections among aspects of climate change. The chapter lead author, federal coordinating lead author, and agency chapter lead authors compiled a list of candidates and asked other organizations to suggest names so as to broaden the search. Once several persons were recruited as chapter authors, they too were asked about gaps in the team's collective expertise, and additional needs were identified along with candidates to address those needs.

The author team met twice monthly to discuss the chapter contents and the writing process. Through these meetings, the team achieved consensus on the approach to take and then on the contents as the team wrote and revised. The team held an online public engagement workshop on January 12, 2022, with approximately 175 persons registered and a maximum of about 90 participants at any given time. The workshop had a wide range of participants, including Indigenous community leaders, academic researchers, government agency personnel, individuals in the private sector, and members of the public. The team also conducted other outreach meetings and workshops to reach specific audiences, such as through the Alaska Forum on the Environment and the Interagency Arctic Research Policy Committee.

Key Message 29.1

Our Health and Healthcare Are at Risk

Description of Evidence Base

A great deal of research has been done on health status, access to healthcare, and other aspects of health in Alaska (e.g., Hennessey et al. 2008;[67] Thomas et al. 2015;[60] Eichelberger 2010;[59] Hahn et al. 2021[82]). The context in which climate change affects health is thus generally well established (KM 15.1).[61] Attention to mental health and community health has been growing in recent years, providing an increasingly firm foundation for this Key Message (KM 15.1).[74,75,76] Research specifically on the implications of climate change for health and mental health has been more limited in Alaska. The findings of that research are generally consistent.

Major Uncertainties and Research Gaps

Much of the literature about climate change and health in Alaska has focused on what is to be expected as the climate continues to warm. Evidence of the actual health effects that are occurring at present is less robust, although what does exist is consistent across studies. There is also a lack of studies documenting health effects, especially mental and community health effects specifically tied to factors related to climate change, and determining effective public health responses. More work can be done to document Indigenous Knowledge with regard to health and mental health in Alaska.

Description of Confidence and Likelihood

Health disparities in Alaska are all too well documented (e.g., Cochran et al. 2013;[55] Thomas et al. 2015;[60] Eichelberger 2010;[59] Sohns et al. 2021[56]). Further challenges to health and to access to healthcare will compound those disparities. This can be said with *high confidence*. There is some evidence for the expected effects of climate-driven hazards and emerging diseases (e.g., Witmer et al. 2022;[84] Hahn et al. 2020,[83] Yoder 2018;[57] Huntington et al. 2021[87]), and the state's experience with COVID-19 has amply illustrated what a new disease can do (e.g., Wong et al. 2022;[64] Eichelberger et al. 2021[62]). The course of climate change in regard to health, however, has many uncertainties, and thus the team has *medium confidence* in the second statement in the Key Message. Similarly, improved health surveillance and healthcare access can be expected to contribute to resilience statewide, but further experience and evidence are needed to show that this is the case. Thus, the team has *medium confidence* in the final statement of the Key Message.

Key Message 29.2

Our Communities Are Navigating Compounding Stressors

Description of Evidence Base

Considerable work has been done to document many aspects of Alaska's communities, including social, economic, cultural, physical, and other research.[96,97,107,108,109] Some work has been done, especially in Alaska Native communities, to document observations of and effects from climate change. The findings are in broad agreement that much is changing rapidly, with far-reaching effects on communities. The details vary from place to place and study to study. There is little disagreement in the literature base. Far less work is available about other segments of the population in Alaska, making it difficult to determine whether there are racial and ethnic disparities in climate change exposure and effects among groups other than Alaska Natives.

Major Uncertainties and Research Gaps

Little is known about the effectiveness of responses and adaptations to climate change among Alaska Native communities. For other demographic groups, and for Alaska Natives in urban environments, more research would be required overall to better assess how climate change is affecting and is expected to affect these communities. More work can be done to document Indigenous Knowledge with regard to community well-being in Alaska.

Description of Confidence and Likelihood

The detailed demographic and other evidence that is available concerning community well-being in Alaska is consistent and has been documented repeatedly in the scientific literature and in reports by Tribal and federal agencies, giving the team *high confidence* in the statements in the Key Message. Risks to infrastructure are well known and not in dispute. The benefits of adaptation are addressed in greater detail in Key Message 29.7 and have been established repeatedly around the state.

Key Message 29.3

Our Livelihoods Are Vulnerable Without Diversification

Description of Evidence Base

The state and federal governments regularly collect relevant economic data, providing a firm foundation for understanding Alaska's livelihoods and employment.[96,120,121,122,123] Similarly, much work has been done to document subsistence harvests, providing reliable and consistent figures for production and participation in this vital sector of the economy of rural Alaska. The effects of climate change have been considered for many economic sectors, although to differing degrees. Not surprisingly, those sectors such as fishing that are perceived as being at highest risk from climate change have received the most attention. The findings to date are broadly consistent, allowing for differences in climate change exposure across different sectors.

Major Uncertainties and Research Gaps

Much of the work to date has focused on sectors perceived as vulnerable to climate change, including fishing and subsistence. Less has been done to examine areas of potential new opportunity (e.g., in agriculture), and more research could improve understanding of the effectiveness of various responses and adaptations to changing climate.

There is uncertainty about the economic consequences of climate-driven declines in commercial and subsistence harvest because the impacts of climate change can be moderated by economic dynamics and alternative harvest opportunities.[125,126,143]

A major uncertainty regarding climate impacts on groundfish, salmon, and crab is the unknown influences of interacting processes and parameters, such as competition, predation, density dependence, food web structure, habitat availability, and harvest.[18,131,142,144] Thus, future research on the impacts of climate on groundfish, salmon, and crab should be interdisciplinary.

Another major topic that could benefit from future research is the mechanisms linking climate drivers to biological effects on salmon, groundfish, and crab.[134,137,320] Elucidation of the details of these mechanisms could help improve predictions of ecosystem change in the context of future climate change. In addition, spatial variation in ecosystem response to climate change lends uncertainty to predicting local impacts.[21,23]

More work can be done to document Indigenous Knowledge with regard to livelihoods and the factors that affect them in Alaska.

Description of Confidence and Likelihood

Documentation of risks posed by climate change to resource-dependent livelihoods is extensive and consistent in the scientific literature and in government reports, giving the author team *high confidence* in the first statement of the Key Message. Looking to the future involves greater uncertainty, and thus the team has *medium confidence* in the second statement of the Key Message. The third statement is supported by the available literature, but there is not a great deal of it, giving the team *medium confidence*.

Key Message 29.4

Our Built Environment Will Become More Costly

Description of Evidence Base

Many major assessments have been done concerning Alaska's built environment, including economic studies of the costs associated with climate change and the risks from coastal and riverbank erosion around the state.[170,171,173,174,181] The findings are consistent that costs will be high and that many communities face high risks. The timing of erosion and other damage is less certain, as is the effectiveness of various measures to slow or stop climate-driven effects.

Major Uncertainties and Research Gaps

More work could improve understanding of the effectiveness of various responses to climate-driven damage to infrastructure. How response capacity can be created or provided, especially to remote communities, is an open question. The fact that models probably underestimate the actual costs and damages suggests another area for further work. These gaps contribute to uncertainty in estimates of the costs associated with infrastructure degradation, destruction, and collapse. More work can be done to document Indigenous Knowledge with regard to the built environment in Alaska. In addition to research gaps, knowledge fragmentation is a major hindrance to effective action. Reducing this fragmentation would require a greater effort to bring together scientists, community members and knowledge holders, and private businesses, especially engineering consulting firms that are already implementing practical solutions.

Description of Confidence and Likelihood

There is little question about the damage being done to Alaska's infrastructure due to climate change and little doubt that more damage will occur. Thus, based on well-documented experiences around the state (e.g., some of the major university and government reports cited in the Key Message text, which are consistent with one another), the author team has *high confidence* in the first two statements of the Key Message concerning what effects climate change is having on infrastructure and the further effects that are expected. The third sentence, about planning and adaptation, is of *high confidence* due to the evidence that planning can work. The team notes here that the question remains as to what is required to implement designs and ideas for protecting infrastructure to withstand the effects of climate change.

Key Message 29.5

Our Natural Environment Is Transforming Rapidly

Description of Evidence Base

Changes in Alaska's marine, terrestrial and freshwater ecosystems, including effects of climate on species ranges, species viability, community structure, ecosystem structure and function, and landscapes and riverscapes are extensively documented in the scientific literature.[1,39,143,192,198]

The strong climatic controls implicated in many, though not all, of these changes may negatively affect the abundance and/or quality of ecosystem goods and services, such as ice transportation or many ocean and anadromous fisheries, but projections of these impacts are easier for some goods and services than others. Confidence is higher for those impacts that are directly mediated by physical drivers (e.g., temperature effects on sea ice[45] or snowpack[46]) than those with complex drivers (multiple climate drivers and ecological interactions, such as berry production.[160]

The fact that some of the stressors are non-climatic and can respond to management choices or strategies indicates the possibility of avoiding some potential impacts through management. The literature on alternative strategies is limited; this is where synthetic and logical arguments can be made on the scientific information describing impacts and plausible future. But it is yet uncertain which management choices would be potentially effective, how they would be implemented, and whether they would be sufficient to decrease impacts.

Major Uncertainties and Research Gaps

As with many impacts of climatic change, attribution of the fraction of the response due directly to climatic change is challenging. Much of the work is correlative rather than deterministic, and in Alaska, the datasets that exist for attribution work are severely limited compared to places in the contiguous United States (CONUS) because of the scarcity of long-term observational datasets that can be used for training downscaling methods. Thus, datasets downscaled from CMIP6 models were not available for Alaska when they were available for CONUS. Downscaling methodology that would accelerate attribution research is also limited. However, even perfect historical and future climatologies would not eliminate uncertainty—useful attribution and projections depend on strong impacts modeling and appropriate bridging to resource management, and understanding impacts on goods and services is not the same as direct modeling of species, community, landscape, and ocean impacts. A major research gap is adequate long-term physical and biological monitoring data needed to support and improve model forecasts. More work can be done to document Indigenous Knowledge with regard to the natural environment in Alaska, keeping in mind important questions of who is doing the documentation, how, and for what purpose. The considerations have implications for climate justice and Indigenous rights. Additionally, there is a need to better coordinate and improve accessibility of existing data to help identify data needs as well as make more effective use of what is already known.

Description of Confidence and Likelihood

A great deal of scientific research, as reported widely in the scholarly literature, has examined ecological change in detail around Alaska. The confidence in ecological change is *high* and not *very high* because other non-climatic factors (such as development and other changes in land use) also contribute to ecosystem change and/or documentation of climate-driven change has yet to emerge for some observed changes.

Confidence concerning ecosystem goods and services is *medium* because 1) although impacts modeling for many species and processes indicates this is probably true, impacts modeling for goods and services is limited compared to direct physical and ecological impacts; and 2) uncertainty in both climate futures and ecosystem responses is large enough that specific predictions are elusive. Although the reasoning is sound, there is a limited body of peer-reviewed published evidence.

Confidence in the ability of careful management to help address climate concerns in the context of other needs and aims is *medium* because there is limited peer-reviewed literature documenting that climate-relevant management practices would be adopted. However, examples exist.

Key Message 29.6

Our Security Faces Greater Threats

Description of Evidence Base

Some research and planning have been done by the branches of the armed services to assess the hazards from climate change in Alaska.[248] Additionally, some work has been done to assess hazards to civilian forms of security, including food security.[75,87,251,254] The literature is consistent in identifying multiple hazards and high uncertainties, which exacerbate risks to security by impeding the ability to plan effectively and efficiently.

Major Uncertainties and Research Gaps

Obvious risks such as coastal erosion and damage from thawing permafrost are well documented. Some other risks, such as the potential for wildfires and associated smoke to disrupt airborne operations, have been recognized. The assessment of many other risks, however, remains speculative and would benefit from further study. Of note here is the unknown degree to which climate change will alter, rather than merely have a modest influence on, geopolitical concerns and national security threats. More work can be done to document Indigenous Knowledge with regard to the various aspects of security in Alaska.

Description of Confidence and Likelihood

Due to the extent and nature of climate change, as documented in numerous academic and government studies, there is *high confidence* that a changing climate has the potential to alter Alaska's security at scales from local to national. Likewise, there is little question—and thus *high confidence*—that further change will continue to create this hazard. Exactly how the appraised risks will turn into actual effects is less certain in the available literature, giving *medium confidence* in the ability to develop and put in place effective response strategies.

Key Message 29.7

Our Just and Prosperous Future Starts with Adaptation

Description of Evidence Base

Peer-reviewed academic research that analyzes or documents climate adaptation successes and challenges is less prevalent than other sources such as online portals, gray and white literature, published adaptation plans, and other reliable sources of information. However, the body of literature is growing, and all of these sources are relatively consistent in their content. Several non-climate stressors have been identified in peer-reviewed literature as factors that can affect a population's ability to adapt to climate change.[270,304,305,321] Building local capacity and connecting adaptation efforts to economic and workforce development are emerging topics that have less evidence base in existing publications,[322,323] but the authors felt it was important to include these issues based on observations and lived experience.

Major Uncertainties and Research Gaps

As noted above, existing research gaps related to climate adaptation and planning exist in the academic literature; however, there are several areas of agreement among white and gray literature and lived experience, as documented in other credible sources. Research focusing on community values, priorities, and needs, including workforce development, is just emerging. Very little research has been done evaluating the implementation of adaptation efforts, especially through Indigenous evaluation methodologies.[324] More work can be done to document Indigenous Knowledge with regard to resilience and climate response in Alaska. Additional work can also be done to learn from what is and is not working in ongoing adaptation activities.

Description of Confidence and Likelihood

There is strong evidence from many reports and studies (see citations in the Key Message text), and thus *high confidence*, that local and regional adaptation efforts are underway and that more have been funded. The new influx of federal funding opportunities is expected to provide much-needed support, building on previous investments in rural Alaska, which together give *high confidence* that the demand for investment is substantial. As of this writing, little work has been done, however, to establish locally acceptable metrics and evaluation plans to assess the actual impact of funding influx. Given that research focusing on community values, priorities and needs, including workforce development, is just emerging, the final sentence of the Key Message has been assigned *medium confidence*.

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