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Adaptation Resources for Agriculture: Responding to Changes in Climate in Alaska

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Cover: A field with hay bales in Delta Junction with the Alaska Range in the background. Photo credit: Brant Dallas, USDA Natural Resources Conservation Service.

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Abstract

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Alaska is a land of extremes. This includes its climate, which ranges from mild to maritime in its southeast, to arctic in its northern slope. Alaska is also at the forefront of experiencing changes in climate and climate variability, including higher temperatures and more precipitation. Over the past century, changes in climate have already led to a longer growing season that has expanded areas suitable for agricultural production. Along with improving opportunities for agricultural production, climate change will also bring challenges, such as increased risks of invasive species, pests, and diseases. With these opportunities and challenges, farmers and ranchers can take actions to reduce negative effects on their operations from climate change and to promote positive outcomes by implementing different adaptation strategies. This publication provides agricultural producers in Alaska with adaptation strategies and tactics to help farmers take actions to improve resilience of their operations to weather extremes and a changing climate. This is a structured and flexible guide to help identify and evaluate climate change impacts, challenges, opportunities, and operation-level resilience tactics. These methods provide guidance on understanding, planning for, and responding to climate change impacts to agriculture in Alaska. Technology transfer specialists and producers can work through the information provided herein to consider different strategies for producers to implement to achieve production goals in the face of rapidly changing and variable climate conditions.

Keywords: Stewardship, climate change, farm, gardeners, livestock, on-farm practices.

Preface

Adaptation Resources for Agriculture: Responding to Changes in Climate in Alaska is a structured and flexible guide to help farmers in Alaska identify and evaluate climate change impacts, challenges, opportunities, and operation-level resilience tactics. It is part of a series of resources that have been published or are forthcoming:

- *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers.*[1]
- *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers, 2nd Edition.*[2]
- *Adaptation Resources for Agriculture: Responding to Climate Variability and Change in the Midwest and Northeast.*[3]
- *Adaptation Workbook for California Adaptation Agriculture (pending).*
- *Climate Adaptation Actions for Urban Forests and Human Health.*[4]

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[1] Swanston, C.; Janowiak, M., eds. 2012. Forest adaptation resources: climate change tools and approaches for land managers. Gen. Tech. Rep. NRS-GTR-87. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 121 p. https://doi.org/10.2737/NRS-GTR-87.

[2] Swanston, C.W.; Janowiak, M.K.; Brandt, L.A.; Butler, P.R.; Handler, S.D.; Shannon, P.D.; Lewis, A.D.; Hall, K.; Fahey, R.T.; Scott, L.; Kerber, A.; Miesbauer, J.W.; Darling, L.; Parker, L.; St. Pierre, M. 2016. Forest adaptation resources: climate change tools and approaches for land managers. Gen. Tech. Rep. NRS-GTR-87-2. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 161 p. https://doi. org/10.2737/NRS-GTR-87-2.

[3] Janowiak, M.; Dostie, D.; Wilson, M.; Kucera, M.; Howard, Skinner, R.; Hatfield, J.; Hollinger, D.; Swanston, C. 2016. Adaptation resources for agriculture: responding to climate variability and change in the Midwest and Northeast. Tech. Bull. 1944. Washington, DC: U.S. Department of Agriculture. 70 p. https://www.climatehubs.usda.gov/sites/default/files/adaptation_resources_workbook_ne_mw.pdf.

[4] Janowiak, M.K.; Brandt, L.A.; Wolf, K.L.; Brady, M.; Darling, L.; Lewis, A.D.; Fahey, R.T.; Giesting, K.; Hall, E.; Henry, M.; Hughes, M.; Miesbauer, J.W.; Marcinkowski, K.; Ontl, T.; Rutledge, A.; Scott, L.; Swanston, C.W. 2021. Climate adaptation actions for urban forests and human health. Gen. Tech. Rep. NRS-203. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 115 p. https://doi. org/10.2737/NRS-GTR-203.

Contents

Introduction

Alaska is a land of extremes. As the largest state in the United States, it spans a vast geographical area that covers a variety of different climates. For example, southeast Alaska has a mild, maritime climate with mean annual temperatures around 40 °F (4.4 °C), with some areas receiving up to 200 inches of rain per year. In contrast, the northern slope has an arctic climate with mean annual temperatures around 10 °F (-12.2 °C), with some areas receiving an average of 12 inches of rain per year (WRCC 2020). At Alaska's northern latitudes, summers are full of sunlight, with more than 17 hours of daylight in the southeast and more than 80 days of uninterrupted light in the northern slope. This wide range of conditions supports a variety of plants and animals. Alaska's long hours of daylight are a benefit for agricultural producers, as they offset the relatively short growing season. A variety of crops, livestock, and aquaculture are grown in Alaska, including fruits, vegetables, root crops, grains, herbs, ornamentals, grass, hay, dairy, meat products, and mollusks (USDA NASS 2017).

There is great potential in Alaska for the agriculture sector to thrive and meet a growing demand for fresh, local food. Throughout the state, the need for produce and meat exceeds the available supply, meaning that people rely on imported food through much of the year, which is considered a significant food security risk (Byrd 2020, Meter and Phillips-Goldenberg 2014, Stevenson et al. 2014). At the same time, the number of farms in Alaska is growing, with a 30-percent increase from 2012 to 2017 and farm size averaging 13 ac (5.3 ha) or less. The number of farms producing cut flowers, hogs, layer chickens, vegetables, honey, and grains is also on the rise. The value of food sold directly to consumers as well as the value of sales of all crops and livestock have also increased. Alaska has the highest rate of young, women, and new farmers in the United States. (USDA NASS 2017, 2021). The relative boom of new farms and young farmers will help supply the demand for more locally sourced food.

Climate change will bring new challenges and opportunities to farmers and gardeners throughout the state. Alaska is at the forefront of climate change, with temperatures across the state rising faster than in the rest of the nation (Ardnt 2016, Hayhoe et al. 2018). Changes in climate are affecting infrastructure, communities, ecosystems, farms, and more (Markon et al. 2018). Farmers and ranchers can act to adapt to help reduce risks and costs as well as make the most of opportunities from change. Although changing climate conditions will be challenging for producers, increasing temperatures in Alaska's agricultural areas also bring opportunities, such as longer growing seasons and the potential to expand operations by growing more and different crops.

Although changing climate conditions will be challenging for producers, increasing temperatures in Alaska's agricultural areas also bring opportunities, such as longer growing seasons and the potential to expand operations by growing more and different crops.

This workbook provides information, resources, and tools for producers, gardeners, educators, and technical transfer specialists to support decisionmaking for adapting terrestrial agricultural practices to climate change in Alaska. This publication follows a stepwise approach to adaptation for agriculture that was established in the *Adaptation Resources for Agriculture: Responding to Climate Variability and Change in the Midwest and Northeast* (Janowiak et al. 2016). However, this workbook has information specific to agriculture in Alaska. Climate change adaptation can aid in reducing risks from variable and changing climate by modifying practices to build resilience and take advantage of future conditions. Based on the current science, this publication provides climate change information and information on decisionmaking and implementation actions that are within the control of agricultural producers for short-term management (less than 5 years) and long-term planning considerations (5–20 or more years) (See About This Publication on p. 3). The goals of profitability, productivity, land stewardship, and food security will be specific to individual farmers and gardeners, and many adaptation actions can benefit these goals, while also adjusting systems to changing conditions.

Information in this workbook is organized as a set of interrelated chapters, each serving as a resource to help incorporate climate considerations into on-farm agricultural practices and develop adaptation actions that can be used to respond to climate variability and change.

- Chapter 1: Climate Change Effects on Agriculture summarizes the effects of climate change on agriculture in Alaska.
- Chapter 2: Adaptation in Agriculture describes the role adaptation plays to help agricultural producers respond to the challenges and opportunities associated with climate variability and change.
- Chapter 3: Adaptation Strategies and Approaches provides a synthesis of on-the-ground farm-scale climate adaptation strategies and approaches as a list of potential responses.
- Chapter 4: Adaptation Workbook presents a structured process for integrating climate change considerations and action-oriented decisions into a farm’s long-range and annual operation plans.
- Chapter 5: Adaptation Workbook Examples demonstrates how to use the Adaptation Workbook together with regional adaptation strategies and approaches to develop tactics for real-world farm operations.

About This Publication

The resources in this publication:

- Aim to support producers, gardeners, service providers, and educators in Alaska
- Address challenges specific to Alaska's agricultural regions
- Can help producers consider both short-term adaptive management actions (less than 5 years) and long-range strategic plans (5 to 20 years, depending on farm type)
- Promote adaptation to the effects of climate change using multiple resources, including the following:
    - A list of adaptation strategies, approaches (chapter 3), and example tactics
    - A five-step process (chapter 4) to help producers incorporate climate change considerations into existing plans and develop adaptation actions for individual farms and gardens
    - Examples of climate change considerations by Alaska farmers who used the five-step process (chapter 5)

The resources in this publication do not:

- Make specific management or policy recommendations
- Address climate and nonclimate risks to agricultural enterprises, such as production, marketing, finances, human resources, or legal factors
- Provide a fully comprehensive list of all possible climate adaptation actions

References

Ardnt, D. 2016. Alaska: last frontier on the front lines [Blog]. May 20. National Oceanic and Atmospheric Administration. https://www.climate.gov/news-features/blogs/beyond-data/alaska-last-frontier-front-lines.

Byrd, A. 2020. Alaska grown, a new look at Mat-Su agriculture. [Video]. Fairbanks, AK: University of Alaska Fairbanks, Alaska Center for Energy and Power. https://www.youtube.com/watch?v=2fynjF0GEeI. (31 March 2022).

Hayhoe, K.; Wuebbles, D.J.; Easterling, D.R.; Fahey, D.W.; Doherty, S.; Kossin, J.; Sweet, W.; Vose, R.; Wehner, M. 2018. Our changing climate. In: Reidmiller, D.R.; Avery, C.W.; Easterling, D.R.; Kunkel, K.E.; Lewis, K.L.M.; Maycock, T.K.; Stewart, B.C., eds. Impacts, risks, and adaptation in the United States: fourth national climate assessment, Volume II. Washington, DC: U.S. Global Change Research Program: 72–144. http://doi.org/10.7930/NCA4.2018.CH2.

Janowiak, M.; Dostie, D.; Wilson, M.; Kucera, M.; Skinner, R.H.; Hatfield, J.; Hollinger, D.; Swanston, C. 2016. Adaptation resources for agriculture: responding to climate variability and change in the Midwest and Northeast. Tech. Bull. 1944. Washington, DC: U.S. Department of Agriculture. 70 p. https://www.climatehubs.usda.gov/sites/default/files/AdaptationResourcesForAgriculture.pdf. (21 March 2022).

Markon, C.; Gray, S.; Berman, M.; Eerkes-Medrano, L.; Hennessy, T.; Huntington, H.; Littell, J.; Trainor, S. 2018. Alaska. In: Reidmiller, D.R.; Avery, C.W.; Easterling, D.R.; Kunkel, K.E.; Lewis, K.L.M.; Maycock, T.K.; Stewart, B.C., eds. Impacts, risks, and adaptation in the United States: fourth national climate assessment. Vol. II. Washington, DC: U.S. Global Change Research Program: 1185–1241. http://doi.org/10.7930/NCA4.2018.CH26.

Stevenson, K.T.; Rader, H.B.; Alessa, L.; Kliskey, A.D.; Pantoja, A.; Clark, M.; Smeenk. J. 2014. Sustainable agriculture for Alaska and the circumpolar north: part III—meeting the challenges of high-latitude farming. Arctic. 67(3): 320–339. https://doi.org/10.14430/arctic4410

U.S. Department of Agriculture, National Agriculture Statistics Service [USDA NASS]. 2017. Census of agriculture, Volume 1, Geographic area series. Part 2, Alaska, state and area data. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_State_Level/Alaska/akv1.pdf. (29 July 2021).

U.S. Department of Agriculture, National Agriculture Statistics Service [USDA NASS]. 2021. 2020 state agriculture overview—Alaska. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=ALASKA. (29 July 2021).

Western Regional Climate Center [WRCC]. 2020. Climate of Alaska. https://wrcc.dri.edu/Climate/narrative_ak.php#:~:text=Withreferencetototalamounts,70.99inchesinNovember1976. (14 October 2020).

Chapter 1: Climate Change Effects on Agriculture in Alaska

Holly R. Prendeville, Paris Edwards, Denise Miller, Dennis Mulligan, and Cory Cole[1]

Climate Change

The climate is changing in Alaska more rapidly than any other U.S. state because of its northerly position and a faster rate of warming near the poles (Taylor et al. 2013). Areas of Alaska have already had a 2.5–6.2 °F (1.4–3.4 °C) increase in annual temperature (fig. 1.1). A variety of climate change impacts are occurring that have local and regional implications (Box 1.1: Climate Change Assessments). Rapid sea ice loss in the Arctic has widespread influence on land, ocean, and atmospheric temperatures, with some of the fastest loss occurring along the Alaska coastline. Sea ice loss contributes to coastal erosion as shores once protected by sea ice are exposed to storms.

Warmer conditions are expected to contribute to increases in the area burned by wildfire in the tundra and boreal forests, with implications to the health and safety of people and wildlife; permafrost (frozen ground) thaw; and carbon storage and emissions (Taylor et al. 2017). Near-surface permafrost is estimated to cover 38 percent of interior Alaska, which is expected to shrink to 18 or even 10 percent by the end of the century because of higher temperatures (Pastick et al. 2015). Permafrost thaw contributes to greenhouse gas emissions and negatively affects land stability and infrastructure, including transportation infrastructure that is critical to local agriculture transport and supply chains (Schoeneberger et al. 2017, Taylor et al. 2017). Shifts in wildfire frequency and size are a concern to agricultural lands. The total amount of land burned due to wildfire in Alaska shows an increasing trend since the 1950s (fig. 1.2A) and is expected to increase in many areas as the climate continues to change. Similarly, the number of smoky days from wildfire has increased over the past two decades (fig. 1.2B), increasing potential for detrimental health effects to outdoor laborers and damage to produce.

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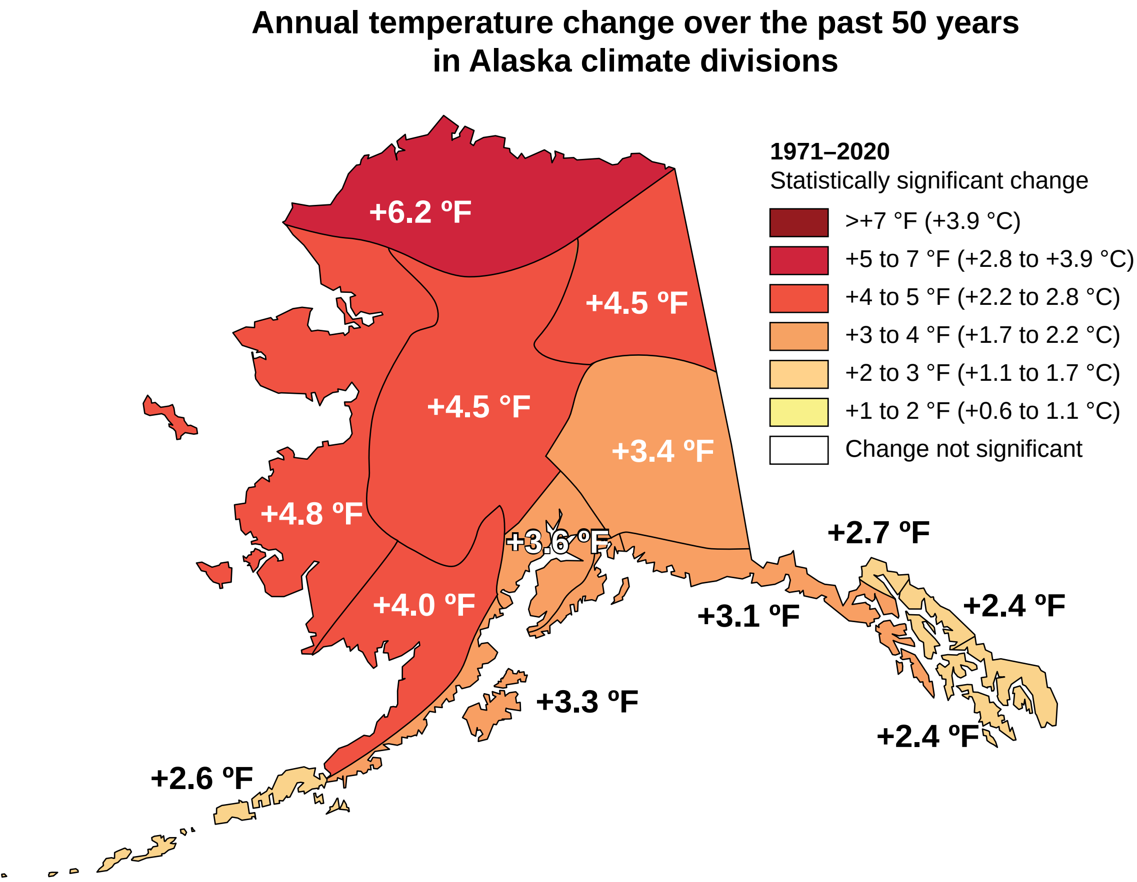

Figure 1.1—Across Alaska, annual temperatures have increased over the past 50 years, though the amount of increase differs among National Oceanic and Atmospheric Administration (NOAA) climate divisions with the North Slope increasing over 6.2 °F and Southeast increasing by 2.5 °F. Data source: NOAA and National Centers for Environmental Information (NCEI).

Global climate model projections for Alaska suggest significant increases in average temperatures (4–8 °F [2.2–4.4 °C]) and more precipitation in the future. Annual average temperatures have already been increasing at a rate of 0.7 °F (0.4 °C) per decade since the 1970s (Hayhoe et al. 2018, Riahi et al. 2011). Since the 1990s, record-high temperatures have occurred three times as often as record lows (Di Liberto 2019). As a result of higher temperatures, the growing season in interior Alaska has already lengthened by 45 percent over the past century (Wendler and Shulski 2009). As the trend toward a longer growing season continues (fig. 1.3), the amounts of suitable acreage and crop varieties are expected to expand. Changes in soil development processes under warmer climate, permafrost thaw, and an expanded growing season all contribute to these potential gains.

As temperatures increase, snowpack accumulation is expected to decrease and melt earlier in spring. In some areas, earlier snowmelt, in addition to glacier melt, could result in more flooding. Projected increases in precipitation (15–30 percent in each season by the end of the century) will further increase flood risk, with the greatest increases expected north of the Alaska Range. Increases in precipitation are projected to be larger than historical, natural variation, and there is uncertainty

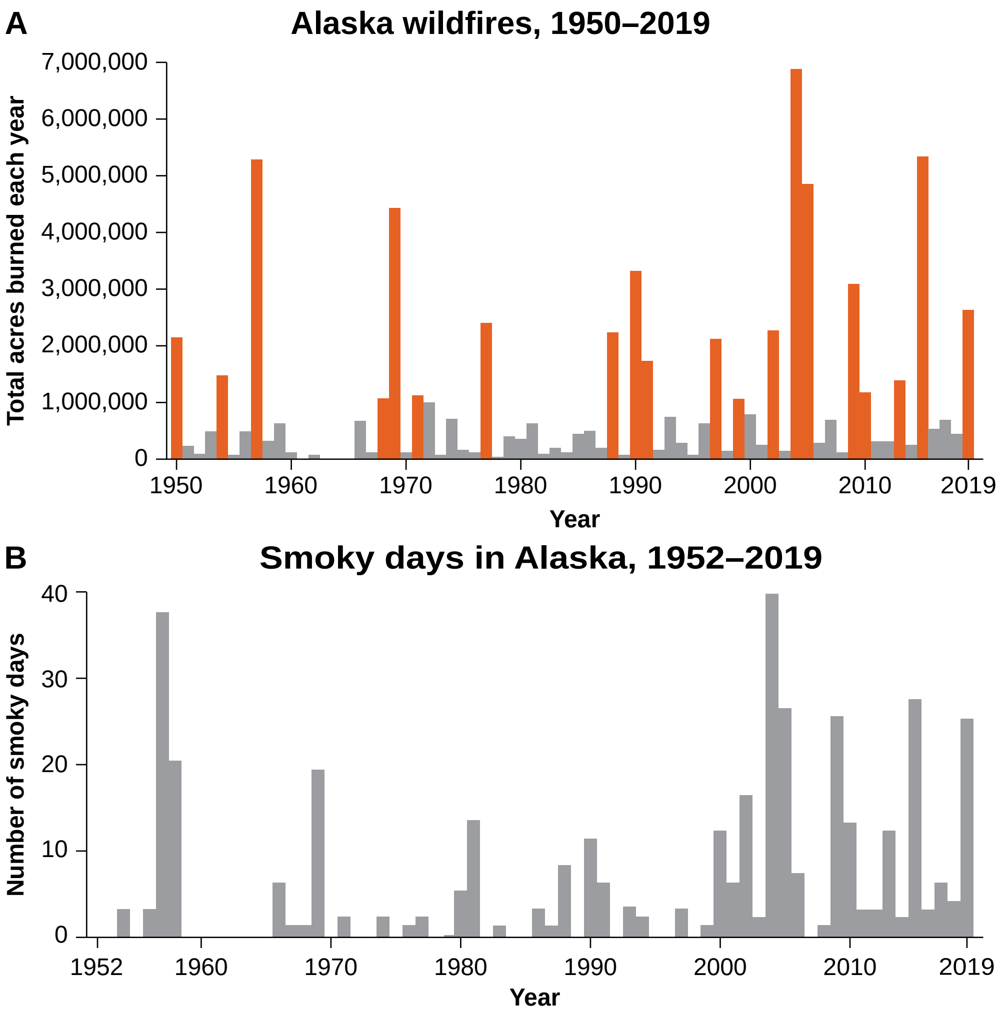

Figure 1.2—(A) Comparing total acres burned each year since 1950, there have been more years with more than 1 million ac (404 686 ha) burned (orange bars) in the most recent decades. Total acres burned each year are expected to increase with climate change. (B) The number of smoky days due to wildfire, with visibility restricted by smoke, has increased over the past two decades.

about how this will affect water resources. Across the state, precipitation change has varied and data from 1920 to 2012 show no clear patterns in precipitation gains or losses (Bieniek et al. 2014). Examining more recent data from 1969 to 2018 did show increases in precipitation, though precipitation varies regionally (fig. 1.4). Although the best available information on future conditions suggests more precipitation along with associated flooding, available water may decrease in rain-fed basins because increased temperatures and evaporation rates outpace precipitation increases (Hinzman et al. 2005). For agriculture in Alaska, these changes translate to changes in water storage and evaporation, increases in storm damage, longer growing seasons, increased potential for flooding and soil erosion, and degradation or loss of permafrost (UAF SNAP, n.d.), which can negatively affect soil and infrastructure (Markon et al. 2018).

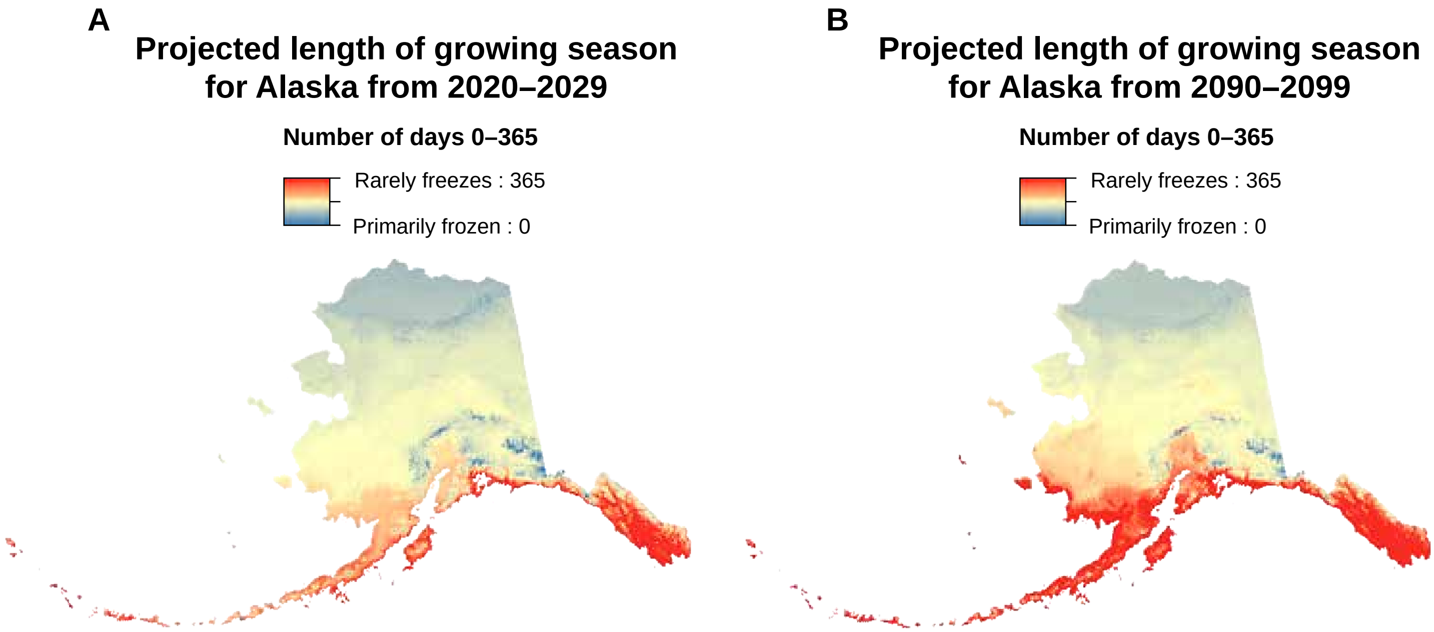

Figure 1.3—Growing season is the time of year that is favorable for plant growth. Climate projections from downscaled, Coupled Model Intercomparison Project Five (CMIP5) five-model show the mean length of growing season (numbers of days: 0–365) at 771 by 771 m spatial resolution and representative concentration pathway (RCP) 8.5, a high-end emissions scenario that aligns with increasing current greenhouse gas emissions for (A) 2020–2029 and (B) 2090–2099. Note that a longer growing season, indicated by red colors, is expected to expand northward with notable change across the southern half of the state. The least amount of change is expected in northern Alaska. Data from the Alaska Center for Climate and Policy.

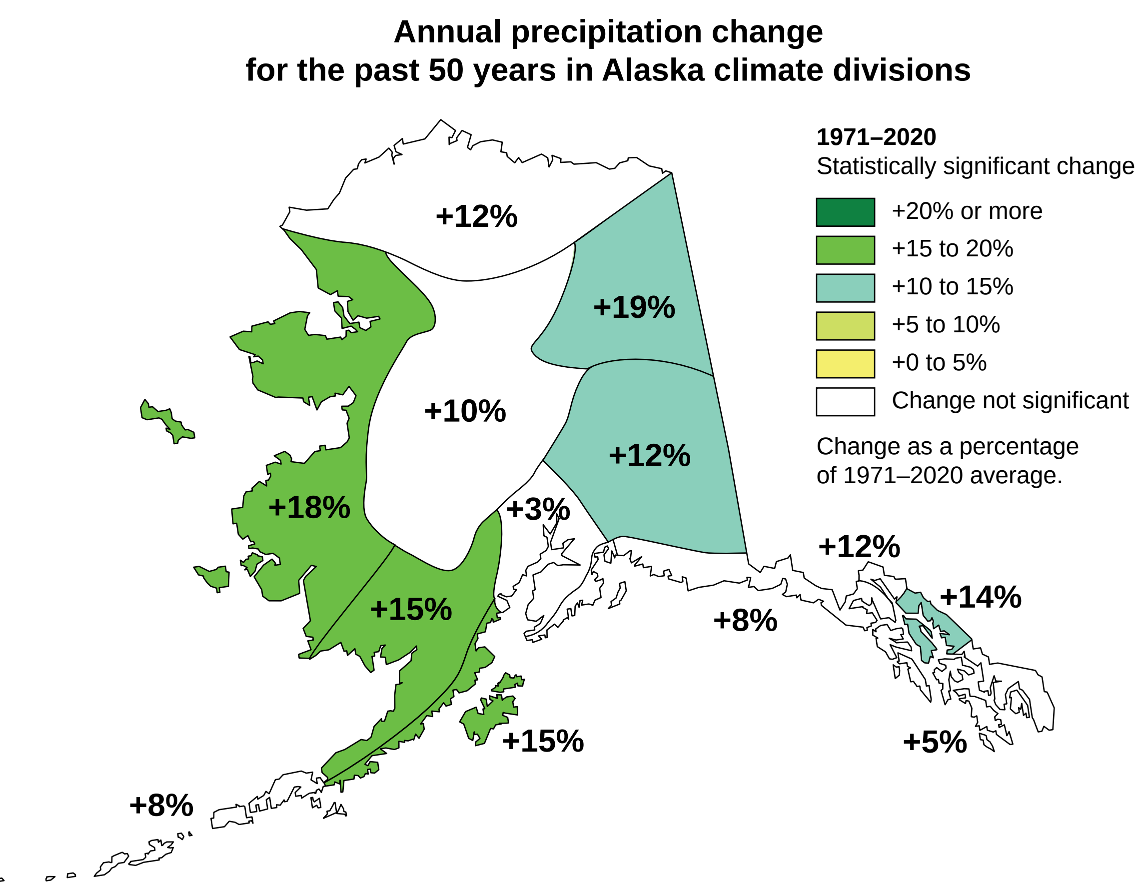

Figure 1.4—Some areas in Alaska have experienced increases in annual precipitation over the past 50 years as indicated by the colored regions. Increases in precipitation have varied by National Oceanic and Atmospheric Administration (NOAA) climate divisions. Only colored regions had statistically significant changes in precipitation. Data source: NOAA and National Centers for Environmental Information (NCEI).

Weather and Climate Change Challenges and Opportunities in Alaska

The following list of climate change effects highlights some of the challenges and opportunities for agriculture in Alaska, but it is not exhaustive (see Box 1.1: Climate Change Assessments).

- **Increasing temperatures** are providing the benefit of a longer growing season, an increase in suitable crops and livestock, and an increase in suitable agricultural lands. Increasing temperatures also mean more risks, such as less available water, precipitation as rain or freezing rain rather than snow, diseases, pests, and other challenges.
- **Decreasing and earlier melt of snowpack** is resulting in earlier peak stream and river flows, which may reduce seasonal available water for irrigation.
- **Precipitation variability** will change the timing, duration, and amount of precipitation. If snowfall shifts to rain, changes in the timing and amount of water availability during the growing season will result in an increased need for irrigation and water delivery and storage infrastructure.
- **Increasing extremes, including flooding and drought**, are expected to occur with higher frequency and intensity, including extreme wet and dry events.

Box 1.1

Climate Change Assessments

The following online climate change assessments provide general information about climate change vulnerability in Alaska:

- Alaska: fourth national climate assessment (Markon et al. 2018) discusses climate change effects on soil and water, provides updated temperature and precipitation change projections, and includes a list of adaptation actions relevant to producers.
- Climate change vulnerability assessment for the Chugach National Forest and the Kenai Peninsula (Hayward et al. 2017) provides temperature, precipitation, and growing season projections for the Kenai Peninsula and Palmer regions.
- Climate change impacts in the United States: the third national climate assessment—Alaska. (Chapin et al. 2014) provides multiple climate change scenarios and highlights permafrost and water resource losses.
- Managing for the future in a rapidly changing Arctic: a report to the president (Hayes et al. 2013) discusses specific challenges to Alaska's Arctic regions and suggests integrated approaches to adaptation.

- **Increasing wildfire and smoke potential** will result from higher temperatures drying out vegetation. Wildfire is a threat to agriculture, and wildland fire smoke can detrimentally affect the health of outdoor workers and degrade some produce.
- **Extreme weather,** such as wind events and heat waves, are increasingly hazardous to crops, livestock health and safety, and operational infrastructure.
- **Permafrost degradation and loss** has the potential to destabilize and destroy transportation infrastructure, on-farm structures, and homes in some parts of the state. Increased flooding and precipitation (water inputs to ice) may contribute to permafrost degradation in some areas. Also, loss of permafrost contributes to greenhouse gas emissions, which are associated with climate change.

Agriculture

Although Alaska is the nation's largest state, it has one of the smallest agricultural industries. In 2017, 990 farms covering nearly 850,000 ac (343 983 ha) produced more than $70 million in products (USDA NASS 2017). Supply does not yet meet demand, and local food production is limited. Alaska therefore relies heavily on imported food and is thus more vulnerable to interruptions in the food-import supply chain. Recently, more Alaskans have been farming (USDA NASS 2017), which is helping to meet the need for supplying locally sourced food. The growth in farming is in part attributed to climate changes that favor agricultural production. Recent data suggest that Alaska farmers are generally cultivating less than 10 ac (4 ha) and more farmers are young, women, and current or former military (USDA NASS 2017) (see Box 1.2: New and Beginning Farmers Resources).

Alaska farmers already produce a variety of meats, vegetables, grains, and fibers. Under warmer conditions, agricultural production levels could increase, and the variety of products is likely to expand. Currently, farmed fish lead sales of meat products, followed by cattle, hogs, sheep, goats, and chickens. Aquaculture is expected to benefit from increased temperatures and milder Alaska winters (Johnson 2012, 2016). Expanded farming of fishes is seen as an adaptive alternative to dependence on commercial fisheries that are vulnerable to negative, climate-related shifts (Johnson 2012, 2016). Seaweed farming (e.g., bull kelp) is a new industry that is a sustainable source of food and revenue that benefits marine ecosystems (Duarte et al. 2017). Reindeer, bison, muskoxen, and yak are also produced in Alaska. Livestock production, particularly of native species, may expand in drier, cooler regions of the state to adapt to warmer conditions. With warmer conditions, pests (e.g., ticks) and diseases may become more common in wildlife, which may increase the risk of transmission to livestock and humans (Hueffer et al. 2013, Van Hemert et al. 2014). Alaska farmers also produce nursery, greenhouse, floriculture,

Under warmer conditions, agricultural production levels could increase, and the variety of products is likely to expand.

Box 1.2

New and Beginning Farmer Resources

U.S. Department of Agriculture's New Farmer website (USDA NF, n.d.) has resources for each step of farming. Find information about how to start a farm and find resources about planning; women, youth, and veterans in agriculture; and how to get startup business support.

Beginning Farmers (Carbon Media Group Agriculture 2017) has a collection of information and resources for new farmers in the United States, including online education, videos, and employment and farming resources.

USDA Service Centers (USDA Farmers.gov, n.d. a) are locations where you can connect with Farm Service Agency and Natural Resources Conservation Service employees to learn and apply for programs. Find your county office by selecting Alaska and your county from the dropdown menus.

Natural Resources Conservation Service's Five Steps to Assistance (USDA NRCS, n.d. a) is a detailed process on how to apply for financial and technical assistance to make improvements to land that you own or lease. Historically underserved customers, including Alaska Natives, may receive greater financial assistance.

University of Alaska Fairbanks Cooperation Extension Service (UAF CES, n.d.) has many publications on a variety of agricultural topics, including farm structures, greenhouses, field crops, soil management, horticulture, agricultural business management, and pest control.

USDA Farm Service Agency Alaska (USDA FSA, n.d.) provides information on land acquisition and operating loans, as well as assistance and relief programs available to new and established farmers.

National Sustainable Agriculture Coalition (USDA FSA 2020) has resources for beginning farmers, including assistance and information.

USDA Beginning Farmer and Rancher Coordinators (USDA Farmers.gov, n.d. b) can help you get started or grow your farming operation through a variety of programs and services. Get connected with the Alaska Coordinator.

Tool Box for Farmland Seekers from Alaska Farmland Trust (Alaska Farmland Trust, n.d.) includes information on lease agreements, how to develop a farm business plan, how to acquire financial assistance, and labor resources.

Alaska Grown: A New Look at Mat-Su Agriculture (Byrd 2020) is a short documentary on how food security challenges in Alaska present new opportunities for farmers. It includes interviews with farmers about how they got started and where they received local training.

and sod products as well as vegetables, berries, apples, potatoes, melons, dry beans, and grains. Alaska's short, intense growing season provides conditions to support the production of record-breaking produce, such as a 18.9-lb (8.5-kg) carrot, 82.9-lb (37.6-kg) rutabaga, 138-lb (62.7-kg) green cabbage, 168.6-lb (76.4-kg) watermelon, and 2,051-lb (930-kg) giant pumpkin (Alaska State Fair 2021). New varieties of specialty crops that thrive under longer growing seasons, lower frost risk, and warmer temperatures are beginning to expand (fig. 1.5). Farmers and gardeners are already wondering what else they can grow as these changes unfold.

Producers in Alaska already contend with and adapt to a variety of challenges. In southeast Alaska, produce is commonly grown in hoop houses or greenhouses to exclude rain as excessive moisture can result in fungal diseases and limit plant growth. In subarctic regions, hoop houses help to increase temperatures to lengthen the growing season (Stevenson et al. 2014). Across the state, wildlife-human interactions increase when wildlife food supply is limited, resulting in wildlife searching for food on farms or in communities. Other challenges, such as insect pests [UAF CES 2018], soils that need fertilizer or other amendments to support plant growth, limited infrastructure, and long supply chains result in higher costs and smaller markets, posing challenges statewide. Also, much of the state contends with occasional frost during the growing season. Even though increased temperatures will improve suitability for desired agricultural production, climate change also comes with an increased risk of variable weather, storm intensity, and likelihood of invasive species (UAF CES, n.d. b), pests and diseases, and wildfire, as well as changes to water timing and availability (Elad and Pertot 2014, Hezel et al. 2012, Howden et al. 2007, Kasischke et al. 2010).

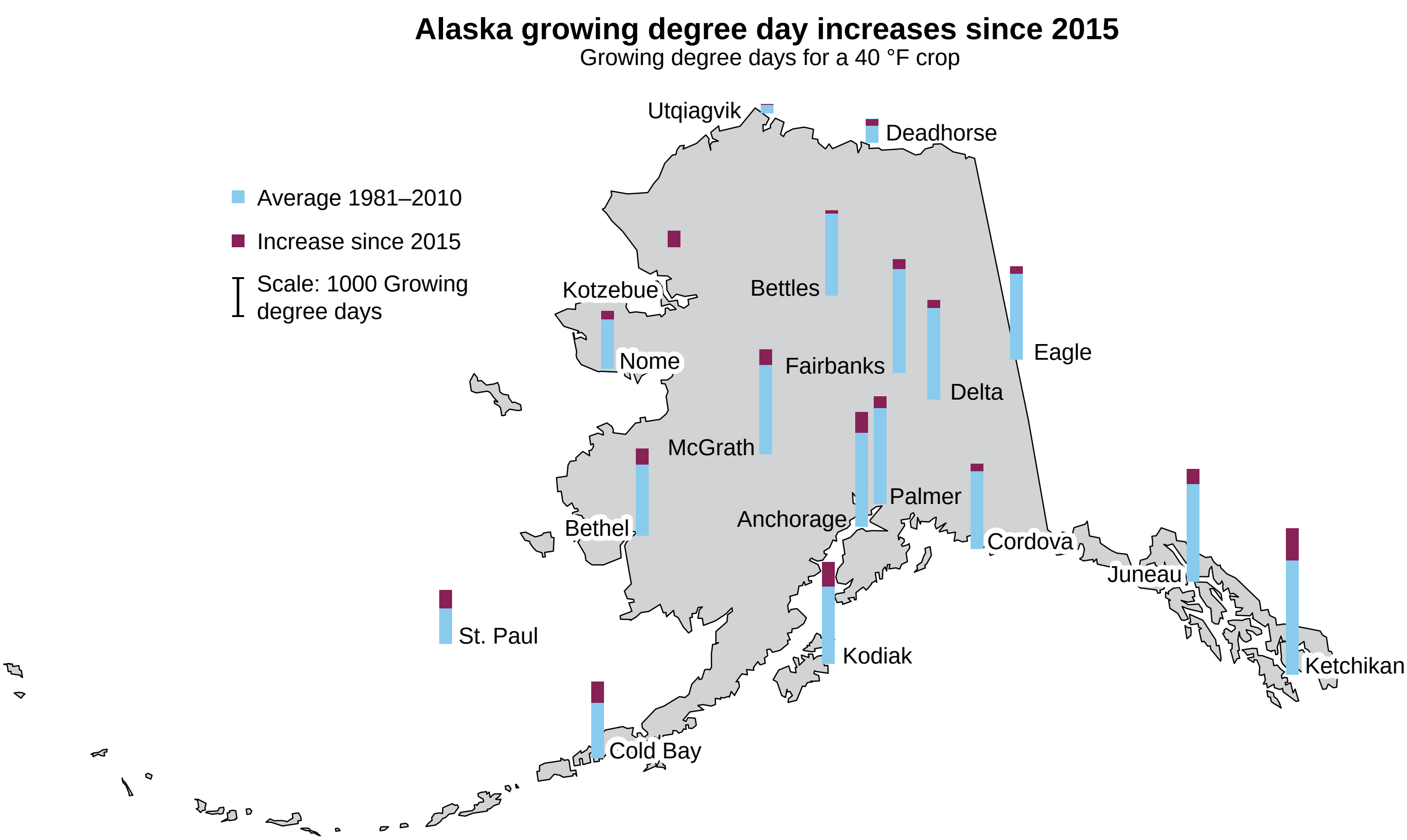

Figure 1.5—Growing degree days for a 40 °F (4.4 °C) crop for different communities in Alaska, with blue bars noting the average growing degree days from 1981 to 2010 and the red portion of the bar noting the increase in growing degree days since 2015 through 2018 in comparison to the average. Adapted from Nancy Fresco, Scenarios Network for Alaska+ Arctic Planning and Rick Thoman, Alaska Center for Climate Assessment and Policy. Data source: NOM/NCEI, NDAWN, Canadian Journal of Plant Science, 2006.

Effects of climate change on agriculture—
Some effects of climate change on agriculture in Alaska are listed below; although it is not an exhaustive list, these are some that will likely affect most farming operations.

- **Longer growing season.** Warmer springs and falls and more frost-free days are lengthening growing seasons. Longer growing seasons benefit certain crops and will likely change the species and varieties (UAF AFES, n.d.) that can be grown in Alaska. A long growing season poses an opportunity to farmers to increase the diversity of crops and meet local demand for Alaska-grown produce.
- **Crop yields may be improved or degraded.** Increased temperatures will shift the growing season by altering the timing of germination, harvest, and storage, which may affect crop yield in positive or negative ways depending on crop and field preparation by the farmer.
- **Increased pressures from weeds and invasive plant species.** New plant species may migrate to Alaska with changes in climate.
- **Pests and diseases increase.** With increases in temperatures, insects that overwinter may appear at higher levels earlier in the season, and new insects and diseases may establish in the state. Also, shorter winters will bring an earlier arrival of migratory insects, which may allow for more generations of pests within a season.
- **Increased risk of plant pathogens.** Increased temperatures can support pathogen survival over winter, lengthen the period of infection potential, allow for more infection cycles within a season, and result in pathogen populations expanding into new areas.

Soil Resource Vulnerability

Soil organic matter supports properties important to soil health and function, including water absorption and holding capacity, aggregate stability, root aeration, and root health. All these soil functions are essential for plant growth. Permafrost is present and is dominant throughout interior Alaska. In soil taxonomy, soils that contain permafrost within about 1 m of the surface are called Gelisols (USDA NRCS 2019a). Decreases in permafrost could benefit soils by increasing the potential for crop cultivation across larger areas of the state over the long term (through mid-century or beyond). Soils with permafrost drain poorly because of the frozen subsoil layer that keeps water higher in the soil or perched water table. As temperatures increase, permafrost may thaw, resulting in improved drainage and increased production of organic matter. At the same time, degradation or loss of permafrost (e.g., increase in depth of permafrost below the soil surface, or the absence thereof) can result in land caving or sinking, particularly where high ice content is present and closer to the surface (Lader et al. 2018). Also, loss of permafrost contributes to greenhouse gas emissions, which are associated with climate change. Questions still remain about how climate change will affect permafrost and soil function in agriculturally productive regions of Alaska.

Expected increases in the frequency and intensity of large rain events may result in more erosion, particularly on croplands that lack vegetative cover during winter and spring months (Markon et al. 2018). Erosion due to wind or rain decreases organic matter and degrades soil function. Erosion weakens soil aggregates, which reduces the ability of soil to hold water and nutrients and reduces beneficial microbial habitat. Soil erosion reduces water quality, which affects downstream users, fish, and wildlife.

Increases in fire frequency and extremes will also affect soil resources. The extent, intensity, and frequency of fire and extreme fires are projected to increase because of climate change and will affect soil by increasing exposure and decreasing infiltration (Markon et al. 2018). The consequences of extreme fire include more severely burned areas that are vulnerable to soil erosion, landslides, and flooding (Sankey et al. 2017). Wildland fires also destroy the insulating layer of organic matter at the soil surface, resulting in permafrost degradation. It is important to keep in mind that changes to soil will vary widely because of complex interactions between location and crop and root productivity, along with soil type, management decisions, and other soil processes (Allen et al. 2011).

The consequences of extreme fire include more severely burned areas that are vulnerable to soil erosion, landslides, and flooding.

Soils in Alaska's Agricultural Regions

Information from the Alaska soil handbook from the USDA Natural Resources Conservation Service (NRCS) (appendix) provides a background on soil properties that can help producers identify productive lands and ultimately maximize and conserve soil benefits under changing climate conditions. Detailed soil information from NRCS can provide insight into soil behavior and help farmers decide how to amend soils as well as inform what and when to plant. A summary of helpful information for a few NRCS soil survey regions addressed in the soil handbook is provided below.

South-central Alaska—

The region covering south-central Alaska is one of the state's most productive agricultural areas, despite having soils with significant limitations. Land capability classification (LCC) (appendix) indicates the ability of soils in an area to support natural and cultivated plant growth. LCC ratings range from class 1 soils, with the fewest restrictions that limit plant growth, to class 8 soils, with major restrictions on plant growth. There are no class 1 or 2 soils in the Matanuska-Susitna (Mat-Su) Valley areas (fig. 1.6A), or on Alaska's western Kenai Peninsula (fig. 1.6B). In the Mat-Su area, class 3 and 4 soils cover 24 percent of the area and generally occur on broad glacial till and outwash plains. The soil orders within these two regions that are best suited to agriculture are Inceptisols and Spodosols. Spodosols (USDA NRCS, n.d. b) are dominant, comprising nearly half of soils in both survey areas. Entisols, Histosols, and Andisols are also present and cover small portions of the survey areas. Except for Histosols, soils in these orders commonly support agriculture.

Copper River area—

Soils in the Copper River area are typically very high in clay, and along with permafrost, can cause drainage challenges (fig. 1.7). Gelisols (permafrost soils) are most common, making up nearly half of soils in the area. In areas with glacial till, Gelisols can be cleared to lower the permafrost table and improve drainage for agricultural use. In the clayey deposits of the lake plain, as permafrost thaws, drainage may continue to be limited, and there is potential for land subsistence (sinking). Entisols, Histosols, and Mollisols are common and suitable for agriculture when not limited by slope wetness. In the Copper River area, class 1, 2, and 3 soils are not present, and class 4 soils cover nearly 30 percent of the area.

Soils of interior Alaska—

There are four agriculturally active areas with soil surveys in interior Alaska. These include the Greater Delta Area, Greater Nenana Area, Gerstle River Area, and Greater Fairbanks Area (fig. 1.8) (USDA NRCS 2019d, 2019e, 2019f, 2019g). The dominant soils used for agriculture are Inceptisols, Entisols, and some Gelisols (after thawing). A defining characteristic for many soils of this area is poor drainage conditions owing to the presence of subsoil permafrost.

Inceptisols are the most common soil types in interior Alaska and are typically very good for agriculture. Gelisols are the next most abundant soil order and make up a third of the Greater Nenana and Greater Fairbanks areas. Deep permafrost with large bodies of ground ice is present in these areas. Gelisols cover less than a quarter of the Greater Delta and Gerstle River areas, where permafrost is discontinuous and is often found near the surface (1–20 inches [2.5–51 cm] deep). Permafrost reduces infiltration or water movement and often limits water storage to areas above the frozen soil layer (i.e., perched water). Removal of insulative, natural vegetation or organic matter on the soil surface by fire or mechanical clearing (e.g., tillage) increases the depth to permafrost or eliminates it entirely (Péwé and Holmes 1964). As average air and soil temperatures increase throughout the year, the permafrost table may lower or disappear altogether in some areas. Permafrost thaw could result in improved soil drainage for a larger area in the future. However, permafrost soils may settle unevenly or develop an irregular landscape (thermokarst). Areas

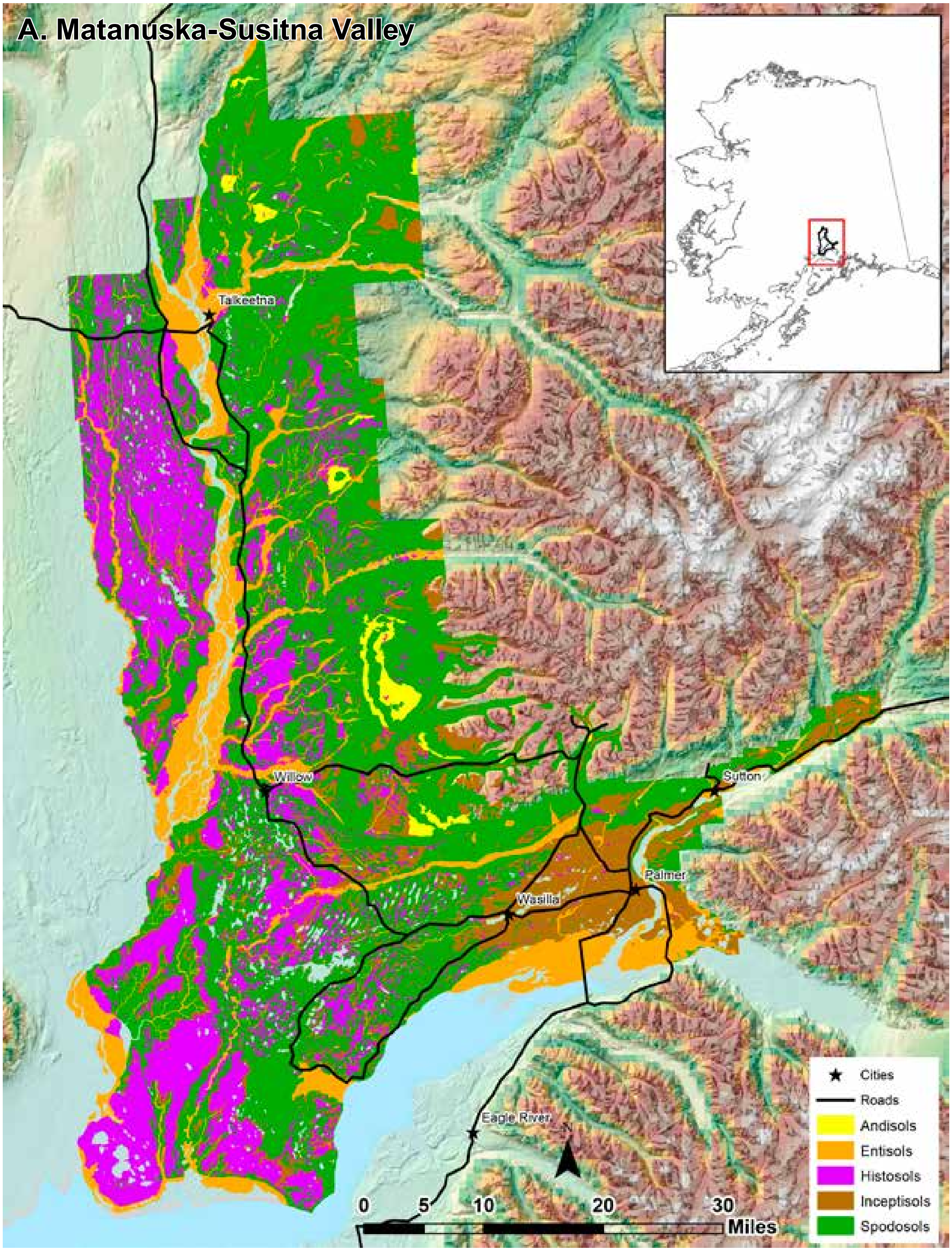

Figure 1.6—Soil taxonomy orders (Andisols = yellow, Entisols = orange, Histosols = purple, Inceptisols = brown, and Spodosols = green) in the (A) Matanuska-Susitna Valley survey areas (USDA NRCS 2019a) and (B) western part of the Kenai Peninsula (USDA NRCS 2019b)

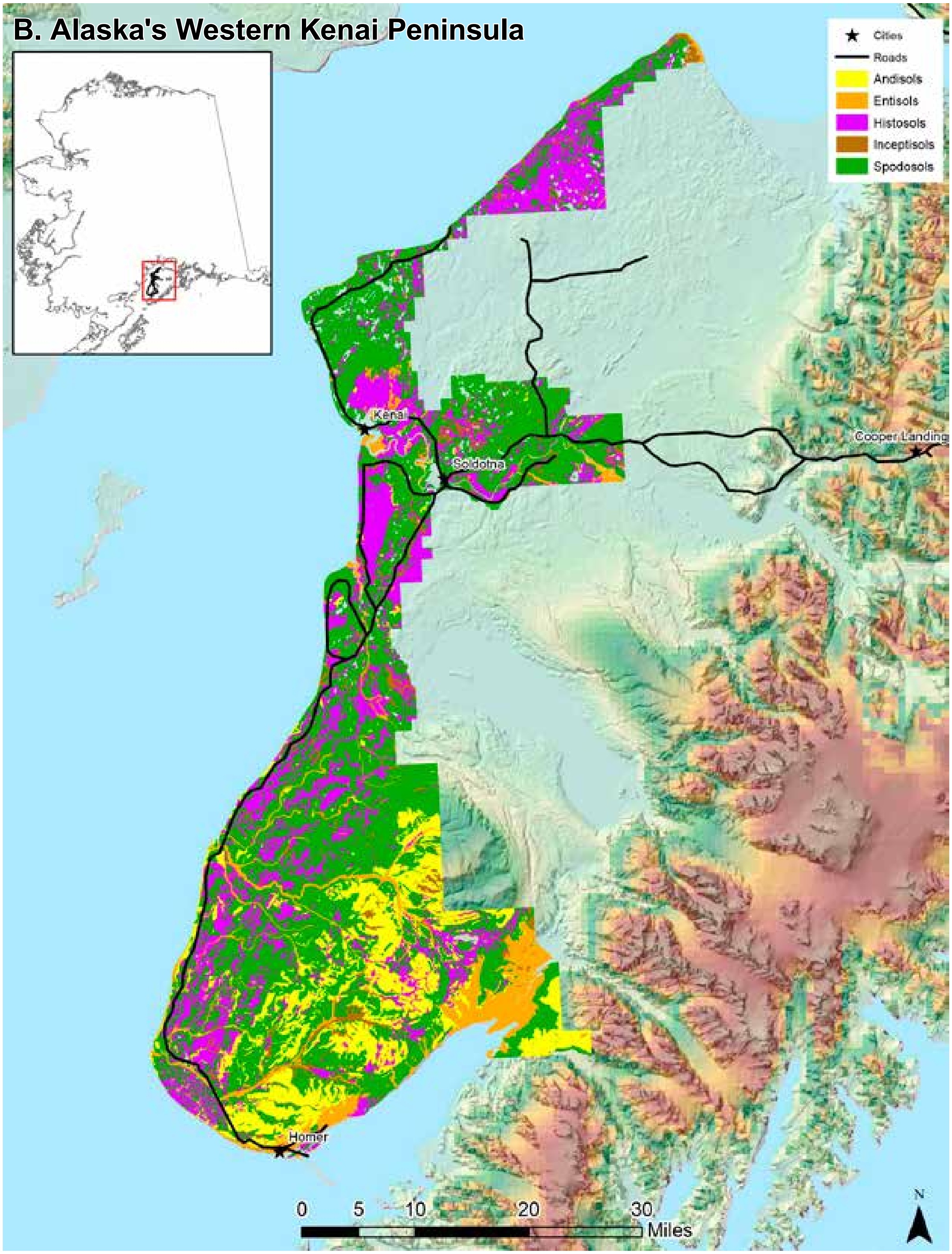

Figure 1.6 (continued)—Soil taxonomy orders (Andisols = yellow, Entisols = orange, Histosols = purple, Inceptisols = brown, and Spodosols = green) in the (A) Matanuska-Susitna Valley survey areas (USDA NRCS2019a) and (B) western part of the Kenai Peninsula (USDA NRCS 2019b)

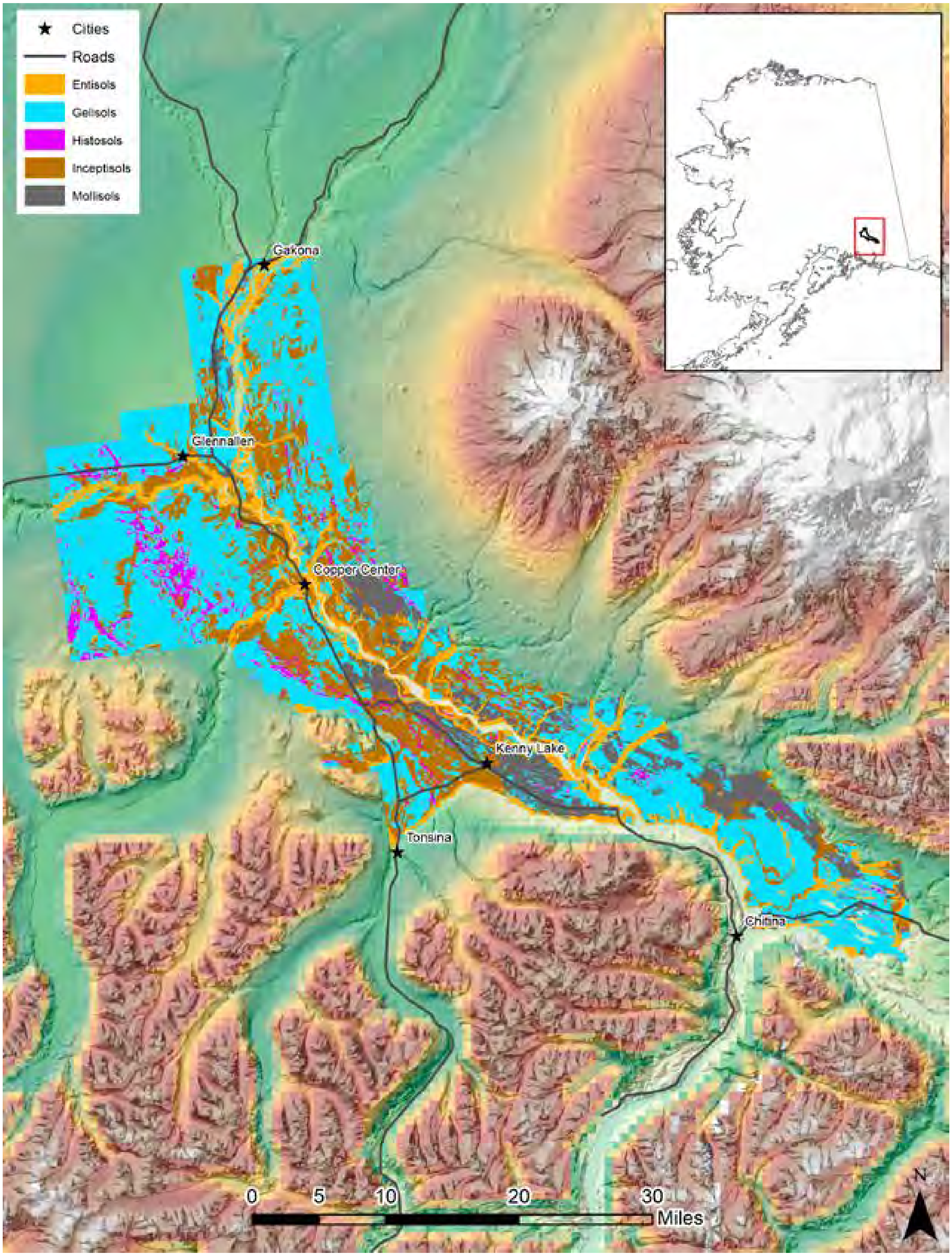

Figure 1.7—Soil taxonomy orders (Entisols = orange, Gelisols = blue, Histosols = purple, Inceptisols = brown, and Mollisols = grey) in the Copper River Valley survey area (USDA NRCS 2019c).

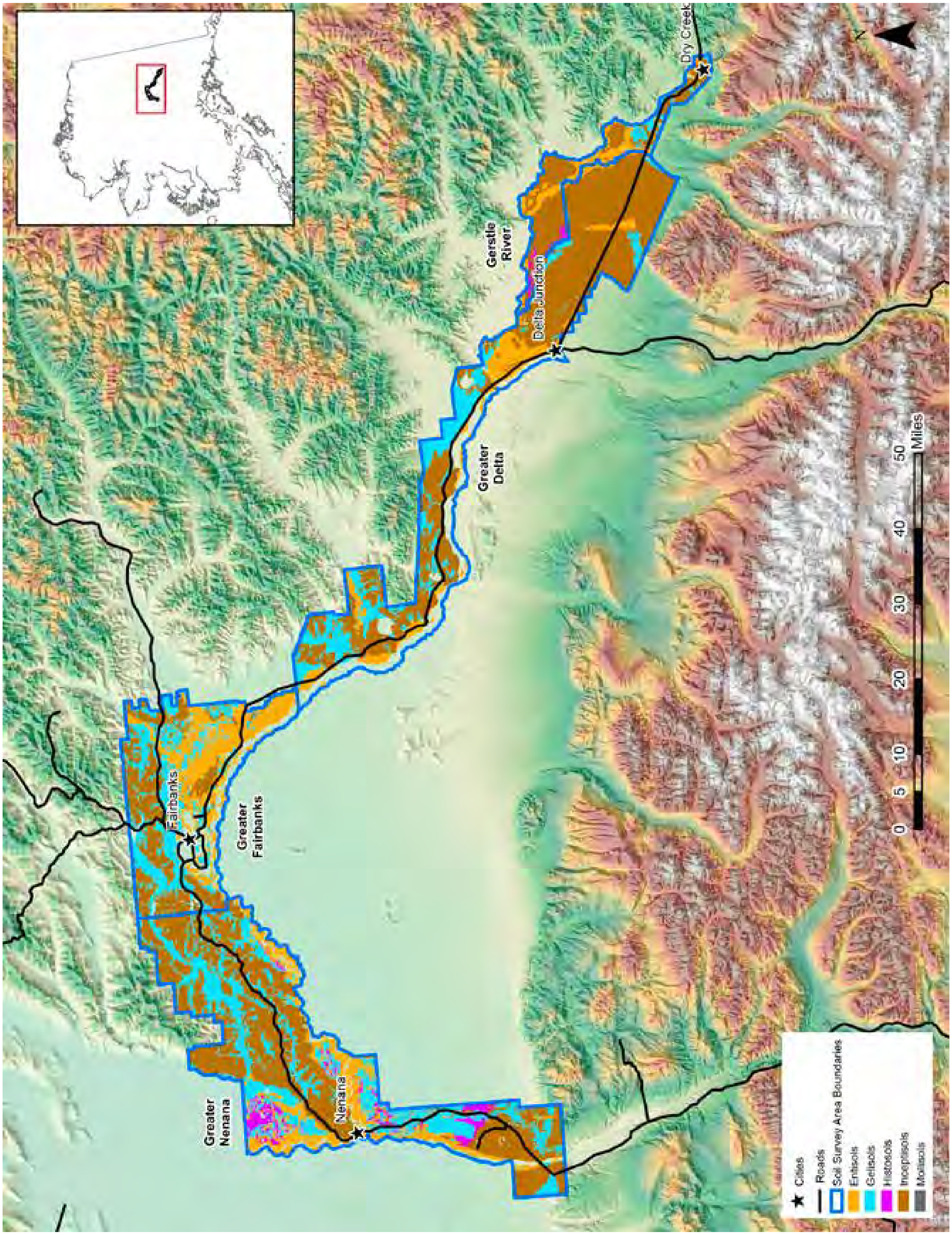

Figure 1.8—Soil taxonomy orders (Entisols = orange, Gelisols = blue, Histosols = purple, Inceptisols = brown, and Mollisols = grey) for a portion of interior Alaska survey area (USDA NRCS 2019g).

with deep permafrost reduce agricultural suitability because of large masses of ground ice that can also contribute to uneven land and sinking. Some Entisols in the interior are highly productive, but the majority of these soils are limited by wetness. These Entisol areas are most common in the Gerstle River and Greater Fairbanks areas. Mollisols are usually considered excellent for agriculture but cover only very small portions of the Greater Nenana and Greater Delta survey regions. Class 2 soils (with moderate limitations) are present and most common in the Delta Junction and Greater Fairbanks areas. Moderately limited class 3 and 4 soils are dominant in the interior as are severely limited class 6 and 7 soils.

References

Alaska Farmland Trust. [N.d.]. Toolbox for farmland seekers. https://www.akfarmland.com/farm-business-resources/toolbox-for-farmland-seekers/. (8 March 2021).

Alaska State Fair. 2021. Giant fruit and vegetable records. https://www.alaskastatefair.org/site/exhibits/giant-fruit-vegetable-records/. (29 July 2021).

Allen, D.E.; Singh, B.P.; Dalal, R.C. 2011. Soil health indicators under climate change: a review of current knowledge. In: Singh B.; Cowie A.; Chan K., eds. Soil health and climate change. Soil Biology. 29: 25–45. Berlin and Heidelberg, Germany: Springer. https://doi.org/10.1007/978-3-642-20256-8_2.

Bieniek, P.A.; Walsh, J.E.; Thoman, R.L.; Bhatt, U.S. 2014. Using climate divisions to analyze variations and trends in Alaska temperature and precipitation. Journal of Climate. 27(8): 2800–2818. https://doi.org.10.1175/JCLI-D-13-00342.1.

Byrd, A. 2020. Alaska grown, a new look at Mat-Su agriculture. [Video]. Fairbanks, AK: University of Alaska Fairbanks, Alaska Center for Energy and Power. https://www.youtube.com/watch?v=2fynjF0GEeI. (31 March 2022).

Carbon Media Group Agriculture. 2017. Beginning farmers. https://www.beginningfarmers.org/. (8 March 2021).

Di Liberto, T. 2019. High temperatures smash all-time records in Alaska in early July 2019. National Oceanic and Atmospheric Administration, Climate.gov. https://www.climate.gov/news-features/event-tracker/high-temperatures-smash-all-time-records-alaska-early-july-2019. (8 March 2021).

Duarte, C.M.; Wu, J.; Xiao, X.; Bruhn, A.; Krause-Jensen, D. 2017. Can seaweed farming play a role in climate change mitigation and adaptation? Frontiers in Marine Science. 4: 100. https://doi.org/10.3389/fmars.2017.00100.

Elad, Y.; Pertot, I. 2014. Climate change impacts on plant pathogens and plant diseases. Journal of Crop Improvement. 28(1): 99–139. https://doi.org/10.1080/15427528.2014.865412.

Hayhoe, K.; Wuebbles, D.J.; Easterling, D.R.; Fahey, D.W.; Doherty, S.; Kossin, J.; Sweet, W.; Vose, R.; Wehner, M. 2018. Our changing climate. In: Reidmiller, D.R.; Avery, C.W.; Easterling, D.R.; Kunkel, K.E.; Lewis, K.L.M.; Maycock, T.K.; Stewart, B.C., eds. Impacts, risks, and adaptation in the United States: fourth national climate assessment, Vol. II. Washington, DC: U.S. Global Change Research Program: 72–144. http://doi.org/10.7930/NCA4.2018.CH2.

Hezel, P.J.; Zhang, X.; Bitz, C.M.; Kelly, B.P.; Massonnet, F. 2012. Projected decline in spring snow depth on Arctic sea ice caused by progressively later autumn open ocean freeze-up this century. Geophysical Research Letters. 39(17): L17505. https://doi.org/10.1029/2012GL052794.

Hinzman, L.D.; Bettez, N.D.; Bolton, W.R.; Chapin, F.S.; Dyurgerov, M.B.; Fastie, C.L.; Griffith, B.; Hollister, R.D.; Hope, A.; Huntington, H.P.; Jensen, A.M. 2005. Evidence and implications of recent climate change in northern Alaska and other Arctic regions. Climatic Change. 72(3): 251–298. https://doi.org/10.1007/s10584-005-5352-2.

Howden, S.M; Soussana, J.-F.; Tubiello, F.N.; Chhetri, N.; Dunlop, M.; Meinke, H. 2007. Adapting agriculture to climate change. Proceedings of the National Academy of Sciences of the United States of America. 104(50): 19691–19696. https://doi.org/10.1073/pnas.0701890104.

Hueffer, K.; Parkinson, A.J.; Gerlach, R.; Berner, J. 2013. Zoonotic infections in Alaska: disease prevalence, potential impact of climate change and recommended actions for earlier disease detection, research, prevention and control. International Journal of Circumpolar Health. 72: 1. https://doi.org/10.3402/ijch.v72i0.19562.

Johnson, T. 2012. Fisheries adaptation to climate change. Alaska Sea Grant Marine Advisory Program. https://seagrant.uaf.edu/bookstore/pubs/M-162.html. (29 July 2021).

Johnson, T. 2016. Climate change and Alaska fisheries. Fairbanks, AK: Alaska Sea Grant Marine Advisory Program. https://alaskaseagrant.org/wp-content/uploads/2018/02/Climate-Change-and-Fisheries_Johnson_WEB.pdf. (29 July 2021).

Kasischke, E.S.; Verbyla, D.L.; Rupp, T.S.; McGuire, A.D.; Murphy, K.A.; Jandt, R.; Barnes, J.L.; Hoy, E.E.; Duffy, P.A.; Calef, M.; Turetsky, M.R. 2010. Alaska's changing fire regime—implications for the vulnerability of its boreal forests. Canadian Journal of Forest Research. 40(7): 1313–1324. https://doi.org/10.1139/X10-098.

Lader, R.; Walsh, J.E.; Bhatt, U.S.; Bieniek, P.A. 2018. Agro-climate projections for a warming Alaska. Earth Interactions. 22(18): 1–24. https://doi.org/10.1175/EI-D-17-0036.1.

Markon, C.; Gray, S.; Berman, M.; Eerkes-Medrano, L.; Hennessy, T.; Huntington, H.; Littell, J.; Trainor, S. 2018. Alaska. In: Reidmiller, D.R.; Avery, C.W.; Easterling, D.R.; Kunkel, K.E.; Lewis, K.L.M.; Maycock, T.K.; Stewart, B.C., eds. Impacts, risks, and adaptation in the United States: fourth national climate assessment. Vol. II. Washington, DC: U.S. Global Change Research Program: 1185–1241. http://doi.org/10.7930/NCA4.2018.CH26.

National Sustainable Agriculture Coalition. 2020. New team at USDA to help new farmers [Blog]. https://sustainableagriculture.net/blog/usda-bfr-coordinators/. (8 March 2021).

Pastick, N.J.; Jorgenson, M.T.; Wylie, B.K.; Nield, S.J.; Johnson, K.D.; Finley, A.O. 2015. Distribution of near-surface permafrost in Alaska: estimates of present and future conditions. Remote Sensing of Environment. 168: 301–315. https://doi.org/10.1016/j.rse.2015.07.019.

Paustian, K.; Lehmann, J.; Ogle, S.; Reay, D.; Robertson, G.P.; Smith, P. 2016. Climate-smart soils. Nature. 532(7597): 49–57. https://doi.org/10.1038/nature17174.

Péwé, T.L.; Holmes, G.W. 1964. Geology of the Mt. Hayes D-4 Quadrangle, Alaska. Miscellaneous Geologic Investigations Map 394, 2 sheets, scale 1:63,360. Reston, VA: U.S. Department of the Interior, Geological Survey. https://dggs.alaska.gov/pubs/id/13611.

Riahi, K.; Rao, S.; Krey, V.; Cho, C.; Chirkov, V.; Fischer, G.; Rafaj, P. 2011. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. Climatic Change. 109: 33. https://doi.org/10.1007/s10584-011-0149-y

Sankey, J.B.; Kreitler, J.; Hawbaker, T.J.; McVay, J.L.; Miller, M.E.; Mueller, E.R.; Sankey, T.T. 2017. Climate, wildfire, and erosion ensemble foretells more sediment in Western USA watersheds. Geophysical Research Letters. 44(17): 8884–8892. https://doi.org/10.1002/2017GL073979

Schoeneberger, M.M.; Bentrup, G.; Patel-Weynand, T. 2017. Agroforestry: enhancing resiliency in U.S. agricultural landscapes under changing conditions. Gen. Tech. Rep. WO-96. Washington, DC: U.S. Department of Agriculture, Forest Service. Appendix A. https://doi.org/10.2737/WO-GTR-96. (4 March 2021).

Stevenson, K.T.; Rader, H.B.; Alessa, L.; Kliskey, A.D.; Pantoja, A.; Clark, M.; Smeenk. J. 2014. Sustainable agriculture for Alaska and the circumpolar north: part III—meeting the challenges of high-latitude farming. Arctic. 67(3): 320–339. https://doi.org/10.14430/arctic4410.

Taylor, P.C.; Cai, M.; Hu, A.; Meehl, J.; Washington, W.; Zhang, G.J. 2013. A decomposition of feedback contributions to polar warming amplification. Journal of Climate. 26(18): 7023–7043. https://doi.org/10.1175/JCLI-D-12-00696.1.

Taylor, P.C.; Maslowski, W.; Perlwitz, J.; Wuebbles, D.J. 2017. Arctic changes and their effects on Alaska and the rest of the United States. In: Wuebbles, D.J.; Fahey, D.W.; Hibbard, K.A.; Dokken, D.J.; Stewart, B.C.; Maycock, T.K., eds. Climate science special report: fourth national climate assessment. Vol. I. Washington, DC: U.S. Global Change Research Program: 303–332. Chapter 11. https://doi.org/10.7930/J00863GK.

U.S. Department of Agriculture, Farmers.gov. **[USDA Farmers.gov]. [N.d. a].** Get started at your USDA service center. https://www.farmers.gov/connect/USDA-Service-Centers. (8 March 2021).

U.S. Department of Agriculture, Farmers.gov [USDA Farmers.gov]. [N.d. b]. Beginning farmer and rancher coordinators: Alaska coordinator. https://www.farmers.gov/manage/newfarmers/coordinators. (8 March 2021).

U.S. Department of Agriculture, Farm Service Agency. [USDA FSA]. [N.d.]. Welcome to the Alaska Farm Service Agency website. Palmer, AK: Alaska State Office. https://www.fsa.usda.gov/state-offices/Alaska/index. (8 March 2021).

U.S. Department of Agriculture, National Agriculture Statistics Service [USDA NASS]. 2017. Census of agriculture, Vol. 1, Geographic area series. Part 2, Alaska, state and area data. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_State_Level/Alaska/akv1.pdf. (29 July 2021).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. [N.d. a]. Get started with NRCS. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/newsroom/features/?cid=stelprdb1193811. (8 March 2021).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. N.d. b. Spodosols map. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/maps/?cid=nrcs142p2_053608. (21 October 2021).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. N.d. c. The twelve orders of soil taxonomy. https://www. nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_053588. (23 June 2022).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019a. Soil Survey geographic (SSURGO) database for Matanuska-Susitna Valley area, Alaska (AK600). [Database]. Spatial data, version 5, updated 5 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019b. Soil Survey Geographic (SSURGO) database for western Kenai Peninsula area, Alaska (AK652). [Database]. Spatial data, version 4, updated 5 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019c. Soil Survey Geographic (SSURGO) database for Copper River area, Alaska (AK612). [Database]. Spatial data, version 4, updated 22 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019d. Soil survey geographic (SSURGO) database for Greater Delta area, Alaska (AK657). [Database]. Spatial data, Version 4, updated 5 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019e. Soil survey geographic (SSURGO) database for Greater Nenana Valley area, Alaska (AK655). [Database]. Spatial data, Version 4, updated 5 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019f. Soil survey geographic (SSURGO) database for Gerstle River area, Alaska (AK615). [Database]. Spatial data, Version 5, updated 22 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. (4 November 2019)

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019g. Soil Survey Geographic (SSURGO) database for Greater Fairbanks area, Alaska (AK610). [Database]. Spatial data, version 5, updated 5 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, New Farmers [USDA NF]. [N.d.]. Getting started. https://newfarmers.usda.gov/new-farmers. (8 March 2021).

University of Alaska Fairbanks, Agricultural and Forestry Experiment Station [UAF AFES]. [N.d. a]. Publication search: vegetable variety trials 2019. http://afesresearch.uaf.edu/publications/?cat=*&pt=*&s=VegetableVarietyTrials2019.

University of Alaska Fairbanks, Cooperative Extension Service [UAF CES]. [N.d.]. https://www.uaf.edu/ces/. (8 March 2021).

University of Alaska Fairbanks, Cooperative Extension Service [UAF CES]. 2018. Alaska IPM: Integrated Pest Management Program. Welcome to our citizen's monitoring portal! http://pestreporter.alaska.edu/. (8 March 2021).

University of Alaska Fairbanks, Cooperative Extension Service [UAF CES]. 2021. Alaska IPM: Integrated Pest Management Program. IPM Alaska Pest Reporter Home: Welcome to our Citizens Monitoring Portal! https://plw.man.mybluehost.me/. (22 June 2022).

University of Alaska Fairbanks: Scenarios Network for Alaska + Arctic Planning [UAF SNAP]. [N.d.]. Report of peony farming in a changing climate: a case study. https://uaf-snap.org/wp-content/uploads/2020/06/Peony-report.pdf.

Van Hemert, C.; Pearce, J.M.; Handel, C.M. 2014. Wildlife health in a rapidly changing north: focus on avian disease. Frontiers in Ecology and the Environment. 12(10): 548–556. https://doi.org/10.1890/130291.

Wendler, G.; Shulski, M. 2009. A century of climate change for Fairbanks, Alaska. Arctic. 62(3): 295–300. https://doi.org/10.14430/arctic149

Chapter 2: Adaptation in Agriculture

Paris Edwards and Holly R. Prendeville[1]

Agriculture in Alaska stands to benefit from changes in climate in several key ways. Although challenges are expected (see chapter 1), opportunities associated with a longer growing season, increases in suitable crop varieties and livestock, and other benefits are anticipated. The relatively fast pace of change across Alaska adds a unique dimension to the importance of strategic planning and general awareness of risks and opportunities. Farmers are constantly adapting to changes on the landscape and planning around climate and weather conditions. This flexibility has an advantage that allows for farmers to add new information into planning and decisionmaking that is relevant to their operations and locations.

This chapter includes adaptation resources for farmers to consider that are specific to Alaska (Box 2.1: Farming and Adaptation Resources) and provides context for the **adaptation strategies and approaches** presented in chapter 3. The adaptation workbook in chapter 4 describes a process for considering climate change effects on operations and developing intentional actions. Additional resources and tools may also be useful for assessing the future effects of climate change, or for adapting agriculture and natural resource management planning and activities to expected future conditions (Box 2.1: Farming and Adaptation Resources).

Farmers and ranchers can consider climate change in planning and operations to reduce risks to their operations, maintain flexibility in the face of climate variability and change, and take advantage of future conditions. Because changes in Alaska's climate are expected to contribute to more extreme weather events than previously experienced, producers need to consider potential direct consequences, as well as changes to long-term climate. To begin, farmers and ranchers can review climate information (chapter 1) to think about how future changes in climate will affect their operations. Producers can then prioritize actions to reduce risks, especially to highly vulnerable aspects of their individual operations, and consider adaptation actions that have multiple benefits (table 2.1), have little to no risk to current operations, and help sequester carbon or reduce greenhouse emissions. Finally, farmers and ranchers can continue to maintain flexible decisionmaking processes that incorporate new information and experiences over time that are related to climate variability and change.

Farmers and ranchers can consider climate change in planning and operations to reduce risks to their operations, maintain flexibility in the face of climate variability and change, and take advantage of future conditions.

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Box 2.1

Farming and Adaptation Resources

Climate change adaptation resources—

Alaska Garden Helper (UAF SNAP, n.d. a) lets users explore local growing conditions now and with future climate change by looking at growing degree days, annual minimum temperatures, and length of the growing season, as well as plant hardiness zone maps.

Adaptation Actions for a Changing Arctic (AMAP 2017) provides perspectives from the Bering Chukchi-Beaufort region on challenges facing communities, including reindeer herders and sled-dog breeders, in Alaska's arctic regions.

Peony Farming in a Changing Climate: A Case Study (UAF SNAP, n.d. b) provides information about peony-specific vulnerabilities to climate change, such as temperature sensitivity, and offers adaptation tips to new and existing growers.

Sustainable Livestock Production in Alaska: Workshop White Paper (Rowell et al. 2013) summarizes current strengths and areas of improvement for livestock management, including availability of affordable land and local feed quality and quantity, which are issues affected by a changing climate.

Government of Canada Climate Scenarios for Agriculture (Government of Canada 2021) covers the potential effects of climate change on Canadian agriculture and strategies for decreasing agricultural emissions, which may be transferable to high-latitude operations.

Climate Atlas of Canada: Agriculture and Climate Change (Prairie Climate Centre 2021) addresses farming in a hotter climate, adaptations such as over planting to cover losses, plant breeding, and mitigation through strategies such as emissions reductions.

Farming resources—

USDA Small and Mid-sized Farmer Resources (USDA n.d.) provides information on funding opportunities and educational resources to support these operations.

University of Alaska Fairbanks, Agricultural and Forestry Experimental Station (UAF AFES, n.d.) provides information on recommended crops for interior Alaska. Vegetable trials provide planting and growing information for new varieties.

University of Alaska Fairbanks Cooperative Extension Service (UAF CES, n.d. a) has a collection of videos on farming equipment, integrated pest management, and enhanced food preservation and security.

Growing All Seasons: NRCS Assistance with High Tunnels (USDA NRCS, n.d.) explains the benefits of high tunnels, including climate control, pest control, and a longer growing season.

Agroforestry: Enhancing Resiliency in U.S. Agricultural Landscapes Under Changing Conditions (Appendix A) (Schoeneberger et al. 2017) summarizes the scale and type of current agroforestry practices in Alaska and highlights areas of economic opportunity.

USDA National Agroforestry Center (USDA NAC, n.d.) has several, detailed resources about how to integrate forestry and agriculture to increase operation resilience, including windbreaks, silvopasture, forest farming, riparian buffering, and more.

Alaska FarmLink (Alaska Farmland Trust, n.d. a) helps to connect producers who want to farm new land with those who have land to sell or lease.

Farm Business Resources (Alaska Farmland Trust, n.d. b) includes land tenure resources, lease information, and more.

Gardens in the Arctic [n.d.] is a local effort in Anaktuvuk Pass to expand produce production at the community level, including enhancing food security for Elders.

Growing Food with Hydroponics Could Provide Lifeline in Arctic (D'Oro 2016) is an article in *Popular Mechanics* that explores how Alaskans in Kotzebue are enjoying pesticide-free, hydroponically grown produce year-round by using shipping containers and energy-conservative, light-emitting diode (LED) lights.

Tyonek Tribal Conservation District's (2021) Tyonek Grown is an effort to improve food security through sustainable community agriculture production.

Alaska Kelp Farming: A New Sustainable Seafood Opportunity (NOAA 2019) is a video on bull kelp farming in Ketchikan, where it is grown as a sustainable source of food and income.

Wine in Alaska (ThomTours 2021) discusses where and how a variety of wines are produced in Alaska.

Peonies as Field Grown Cut Flowers in Alaska (Halloway 2019) reviews the history of horticulture in Alaska and ongoing research, and highlights challenges and advantages of peony cultivation in different areas.

Sustainable Southeast Partnership (2021) is an organization dedicated to sustainability that addresses food security in southeast Alaska by connecting producers and consumers.

Kenai AgHort (UAF CES 2020) has informational videos on composting, soil testing, organic and conventional fertilizing techniques, and more.

Agricultural Marketing Service: Local and Regional Food Sector (USDA AMS, n.d.) provides multiple resources that help farmers meet increasing demand for local food sources.

Hear from farmers and ranchers in Alaska—Alaska Grown: A New Look at Mat-Su Agriculture (Byrd 2020) highlights the weather-dependent nature of farming and interviews several producers about crops and techniques.

Where does hydroponics fit into Alaska's food system? (McCoy 2020) includes perspectives from three year-round farmers and information about hydroponic farming that is improving year-round food availability.

Indie Alaska (Alaska Public Media 2014) covers a variety of activities in Alaska, including muskox farming, high tunnels and greenhouse farming, farming frozen soils, and more:

- Growing peonies in the Alaska bush (Alaska Public Media 2019)
- Running the largest commercial farm in rural Alaska (Alaska Public Media 2020a)
- From mammoth to kale: a look at gardening in the Arctic (Alaska Public Media 2020b)
- I am a musk ox farmer (Alaska Public Media 2013)

**Note the above links may become outdated and no longer function. In such cases, search the resource by name to find an updated link if available.*

Table 2.1—Examples of actions to address different soil and land conditions that have multiple benefits, including sequestering or reducing greenhouse gas emissions

Baseline condition	Actions	Benefits
Degraded or marginal land	Convert to perennial vegetation, plant trees	Reduce soil erosion, increase biodiversity and water quality
Drained, cropped, organic (Histosol) soils	Restore to wetland	Increase biodiversity and water quality
Severe nutrient deficiency	Adjust nutrients and lime additions with increasing amounts of precipitation; grow nitrogen-fixing species	Increase food security and water quality
Extensive bare fallow fields	Grow cover crops to increase soil cover and reduce loss of soil organic matter, especially during extreme weather events	Decrease soil erosion and increase water quality; increase soil health and food security
Excess nitrogen fertilizer use	Reduce to economically optimal rates	Increase water quality
Intensive tillage	Reduce or halt tilling; implement residue retention	Reduce soil erosion; increase water quality and soil health

Adapted from Paustian et al. (2016).

Short- and Long-Term Time frames

Producers are already planning at various time scales, from day-to-day decisions to long-term investments. The timing of the spring thaw and the first fall freeze set crop and livestock calendars by determining the timing of planting, harvesting, livestock reproduction, and available forage. Forecasts regarding the length of the growing season and the potential for hotter and wetter seasons may affect selection of crop varieties, whether to grow more crops in high tunnels or outside, equipment needs, resources needed for cultivation, and other longer term decisionmaking. Part of adaptation planning is incorporating anticipated change into decisionmaking processes. Below is a list of frameworks useful to considering adaptation planning at different time scales (fig. 2.1).

Part of adaptation planning is incorporating anticipated change into decisionmaking processes.

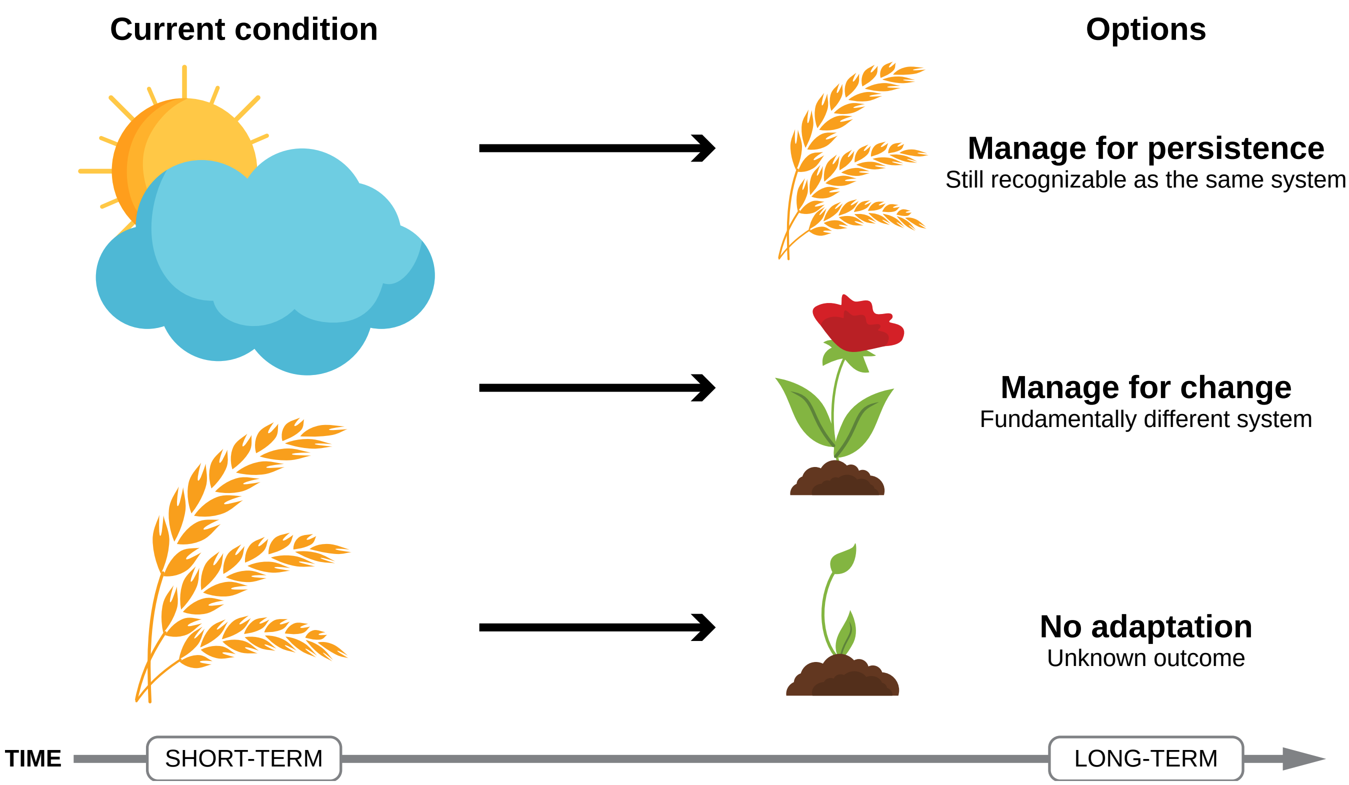

Figure 2.1—An illustration of adaptation options to manage for persistence, change, and no adaptation, over short- and long-term tim frames. Note that producers can switch options at any point, such as managing for persistence until conditions meet a threshold where change is preferable, required, or more feasible. Adapted from Janowiak et al. 2016.

Managing for Persistence and Change

Adaptation responses will differ widely, from actions that maintain existing conditions to transformational changes to the farm that include changing production systems or lands used to produce commodities. This continuum can be roughly categorized into two contrasting options for responding to climate change: managing for persistence versus managing for change (Stein et al. 2014).

1. **Managing for persistence** generally focuses on maintaining the current system by reducing the effects of climate change that are pushing it in an unproductive direction. This includes actions to increase the resistance of a farm or agricultural system to change as well as actions that increase its resilience (i.e., ability to bounce back) from disruptions.
2. **Managing for change** moves farm activities toward the new conditions created by climate change. Managing for change can range from small changes, such as trying new crop or livestock varieties that are better suited to warmer climates, to major changes that fundamentally transform farm operations, such as growing new commodities.

3. **Managing for persistence and for change** are not mutually exclusive ideas, and any farm enterprise may do some of both. Further, there are instances where a nearer term focus on managing to reduce negative effects and maintaining current conditions sets up a longer term plan to change management goals and practices. For example, a farmer could focus on maintaining the current rotation of field crops and use cover crops to build better soils before shifting to an entirely new cropping system. The **adaptation strategies and approaches** in the next chapter describe a diverse list of adaptation responses that producers can use to intentionally develop customized actions based on their needs and goals.

References

Alaska Farmland Trust. [N.d. a]. Alaska FarmLink. http://akfarmland.com/farmlink/. (9 March 2021).

Alaska Farmland Trust. [N.d. b]. Alaska farm business resources link. https://www.akfarmland.com/farm-business-resources/. (9 March 2021).

Alaska Public Media. 2013. I am a musk ox farmer [Video]. PBS Digital Studios. https://www.youtube.com/watch?app=desktop&v=KQbZGfj5l7A&list=PLCxq7fEuLsFCUHReeBNy8jFOk4LpbTlpn&index=7. (9 March 2021).

Alaska Public Media 2014. Welcome to indie Alaska. [Video]. PBS Digital Studios. https://www.youtube.com/watch?v=rJe4DHPDUUghttps://www.youtube.com/channel/UCHqlMF1EvvZNFDpS1UWdG7A?app=desktop. (27 October 2021).

Alaska Public Media. 2019. Growing peonies in the Alaska bush. [Video]. PBS Digital Studios. https://www.youtube.com/watch?app=desktop&v=ZjL7fpzMJLc. (27 October 2021).

Alaska Public Media. 2020a. Running the largest commercial farm in rural Alaska. [Video]. PBS Digital Studios. https://www.youtube.com/watch?app=desktop&v=lKrfpE152_g. (9 March 2021).

Alaska Public Media. 2020b. Gardening in the Arctic—how food's gone from mammoth to kale. [Video]. PBS Digital Studios. https://www.youtube.com/watch?app=desktop&v=hIE2eNDmV5s&list=PLCxq7fEuLsFA3CQMnWg5jQJiREWyZn13o&index=15. (9 March 2021).

Arctic Monitoring and Assessment Programme [AMAP]. 2017. Adaptation actions for a changing Arctic: perspectives from the Bering-Chukchi-Beaufort region. https://www.amap.no/documents/download/2993/inline. (9 March 2021).

Byrd, A. 2020. Alaska grown, a new look at Mat-Su agriculture. [Video]. Fairbanks, AK: University of Alaska Fairbanks, Alaska Center for Energy and Power. https://www.youtube.com/watch?v=2fynjF0GEeI. (31 March 2022).

D'Oro, R. 2016. Growing food with hydroponics could provide lifeline in Arctic. Popular Mechanics. November 6. https://www.popularmechanics.com/technology/a23723/hydroponics-arctic/. (9 March 2021).

Gardens in the Arctic: Anaktuvuk Pass, Alaska [Gardens in the Arctic]. [N.d.]. https://gardensinthearctic.com/. (9 March 2021).

Government of Canada, Agriculture and Agri-Food Canada. 2021. Climate scenarios for agriculture. https://www.agr.gc.ca/eng/agriculture-and-the-environment/agricultural-practices/climate-change-and-agriculture/climate-scenarios-for-agriculture/?id=1329321981630. (9 March 2021).

Holloway, P. 2019. Peonies as field grown cut flowers in Alaska. Chronica Horticulturae. 59(3): 25–29. https://www.peonysociety.eu/wp-content/uploads/2020/02/PeoniesInAlaska-ChronicaHorticulturae2019.pdf. (9 March 2021).

Janowiak, M.; Dostie, D.; Wilson, M.; Kucera, M.; Skinner, R.H.; Hatfield, J.; Hollinger, D.; Swanston, C. 2016. Adaptation resources for agriculture: responding to climate variability and change in the Midwest and Northeast. Tech. Bull. 1944. Washington, DC: U.S. Department of Agriculture. 70 p. https://www.climatehubs.usda.gov/sites/default/files/adaptation_resources_workbook_ne_mw.pdf.

McCoy, K. 2020. Where does hydroponics fit into Alaska's food system? Hear perspectives from three year-round farmers. Alaska Public Media. May 30. https://www.alaskapublic.org/2020/05/30/where-does-hydroponics-fit-into-alaskas-food-system-hear-perspectives-from-three-year-round-farmers/. (9 March 2021).

National Oceanic and Atmospheric Administration [NOAA]. 2019. Alaska kelp farming: a new sustainable seafood opportunity. [Video]. https://www.fisheries.noaa.gov/video/alaska-kelp-farming-new-sustainable-seafood-opportunity. (9 March 2021).

Paustian, K.; Lehmann, J.; Ogle, S.; Reay, D.; Robertson, G.P.; Smith, P. 2016. Climate-smart soils. Nature. 532(7597): 49–57. https://doi.org/10.1038/nature17174.

Prairie Climate Centre. 2021. Climate atlas of Canada: agriculture and climate change. https://climateatlas.ca/agriculture-and-climate-change. (9 March 2021).

Rowell, J.E.; Shipka, M.P.; Greenberg, J.A.; Gerlach, S.C.; Paragi, T. 2013. Sustainable livestock production in Alaska: workshop white paper. Fairbanks, AK: University of Alaska Fairbanks, Agricultural and Forestry Experiment Station, School of Agriculture and Land Resources Management. http://hdl.handle.net/11122/2758. https://scholarworks.alaska.edu/bitstream/handle/11122/2758/MP_13_04.pdf?sequence=1&isAllowed=y. (9 March 2021).

Schoeneberger, M.M.; Bentrup, G.; Patel-Weynand, T. 2017. Agroforestry: Enhancing resiliency in U.S. agricultural landscapes under changing conditions (Appendix A Regional Summaries). Gen. Tech. Rep. WO-96. Washington DC: U.S. Department of Agriculture, Forest Service. 228 p. https://doi.org/10.2737/WO-GTR-96. (9 March 2021).

Stein, B.A.; Glick, P.; Edelson, N.; Staudt, A., eds. 2014. Climate-smart conservation: putting adaption principles into practice. Washington, DC: National Wildlife Federation. 272 p.

Sustainable Southeast Partnership. 2021. Food sovereignty. http://sustainablesoutheast.net/focus_areas/food-sovereignty/. (March 2021).

ThomTours, LLC. 2021. Alaska wine. Exploring worlds old and new. https://exploringworldsoldandnew.com/united-states/alaska/taste-alaska/alaska-wine/. (9 March 2021).

Tyonek Tribal Conservation District. 2021. Tyonek grown. https://ttcd.org/programs/tyonek-grown-program/. (9 March 2021).

U.S. Department of Agriculture, Agricultural Marketing Service [USDA AMS]. [N.d.]. Local and regional food sector. https://www.ams.usda.gov/services/local-regional/food-sector. (9 March 2021).

U.S. Department of Agriculture, National Agroforestry Center [USDA NAC]. [N.d.]. Silvopasture. https://www.fs.usda.gov/nac/practices/silvopasture.php. (9 March 2021).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. [N.d.]. Growing all seasons: NRCS assistance with high tunnels. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/organic/?cid=nrcseprd1364702. (27 October 2021).

University of Alaska Fairbanks: Scenarios Network for Alaska + Arctic Planning [UAF SNAP]. [N.d. a]. Alaska garden helper. https://www.snap.uaf.edu/tools/gardenhelper. (9 March 2021).

University of Alaska Fairbanks, Scenarios Network for Alaska + Arctic Planning [UAF SNAP]. [N.d. b]. Report of peony farming in a changing climate: a case study. https://uaf-snap.org/wp-content/uploads/2020/06/Peony-report.pdf. (9 March 2021).

University of Alaska Fairbanks, Agricultural and Forestry Experiment Station. [N.d.]. Search the agricultural & forestry experiment station research database search tool. http://afesresearch.uaf.edu/. (9 March 2021).

University of Alaska Fairbanks, Cooperative Extension Service [UAF CES]. [N.d. a]. UAF Extension YouTube video channel. https://www.youtube.com/user/UAFExtension?app=desktop. (27 October 2021).

University of Alaska Fairbanks, Cooperative Extension Service [UAF CES] [N.d. b]. Gardening and agriculture. https://www.youtube.com/playlist?list=PLaq6r5nsLDdfW_NH3u2FckEymjD23U4Hy. (9 March 2021).

University of Alaska Fairbanks, Cooperative Extension Service [UAF CES]. 2020. Kenai AgHort. [Video]. https://www.youtube.com/channel/UClNbMHOxlXVuqz8u_SCT9Sw?app=desktop. (9 March 2021).

Chapter 3: Adaptation Strategies and Approaches

Paris Edwards and Holly R. Prendeville[1]

In this chapter, adaptation strategies and approaches are presented as a list of possible responses that producers may consider for their operation. These strategies and approaches are designed to help farmers and ranchers think about different options and take appropriate actions to adapt to climate variability and change (see Box 3.1: Using the Adaptation Strategies and Approaches Menu). In the Adaptation Workbook (chapter 4), producers can select relevant adaptation strategies and approaches, make adjustments to develop relevant tactics, and reach a specific management objective for their location. Chapter 5 has examples from two producers from south-central Alaska.

Importantly, the adaptation strategies and approaches included in this resource build upon current terrestrial farm practices and conservation actions that work to sustain and conserve working lands over the long term. Many conservation activities already promote system health and resilience. A changing climate may cause producers to enhance existing sustainable practices or adopt new ones. Alaskans have often looked to other cold-climate regions to learn and may find it helpful to explore adaptation efforts in Canada, Scandinavian countries, and elsewhere. See additional resources in Box 2.1: Farming and Adaptation Resources.

The adaptation strategies and approaches included in this resource build upon current terrestrial farm practices and conservation actions that work to sustain and conserve working lands over the long term.

Adaptation strategies in this chapter focus on terrestrial, on-farm practices. Producers are encouraged to also consider adaptation strategies for beyond the farm, specifically what changes may be needed for processing, storage, transportation, and marketing to reduce impacts of climate change on food production and distribution. For instance, producers can take steps to reduce the potential for negative effects from extreme weather events that may affect product transportation, and consider ways to improve the availability and efficiency of local and regional processing, storage, and distribution to farmers' markets and online marketplaces. For ideas on how to support more local food production read this resource, *Local Foods, Local Places: A Community-Driven Action Plan From Palmer, Alaska* (USDA AMS 2016). Also, the U.S. Department of Agriculture has many programs to support farm and business opportunities (USDA AMS, n.d.). Information on where to find these and other resources is in Box 2.1.

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Box 3.1

Using the Adaptation Strategies and Approaches Menu

The adaptation strategies and approaches menu offers the following:

- A range of possible adaptation responses that can help sustain and maintain healthy agricultural systems, or transform unviable ones to meet the challenges of climate change
- A menu of adaptation strategies and approaches from which producers can better understand the rationale for making decisions and develop tactical actions best suited to meeting their goals and needs
- Examples of tactics to implement an approach, recognizing that the producer will design specific actions
- A platform for discussing climate change-related topics and adaptation methods

The adaptation strategies and approaches do not make recommendations or set guidelines for management decisions or actions; it is up to the producer to decide how this information is used in their operation. Also, this workbook does not express preference for any strategies or approaches within a particular agricultural system, location, or situation. Rather, a combination of location-specific factors and professional/landowner expertise informs the selection of any strategy or approach. Also, this workbook does not list all possible adaptation strategies that a producer may consider or implement.

Finally, adaptation strategies and tactics specific to aquaculture and seafood producers, shellfish growers, and fisheries are not included in this chapter, though general themes presented in this chapter may be helpful in thinking of strategies for aquatic and marine producers. Sea Grant Alaska (NOAA SGA 2021) provides information specific to climate change and adaptation strategies for aquaculture, fisheries, and seafood producers.

Menu of Adaptation Responses

This set of adaptation strategies and approaches serves as a list of potential adaptation responses (Box 3.2: Adaptation Strategies and Approaches) to help producers identify their adaptation intentions. It also helps to support producers in developing and implementing their own specific adaptation actions that are most suitable to their individual situation. Adaptation responses can be applied in various combinations to achieve desired outcomes. However, actions that work well in one location or with a particular crop, livestock type, or system may not work with another crop, livestock type, or system; it is up to the producer to decide what actions will work best.

Box 3.2

Adaptation Strategies and Approaches

Strategy 1: Sustain Fundamental Functions of Soil and Water—
- Approach 1.1: maintain and improve soil health
- Approach 1.2: protect water quality
- Approach 1.3: match practices to water supply and demand

Strategy 2: Reduce Existing Stressors of Crops and Livestock—
- Approach 2.1: reduce the effects of pests and pathogens on crops
- Approach 2.2: reduce competition from weedy and invasive species
- Approach 2.3: maintain livestock health and performance

Strategy 3: Reduce Risks From Warmer Conditions—
- Approach 3.1: adjust the timing or location of on-farm activities
- Approach 3.2: manage crops to cope with warmer conditions
- Approach 3.3: manage livestock to cope with warmer conditions

Strategy 4: Prepare for and Mitigate Consequences From Extreme Weather—
- Approach 4.1: reduce peakflow, runoff velocity, and soil erosion
- Approach 4.2: reduce severity or extent of water-saturated soil and flood damage
- Approach 4.3: reduce severity or extent of wind damage to soils and crops

Strategy 5: Manage Farms and Fields as Part of a Larger Landscape—
- Approach 5.1: maintain or restore natural ecosystems
- Approach 5.2: promote biological diversity across the landscape
- Approach 5.3: enhance landscape and waterway connectivity

Strategy 6: Alter Management to Accommodate Expected Future Conditions—
- Approach 6.1: diversify crop or livestock varieties, breeds, or products
- Approach 6.2: diversify existing systems with new crop combinations
- Approach 6.3: switch to commodities expected to be better suited to future conditions

Strategy 7: Alter Agricultural Systems or Lands to New Climate Conditions—
- Approach 7.1: minimize potential negative consequences following disturbance
- Approach 7.2: realign severely altered systems toward future conditions
- Approach 7.3: alter lands in agricultural production

Strategy 8: Alter Infrastructure to Match New and Expected Conditions—
- Approach 8.1: expand or improve water systems to match water demand and supply
- Approach 8.2: use structures to increase environmental control for plant crops
- Approach 8.3: improve or develop structures to reduce animal heat stress
- Approach 8.4: match infrastructure and equipment to new and expected conditions

Strategy 1: Sustain Fundamental Functions of Soil and Water

A warming climate will warm soils across Alaska, with a range of effects that depend on soil type and location. Climate has the potential to both improve and disrupt critical functions of soil and water, and many management actions will be needed to work directly and indirectly to improve and maintain the health of agricultural systems in the face of climate change. Many existing soil health guidelines and conservation practices describe actions to reduce negative effects on soil and water; many of these actions are also likely to be beneficial in the context of adaptation, either in their current form or with modifications to address potential climate change effects.

Approach 1.1: maintain and improve soil health—
Healthy soils are soils higher in organic matter, stable (resistant to erosion) and balanced in mineral content, with adequate infiltration of water and air passage, and with a diversity of bacteria and microorganisms present. Ultimately, healthy soils can function as vital, living ecosystems that sustain production over the long term and in the face of rapid and uncertain change. Soil, like plants, animals, and humans, is necessary to ensure the productivity and profitability of diverse agricultural enterprises (Palm et al. 2014). Healthy soils sustain biological activity and diversity, affect water quality and quantity, provide nutrients to plants, and sequester carbon. The ability of soils to provide these functions and services depends on the physical, chemical, and biological characteristics or properties of the soil, some of which are easily altered, while others are more resistant to change. Climate change creates multiple benefits and threats on soil health, which in turn create opportunities and challenges for agricultural productivity.

Healthy soils can function as vital, living ecosystems that sustain production over the long term and in the face of rapid and uncertain change.

Practices that improve soil health help to buffer against extreme events, such as drought and flooding. For example, crop residues and soil organic matter can help protect against both dry and wet precipitation extremes; increased organic matter can improve water infiltration and reduce nutrient losses during extreme precipitation events as well as retain moisture in the soil during dry conditions (Anwar et al. 2013, FAO 2007). Producers such as Bushes Bunches Produce Stand and Ridgeway Farms[2] in south-central Alaska are using and expanding cover crops in vegetable production as well as covering fallowed fields with nutrient-rich mixes of Austrian winter pea and oats that benefit potato fields. Also, both operations are using composted manure and on-farm vegetable waste to develop soil organic matter, which improves aggregate stability and water infiltration and reduces runoff potential (fig. 3.1) (see chapter 5 for case studies).

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[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

USDA Natural Resources Conservation Service

Figure 3.1—Hands holding compost. Using on-farm compost reduces disposal costs and enhances fertility, microbial activity, and structure when added to soil.

Altering the land use, production system, or infrastructure may also maintain and improve changes in soil, such as permafrost change or loss of existing soil properties. See below for the approaches for “Strategy 7: Alter Agriculture Systems or Lands to New Climate Conditions” and “Strategy 8: Alter Infrastructure to Match New and Expected Conditions” for examples of these types of adaptation tactics.

Soil Health Management in the Face of Climate Change

There is a suite of soil health management practices from the USDA Natural Resources Conservation Service (NRCS) that land managers can adopt to reduce their risks and build greater resilience in the face of more extreme and variable weather (Box 3.3: Soil Management Resources). Four principles targeting improved soil health also help increase soil resilience (fig. 3.2). Managing for soil health can address multiple issues facing producers, including challenges like temperature change, water loss, and extreme wind and rain events (see Strategy 4: Reduce the Risk and Long-Term Impacts of Extreme Weather). Comprehensive planning that considers short- and long-term goals needs to be developed to gauge the range of challenges and opportunities specific to a particular cropping system and location. When making modifications, maintaining flexibility and reassessing plans to address unexpected outcomes and realign goals is optimal.

Box 3.3

Soil Management Resources

NRCS Soil Resources and Publications (USDA NRCS, n.d. a) provides a comprehensive list of information on soil management, soil quality indicators, crop rotation, cover cropping, and more.

Soil Management and Composting in Alaska (UAF CES, n.d. b) includes on-farm soil management and composting tips to enhance soil quality and resilience.

Kenai Farm Central (KSWCD 2017) has information for Kenai Peninsula farmers and market gardeners that includes guidance on soil preparation and testing, high tunnel selection and construction, and more.

Soil Preparation: Soil Testing, Soil Building, Soil Quality (High Tunnel Alaska 2021) provides helpful information for Alaska farmers on how to take soil samples, where to send them for testing, where to get soil amendments, and more.

Community Permafrost Data from Scenarios Network for Alaska + Arctic Planning (UAF SNAP, n.d.) provides online, community-scale data on permafrost loss risk.

Alaska Farmers on a Quest for Healthy Soils (USDA NRCS 2020) is a story map that details soil health practices underway in Alaska to address farmer interest in more information on how to make improvements.

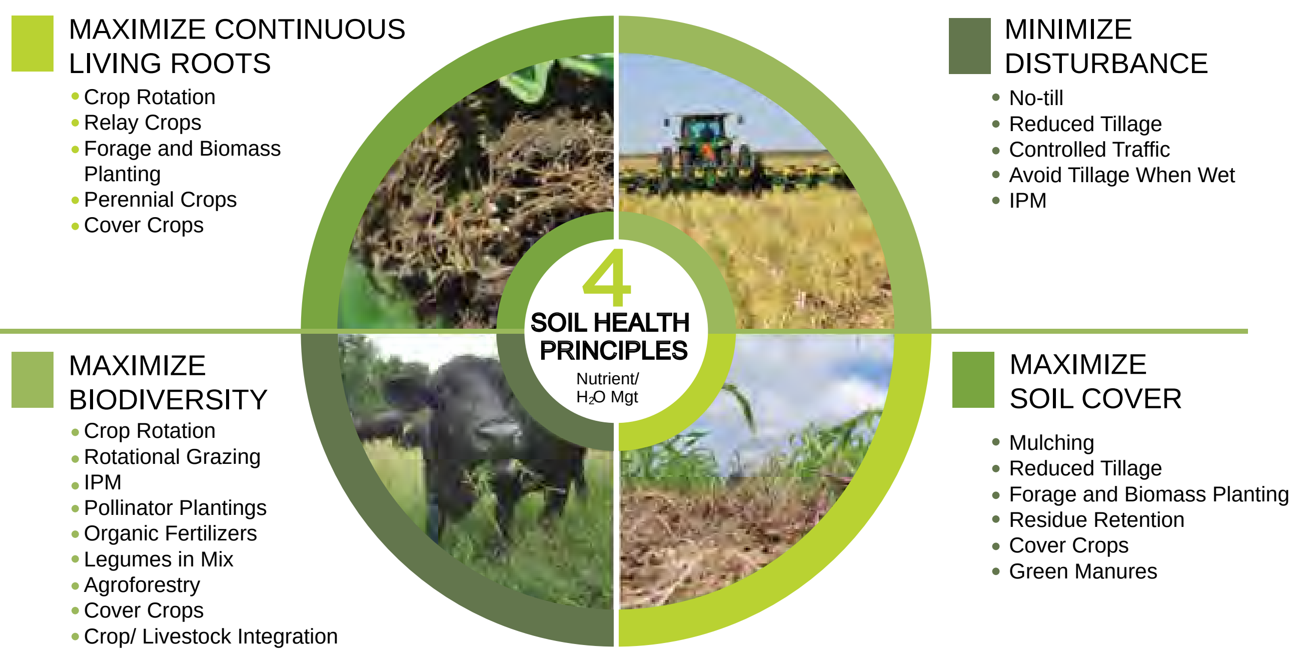

Figure 3.2—The four key principals of soil health can help improve soil quality and build resilience to a range of potential current issues and future climate change effects as noted in *Applying Soil Health Management Systems to Reduce Climate and Weather Risks in the Northwest* (Roesch-McNally et al. 2019).

Key Management Considerations for Increasing Soil Health

Key management considerations for increasing soil health include increasing biodiversity, minimizing soil disturbance, and maximizing soil cover. The information below provides farmers with several common approaches to achieve soil health improvements and improve on-farm resilience (see also "Example adaptation tactics 3.1.1").

Increase biodiversity and the presence of living roots in soils by using crop rotations, cover crops, agroforestry, amendment applications (e.g., compost and manure), and crop or livestock integration. These options can benefit the soil in the following ways:

- Increasing the amount of organic inputs, building soil organic matter, and increasing carbon storage in soil.
- Selecting cover crops that suppress weeds and limit wind erosion, thereby reducing labor, energy, materials, and fuel costs.
- Selecting cover crops that capture and recycle nutrients, improve internal nutrient cycling, and reduce need for inputs.
- Enhancing diversity of microbial and faunal communities. Soils with diverse communities of helpful microbes are better able to resist disease, environmental stressors, and pest pressure. Soil microbes, living and dead, support decomposition and help draw mineral nutrients into soils.
- Improving the formation of stable soil aggregates that are critical to resist erosive forces of wind and water, aid in infiltration, and increase water storage capacity.

Increase biodiversity and the presence of living roots in soils by using crop rotations, cover crops, agroforestry, amendment applications (e.g., compost and manure), and crop or livestock integration.

Minimize disturbance and maximize soil cover by reducing tillage and using cover crops and agroforestry techniques. These practices will achieve the following:

- Protect soil organic matter and soil aggregates important for water infiltration, aeration, and microbial habitat.
- Insulate soil to protect against temperature changes, which helps reduce plant and microbial stress.
- Reduce evaporative losses by keeping more water in the soil. Water helps absorb heat from solar radiation, and because water takes more solar radiation to heat up in comparison to soils, water can help soils stay cool when temperatures are high.
- Absorb solar radiation and sequester carbon dioxide. Dead and decaying residue from living cover reduces the amount of heat from the sun absorbed by plants and reduces wind and water erosion.

Example adaptation tactics 3.1.1

Tactics for all farming activities that cause soil disturbance, such as annual field, forage, vegetable, and small fruit production and when establishing pastures, orchards, vineyards, or perennial cropping systems:

- Minimize soil disturbance by avoiding or reducing tillage for planting, weed control, or other purposes.
- Provide nearly year-round ground cover of residue or plants to reduce soil exposure to erosive forces of water and wind.
- Increase soil organic matter to improve soil water-holding capacity, soil structure, and water infiltration, and to reduce erosion (use cover crops and mixes, crop or livestock residues, compost, mulch, biochar, or other organic amendments).
- Diversify crop rotations to include plant species that can be used to improve belowground conditions for soil life, and address threats from disease, weeds, and insect pests.
- Shift planting dates to avoid field operations during wet conditions.
- Control vehicle traffic to minimize soil compaction by equipment.
- Designate high-traffic areas and protect soil with gravel to limit rutting and wind erosion.
- Integrate grazing on field or cover crops to further improve soil biology.
- Consider windbreaks where soil erosion by wind is a concern.
- Consider land leveling or subsurface drainage under the list of approaches for strategy 8. Alter infrastructure if altering inherent soil properties, such as soil surface topography and drainage, is feasible.

Approach 1.2: protect water quality—
Clean water is vital to most living things. Because agricultural practices can potentially affect aquifers and water sources both on-farm as well as downstream from the farm, it is important that practices protect water quality through the entire cycle (see “Example adaptation tactics 3.1.2”). Anticipated alterations of the water cycle due to climate change will have wide-ranging effects on agricultural production, depending on the farm location, the type of agricultural system, and the type of change. This approach focuses on additional agricultural practices needed in the field beyond those listed in “Approach 1.1: maintain and improve soil health.” “Strategy 4: Reduce the Risk and Long-Term Impacts of Extreme Weather” suggests responses specifically for extreme precipitation events.

Example adaptation tactics 3.1.2

Tactics for all cropping activities at risk of causing water pollution, such as nutrient and pesticide applications in annual and perennial field and forage crops, vegetable, tree, berry, and vine fruit production:

- Reassess nutrient applications and ensure that use of organic materials, fertilizers, amendments, and all sources of nutrients are matched to changing climate conditions (e.g., increases in seasonal variability of storm intensity or frequency at your location, or forecasted wind or precipitation events).
- Reassess pesticide risk and ensure that all pesticide applications consider changing climate conditions (e.g., increases in seasonal variability of storm intensity or frequency at your location, or forecasted wind or precipitation events).
- Manage water to prevent ponding, running, erosion, and nutrient leaching where rainfall increases. Typical water management practices include diversions, terraces, waterways, and grade stabilization structures.

Tactics for confined animal agriculture, greenhouse, and nursery production:

- Limit livestock access to streams to maintain natural vegetation and reduce erosion.
- Divert clean water from areas at risk for contamination.
- Minimize the effects of agricultural waste on surface and groundwater resources.

Approach 1.3: match management practices to water supply and demand—Warmer temperatures increase water loss through evaporation and plant transpiration, requiring more water to maintain productivity under warmer conditions. Further, altered volume and timing of water availability due to changes in snowmelt timing and precipitation patterns have the potential to increase conflict among overlapping water uses (e.g., instream water rights that protect migrating or spawning fish and irrigation water rights for agriculture). On-farm water stewardship can extend the availability of water under changed climatic conditions (Ames and Dufour 2014). This approach builds upon the practices used in the field to improve the water infiltration function of the soil as listed in "Approach 1.1: maintain and improve soil health." This approach emphasizes practices and technologies for on-farm water management to improve the efficiency of water use in order to sustain water supplies over the long term (see "Example adaptation tactics 3.1.3"). More substantial changes may require investments in new infrastructure, which are described in "Strategy 8: Alter Infrastructure to Accommodate New and Expected Conditions."

Example adaptation tactics 3.1.3

Tactics for all cropping activities that use substantial water quantities, such as irrigated cropping systems:

Increase irrigation capacity, particularly for high-value crops, where soils have adequate infiltration rates and evaporation rates are minimized.
Improve irrigation efficiency for water conveyance and application with the latest technology, such as micro or drip irrigation.
Enable increased crop planting density through irrigation and improved soil fertility management.
Use technologies to harvest water, conserve soil moisture (e.g., crop residue retention), and use and transport water more effectively where rainfall decreases.
Use new technology for subsurface irrigation and irrigate with gray or reclaimed water to reduce water use.

Strategy 2: Reduce Existing Stressors of Crops and Livestock

Climate change is likely to increase stress on agricultural systems through a variety of direct and indirect effects (Gowda et al. 2018, Walthall et al. 2012). Systems may already be performing poorly because of stressors, such as insect pests, pathogens, or competing species, which can make agricultural commodities more susceptible to climate change effects. Reducing stressors on agricultural commodities that are presently unaffected or indirectly affected by climatic stressors will often increase the ability of the system to cope with future changes in climate.

Approach 2.1: reduce the impacts of insect pests and pathogens on crops—Even modest changes in climate may cause substantial increases in the distribution and number of many insect pests and pathogens, potentially resulting in reduced productivity or increased plant stress and mortality. Alaska is already seeing new and native pests in greater numbers. Climate change effects may exacerbate other stressors and interact with site conditions to increase crop vulnerability (see Box 3.4: Resources for Monitoring and Reducing Pests, Weeds, and Invasive Species). This approach emphasizes actions to be taken onsite, whereas “Strategy 5: Manage Farms and Fields as Part of a Larger Landscape,” suggests complementary tactics needed across the landscape (see “Example adaptation tactics 3.2.1” below).

Even modest changes in climate may cause substantial increases in the distribution and number of many insect pests and pathogens, potentially resulting in reduced productivity or increased plant stress and mortality.

Box 3.4:

Resources for Monitoring and Reducing Pests, Weeds, and Invasive Species

University of Alaska Fairbanks, Cooperative Extension Service's Integrated Pest Management Program (UAF CES, n.d. c) provides information on an alternative approach to chemical-based pest management with minimal effect on water, soil, and human health.

Alaska Integrated Pest Management Citizen Monitoring Portal (Alaska IPM 2018) is a citizen-science effort to help farmers manage and adapt to changes in pests and invasive species through detection and location tracking.

Alaska Department of Fish and Game's Invasive Species Reporter (ADFG, n.d. a) is an online platform that connects users to various reporting resources for sharing information about a variety of invasive species, including plants, fish, and mammals.

Alaska Division of Agriculture's Invasive Plants and Agricultural Pest Management Program (ADNR, n.d.) has environmental assessments, pesticide use permitting information, and management plans on pest management efforts by region and location.

USDA Forest Service Alaska Region (USDA FS, n.d.) has an invasive plant pocket-guide and other publications from the Forest Health Program.

National Invasive Species Information Center (USDA NISIC, n.d.) provides information on invasive species to assist in limiting the negative consequences of invasive species.

Plant Protection and Quarantine (USDA CH, n.d. a) is responsible for safeguarding and promoting U.S. agricultural health and tasked with assessing risk and predicting where an invasive plant pest may be introduced, establish, and spread.

Example adaptation tactics 3.2.1

Tactics for all cropping and livestock activities at risk from adverse insect pest and pathogen impacts:

- Increase monitoring for pests and pathogens.
- Enhance use of integrated pest management (IPM).
- Improve rapid response plans and regional monitoring efforts to allow for targeted control of new pests before they become established.
- Use varieties, breeds, and species resistant to pests and diseases.
- Alter crop rotations.
- Limit livestock and wildlife interactions to reduce disease introduction and spread.
- Lengthen timing of cropping systems (greater diversity and longer rotations).

Approach 2.2: reduce competition from weedy and invasive species— Climate change is expected to increase potential habitat for many weedy and invasive plant species, which may increase competition for light, water, and nutrients (fig. 3.3). Although plant productivity may increase because of the positive effects of carbon dioxide fertilization and longer growing seasons, not all species will be able to take equal advantage of these positive effects (Rosenzweig et al. 2014, Ziska et al. 2012), and the competitive association between weeds and crops may change, with some weeds gaining an advantage (Ziska and Bunce 1997). Reducing competition for resources can enhance the persistence of desired species and increase the ability of systems to cope with effects of climate change (see “Example adaptation tactics 3.2.2”). Management of highly mobile invasive species may require increased scouting and coordination across property boundaries, and it will likely require an increasing budget for control efforts (see Box 3.4: Resources for Monitoring and Reducing Pests, Weeds, and Invasive Species).


Ron Adams

Figure 3.3—Orange hawkweed is an existing invasive species. Changing climate conditions may help the spread of new invasive species and expand the range of existing invasive species, which currently threaten Alaskan pastures and hayfields.

Example adaptation tactics 3.2.2

Tactics for all crop production activities (field, forage, small fruit and vegetables, orchards, etc.) at risk from increased competition from weeds and invasive species:

- Increase monitoring for weedy species.
- Increase use of integrated pest management (IPM) strategies (prevention, avoidance, monitoring, and suppression) to prevent economic crop damage from weeds, minimize resistance in weeds, and prevent or mitigate unnecessary risks to natural resources and humans.
- Eradicate harmful weeds.
- Control or eradicate other invasive plant species adversely affecting the desired plant community.

Approach 2.3: maintain livestock health and performance—
Climate change is expected to affect livestock production by increasing animal stress from diverse changes that include higher temperatures, changes in forage quality and quantity, and increases in pest and pathogen incidence (Walthall et al. 2012). This approach works to reduce the risks associated with livestock production systems by maintaining animal performance levels and reducing the negative effects of environmental changes that increase animal vulnerability (Box 3.5: Livestock Information). Information from tracking livestock performance and health, along with pasture condition, can be used to support adaptive management, allowing producers to respond to variable conditions and maintain flexible operations that can handle changing and extreme conditions (see "Example adaptation tactics 3.2.3") (Derner et al. 2018). For livestock species or breeds suited to cooler temperatures found in northern latitudes, producers may require new tactics to respond to heatwaves.

Box 3.5

Livestock Information

University of Alaska Fairbanks, Reindeer Research Program (UAF IANRE 2016) provides information on domesticated herd research, education opportunities, and disease relevant to changing climate conditions.

Alaska Department of Fish and Game's Muskox web page (ADFG, n.d. b) has information on domestication and care for muskox, which may be suitable for expanded production in drier, cooler northern climates for meat, fiber, horn, and pelt production.

University of Alaska Fairbanks, Cooperative Extension Service's Livestock publications (UAF CES, n.d.d) provides past publications on livestock production and care, such as ideal climate, heat, and cold sensitivity that producers can consider when selecting animal varieties or considering increased production.

Example adaptation tactics 3.2.3

Tactics for animal production activities vulnerable to normal environmental conditions and as applicable to the species:

Maintain adequate nutrition and access to adequate exercise, clean housing, water, and feed supplies.
Prevent infectious disease and control parasites.
Follow recommended veterinary practices and biosecurity procedures.
Seek out and implement traditional knowledge and practices for care of native species (e.g., seek out existing, publicly available information from Alaska Native, Tribal, and First Nations sources). Form mutually beneficial partnerships to address information gaps alongside interested indigenous experts.

Strategy 3: Reduce Risks and Maximize Opportunity From Warmer Conditions

Many key climate variables affecting agricultural productivity are directly tied to increases in temperature (Gowda et al. 2018). A longer growing season plus warmer daytime and nighttime temperatures are expected to have effects on agricultural crops and livestock. In many areas of Alaska, these effects are already being observed (Markon et al. 2018). Higher temperatures will result in different effects experienced by each farm operation because their farming histories, changes in operation, and local conditions differ.

Approach 3.1: adjust timing or location of on-farm activities—
As climate changes, producers may consider adjusting farm practices to take into account altered seasonality and changes to the timing of crop calendars (i.e., changes to timing of preparation, seed sowing, harvesting, available forage, pests, livestock reproduction, etc.) (see "Example adaptation tactics 3.3.1"). Producers have always made adjustments to cope with variable weather conditions by changing the timing or type of field operations, and many of these types of changes are already occurring as conditions change and without specific consideration of longer term climate trends (Smit and Skinner 2002). This approach emphasizes alterations in the timing and location of on-farm activities that consider long-term trends and projections in climate, as well as interannual variation of weather. A small-scale example is the use of poultry waste as an on-hand source of fertilizer for timely soil amendments (fig. 3.4). Another example is managed rotational grazing of muskoxen to graze pasture intensely for short periods, as that mimics the wild muskoxen behavior, prevents land degradation, and improves soil health (Starr et al. 2020).

Example adaptation tactics 3.3.1

Tactics for field and forage crops and vegetables as well as nursery, tree, berry and vine fruit production as applicable:

- Adjust timing of planting, such as using earlier planting dates to take advantage of a longer growing season.
- Use shade cloth or structures to protect crops from increased sun exposure and high heat.
- Adjust timing or sequencing of cropping operations, such as altering amount of timing of irrigation or fertilizer application.
- Match crops to local conditions, such as on slope, aspect, or microsite.
- Implement techniques to prevent frosting.
- Add additional plants to support pollinators when crops are not in bloom.
- Bring in honeybees, or support native pollinators with habitat and food resources, as changes in temperature may result in mismatched timing between plants and pollinators.
- Adjust synchronization of crop nitrogen needs and application for improved nitrogen use efficiency.

Tactics for animal agriculture:

- Adjust the timing of grazing and pasture use to forage availability for livestock.
- Use grazing strategies that mimic the short but intense grazing of wild, migratory ungulates (i.e., intensively managed rotational grazing).
- Alter the timing of animal reproduction to match suitable temperatures and feed availability.

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Figure 3.4—Beginning farmers in Willow, Alaska, tend poultry and as a result can use poultry waste to improve soil quality when needed.

Approach 3.2: manage crops to cope with warmer conditions—
Because Alaska will experience warmer temperatures and seasonal changes in precipitation, it is likely that snowpack will decrease in some areas, drought may occur, timing and volume of streamflow will shift, and soil moisture will change. To safeguard against these changes affecting farm operations, crop management changes are needed (see "Example adaptation tactics 3.3.2"). Valuable commodities, such as peonies and other perennials, are at higher risk of frost and freeze damage with less snowpack available to protect roots. Although there is variation among model projections, longer growing seasons and warmer temperatures are generally expected to result in greater evapotranspiration losses and lower soil-water availability later in the growing season (Markon et al. 2018). The effects of warmer temperatures on photosynthesis are one of the biggest determinants of crop yields, and temperatures only slightly above optimum can cause mild heat stress and begin to inhibit photosynthesis (Ainsworth and Ort 2010).

With warmer conditions, wildlife may seek food in agricultural fields as productivity of wild plants changes, so farmers may want to consider protecting crops from wildlife. This approach emphasizes the management of existing crops, whereas Strategy 6 ("Alter Management to Accommodate New and Expected Conditions") presents example actions to diversify crops or switch to new crops. The effectiveness of actions under this approach is highly interrelated and dependent on adequately functioning soil and water crop resources addressed by actions in Strategy 1 ("Sustain Fundamental Functions of Soil and Water").

Example adaptation tactics 3.3.2

Tactics to manage crops growing under warmer conditions:

Select longer growing-season, heat-resistant, or drought-resistant varieties of crops.
Adjust timing of planting to avoid heat stress during critical periods of plant development.
Consider covering perennials (e.g., peonies) with row-cover fabric, drop cloth, or plastic to protect from frost damage during warmer, low-snow years.
Alter plant population density to reduce crop demands for water or nutrients.
Increase the efficiency of water transportation or irrigation systems.
Increase soil cover (mulch, cover crop) to conserve soil moisture and reduce soil temperatures.
Use seasonal and short-term weather forecasts to inform the type and timing of soil management (e.g., disturbance or amendments).
Study soil types and permafrost areas to assess potential for damage and opportunity for future cultivation, particularly for new operations.
Build protection or implement monitoring of wildlife to prevent losses, and inform approaches to reduce crop damage.

Approach 3.3: manage livestock to cope with warmer conditions—As with crops, altered climate will affect livestock production through changes in feed grain production, pasture and forage crop production, animal productivity, and effects from diseases and pests. In particular, livestock respond to changes in temperature by altering their core body temperature, metabolic rates, or behavior, all of which can lead to increased stress and disrupt their growth, production, or reproduction. For instance, caribou reduce foraging and increase movement with high temperatures, which can lead to stress (Mörschel and Klein 1997). Thus, providing shade structures to reduce temperatures may protect livestock, especially during short heatwaves. Also, warmer temperatures may result in freezing rain on snow during winter, making it challenging for livestock to break through ice and access forage.

Providing shade structures to reduce temperatures may protect livestock, especially during short heatwaves.

Generally being prepared for increased variability by being more flexible will reduce negative effects on operations. Tactics below (see "Example adaptation tactics 3.3.3") focus on actions that manage the current livestock systems. For future conditions, Strategy 6 ("Alter Management to Accommodate New and Expected Conditions") describes actions to transition to new species, breeds, or systems, whereas Strategy 8 ("Alter Infrastructure to Accommodate New and Expected Conditions") describes the use of infrastructure to protect livestock.

Example adaptation tactics 3.3.3

Tactics for animal agriculture:

Provide partial or total shelter to reduce heat stress during extreme heat.
Increase available shade for pastured animals.
Alter grazing management practices or rotations to match stock rates to forage production, such as by moving livestock to fresh pasture at night.
Use grass or fodder banks (to rest pastures for more than 1 year) to provide forage during dry periods.
Have feed available to support livestock during rain-on-snow events if livestock cannot access forage through ice.
Alter the timing or placement of feeder animals and subsequent finishing time of these animals to reduce stress associated with heatwaves.
Alter livestock stocking rates to reflect food and available water (e.g., rate reductions during a drought event).
Select more heat-tolerant breeds.
Increase herd disease surveillance in livestock.
Make more fresh, clean water available.
Alter animal diets, such as by switching rations from forage to other feed, using supplementary feeds and concentrates, or implementing feed conservation.
Use shade structures to protect livestock from increased sun exposure and high heat.
Monitor animal temperatures to provide early warning of stress.

Strategy 4: Reduce the Risk and Long-Term Impacts of Extreme Weather

Climate change increases overall climate variability (IPCC 2012, Peterson et al. 2013). In addition, climate change is expected to increase the likelihood of extreme weather, including extreme precipitation and storms, which will increasingly challenge agricultural activity (Walthall et al. 2012). In 2019, “extreme” and “exceptional” drought developed in the southeast and Anchorage areas, which led to a reduction in available water and high energy costs because of reduced hydropower generation. Increasingly, producers will need to consider the unique effects of temperature and precipitation changes on existing commodities and look ahead to potential opportunities for increased crop and livestock diversity. Adaptation actions that improve the capacity to adapt to increased weather variability (e.g., soil water-holding capacity), and extreme events in particular (e.g., “hardening” canals or berms [USDA NRCS 2015] to reduce failure and flooding), will generally improve overall climate change preparedness (see Box 3.6: Flood Information) (Bradshaw et al. 2004).

Box 3.6:

Flood Information

National Weather Service Alaska-Pacific River Forecast Center (NOAA NWS, n.d.) provides information and forecasts on rivers and water supply.

This ArcticToday article on rain-on-snow events in Alaska (north) (Rosen 2019) discusses the increased likelihood of rain-on-snow events under future, warmer winter conditions.

Where can I find flood maps? (DOI USGS) provides a collection of flood maps, including Coastal Inundation Dashboard maps for several locations along the Aleutian Islands.

Flood Preparedness Factsheets (ISU 2021) lists several resources to help rural communities prepare for disasters and other hazards.

Protecting a village from its lifeblood, McGrath, Alaska (USDA NRCS 2015) provides a summary how this community used the emergency watershed protection program to protect themselves from floods.

Approach 4.1: reduce peak flow, runoff velocity, and soil erosion—
Extreme precipitation events increase risk of damage to soils, crops, and infrastructure. Increases in on-farm runoff flow volume and velocity following severe precipitation events can lead to an increase in soil erosion, although the risk of soil erosion, nutrient runoff, and other effects on a specific site ultimately depends on local soil and landscape conditions (fig. 3.5). To reduce negative effects of extreme precipitation events on soil and water resources, managers can take actions to slow the flow of water across the landscape (see "Example adaptation tactics 3.4.1"). This approach builds on actions developed under Strategy 1 ("Sustain Fundamental Functions of Soil and Water") to maintain and improve soil health and protect water quality in response to higher peak flows, runoff velocities, and soil erosion that result from increasingly severe storm events. If the cost of these enhancements or risks of failure become prohibitive, actions to alter management, systems, or infrastructure (Strategies 6, 7, and 8, respectively) may also be suitable.

Jack Dykinga, USDA

Figure 3.5—Soil erosion in a field can occur after intense rainfall events, which can damage crops. Farmers can implement tactics proactively to reduce vulnerabilities on their land.

Example adaptation tactics 3.4.1

Tactics for annual cropping activities:

Diversify existing annual cropping systems with new combinations of annual crop species or varieties more resistant to higher peak-flows, runoff velocities, and erosion.

Convert in-field areas at high risk of erosion and pollution transport to perennial crops (grass, shrub, or tree crops), pasture/grazing lands, forest cover, or conservation buffers suitable to conveying water.

Tactics for animal agriculture and associated agriculture lands:

Diversify existing forage crops with new combinations of forage species or varieties more resistant to higher peak flows, runoff velocities, and erosion.

Use wetlands, buffer strips, swales, and other landscape features to buffer against hydrologic variability and increase infiltration after extreme precipitation events.

Maintain or improve infrastructure (water conveyances, lanes, roads, culverts, ponds, waste storage facilities, roofs and covers, roof runoff structures, heavy use areas, etc.) to accommodate more intense precipitation events.

Approach 4.2: reduce severity or extent of water-saturated soil and flood damage—

Flooding in Alaska is caused by many factors, including flash floods from storms and seasonal snow and glacier melt, and riverine floods from river ice melt and damming. Seasonal river ice break-up and glacial lake dam bursts are seasonal flooding hazards in the state. A future challenge that is expected to affect agriculture is the likelihood of less predictability in the timing, magnitude, and frequency of flood threats. As a result, farming operations are encouraged to become aware of the potential for changes in flood risk at their location (see Box 3.6: Flood Information). Those currently situated in low-lying areas and floodplains may need to consider short- and long-term adaptations to reduce risk of crop, animal, and infrastructure damage, especially in areas of the operation that are likely to be affected by flooding more frequently.

The timing, magnitude, and frequency of floods are expected to become less predictable.

Impacts on the ground are in part related to the timing and stage of plant and animal development (e.g., germination or calving season). Wet soils can hinder field operations and animal agriculture activities, such as grazing or exercise. This approach builds on actions developed in Strategy 1 (“Sustain Fundamental Functions of Soil and Water”) to maintain and improve the soil’s function to infiltrate water and protect water quality in response to higher peak flows, runoff velocities, and soil erosion resulting from increasingly severe storm events (see "Example adaptation tactics 3.4.2"). If the cost of these enhancements or risks of failure become prohibitive, actions to alter management, systems, or infrastructure (Strategies 6, 7, and 8, respectively) may also be suitable.

Example adaptation tactics 3.4.2

Tactics for cropping and animal agriculture activities:

- Shift production zones away from flood-prone areas.
- Shift to more flood-tolerant varieties or crops.
- Use new field drainage practices to reduce excess seasonal soil water conditions, such as tile drainage or flashboard risers, to adjust water drainage outlets.

Approach 4.3: reduce severity or extent of wind damage to soils and crops—Wind can damage soils and crops by removing nutrients needed by plants to be productive. In addition, wind can carry soil long distances to snow-covered areas, which can accumulate and darken snow. Darkened snow absorbs more heat and contributes to increased snowmelt, which changes stream and water flows. Future projections on severe weather, including strong wind events, are uncertain; however, soil erosion caused by wind is a current challenge for farmers in Alaska. In response, a variety of conservation techniques exists to reduce the exposure of crops to wind (USDA NRCS 2020) (e.g., vegetative windbreaks [USDA NAC, n.d.]) and keep soils in place (see "Example adaptation tactics 3.4.3").

Example adaptation tactics 3.4.3

Tactics for cropping activities:

- Maintain crop residues to reduce exposure of young sensitive crops to damaging winds.
- Cover soil with crop residues or cover crops to protect it from erosive winds.
- Install windbreaks, hedgerows, or vegetative wind barriers to reduce wind exposure for sensitive crops.

Strategy 5: Manage Farms and Fields as Part of a Larger Landscape

Individual farms, fields, pastures, and grazing lands are part of a larger, landscape-level agroecosystem that provides critical ecosystem services, noncommodity goods, and cultural resources in addition to agricultural products (McGranahan 2014). Because of the global nature of climate change, impacts will be observed across landscapes and regions. Actions to increase landscape diversity and connectivity can increase the ability of systems to adapt to changing environmental conditions and stresses (FAO 2007, Liebman and Schulte 2015, McGranahan 2014). Although the ability of individual producers to affect landscape-level change will vary widely, the integration of landscape considerations into farm management may help to increase adaptive capacity of the agriculture sector in the long term.

Approach 5.1: maintain or restore natural ecosystems within or adjacent to farmland—

In the context of climate change, actions to maintain and restore natural ecosystems can help protect key features on the landscape and maintain a diversity of species and ecological functions (see "Example adaptation tactics 3.5.1") (Stein et al. 2014). Although land that is maintained in natural systems is not available for farm production, there is evidence that the integration of natural ecosystems with agricultural production lands can have notable benefits to soil and water quality without substantially reducing agricultural production (Schulte-Moore 2014). Farm operations often include incidental areas, ditches and watercourses, riparian areas, field edges, seasonal and permanent wetlands, and other similar areas not purposefully managed for food, forage, or fiber production. These incidental areas are typically near to and associated with agriculture production or conservation lands. They may be functional natural ecosystems, but more typically are degraded and have substantial opportunity to diversify and improve ecosystem services.

Although land that is maintained in natural systems is not available for farm production, there is evidence that the integration of natural ecosystems with agricultural production lands can have notable benefits to soil and water quality without substantially reducing agricultural production.

Example adaptation tactics 3.5.1

Tactics for nearby, nonagricultural lands:

- Maintain or restore riparian areas, wetlands, bottomlands, and floodplains.
- Maintain and enhance species and structural diversity by promoting diverse vegetation types and retaining natural ecosystems and biological legacies.
- Restore or maintain fire in fire-adapted ecosystems.

Approach 5.2: promote biological diversity across the landscape— A diversity of species and structures across a landscape may help reduce the susceptibility of its individual components to climate change, as well as other changing environmental conditions and stressors (FAO 2007, Liebman and Schulte 2015, McGranahan 2014, Peterson et al. 1998). Many agricultural systems are inherently low in diversity in order to maximize production; however, supporting diversity across landscapes can reduce the risks associated with climate change (Liebman and Schulte 2015, Schulte-Moore 2014) (see "Example adaptation tactics 3.5.2"). At a landscape level, natural ecosystems and naturalized settings (e.g., field borders, native plantings) can increase environmental services, such as water quality, wildlife abundance, pollinator habitat, and carbon sequestration (fig. 3.6) (Liebman and Schulte 2015). Tradeoffs to consider include implementing good agricultural practices to prevent plant and wildlife disease vectors from establishing in naturalized settings, and following any necessary guidelines as required for food safety inspections. For example, an agricultural producer can create a pollinator habitat with native plants that share no pests or diseases with nearby crops; reducing or changing the timing of using herbicides and pesticides to support native pollinators may increase pollination of certain crops and promote pollinator diversity across the landscape (see Box 3.7: Pollinator and Planting Guides).

Example adaptation tactics 3.5.2

Tactics for nearby, nonagricultural lands:

- Increase managed habitats across a range of landscapes.
- Protect at-risk species and habitats.
- Maintain or create species-specific refuges to improve survival through a period of unfavorable conditions (e.g., intentional planting of pollinator habitat throughout the season, construction of bat houses and bumblebee nest boxes).
- Create habitat for pollinators or other beneficial organisms.

USDA Natural Resources Conservation Service

Figure 3.6—Planting wildflowers, such as Alaskan lupine, near pollinator-dependent crops can increase crop yields by attracting more wild or managed pollinators.

Box 3.7:

Pollinator and Planting Guides

Insect Pollinators of Alaska (USDA NRCS, n.d. c) is a two-page fact sheet from the USDA Natural Resources Conservation Service that details important native and nonnative pollinators.

How to build a pollinator garden (DOI FWS 2022) is a short guide to choosing a location, plants, preparation of a pollinator garden, which can help increase pollinators and benefit nearby crops and gardens.

Approach 5.3: enhance landscape and waterway connectivity—
Connections across natural ecosystems also enable large-scale adaptation by creating a mosaic of habitats to support natural and facilitated migrations of plants, animals, and other organisms across the landscape (Stein et al. 2014). Although species migration and floodplain connectivity are critical factors in maintaining natural ecosystem function in a changing climate, the fragmentation of waterways and landscapes contributes to degraded habitat. Many species, including anadromous fish species (e.g., salmon), are not expected to be able to migrate at a rate sufficient to keep up with climate change. Increasing landscape connectivity may help species to migrate without additional assistance by allowing for easier species movement, reducing lags in migration, and enhancing the flow of genetic material (see "Example adaptation tactics 3.5.3") (Heller and Zavaleta 2009, Stein et al. 2014).

Example adaptation tactics 3.5.3

Tactics for nearby, nonagricultural lands:

- Use landscape-scale planning and partnerships to reduce fragmentation and enhance connectivity.
- Maintain and create naturalized habitat corridors.

Strategy 6: Alter Management to Accommodate Expected Future Conditions

As climate change effects increase, there will be a greater need to move from short-term, reactive management toward more intentional, planned adaptation actions (Smit and Skinner 2002). Although adaptation actions vary widely in intent, timing, and scale, this strategy emphasizes a clear shift toward more substantial changes that ultimately transform the activities for a particular farm or producer.

Approach 6.1: diversify crop or livestock varieties or breeds, or products—
Farm-level diversification can reduce the risk of climate change effects on a farm and lower the economic risks associated with lower yields or market fluctuations (Ames and Dufour 2014, Bradshaw et al. 2004). At the same time, there are costs to diversification, especially in the near term, including startup costs and learning needed to start a new variety or breed (UAF AFES, n.d), as well as reduced economies of scale (Bradshaw et al. 2004). Adding to these challenges is the limited availability of seed and equipment that farmers in Alaska currently face, which limits what they can grow.

Farmers can adapt to climate change by choosing or breeding new varieties that are adapted to current and potential future climates (see "Example adaptation tactics 3.6.1”). For example, Bushes Bunches Produce Stand is conducting trials to examine ideal varieties of potato and other vegetables under changing climate conditions in south-central Alaska (see case studies in chapter 5). Farmers in Alaska benefit from having fewer diseases that affect crops, which allows farmers to grow one variety on the same land for more than a decade. Extra care can be taken to verify new crop varieties or livestock breeds are disease free. This approach will reduce negative effects of climate change on farm productivity, as diverse commodities can provide a buffer from variable climate conditions.

Example adaptation tactics 3.6.1

Tactics for all agriculture as applicable:

- Add more farming activities or new commodities to diversify farm products and revenue.
- Increase or change varieties, breeds, genetic sources, or species among commodities.
- Diversify animal products or ages.
- Diversify varieties or breeds for different tolerances of cold hardiness, drought and heat tolerance, or other attributes.

Approach 6.2: diversify existing systems with new crop and livestock combinations—

Along with diversification of crop varieties and livestock breeds, it may also be useful to diversify systems to include new combinations of species, including grazing cows on agricultural fields to clear cover crops and fertilize soils (fig. 3.7) (also see “Example adaptation tactics 3.6.2”). Another example is an agricultural system that includes a combination of breeds or species that are adapted to current and future climates to reduce the risk associated with one breed or species performing poorly and to provide time to gain experience with new breeds or species. At the same time, there is risk in anticipating which breed or species will do well in current as well as future climates, as climate variability can have a greater effect on production than the long-term changes in climate. Agroforestry, the integration of trees and shrubs into crop and animal farming systems, is another approach to system diversification that has the potential to contribute to climate change mitigation and adaptation for agricultural lands (see Box 2.1) (Schoeneberger et al. 2012).

Agroforestry, the integration of trees and shrubs into crop and animal farming systems, is another approach to system diversification that has the potential to contribute to climate change mitigation and adaptation for agricultural lands.

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Figure 3.7—Managed grazing of cattle on cover crops enhances soil quality and reduces feed and fertilizer costs.

Example adaptation tactics 3.6.2

Tactics for field and forage crops:

- Plant multispecies cover crop mixtures adapted to warmer climates.
- Integrate livestock into cropping enterprises to use aftermath grazing on crop residues and cover crop grazing to enhance soil microbes.

Tactics for animal agriculture:

- Integrate livestock into cropping enterprises to access additional forage, reduce feed costs, eliminate manure concentration areas, or improve overall farm efficiency.
- Alter mix of grazing species.
- Plant multispecies pasture mixtures, including species currently adapted to warmer climates.

Tactics for integrated agricultural systems:

- Diversify and expand farm production to include more annual crops, perennial fruits or nuts, timber or other forest products, livestock, or other commodities (may or may not include agroforestry approaches).

Approach 6.3: switch to commodities expected to be better suited to future conditions—
As climate conditions change, it may become necessary to switch to new plants, animals, or systems to maintain a viable farm. This is not a new idea, and agricultural producers have a long history of changing practices in response to changing markets, technologies, and environmental conditions (Walthall et al. 2012). The degree of anticipated climate change, however, may require greater investment and experimentation with new plants, animals, and other commodities and at a much larger scale, and farms may need to change to different systems altogether (see "Example adaptation tactics 3.6.3"). For agricultural producers to successfully shift to new commodities and systems, accompanying advances in technologies (e.g., alternative crops/livestock, decision-support tools) and markets are also needed (see Boxes 3.5 and 3.6 for resources) (Walthall et al. 2012).

Example adaptation tactics 3.6.3

Tactics for cropping systems:

- Use new cultivars and new species that are better suited to future climate.
- Shift to more water-efficient crops or cropping systems.
- Preserve genetic resources by relocating at-risk varieties to locations that are expected to provide future habitat or reserving seed for future use.
- Shift crops to types that can be grown in a controlled environment, and make use of hoop houses, high tunnels, or greenhouses.

Tactics for animal agriculture:

- Switch to alternative livestock breeds, class, or species, especially those with a higher heat, drought, and parasite tolerance.
- Preserve genetic resources by relocating at-risk breeds to locations that are expected to provide future habitat.

Strategy 7: Alter Agricultural Systems or Lands to New Climate Conditions

Beyond deliberate changes in farm commodities and practices, there may be a need for wholesale change within agricultural systems because of the degree of climate change in a particular place. Although agriculture has been able to largely adapt to recent changes in climate, substantial pressures from climate change and associated socioeconomic changes will create considerable challenges in coming decades (Markon et al. 2018). This strategy touches on actions to respond to severely changed conditions in a way that anticipates continued change and uncertainty in the future (see "Example adaptation tactics 3.7.1").

Example adaptation tactics 3.7.1

Tactics for cropping systems:

- Seed cover crops to protect and stabilize soils.
- Remove or prevent establishment of invasive plants and competitors following disturbance with herbicides, tilling, or other control measures.
- Convert severely affected areas or areas at risk of repeat disturbances to plants that are less susceptible to disturbance, such as other crops, perennial forage, or native plants.
- Reshape damaged areas before replanting.

Tactics for associated agriculture lands:

- Ensure that emergency response actions do not do more damage to resources than the emergency itself (e.g., avoid cover cropping with invasive species or restarting field operations when fields are overwetted).

Approach 7.1: minimize potential impacts following disturbance—Increases in the frequency, intensity, and extent of disturbances, such as extreme precipitation, may disrupt vegetation and result in the loss of plant cover, productivity, or function. Prompt restoration and revegetation of sites following disturbance helps reduce soil loss and erosion, maintain water quality, and discourage weedy species in the newly exposed areas. Because many of the best opportunities for addressing disturbance-related issues are likely to occur immediately after the disturbance event, having a suite of preplanned options in place may facilitate a faster and more effective response. Where a particular event exceeds the resilience of a particular location or system and a return to previous conditions is no longer feasible, this approach complements Approach 7.2 below.

Because many of the best opportunities for addressing disturbance-related issues are likely to occur immediately after the disturbance event, having a suite of preplanned options in place may facilitate a faster and more effective response.

Approach 7.2: realign severely altered systems toward future conditions—Agricultural lands may face significant effects of disturbance, including drought, wildland fire, severe weather events, and invasive species, in a changing climate (Walthall et al. 2012). Some systems may experience significant disruption and decline such that even intensive management may be insufficient to maintain desired conditions or achieve intended goals (Millar et al. 2007). In this circumstance, producers can select new commodities or production systems that are expected to be better matched to current and anticipated future climate conditions (see “Example adaptation tactics 3.7.2”).

Example adaptation tactics 3.7.2

Tactics for all agricultural systems:

- Convert affected areas to plants or animal commodities that are expected to thrive under future conditions.
- Shift agricultural production spatially, matching commodities to climate conditions or water availability.

Approach 7.3: alter lands in agricultural production—
Warmer conditions may increase the viability of agricultural commodities in Alaska and allow for expanded production (Rosenzweig et al. 2014) (see “Example adaptation tactics 3.7.3”). As temperatures increase, permafrost will thaw or degrade, which may increase the amount of land available for agricultural production. Although many of these changes will occur at broad spatial scales, individual producers and landowners will make the decisions about site-level production (Adger et al. 2005, Smit et al. 1999).

Example adaptation tactics 3.7.3

Tactics for all agricultural systems:

- Shift agricultural production spatially, matching commodities to climate conditions or water availability.
- Convert agricultural lands to new commodities based on altered climatic conditions, such as converting row crops to perennial forage where water availability decreases.
- Remove lands from agricultural production.
- Add lands to agricultural production, recognizing the potential for negative impacts on natural ecosystems or environmental benefits.

Strategy 8: Alter Infrastructure to Match New and Expected Conditions

Infrastructure generally has a high cost and long lifespan relative to other farm practices and activities, so there is a greater need to consider the long-term implications of these investments. Changes and upgrades in farm infrastructure represent a specific opportunity for agricultural producers to consider expected future climate conditions, risks, and opportunities that could affect farm productivity and sustainability. Changes in infrastructure can be used to adjust to the effects of climate change and maintain current practices in place for a longer period of time, including through the use of increased irrigation to offset increased dryness. On the other end of the spectrum, altering infrastructure may facilitate a transition to entirely new systems, such as through the purchase of new facilities or equipment necessary for the production of a new, future-adapted commodity (see Box 3.8: USDA Support for Farmers Making Adaptations and Monitoring Climate Change Impacts).

Box 3.8:

USDA Support for Farmers Making Adaptations and Monitoring Climate Change Impacts

U.S. Department of Agriculture (USDA) Programs and Resources to Assist with Adaptation to Climate Change (USDA CH, n.d.) is a searchable guide with more than 140 USDA programs and resources that provides financial or technical assistance, insurance, or services to assist with adaptation and mitigation of climate change. A few examples are listed below:

Commodities and markets—
Farmers' Market Promotion Program (USDA Climate Hubs 2018a) aims to increase domestic consumption of, and access to, locally and regionally produced agricultural products, and to develop new market opportunities for farm and ranch operations serving local markets.

Local Food Promotion Program (USDA Climate Hubs 2018b) offers grants with a 25-percent match to support the development and expansion of local and regional food business enterprises to increase domestic consumption of, and access to, locally and regionally produced agricultural products, and to develop new market opportunities for farm and ranch operations serving local markets.

Market Access Program (USDA CH 2019b) helps U.S. exporters, including Tribal communities, share the costs of marketing and promotional activities overseas to build commercial export markets for U.S. agricultural products and commodities.

Improved facilities—
Rural Energy for America Program Renewable Energy Systems & Energy Efficiency Improvement Loans & Grants (USDA CH 2019c) provides guaranteed loan financing and grant funding to agricultural producers and rural small businesses for renewable energy systems or to make energy efficiency improvements.

Community Facilities—Economic Impact Initiative Grants (USDA CH 2019d) provides funding to assist in the development of essential community facilities in rural communities.

Approach 8.1: expand or improve water systems to match water demand and supply—
Increasing temperatures will likely increase water demand through enhanced evaporation from soils and transpiration from plants. Agriculture in Alaska is likely to be affected where increased temperatures may not be offset by corresponding increases in precipitation, causing moisture stress (Markon et al. 2018). In addition to practices to increase soil water retention and adjust plant crops or animal breeds to match warmer conditions (described earlier), it may be necessary to expand infrastructure to increase the amount of water available to plants and animals (see "Example adaptation tactics 3.8.1"). Because of the cost associated with many of these practices, efforts to increase the extent, capacity, or efficiency of water systems may be best suited to high-value or less water-intensive commodities (Blanc and Reilly 2015). Farmers such as Bruce Bunch in Palmer, Alaska, are planning for drier soil conditions by expanding existing irrigation systems and prioritizing dry soil areas on the farm (see chapter 5).

Example adaptation tactics 3.8.1

Tactics for animal agriculture:

- Construct ponds and swales, dig wells, and collect rainwater.

Tactics for cropping systems:

- Increase irrigation capacity or land under irrigation, particularly for high-value crops.
- Improve irrigation efficiency with latest technology, such as micro or drip irrigation, subsurface irrigation, or irrigation with gray or reclaimed water.
- Expand water storage, irrigation, and drainage with deeper wells, cisterns, farm ponds, and more efficient irrigation.
- Construct ponds and swales, dig wells, and collect rainwater to maintain water on the landscape.
- Install or enhance drainage systems.
- Dig deeper wells and install more cisterns, farm ponds, and more efficient irrigation to accommodate hydrologic change.

Approach 8.2: use structures to increase environmental control for crops—
Excess precipitation, heat stress, and other changes in climate pose substantial challenges for crops. Approach 3.2: ("manage crops to cope with warmer and drier conditions") describes actions to manage current crop systems for reduced heat stress by modifying plant density, soil moisture availability, or plant genetics or variety. This approach focuses on changes to infrastructure that reduce the effects of altered climate on crops, including heat stress and extreme weather events (see "Example adaptation tactics 3.8.2"). In some instances, technological solutions may help transition to a new, future-adapted commodity in anticipation of future climate changes. For example, hoop houses or high tunnels create warmer conditions that are necessary at northern sites for crops. However, with warmer conditions, crops may be grown without protection (fig. 3.8).

Example adaptation tactics 3.8.2

Tactics for cropping systems:

Move crops into a controlled environment, such as hoop houses, high-tunnels, or greenhouses.
Move crops from a controlled environment to field production.
Enhance energy efficiency in greenhouses.
Enhance irrigation efficiency in controlled environments, such as hoop houses, high tunnels, or greenhouses.
Use technologies to protect orchards from frost, such as sprinklers, heaters, and wind machines, to allow for more cold-sensitive varieties to be grown.

Approach 8.3: improve or develop structures to reduce animal exposure to extreme events—
Temperature stress poses substantial challenges for animal agriculture. Approach 3.3: ("manage livestock to cope with warmer conditions") outlines actions to manage current livestock systems for reduced heat stress by modifying stocking density, forage availability and type, and animal genetics or breed. This approach focuses on changes to infrastructure that reduce stress on animals from variable weather conditions (see "Example adaptation tactics 3.8.3").

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Figure 3.8—In some parts of Alaska, future climate conditions may shift to allow farmers to grow more crops outside of high tunnels. In other areas, the controlled environment provided by high tunnels may help protect crops from increased precipitation or freeze damage as insulating snowpack is lost. Seasonal high tunnels enhance crop production for the Tyonek community.

Example adaptation tactics 3.8.3

Tactics for animal agriculture:

- Build new barns with adequate heating/cooling.
- Improve climate control in existing facilities with fans, misters, soakers, heaters, etc.
- Enhance energy efficiency in facilities with light-emitting diode (LED) lights and other features to reduce long-term costs and heat.
- Design and implement new housing for animal agriculture with consideration of extreme weather events and future climate.
- Provide shade structures for livestock during extreme high temperatures.

Approach 8.4: match infrastructure and equipment to new and expected conditions—
Farm infrastructure can be altered to operate under new and expected conditions or to match other changes in management practices. For example, producers can use irrigation systems and best management practices for more efficient irrigation (see "NRCS irrigation handbooks and manuals [USDA NRCS, n.d. c]"). Tactics under this approach may vary widely depending upon the farm operation and could include adding new machinery to implement new practices, growing new commodities; or it could include upgrading buildings, structures, and facilities to handle increased snow or wildlife browsing (see "Example adaptation tactics 3.8.4").

Example adaptation tactics 3.8.4

Tactics for all agricultural systems:

- Update farm machinery to match new and future farm practices and commodities.
- Consider precision nutrient and pesticide application systems.
- Upgrade to more energy-efficient equipment or integrate on-farm renewable energy generation enterprises (e.g., manure and biomass conversion and combustion, wind, solar).
- Upgrade building facilities to handle expected increased snow loads.
- Upgrade facilities and infrastructure to limit wildlife impacts to crops and livestock.
- Upgrade facilities and infrastructure air filtration to limit impacts from wildland fire smoke.
- Improve fire safety for all buildings, and develop protocols for wildfire impacts to air and water quality to protect outdoor workers, livestock, and crops.
- If available, use on-farm excess biogas heat to benefit livestock operations, greenhouse, or aquaculture production. As the Alaska climate warms, potential for the use of biogas, such as methane digestion, may become more widespread.

References

Adger, W.N.; Arnell, N.W.; Tompkins, E.L. 2005. Successful adaptation to climate change across scales. Global Environmental Change. 15(2): 77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005.

Ainsworth, E.A.; Ort, D.R. 2010. How do we improve crop production in a warming world? Plant Physiology. 154(2): 526–530. https://doi.org/10.1104/pp.110.161349.

Ames, G.K.; Dufour, R. 2014. Climate change and perennial fruit and nut production: investing in resilience in uncertain times. [Brochure]. Butte, MT: National Center for Appropriate Technology. 12 p. https://attra.ncat.org/wp-content/uploads/2019/05/climate_change_fruit_nut_production.pdf?

Anwar, M.; Liu, D.; Macadam, I.; Kelly, G. 2013. Adapting agriculture to climate change: a review. Theoretical and Applied Climatology. 113(1–2): 225–245. https://doi.org/10.1007/s00704-012-0780-1.

Blanc, E.; Reilly, J. 2015. Climate change impacts on US crops. Choices [Magazine]. Milwaukee, WI: Agricultural and Applied Economics Association. 30(2): 2nd Quarter. https://www.choicesmagazine.org/UserFiles/file/cmsarticle_430.pdf.

Bradshaw, B.; Dolan, H.; Smit, B. 2004. Farm-level adaptation to climatic variability and change: crop diversification in the Canadian prairies. Climatic change. 67(1): 119–141. https://doi.org/10.1007/s10584-004-0710-z.

Derner, J.; Briske, D.; Reeves, M.; Brown-Brandl, T.; Meehan, M.; Blumenthal, D.; Hendrickson, J. 2018. Vulnerability of grazing and confined livestock in the northern Great Plains to projected mid- and late-twenty-first century climate. Climatic Change. 146(1–2): 19–32. https://doi.org/10.1007/s10584-017-2029-6.

Food and Agriculture Organization of the United Nations [FAO]. 2007. Adaptation to climate change in agriculture, forestry, and fisheries: perspective, framework and priorities. Rome, Italy: Interdepartmental Working Group on Climate Change. 32 p. http://www.fao.org/nr/climpag/pub/adaptation_to_climate_change_2007.pdf. (22 March 2022).

Gowda, P.; Steiner, J.L.; Olson, C.; Boggess, M.; Farrigan, T.; Grusak, M.A. 2018. Agriculture and rural communities. Impacts, risks, and adaptation. In: Reidmiller, D.R.; Avery, C.W.; Easterling, D.R.; Kunkel, K.E.; Lewis, K.L.M.; Maycock, T.K.; Stewart, B.C., eds. Impacts, risks, and adaptation in the United States: fourth national climate assessment. Vol. II. Washington, DC: U.S. Global Change Research Program: 391–437. http://doi.org/10.7930/NCA4.2018.CH10.

Heller, N.E; Zavaleta, E.S. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation. 142(1): 14-32. https://doi.org/10.1016/j.biocon.2008.10.006.

High Tunnel Alaska. 2021. AK HighTunnels: soil preparation—soil testing, soil building, soil quality. http://akhightunnels.org/soil-and-site-prep.html. (10 March 2021).

Intergovernmental Panel on Climate Change [IPCC]. 2012. Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom; New York: Cambridge University Press. 582 p. https://doi.org/10.1017/CBO9781139177245.

Iowa State University [ISU]. 2021. All hazards—floods: resources to help rural communities prepare for disasters and other hazards. http://www.prep4agthreats.org/Natural-Disasters/floods. (10 March 2021).

Kenai Soil & Water Conservation District [KSWCD] 2017. Kenai farm central: helpful resources for Kenai Peninsula farmers and market gardeners. https://kenaisoilandwater.org/projects/kenaifarmcentral/. (10 March 2021).

Liebman, M.; Schulte, L.A. 2015. Enhancing agroecosystem performance and resilience through increased diversification of landscapes and cropping systems. Elementa: Science of the Anthropocene. 3(1): 41. https://doi.org/10.12952/journal.elementa.000041.

Markon, C.; Gray, S.; Berman, M.; Eerkes-Medrano, L.; Hennessy, T.; Huntington, H.; Littell, J.; Trainor, S. 2018. Alaska. In: Reidmiller, D.R.; Avery, C.W.; Easterling, D.R.; Kunkel, K.E.; Lewis, K.L.M.; Maycock, T.K.; Stewart, B.C., eds. Impacts, risks, and adaptation in the United States: fourth national climate assessment. Vol. II. Washington, DC: U.S. Global Change Research Program: 1185–1241. http://doi.org/10.7930/NCA4.2018.CH26.

McGranahan, D.A. 2014. Ecologies of scale: multifunctionality connects conservation and agriculture across fields, farms, and landscapes. Land. 3(3): 739–769. https://doi.org/10.3390/land3030739.

Millar, C.I.; Stephenson, N.L.; Stephens, S.L. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications. 17(8): 2145–2151. https://doi.org/10.1890/06-1715.1.

Mörschel, F.M.; Klein, D.R. 1997. Effects of weather and parasitic insects on behavior and group dynamics of caribou of the Delta Herd, Alaska. Canadian Journal of Zoology. 75: 1659–1670. https://doi.org/10.1139/z97-793.

National Oceanic and Atmospheric Administration National Weather Service [NOAA NWS]. [N.d.]. Alaska-Pacific River Forecast Center. https://www.weather.gov/aprfc/. (10 March 2021).

National Oceanic and Atmospheric Administration, University of Alaska Fairbanks, Sea Grant Alaska [NOAA SGA]. 2021. Coastal community resilience. https://alaskaseagrant.org/our-work/coastal-resilience/. (8 March 2021).

Palm, C.; Blanco-Canqui, H.; DeClerck, F.; Gatere, L.; Grace, P. 2014. Conservation agriculture and ecosystem services: an overview. Agriculture, Ecosystems & Environment. 187: 87–105. https://doi.org/10.1016/j.agee.2013.10.010.

Peterson, G.; Allen, C.R.; Holling, C.S. 1998. Ecological resilience, biodiversity, and scale. Ecosystems. 1(1): 6–18. https://doi.org/10.1007/s100219900002.

Peterson, T.C.; Heim, R.R., Jr.; Hirsch, R.; Ka, D.P.; Brooks, H.; Diffenbaugh, N.S.; Katz, R.W. 2013. Monitoring and understanding changes in heat waves, cold waves, floods, and droughts in the United States: state of knowledge. Bulletin of the American Meteorological Society. 94(6): 821–834. https://doi.org/10.1175/BAMS-D-12-00066.1.

Roesch-McNally, G.; Moore-Kucera, J.; Owens, C. 2019. Applying soil health management systems to reduce climate and weather risks in the Northwest. Version 1: April 2019. Portland, OR: U.S. Department of Agriculture, Natural Resources Conservation Service.

Rosen, Y. 2019. Dangerous, disruptive rain-on-snow events are expected to increase in northern Alaska. (March 6). Arctic Today. https://www.arctictoday.com/dangerous-disruptive-rain-on-snow-events-are-expected-to-increase-in-northern-alaska/. (10 March 2021).

Rosenzweig, C.; Elliott, J.; Deryng, D.; Ruane, A.C.; Müller, C.; Arneth, A.; Neumann, K. 2014. Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. Proceedings of the National Academy of Sciences of the United States of America. 111(9): 3268–3273. https://doi.org/10.1073/pnas.1222463110.

Schoeneberger, M.; Bentrup, G.; De Gooijer, H.; Soolanayakanahally, R.; Sauer, T.; Brandle, J.; Current, D. 2012. Branching out: agroforestry as a climate change mitigation and adaptation tool for agriculture. Journal of Soil and Water Conservation. 67(5): 128A–136A. https://doi.org/10.2489/jswc.67.5.128A.

Schulte-Moore, L.A. 2014. Prairie strips: bringing biodiversity, improved water quality, and soil protection to agriculture. Missouri Prairie Journal. 35(1): 12–15.

Smit, B.; Burton, I.; Klein, R.J.T.; Street, R. 1999. The science of adaptation: a framework for assessment. Mitigation and Adaptation Strategies for Global Change. 4(3–4): 199–213. https://doi.org/10.1023/A:1009652531101.

Smit, B.; Skinner, M. 2002. Adaptation options in agriculture to climate change: a typology. Mitigation and Adaptation Strategies for Global Change. 7(1): 85–114. https://doi.org/10.1023/A:1015862228270

Starr, L.; Greenberg, J.; Zhang, M.; Seefeldt, S.; Rowell, J. 2020. Utilizing grassland resources for sub-arctic agriculture: sustainable muskox farming in Alaska. Proceedings of the 23rd International Grasslands Congress. New Delhi, India: Range Management Society of India. 4 p. https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1977&context=igc. (4 March 2021).

State of Alaska Department of Fish and Game [ADFG]. [N.d. a]. Invasive species online reporting. http://www.adfg.alaska.gov/index.cfm?adfg=invasivespeciesreporter.main. (27 October 2021).

State of Alaska Department of Fish and Game [ADFG]. [N.d. b]. Muskox species profile. https://www.adfg.alaska.gov/index.cfm?adfg=muskox.main. (27 October 2021).

State of Alaska, Department of Natural Resources, Division of Agriculture [ADNR]. [N.d.]. Invasive plants and agricultural pest management. http://plants.alaska.gov/invasives/InvasivesNews.htm. (10 March 2021).

Stein, B.A.; Glick, P.; Edelson, N.; Staudt, A., eds. 2014. Climate-smart conservation: putting adaption principles into practice. Washington, DC: National Wildlife Federation. 272 p.

University of Alaska Fairbanks, Agricultural and Forestry Experiment Station [UAF AFES]. [N.d.]. Publication search: vegetable variety trials 2019. http://afesresearch.uaf.edu/publications/?cat=*&pt=*&s=VegetableVarietyTrials2019. (8 March 2021).

University of Alaska Fairbanks, Cooperative Extension Service [UAF CES]. 2021. Alaska IPM: Integrated Pest Management Program. IPM Alaska Pest Reporter Home: Welcome to our Citizens Monitoring Portal! https://plw.man.mybluehost.me/. (22 June 2022).

University of Alaska Fairbanks, Cooperative Extension Service [UAF CES]. [N.d. a]. Soils. https://uaf.edu/ces/agriculture/soil/. (10 March 2021).

University of Alaska Fairbanks, Cooperative Extension Service [UAF CES] [N.d. b]. Integrated pest management program. https://uaf.edu/ces/invasives/ipm/index.php. (10 March 2021).

University of Alaska Fairbanks, Cooperative Extension Service [UAF CES] [N.d. c]. Livestock in Alaska. https://uaf.edu/ces/agriculture/livestock/index.php. (10 March 2021).

University of Alaska Fairbanks, Institute of Agriculture, Natural Resources and Extension [UAF IANRE]. 2016. Reindeer program. http://reindeer.salrm.uaf.edu/. (10 March 2021).

University of Alaska Fairbanks, Scenarios Network for Alaska + Arctic Planning [UAF SNAP]. [N.d.]. Community permafrost data: explore community risk to permafrost. https://snap.uaf.edu/tools/permafrost. (10 March 2021).

U.S. Department of Agriculture [USDA]. [N.d.]. Small and mid-sized farmer resources. https://www.usda.gov/topics/farming/resources-small-and-mid-sized-farmers. (10 March 2021).

U.S. Department of Agriculture, Agriculture Marketing Service [USDA AMS]. [N.d.]. Local and regional food sector. https://www.ams.usda.gov/services/local-regional/food-sector. (8 March 2021).

U.S. Department of Agriculture, Climate Hubs [USDA CH]. [N.d.]. USDA programs and resources to assist with adaptation to climate change. https://www.climatehubs.usda.gov/actions-and-resources/programs. (10 March 2021).

U.S. Department of Agriculture, Climate Hubs [USDA CH]. 2018a. Farmer's market promotion program. https://www.climatehubs.usda.gov/node/1548. (10 March 2021).

U.S. Department of Agriculture, Climate Hubs [USDA CH]. 2018b. Local food promotion program. https://www.climatehubs.usda.gov/node/1547. (10 March 2021).

U.S. Department of Agriculture, Climate Hubs. [USDA CH]. 2019a. Plant protection and quarantine. https://www.climatehubs.usda.gov/node/1571. (10 March 2021).

U.S. Department of Agriculture, Climate Hubs [USDA CH]. 2019b. Market access program. https://www.climatehubs.usda.gov/node/1610. (10 March 2021).

U.S. Department of Agriculture, Climate Hubs [USDA CH]. 2019c. Rural energy for program renewable energy systems & energy efficiency improvement loans & grants. https://www.climatehubs.usda.gov/node/1669. (10 March 2021).

U.S. Department of Agriculture, Climate Hubs [USDA CH]. 2019d. Community facilities - economic impact initiative grants. https://www.climatehubs.usda.gov/node/1672. (10 March 2021).

U.S. Department of Agriculture, Forest Service [USDA FS]. [N.d.]. Forest and grassland health: invasive plants. https://www.fs.usda.gov/detailfull/r10/forest-grasslandhealth/?cid=FSEPRD695230&width=full. (10 March 2021).

U.S. Department of Agriculture, Marketing Service. 2016. Local Foods, Local Places—A Community-Driven Action Plan for Palmer, Alaska. https://www.ams.usda.gov/sites/default/files/media/LFLP2PalmerAKActionPlan.pdf (14 July 2022).

U.S. Department of Agriculture, National Invasive Species Information Center [USDA NISIC]. [N.d.] National invasive species information center. https://www.invasivespeciesinfo.gov/. (27 October 2021).

U.S. Department of Agriculture, National Agroforestry Center [USDA NAC]. [N.d.]. Silvopasture. https://www.fs.usda.gov/nac/practices/silvopasture.php. (9 March 2021).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. [N.d. a]. Resources and publications. https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/resource/#atn. (10 March 2021).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. [N.d. b] Insect pollinators of Alaska. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1361251.pdf. (12 March 2021).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. [N.d. c]. Irrigation—handbook and manuals. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/irrigation/?cid=stelprdb1045075. (25 October 2021).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2020. Alaska farmers on a quest for healthy soils: field trial seeks answer to cover cropping and no-till on the Last Frontier. Palmer, AK: Alaska Field Office. https://www.nrcs.usda.gov/wps/portal/nrcs/ak/newsroom/stories/945d48c1-0cd7-4777-9a6a-1af4e74c02cd/. (9 November 2021).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2015. McGrath, Alaska. Protecting a village from its lifeblood. [Brochure]. Palmer, AK: Alaska State Office, Emergency Watershed Protection Program. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1356137.pdf. (9 March 2021).

U.S. Department of the Interior, Fish and Wildlife Service [DOI FWS]. 2022. How to build a pollinator garden. https://www.fws.gov/story/how-build-pollinator-garden. (30 June 2022).

U.S. Department of the Interior, Geological Survey [DOI USGS]. [N.d.]. Where can I find flood maps? https://www.usgs.gov/faqs/where-can-i-find-flood-maps?qt-news_science_products=0#qt-news_science_products. (10 March 2021).

Walthall, C.L.; Hatfield, J.; Backlund, P.; Lengnick, L.; Marshall, E.; Walsh, M.; Ziska, L. H. 2012. Climate change and agriculture in the United States: effects and adaptation. Tech. Bull. 1935. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service. https://www.usda.gov/sites/default/files/documents/CC%20and%20Agriculture%20Report%20(02-04-2013)b.pdf.

Ziska, L.; Bunce, J. 1997. Influence of increasing carbon dioxide concentration on the photosynthetic and growth stimulation of selected C4 crops and weeds. Photosynthesis Research. 54(3): 199–208. https://doi.org/10.1023/A:1005947802161.

Ziska, L.H.; Bunce, J.A.; Shimono, H.; Gealy, D.R.; Baker, J.T.; Newton, P.C.; Reynolds, M.P.; Jagadish, K.S.; Zhu, C.; Howden, M; Wilson, L.T., 2012. Food security and climate change: on the potential to adapt global crop production by active selection to rising atmospheric carbon dioxide. Proceedings of the Royal Society B: Biological Sciences. 279(1745): 4097–4105. https://doi.org/10.1098/rspb.2012.1005.

Chapter 4: Adaptation Workbook

Paris Edwards and Holly R. Prendeville[1]

Climate change is an important component of land management planning and decisionmaking. Chapter 4 outlines a flexible, five-step process to help agricultural producers, service providers, or educators consider the potential effects of increasing climate variability and change and to identify actions that facilitate adaptation to changing conditions (Box 4.1: Using this Adaptation Workbook). This chapter was adapted from Janowiak et al. 2016.

The process of adapting to climate change begins with defining current goals and objectives for agricultural production, profitability, and natural resource stewardship in a particular location (fig. 4.1). The next step assesses potential climate change effects to the region and incorporates them as an additional consideration to evaluate the goals and objectives. Once appropriate adaptation actions are identified, a monitoring and evaluation process is used to determine if

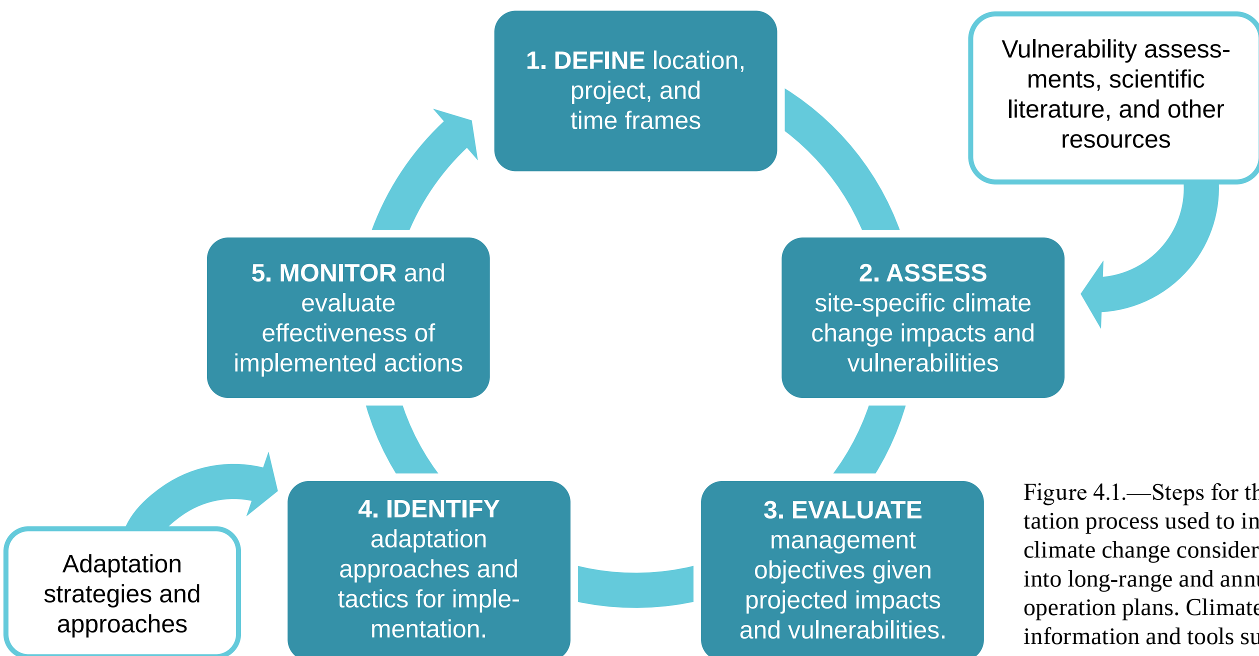

Figure 4.1.—Steps for the adaptation process used to include climate change considerations into long-range and annual operation plans. Climate change information and tools support the adaptation decisionmaking process. Adapted from Swanston et al. (2016).

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Box 4.1

Using this Adaptation Workbook

Purpose of this workbook—

This adaptation workbook can help producers, service providers, and educators:

- Incorporate climate change considerations into long-range and annual operations planning and decisionmaking based on experience and expertise.
- Incorporate adaptation actions into revision or development of farm or project plans.
- Discuss climate change-related topics with project stakeholders and clients.
- Continuously learn by doing and evaluating incremental changes that inform longer term strategies.
- Document considerations, decisions, and outcomes regarding climate change adaptation.

What this adaptation workbook does not do:

- Make recommendations or set criteria for making decisions.
- Provide specifications for implementing response actions.
- Establish a plan to implement the selected actions and monitoring efforts.

Getting prepared—

- Before you begin, it will be helpful to review information about your farm or project area, such as business or project plans, conservation plans, maps, and production and land management records for the past 5 years.
- It may take several hours to move through all the steps of the adaptation workbook, especially if you are just getting familiar with climate change information, or if you have a complex operation.
- Print the blank worksheets provided at the end of this workbook for use with step-by-step instructions. You may want to use this workbook in facilitated small group settings, or with an advisor to help identify and access additional resources needed to complete the worksheets.

Step-by-step instructions—

- Follow the five steps in order, although you can always go back to add or clarify earlier responses. Review workbook items and key questions for each step, then fill out each item in the worksheet. Some steps have additional details.
- Where applicable, see additional guidance under the heading "Slow down to consider."
- When you have completed all the steps in the adaptation workbook, you will have a set of worksheets to combine with or add to your existing plans for the farm or project.
- You can work toward implementing adjustments or transformations through time, either on your own or with your trusted financial, production, and conservation advisors and service providers.

expected outcomes are being achieved. This flexible process draws upon locally relevant information resources about anticipated climate change effects, such as the national-, regional-, and state-level assessments as well as the adaptation strategies and approaches described in chapter 3.

Step 1: Define Management Goals and Objectives

About This Step

This step records fundamental information about the farm or project area. Because it serves as a starting point for the subsequent steps, it is important to clearly define the current farm management goals and objectives. This information may already be available as part of a management plan or other planning document. If you will be going through the workbook as part of a group, it may be most efficient for one or two people to compile information for this step in advance of any group discussions.

Description of Workbook Items

Farm or project area—
Name of the farm or the project area. Projects can be individual farms and properties or a group of multiple lands in a geographical area, such as a watershed, landscape feature, or community.

Key Questions 4.1:

- Where are you located?
- What do you care about?

Location—
Describe the geographic location of the farm or project area (e.g., county, township, or watershed).

Management unit—
List any management units (e.g., properties, fields, or groups of fields) that are relevant to your farm or project area.

Management goals—
List the management goals for the farm or project area (Box 4.2: Goals and Objectives). These may include short- and long-term goals for products or services provided from the land, business profitability, and or stewardship of natural resources.

Management objectives—
List any management objectives for the farm or project area (Box 4.2: Goals and Objectives). These will explain how to achieve management goals. There may be multiple objectives for a single management goal.

Box 4.2

Goals and Objectives

Management goals—

Management goals are broad, general statements, usually not quantifiable, that express a desired state or outcome to achieve (table 4.1). They are often not attainable in the short term and provide the context for more specific objectives.

Management objectives—

Management objectives define specific, measurable, achievable, results-oriented, and time-bound actions needed to achieve desired outcomes expressed by the broad management goals. Objectives commonly include information on resources or methods to use, and they form the basis for further planning to define the precise steps to take.

Table 4.1—Examples of management goals and corresponding objectives

Management goal	Management objectives
Maintain and improve farm production and revenue.	Monitor herd health through annual veterinary checkups. Expand herd from 800 to 950 animals over the next 5 years.
Protect water quality and quantity of water in local streams, groundwater sources, and other waterbodies.	Reduce annual nitrogen load in runoff by 10 percent. Prevent annual soil erosion rates from exceeding tolerable loss on all cropland. Convert all highly erodible lands to perennial crops within 5 years. Improve water infiltration and soil moisture retention by increasing soil organic matter to 5 percent within 10 years.
Mitigate greenhouse gases.	Increase carbon sequestration in plants and soil organic matter by fertilizing perennial crops annually. Reduce annual nitrogen fertilizer use and associated nitrous oxide emissions by avoiding applications on wet soils and applying them as close to the period of crop uptake as possible. Receive economic benefits from a variety of carbon trading markets (USDA OCE, n.d.).

Time frames—
List approximate periods for achieving farm or project goals and objectives. As a default, identify the point in both the short term (within the next 5 years) and the long term (5 to 20 or more years) that you can use to consider and monitor how things may change over time.

Step 2: Assess Site-Specific Climate Change Impacts and Vulnerabilities

About This Step

Climate change will have a wide variety of negative and positive effects on agricultural production. For this reason, it is critical to not only think about the general (e.g., regional, or statewide) effects of a changing climate but also to consider how your farm and agricultural production system may be uniquely affected (see chapter 1).

In this step, you will consider broad-scale scientific information about the expected effects of climate change in your region by using vulnerability assessments or other published sources. After identifying these relatively general effects, you will use your expertise and experience to evaluate how climate change may affect your farm or project area. Because there is a great deal of variation among different locations, your understanding of specific local conditions will help you identify the more relevant response actions in later steps. Some of the things you will want to consider include soils, topography, past management, current infrastructure and equipment, current access to technology or markets, or other factors that increase or reduce the ability of the farm or project area to cope with change. Importantly, this step focuses on the effects of climate change on the farm or project area, whereas step 3 considers how management objectives may be affected.

Consider broad-scale scientific information about the expected effects of climate change in your region by using vulnerability assessments or other published sources.

Key Question 4.2:

- How might the area be uniquely affected by climate change?

Description of Workbook Items

Management unit—
Insert the management unit that you identified in step 1.

Regional climate change impacts and vulnerabilities—
Begin by creating a list of relevant climate change effects and vulnerabilities for the region or area that you are working in. You may also want to identify the source of this information. Some of it may be relevant to the entire farm, while other information may only apply to specific locations on the farm as identified in step 1.

Many resources on climate change effects and vulnerabilities exist, such as reports and peer-reviewed papers on climate change. Several regions and states have vulnerability assessments that provide this information for an entire area, as well as by sector.

Climate change impacts and vulnerabilities for the farm or project area—
As you consider the regional effects and vulnerabilities (above), draw upon your experience and knowledge to define the specific ways that your farm or project area may be affected by a changing climate (Box 4.3: Climate Change and Your Farm or Project Area). For example, a field may have greater vulnerability to anticipated increases in the frequency and intensity of storm events because of steeper slopes or less vegetative cover.

Box 4.3

Climate Change and Your Farm or Project Area

Most of the available information on the potential effects of climate change has likely been developed for spatial scales that are larger than your farm or project area. It is important to consider not only this broad-scale information but also how your location may be uniquely susceptible to these effects. Factors that may influence the risk to a specific location include the following:

- Landscape characteristics, such as topographic position, slope, or aspect
- Soil characteristics, including texture, nutrient levels, and organic matter content (see appendix)
- Management history
- Current management, land cover, or land use
- Presence of or susceptibility to pests, disease, or nonnative species that may become more problematic under future climate conditions

Step 3: Evaluate Management Objectives With Projected Changes and Vulnerabilities

About This Step

In earlier steps, you defined management goals and objectives for your farm or project area (step 1) and considered climate change effects and vulnerabilities for this area (step 2). In this step, you will identify management challenges and opportunities associated with climate change. You will also evaluate the feasibility of meeting your management objectives under current management and consider altering or refining them to account better for changes in climate.

Identify management challenges and opportunities associated with climate change.

Note: It is inevitable that discussion will jump ahead at times to identifying approaches or developing tactics that can help agriculture cope with the anticipated effects. Rather than lose these ideas or skip critical steps in the process, be sure to record any ideas that will be useful in later steps.

Key Questions 4.3

- What management challenges or opportunities does climate change present?
- Can current management goals and objectives be met? Or do they need to change?
- What other considerations affect your decision?

Description of Workbook Items

Management unit—
Insert the management unit(s) that you identified in step 1.

Management objectives—
Insert the management objectives that you identified in step 1.

Challenges to meeting management objectives with climate change—
List ways in which climate change effects and associated site-specific vulnerabilities may make it more difficult to achieve each management objective. For example, warmer conditions may limit the ability to bring a specific product to market economically. Focus on concerns related to on-farm challenges. Other considerations (e.g., insurance, government programs) will be included later in this step.

Opportunities for meeting management objectives with climate change—
List ways in which climate change effects and associated vulnerabilities may make it easier to achieve each management objective or create new management opportunities. For example, longer growing seasons may increase the opportunity for more production. Focus on farm challenges, because other considerations (e.g., insurance, government programs) will be included later in this step.

Feasibility of meeting management objectives under current management—
Consider how the challenges and opportunities that you have identified may affect the feasibility of meeting objectives by using actions within the current management trajectory (i.e., without intentional climate change adaptation). Consider the following levels of feasibility for individual or multiple time frames (e.g., short term versus long term):

- High: existing management options can be used to overcome the challenges for meeting management objectives under climate change. Opportunities likely outweigh challenges.
- Moderate: some challenges to meeting management objectives under climate change have been identified, but these can likely be overcome by using existing management options. Additional resources or enhanced efforts may be necessary to counteract key challenges or promote new opportunities.
- Low: existing management options may be insufficient to overcome challenges to meeting management objectives under climate change. Additional resources or enhanced efforts will be necessary to counteract key challenges or promote new opportunities.

Other considerations—
List any other considerations that you may have, such as social, financial, administrative, or other factors that are part of your decision to pursue or change your management objectives but that may not be within the purview of farm-level decision making.

Slow Down to Consider

Climate change may make some management goals and objectives more difficult to achieve in the future, and there may be situations in which they need to be altered or refined to better account for anticipated climate change effects. After completing the above step-3 workbook items, you may have a much better idea about whether your management objectives are feasible, given the current management options that are available to you. You have also identified social, economic, or other considerations that may affect your decision to pursue certain management objectives.

Are you going to continue with the management objectives you have identified?—If you have high feasibility of meeting your management objectives and these objectives are still sound, given projected climate changes, you can proceed to step 4 to explore adaptation actions.

If some or all of your management objectives have moderate or low feasibility, or if they no longer seem sensible under climate change (e.g., managing a crop that may not be viable in the long term), you may reconsider your management objectives or your broader management goals. You can record any potential issues or changes in the "Other considerations" section of the above step-3 workbook items, or return to step 1 to alter your management goals and objectives. Use the information that you have gathered up to this point to create goals and objectives that are more likely to succeed, given projected climate changes.

Step 4: Identify Adaptation Approaches and Tactics for Implementation

About This Step

To address the challenges or opportunities brought about by climate change, it may be necessary to adjust existing practices, try completely new ones, or start a new system. This step helps you identify and evaluate specific actions that can help prepare for changing conditions, given the challenges and opportunities that were identified in step 3. In doing this, you will generate a custom set of adaptation **tactics**—prescriptive actions specifically designed for your farm or project area and your unique management objectives.

Key Question 4.4

- What actions can enhance the ability of your property or project area to adapt to anticipated changes and meet management goals?

The step also helps you create a clear rationale for your suggested tactics by connecting them to broader adaptation ideas. Chapter 3 contains a menu of adaptation strategies and approaches (Box 3.2: Adaptation Strategies and Approaches) for agriculture. As you brainstorm and evaluate ideas for adaptation tactics, you will also link these specific ideas to the list of more general adaptation strategies and approaches. These links will provide important context and rationale to justify your adaptation tactics. If you need help brainstorming specific adaptation tactics, you can use these adaptation strategies and approaches as a springboard to develop specific tactics that can help achieve your management objectives.

Description of Workbook Items

Management unit—

Insert the management unit(s) that you identified in step 1.

Adaptation actions—

- Adaptation strategies and approaches: review the adaptation strategies and approaches (chapter 3), and select any strategies and approaches that you think may be applicable. Also, include any additional approaches that you devise.
- Adaptation tactics: describe specific actions that you can take on your farm or project area by using your own or your advisor's experience and expertise.

Because adaptation strategies and approaches provide long-range context for specific tactics that will be implemented, we encourage you to identify both; however, you may find it easier to list tactics first and then go back to identify the corresponding strategies and approaches (fig. 4.2).

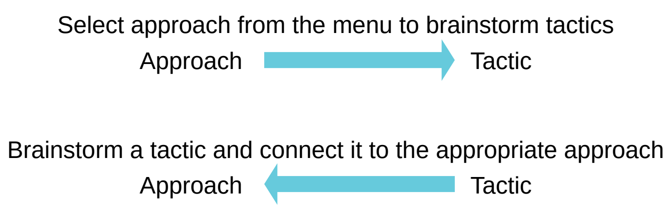

Figure 4.2—This sequence is flexible. Start with approaches or tactics, but be sure to relate them to each other.

Time frame(s)—

List the approximate time frame(s) in which the new tactics would be implemented. The nature of the action can help determine an appropriate time frame. Some actions may occur in the short term (i.e., the next 5 years), whereas others may not occur for several decades or will occur only in certain situations (such as after a large storm event).

Benefits—

List any benefits associated with each tactic. For example, note if a tactic addresses your biggest challenge, addresses multiple challenges, or has a side benefit, such as improving overall ecosystem health.

Drawbacks and barriers—

For each tactic, list any drawbacks that may arise, such as negative ecosystem effects, or any barriers to implementing the tactic, including legal, financial, infrastructural, social, or physical barriers.

Effectiveness and feasibility of tactics—
An adaptation tactic is practicable if it is both effective (it will meet the desired intent) and feasible (it is capable of being implemented). Both characteristics increase the likelihood of success. Consider the benefits, drawbacks, and barriers associated with each tactic to determine which of the following levels of practicability to use to meet your management goals and objectives:

- High: the tactic is expected to be both effective and feasible. Benefits of the tactic clearly outweigh drawbacks and barriers.
- Moderate: there are drawbacks or barriers that could reduce the effectiveness or feasibility of the tactic. Some drawbacks or barriers may be overcome through other adaptation tactics or management actions.
- Low: the tactic does not appear to be effective or feasible. The drawbacks and barriers are too great to overcome, or the benefits are too small relative to the required effort. The tactic may need adjustment to improve effectiveness or feasibility.

An adaptation tactic is practicable if it is both effective (it will meet the desired intent) and feasible (it is capable of being implemented).

Recommend tactic(s)—
For service providers and educators, consider the time frame, benefits, drawbacks, barriers, and practicability for each tactic, and select the tactic(s) that you recommend for consideration in future management decisions. Identify tactics that overcome or avoid challenges, have high practicability, or have major benefits.
For each tactic, determine if you would recommend it for consideration in future management decisions, and select one of the following:

- Yes: this tactic will likely be helpful in overcoming management challenges from climate change and meeting management objectives, and it is encouraged to be considered in future management decisions. If needed, note any barriers that need to be overcome to use this tactic.
- No: this tactic is not helpful, and it is not recommended for current consideration in future management activities.

As you determine which tactics to recommend, consider how they work together as a set of actions. The goal is to identify a set of actions that are complementary and help to overcome the barriers identified in the previous step to achieve your management goals and objectives.

Step 5: Monitor and Evaluate Effectiveness of Implemented Actions

About This Step

Monitoring is critical for understanding what changes are occurring from climate change as well as whether selected actions were effective in meeting management goals and adapting your farm to future conditions. This step helps to identify metrics that will be used to monitor whether management goals are achieved in the future and to determine whether the recommended management tactics were effective. The outcome of this step is a realistic and feasible monitoring scheme that can be used to help determine whether management could be altered in the future to account for new information and observations.

Consider what existing monitoring information is available (such as farm records) and if it needs to be modified to better monitor the results of your adaptation actions. Also, consider what new monitoring items you may need to evaluate whether you have met your management goals.

Monitoring is critical for understanding what changes are occurring from climate change and if selected actions were effective in meeting management goals and adapting your farm to future conditions.

Description of Workbook Items

Management unit—
Insert the management unit(s) that you identified in step 1.

Adaptation monitoring variable—
Identify monitoring items that will be used to evaluate whether you have achieved your management objectives and goals, or whether you have achieved a milestone that indicates that you are working toward your goal. When possible, select monitoring items that will also help you understand whether the adaptation tactics recommended in the previous step were effective in working toward your management goals under climate change.

Criteria for evaluation—
Identify a value or threshold that is meaningful for this monitoring item.

Monitoring implementation—
Describe how and when this information will be gathered.

Next Steps

The previous steps in this adaptation workbook help you consider the effects of climate change on your farm or project area, and identify management tactics and monitoring efforts to help you meet your management objectives under those effects. Once you have completed steps toward improving the ability of your farm or project area to adapt to the anticipated effects of climate change, you can work to add the information from the workbook, especially steps 4 and 5, into existing management plans and decision-making processes.

As you work to add this information to your existing plans, it is important to keep in mind that the tactics you identified by completing this adaptation workbook have been recommended for further consideration (step 4). Taking this step does not necessarily mean, however, that the tactics must be implemented or that the recommendations must replace other considerations. The workbook is designed to lead you through a process for considering climate change, and it is up to you and your organization to determine the ways in which you will use the information and ideas you have developed.

Finally, this workbook is designed as part of an adaptive management process, which, by definition, needs to be able to incorporate new information as it becomes available. When developing a plan to implement your adaptation tactics, and when monitoring the results, also revisit this workbook as often as necessary to evaluate whether any changes are needed to your management strategy. Consult with experts whenever possible to gather new information and further refine your management decisions. As new information becomes available through scientific research, monitoring activities, or other avenues, use that information to consider how it may change your expectations regarding future conditions and whether it is appropriate to adjust your management or monitoring to help the systems adapt to a changing climate.

Adaptation Workbook Worksheets

Worksheet # 4.1: **Define** your key management goals and objectives, project location, and most valued resources.

Worksheet # 4.2: **Assess** how climate change may affect your operation by evaluating site-specific climate change effects. Also note how vulnerable the project area is to climate change (low: some potential change, moderate: expected impacts within normal variability, or high: climate change impacts will exceed project/operation/ecosystem's capability to handle these challenges).

Worksheet # 4.3: **Evaluate** management objectives given projected changes and vulnerabilities. Consider how the climate impacts identified above may lead to challenges or opportunities for the management of your operation. Identify the feasibility of your objectives: Do they have high (we can do it!), medium (possible with a little effort), or low feasibility (we'll need more resources, information, or effort to achieve these objectives)?

Worksheet # 4.4: **Identify** adaptation approaches and tactics for implementation. Consider these questions: What are you already doing that is even more important because of climate change? What possible small improvements can be made to existing actions to limit impacts of climate change? Do you have any wild and crazy ideas or thoughts on major changes to the way things are done now to build a more resilient operation?

Worksheet # 4.5: **Monitor** and evaluate effectiveness of implemented actions. Consider how you will evaluate whether your management actions achieved the desired goals.

Acknowledgments

This chapter was adapted from Janowiak et al. 2016.

References

Janowiak, M.; Dostie, D.; Wilson, M.; Kucera, M.; Skinner, R.H.; Hatfield, J.; Hollinger, D.; Swanston, C. 2016. Adaptation resources for agriculture: responding to climate variability and change in the Midwest and Northeast. Tech. Bull. 1944. Washington, DC: U.S. Department of Agriculture. 70 p. https://www.climatehubs.usda.gov/sites/default/files/adaptation_resources_workbook_ne_mw.pdf.

Swanston, C.W.; Janowiak, M.K.; Brandt, L.A.; Butler, P.R.; Handler, S.D.; Shannon, P.D.; Lewis, A.D.; Hall, K.; Fahey, R.T.; Scott, L.; Kerber, A.; Miesbauer, J.W.; Darling, L.; Parker, L.; St. Pierre, M. 2016. Forest adaptation resources: climate change tools and approaches for land managers. Gen. Tech. Rep. NRS-GTR-87-2. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 161 p. https://doi.org/10.2737/NRS-GTR-87-2.

U.S. Department of Agriculture, Office of the Chief Economist [USDA OCE]. [N.d.] Carbon. https://www.usda.gov/oce/energy-and-environment/markets/carbon. (10 November 2021).

Worksheet 4.1: Define management goals and objectives, including your key goals and objectives, project location, and most valued resource (management unit).

Farm or project area:

Location:

Management unit	Management goals	Management objectives	Time frames

Worksheet 4.2: Assess how climate change may affect your operation by evaluating site-specific climate change effects. Also note how vulnerable the project area is to climate change (low: some potential change, moderate: expected impacts within normal variability, or high: climate change impacts will exceed the project/operation/ecosystem's abilities to handle these challenges).

Management unit (from step 1)	Regional climate change impacts and vulnerabilities	Climate change impacts and vulnerabilities for your farm or project area
	☐ Longer growing season	
	☐ Increases in invasive plant species	
	☐ Increases in pests	
	☐ Increases in pathogens	
	☐ Increases in seasonal temperatures	
	☐ Increases in seasonal precipitation	
	☐ Decreases in seasonal precipitation	
	☐ Increases in the frequency and intensity of seasonal flooding	
	☐ Decreases in summer soil moisture	
	☐ Decreases in summer/early fall streamflow	
	☐ Decrease in glacial water inputs	
	☐ Decreases in seasonal snowpack	
	☐ Decreases and changes in permafrost	
	☐ Fewer days with extreme cold	
	☐ More days with extreme heat	
	☐ Increased risk of wildfire and smoke	
	☐ Increased frequency and intensity of extreme wind events	
	☐ Increased frequency and intensity of extreme precipitation events	
	☐ Increased frequency of drought	
	☐ Shifts in successful plant species	
	☐ Shifts in successful livestock/aquaculture species	

Worksheet 4.3: Evaluate management objectives with projected changes and vulnerabilities. Consider how the climate impacts identified in worksheet 4.2 may create challenges or opportunities for the management of your operation. Identify whether your objectives have high (we can do it!), medium (possible with a little effort), or low (we will need more resources or effort) feasibility.

Management unit (from step 1)	Management objectives (from step 1)	Challenges to meeting management objective with climate change	Opportunities for meeting management objective with climate change	Feasibility of objectives under current management	Other considerations

Worksheet 4.4: Identify adaptation approaches and tactics for implementation. What are you already doing that is even more important because of climate change? What possible small improvements can be made to these existing actions? Do you have any wild and crazy ideas or thoughts on major changes to the way things are done now?

Management unit (from step 1)	Adaptation actions		Time frames	Benefits	Drawbacks and barriers	Effectiveness and feasibility of tactic	Recommend tactic?
	Approach	Tactic					

Worksheet 4.5: Monitor and evaluate effectiveness of implemented actions. Consider what you could monitor to evaluate if your management actions achieve the desired goals.

Management unit (from step 1)	Adaptation monitoring variable	Criteria for evaluation	Monitoring implementation

Chapter 5: Adaptation Workbook Case Studies

Paris Edwards, Joan Howard, Miho Morimoto, and Holly R. Prendeville[1]

This chapter illustrates how the adaptation strategies and approaches (chapter 3) and the adaptation workbook (chapter 4) can be used together to translate broad-scale climate change information into specific actions to adapt to changing conditions while meeting goals for productivity, profitability, and stewardship. Examples of adaptation approaches on farms in south-central Alaska show some of the ways producers are working to minimize negative effects and maximize potential benefits from changing climate conditions (fig. 5.1). Keep in mind that the content provided by these case studies reflects farmers' experiences and planning processes that are specific to their location and land.

Examples of adaptation approaches on farms in south-central Alaska show some of the ways producers are working to minimize negative effects and maximize potential benefits from changing climate conditions.

Case Study 1: Palmer, Alaska—Bushes Bunches Produce Stand

Step 1: Define Management Goals and Objectives

Bushes Bunches Produce Stand, a family-owned business that has operated in Palmer and neighboring Wasilla and Anchorage since 1954, applied the five-step adaptation workbook process (chapter 4). The 14-acre farm produces table and seedstock potatoes and other vegetable crops, including its popular rhubarb and Bushes Peanut Potato (fig. 5.2). Bushes Bunches Produce Stand manages several farm-related businesses, including a retail shop for produce and dry goods sales, a winter produce market, online and wholesale produce sales to restaurants and others, and a booth at the annual Alaska State Fair. The business worked with the USDA Natural Resources Conservation Service (NRCS) Alaska State Office (USDA NRCS, n.d.), and the Northwest Climate Hub to use the adaptation workbook process and consider how climate change might affect the activities occurring on the farm over the next several decades and beyond.

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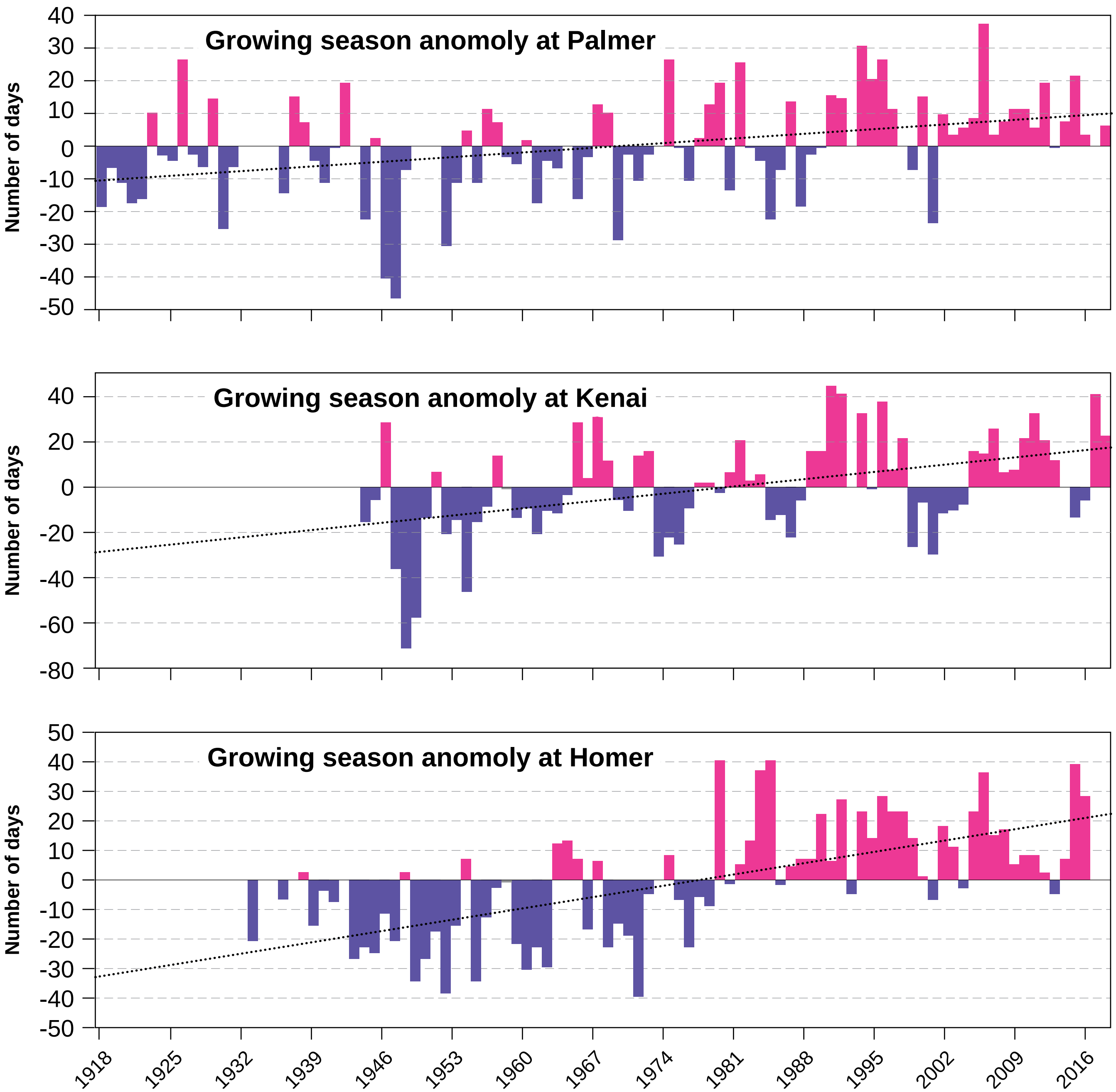

Figure 5.1—Growing season differences (anomaly or deviation) from the long-term average for Homer, Kenai, and Palmer weather stations from 1918 to 2017. Data availability at each weather station varied, but long-term mean temperatures include all available data at each weather station (Palmer: 1918–2017, Kenai: 1944–2017, Homer: 1933–2017). The take-home message is that each location has more growing days since the 1980s.

Figure 5.2—Bushes Bunches Produce Stand produces and sells a variety of vegetables including rhubarb, originally planted in the 1950s. As temperatures increase and the growing season extends, they are considering growing more and different varieties of vegetables.

In 2018, the main management goal for the operation was to expand production, particularly for potatoes and rhubarb. Bushes Bunches Produce Stand planned to add new produce stand locations in Wasilla, expand current retail sales, and increase sales to restaurants and at the Alaska State Fair. To reach these goals, they were seeking more land to increase production, planning for additional irrigation infrastructure in dry-soil areas, and planning to build a new potato-washing shed and barn to accommodate expanded yields (fig. 5.3). Bushes Bunches Produce Stand also planned to expand its Palmer retail location and continue to increase value-added products, such as seasonal rhubarb lemonade and meal-prepared produce. The retail locations sell a variety of produce from other farms to help draw customers and meet demand across businesses (table 5.1).

Bushes Bunches Produce Stand has developed a long list of adaptation approaches and adoption strategies for their operation, with a focus on potato production. To improve and maintain soil health, they are considering fallowing potato fields every 3 years to cover crop with an oat and pea combination. Even though taking the fields out of production is perceived to have potential short-term financial

USDA Natural Resources Conservation Service

Figure 5.3—Drip irrigation on a peony farm. Drip irrigation improves on-farm water conservation by increasing water use efficiency and reducing soil erosion, fertilizer use, and nutrient loss.

Table 5.1—Farm management goals and objectives for Bushes Bunches Produce Stand, south-central Alaska

Farm: Bushes Bunches Produce Stand
Location: About 4 mi (6.4 km) east of downtown Palmer, Alaska

Management unit	Management goals	Management objectives	Time frames
Potatoes	Manage existing space and clear more land	Expand potato production Build a new wash shed/potato barn and expand store	Current to future
Rhubarb	Continue growing and expanding rhubarb for sale and expand the market for rhubarb juice	Expand rhubarb next year	1 to 2 years
Vegetable crops: zucchini, squash, cabbage, beets, turnips, berries	Expand processing facilities for preserving vegetable and potential future fruit crops	Increase value-added products for retail store	Current to future

drawbacks, NRCS promotes cover cropping because of its nutrient-adding potential that builds long-term soil resilience and improves water-holding capacity.

As air and soil temperatures warm and the growing season lengthens, additional irrigation needs are anticipated across the farm. To conserve water and build resilience in anticipation of increased demand on water resources, Bushes Bunches Produce Stand is considering implementing drip irrigation (fig. 5.3). Although this approach requires time and financial investment, providing direct water contact to the plants will allow the farm to continue growing water-intensive crops like squash and rhubarb.

Step 2: Assess Site-Specific Climate Change Impacts and Vulnerabilities

Vulnerability assessments provide useful information about the anticipated effects of climate change for a region. This information was combined with knowledge of the local landscape, including actual effects, to identify attributes of the property that would make it more or less vulnerable to climate change than the region as a whole (see chapter 1).

Climate change effects are evident and expected to increase on the farm in several ways. Population growth in areas surrounding the farm is evident, increasing the potential to expand existing markets, but also increasing land prices and reducing land availability. At the same time, the trends toward an extended growing season, warmer winters, and earlier springs are advantageous to earlier spring planting dates and overall production potential. In the recent past, the farm has experienced more sunny days during the year, shorter and warmer winters, and earlier spring snowmelt. These changes come with the advantages of longer growing seasons and larger sized produce, but they also come with the disadvantages of increased pest and pathogen potential and plant stress that lead to bolting, particularly for its radish and turnip crops. Some of the recent challenges Bushes Bunches Produce Stand has faced include an increase in slugs and the presence of chickweed, an invasive species (table 5.2). Moose have also become a more frequent problem, which could be an indirect result of climate change affecting the timing and abundance of food availability for local wildlife, along with the predisposition of moose to train their young where to find available food sources, according to Bushes Bunches Produce Stand.

Table 5.2—Site-specific climate change impacts: challenges, opportunities, and feasibility of meeting current management objectives, given projected changes and risks for Bushes Bunches Produce Stand

Management objective (step #1)	Challenges to meeting objective with climate change	Opportunities for meeting objective with climate change	Feasibility under current management	Other considerations
Prepare peanut potatoes for Alaska State Fair	Waiting to plant, which depends upon the last frost date	Fine-tune potato harvest timing in response to longer summers; may include delaying the timing of digging and selling potatoes	High: this strategy is in place and has been working	None
Weed control and crop rotation	Ensure enough space to grow potatoes and crops	Potatoes are sprayed to keep weeds out of row crops	High: spraying has been effective	Fewer slugs in rhubarb Ground is warmer Culls of potato “weeds” protect soil in rows that are not growing potatoes
Irrigate dry soils	Squash and rhubarb need a lot of water	Potatoes: peanut potatoes stay small for market and fair	Medium	Using T-tape for direct water contact to plant

Step 3: Evaluate Management Objectives With Projected Changes and Vulnerabilities

Climate change is expected to create both challenges and benefits to productivity for Bushes Bunches Produce Stand (chapter 1). A top priority for the operation was the preparation of peanut potatoes (a cross between Yukon gold and fingerling potatoes) for the Alaska State Fair. Their approach has been to plant and harvest as late as possible, remaining flexible based on the variability in timing of the last spring frost and the prolonged summer growing potential. Additional management objectives include weed control, which is currently done by spraying the potato crop and rotating a variety of vegetables sold at market. These approaches have led to a noticeable decrease of slug damage to the rhubarb crop. As air and soil temperatures warm and the growing season lengthens, additional irrigation needs are anticipated. To conserve water and build resilience in anticipation of increased demand on water resources, Bushes Bunches Produce Stand is considering implementing drip irrigation. Although this approach requires time and financial investment, providing direct water contact to the plants will allow the farm to grow water-intensive crops like squash and rhubarb more efficiently.

Their approach has been to plant and harvest as late as possible, remaining flexible based on the variability in timing of the last spring frost and the prolonged summer growing potential.

Step 4: Identify Adaptation Approaches and Tactics for Implementation

Bushes Bunches Produce Stand developed a long list of adaptation approaches and strategies with a focus on potato production. To improve and maintain soil health, the farm considered fallowing potato fields every 3 years to cover crop with an oat and pea combination. Taking the fields out of production is often perceived to have potential short-term financial drawbacks; however, cover cropping has nutrient-adding potential that builds long-term soil resilience and improves water-holding capacity (table 5.3).

Table 5.3—Adaptation approaches and tactics for implementation for Bushes Bunches Produce Stand

Adaptation actions						
Approach[a]	Tactic	Time frames	Benefits	Drawbacks and barriers	Effectiveness and feasibility	Recommend tactic?
Approach 1.1: maintain and improve soil health	Cover crops: oats/ peas	Current	Increases nutrients for potatoes	Land is out of production	High: not used every year	Yes
Approach 1.2: protect water quality	Use groundwater because of potential water quality issues from nearby development	Current	Groundwater is less susceptible to contamination than nearby surface sources	This works as long as well continues to function	High	Yes
Approach 1.3: match practices to water supply and demand	Well improvements	Current	Meets irrigation needs and protects crops	Higher electricity costs to run well pump	High	Yes
Approach 2.1: reduce the effects of pests and pathogens on crops	Spray use nets to control flies	Current	Controls insects Keeps plants warm Reduces need to spray squash	Shipping costs Trapping heat with nets	Medium: insects inhibit plant growth	Yes
Approach 2.2: reduce competition with weeds and invasive species	Spray and fine netting	Current	Controls weeds	Cost of netting and fewer chemicals on hand	High: some chemicals are available	Yes
Strategy 5: manage farms and fields as part of a larger landscape	Lease land	Current	More land to grow crops to sell at produce stand	Increases in development are reducing land available	Medium	Yes
Approach 3.1: adjust the timing or location of on-farm activities	Irrigate and get crops up faster	Current	First to have produce to sell Irrigation increases squash season by a month	Short growing season Equipment and shipping expenses	High	Yes
Approach 4.1: reduce peakflow, runoff velocity, and soil erosion.	Use compost from potato processing Cover cropping	Current	Build up soil	Reduces space for market crops Hard to get soil back to conditions before harvest	High	Yes
Approach 6.1: diversify crop or livestock species, varieties or breeds, or products	Use more crop varieties, such as raspberries	1 to 2 years	More varieties to sell at produce stand	None	High	Yes
Approach 6.3: switch to commodities suited to future conditions	Use processing plants	3 to 5 years	More processing plants for jellies, jams, and pickling	Applications: submitting and waiting for permits	Low	Yes

[a] See chapter 3.

Additional on-farm adaptation strategies at Bushes Bunches Produce Stand include:

- Protecting water quality by switching to groundwater sources
- Spraying and using fine netting (45–90 m sheets of Reemay, a spun bonded polyester product) to protect crops from pests, pathogens, weeds, and invasive species
- Improving soil health by cover cropping and adding composted potato waste to soils
- Increasing crop diversity, including berries, to sell at retail
- Developing long-term plans to process and preserve more produce to prolong sale value

Step 5: Monitor and Evaluate Effectiveness of Implemented Actions

As adaptation tactics are implemented, it will be critical to evaluate whether they have their intended effect and help to meet farming objectives in a changing climate (table 5.4). Bushes Bunches Produce Stand, in collaboration with University of Alaska Fairbanks Cooperation Extension Service, is conducting trials to examine ideal varieties of potatoes and other vegetables under changing climate conditions in south-central Alaska.

In many situations, the current system of recording farm activities and production can be used to provide information about the effectiveness of the adaptation actions. For example, as management changes, crop yields can be compared to past yields (10-year time frame or longer) to see if they stay the same or increase. Likewise, on-farm crop yields can be compared to county or local averages to evaluate the performance of the farm relative to neighboring farms, particularly those with similar soils and management history. Record and monitor the effects of management adjustments, such as the severity or extent of soil erosion or runoff occurring after a high-intensity rainfall event (e.g., 2 inches [50 mm]) after cover crops are established.

Table 5.4—Potential monitoring activities to evaluate the effectiveness of actions for Bushes Bunches Produce Stand

Monitoring item	Criteria for evaluation	Monitoring implementation
Variety trials	Potatoes and other vegetables	Examine success under changing climate conditions

Case study 2: Kenai, Alaska—Ridgeway Farms

Step 1: Define Management Goals and Objectives

Ridgeway Farms is an original homestead, family farm currently owned by Abby Ala, located 8 mi (13 km) east of the city of Kenai and is part of the Kenai Peninsula farming community. Four generations of Abby Ala's family have been working the land since 1948. Currently, it generates most of the farm's income from fruit and vegetable production for a Community Supported Agriculture (CSA) group. The main farm includes 35 ac (14 ha) of land in vegetable production and horse pasture, 35 ac (14 ha) of on-farm hayfields, and an additional 20 ac (8.1 ha) in hay production nearby. The farm primarily produces and sells Timothy hay and offers horseback riding lessons in addition to limited boarding.

As of 2018, one of Ridgeway Farms' primary management goals is to increase CSA membership from 51 to 70 and support additional restaurants (table 5.5). Vegetables for the CSA are primarily produced by using 14 high tunnels and interspersed, small gardens. Ridgeway Farms uses hydroponic systems and single-crop rotation and modifies its selection of vegetable and fruit plants yearly to maintain production from April to August. The operation aims to grow and produce a variety of vegetable and fruit crops for a 4-month period to help increase revenue from

Table 5.5—Farm management goals and objectives for Ridgeway Farms, south-central Alaska

Management unit	Management goals	Management objectives	Time frames
20-ac hayfield that yields 1,000 bales of hay per cutting	Turn over hay production and farm to the next generation	Increase hay production because of the potential for a longer growing season may lead to more than one cutting per cycle	Gradual: transition
15-ac hayfield Engmo variety of Timothy hay that yields 200 to 350 bales per cutting	Turn over hay production and farm to the next generation	Increase hay production because of the potential for a longer growing season may lead to more than one cutting per cycle	Gradual: transition
7 pastures with 9 horses, 3 cows, 7 pigs, and free-roaming chickens	Increase quality of pasture	Increase pasture rotation by splitting and making pastures smaller using electric fencing to help in pasture rotation and pasture health	Ongoing: dividing pastures now
14 high tunnels for growing vegetable and fruit crops	Grow a variety of vegetable and fruit crops and have at least 4 months of crops for community-supported agriculture production	Use and increase hydroponics systems and single crop rotation, and increase varieties of vegetable and fruit plants to grow through spring and fall	Gradual: transition to next generation
1 acre (outdoor) for potato crops	Grow potatoes and possibly other vegetable as temperatures increase	Use ground to grow root crops	Gradual: transition to next generation

crops for CSA production. To help do this, the farm is working with NRCS-Alaska (USDA NRCS, n.d.) to increase existing high tunnels, hydroponics, and irrigation systems, and planning the future installation of a new well to help with irrigation water pressure.

Ridgeway Farms is a primary source of Timothy hay (Engmo variety) for the Kenai Peninsula, producing one cutting of hay per growing season across two land parcels. Another goal of the operation is to increase annual hay production, with the potential for more than one cutting if a longer growing season occurs. To increase pasture quality and rotational grazing on seven, small pastures, the farm is working with NRCS to increase soil organic matter by spreading composted manure and splitting pastures into smaller field systems using electric fencing.

Step 2: Assess Site-Specific Climate Change Impacts and Vulnerabilities

Across the region, average winter temperatures are expected to increase by 3.0 to 3.5 °C (Markon et al. 2018). Changes in precipitation are uncertain but expected shifts from a snow- to a rain-dominated pattern will have broad effects to the timing and quantity of water resources. As a result of changes and increased variability of seasonal temperature and precipitation, several related opportunities and challenges are expected at Ridgeway Farms:

- Higher quality hay production may be possible with less precipitation and fewer cloudy days
- Winters with increased freeze-thaw can create more ice and damage to outdoor plants as periods of thaw reduce snow insulation exposing plants to freezing temperature once they return, rather than remaining covered in snow throughout the winter.
- Increases in pests and pathogens, specifically slugs on this site
- Increases in nonnative plants, most notably fireweed at this site

Step 3: Evaluate Management Objectives with Projected Changes and Vulnerabilities

Ridgeway Farms identified several management challenges and opportunities because of anticipated changes in climate (table 5.6). According to Abby Ala, the farm has recently experienced warmer winters and earlier springs, which can be advantageous for earlier spring planting dates. The warmer winters are resulting in less snow cover that can lead to greater damage of overwintering vegetation because of the lack of insulating snow cover. The longer growing season and

The farm has recently experienced warmer winters and earlier springs, which can be advantageous for earlier spring planting dates.

Table 5.6—Select climate change-related challenges, opportunities, and feasibility of meeting current management objectives, given projected changes and risks for Ridgeway Farms

Management Unit	Management objectives	Challenges to meeting objective with climate change	Opportunities for meeting objective with climate change	Feasibility of objectives under current management
Hayfields	Pass on hayfields to third-generation family ownership (son), and keep producing hay	Weed-free hayfields	A good chance to go from one to two cuttings per year due to less drizzle, per availability of equipment	High
Pasture	Increase pasture rotation and improve pasture quality	Increased intensity of new and existing weeds	Keep horses on grass longer and decrease hay needs	High
14 high tunnels	Grow a variety of crops, and have at least 4 months of crops for community-supported agriculture production	Hotter summers increase need to vent hoop houses Use of IRT[a] plastic for planting	Increase community-supported agricultural business More vegetable varieties to sell Use of black pipe for irrigation (less freeze potential)	High
Outside garden	Grow potatoes Expand variety of vegetables as temperatures increase	Equipment needs Increase in weed intensity New noxious and invasive weeds	Better weather conditions for vegetables Longer growing season for outside vegetable production	High: can rent equipment from Soil & Water Conservation District

[a] IRT = infrared transmitting.

warmer summers have enabled the expansion of garden varieties but have also resulted in an increase of pests, pathogens, and invasive plant species previously not seen on the farm. Expected future climate challenges include an increased intensity of common weeds and new invasive species, which could be detrimental to the goal of producing high-quality hay. Ala expects that weeds will also be an issue, with the expectation of new invasive species. Some of the strategies to overcome challenges include increased mowing and rotation of pastures, with the drawbacks of the time spent mowing pastures and the cost of fencing. Potential opportunities from climatic change include an increase in grazing days for livestock and the accompanied decrease in hay needs. There may also be an opportunity to gain a second hay cutting each year. Under warmer conditions, the continued use of high tunnels will expand the growing season and increase production. Warmer conditions throughout the year may allow for use of black irrigation pipe that can absorb daytime warmth during winter days and thus avoid freezing overnight. Outside vegetable production may also benefit from warmer summers that help to lengthen the growing season.

Step 4: Identify Adaptation Approaches and Tactics for Implementation

Several adaptation strategies, approaches, and tactics can help this farm respond to identified adverse climate change effects and achieve its current goals as well as take advantage of potential opportunities (table 5.7). Planned on-farm adaptation actions at Ridgeway Farms include:

- Improving soil health by incorporating composted manure on pastures and using cover crops on outdoor gardens
- Reducing weeds and invasive species on pastureland with rotation and mowing
- Reducing weeds and invasive species in high tunnels by using infrared transmitting plastic mulch
- Reducing pests and pathogens in high tunnels by disinfecting annually
- Increasing species diversity across the farm (pastures and high tunnels) with warmer weather adapted varieties

Step 5: Monitor and Evaluate Effectiveness of Implemented Actions

Ongoing monitoring will be essential to maximize the long-term success of adaptation efforts at Ridgeway Farms. Finer scale nutrient management planning for each unit (e.g., hoop house) can help facilitate long-term soil health objectives. Recording daily air and soil temperatures outdoors and in greenhouses will help optimize plant variety choices and timing of planting (table 5.8).

Table 5.7—Adaptation approaches and tactics for implementation for Ridgeway Farms

Unit	Adaptation action	Tactic	Time frame	Benefits	Drawbacks and barriers	Effectiveness and feasibility	Recommend tactic?
Pasture	Approach 1.1: maintain and improve soil health	Decrease fertilizer cost by using composted manure	Current	Decrease fertilizer costs	Increase in weeds from feeds with seed from other areas	High	Yes
Pasture	Approach 2.2: reduce competition from weedy and invasive species	Increase mowing and rotation of pastures	Current	Reduce invasive weeds from expanding	Time to mow pastures	High	Yes
Pasture	Approach 7.3: alter lands in agricultural production	Rotate pastures	Current	Reduce invasive weeds from expanding, and increase pasture production	Cost of new fencing	High	Yes
Hoop houses	Approach 1.1: maintain and improve soil health	Cover crops	1 to 5 years	Decrease fertilizer costs and increase organic matter	Taking hoop house out of production	Medium	Not certain of varieties due to warmer temperatures
Hoop houses	Approach 1.3: match practices to water supply and demand	New well and pumps	1 to 5 years	Increase water pressure	Paperwork and cost	High	Increase in water usage, will require permit
Hoop houses	Approach 2.2: reduce competition from weedy and invasive species	Use IRT[a] plastic automatic watering, and polypropylene fabric between crop rows	1 to 5 years	Durability and soil-warming benefits	Costs	High	Yes
Hoop houses	Approach 3.1: adjust the timing or location of on-farm activities	Provide more varieties of vegetables to grow	1 to 5 years	Grow community-supported agriculture to goal of 100 subscribers	Cost of putting up more hoop houses and a new well	High	Need to evaluate costs
Hoop houses	Approach 6.3: switch to commodities expected to be better suited to future conditions	Select crops and different varieties of tomatoes and squash that can grow in warmer temperatures and a longer growing season	1 to 5 years	More varieties of crops to choose from for community-supported agriculture	No drawbacks, everyone is excited for the opportunity to grow different types of fruits and vegetables	High	Yes
Hoop houses	Approach 8.1: expand or improve water systems to match water demand and supply	New well, cover crops, black pipe to pump warmer water	1 to 5 years	Able to grow more vegetable crops	Cost of well	High	Yes
Outside garden	Approach 1.1: maintain and improve soil health	Use of compost horse/animal manure	Current	Decrease in fertilizer costs	None	High	Yes
Outside garden	Approach 8.2: use structures to increase environmental control for plant crops	Use cover crops and IRT[a] plastic to help increase soil temperatures	Current	Ability to grow cauliflower and start other vegetable crops sooner	Cost of IRT[a] plastic	High	Yes

[a] IRT = infrared transmitting.

Table 5.8—Potential monitoring items to evaluate the effectiveness of actions for Ridgeway Farms

Management unit (step #1)	Adaptation monitoring variable	Criteria for evaluation	Monitoring implementation
Entire farm	UAF CES[a] or USDA NRCS[b] planning-nutrient management plan	Soil temperature, air temperature in hoop houses (high and low), water use, fertilizer use, to-do list development that targets what to change	Nutrient management plan and whiteboard in each hoop house to monitor and record activities

[a] UAF CES = University of Alaska Fairbanks Cooperation Extension Service.
[b] USDA NRCS = U.S. Department of Agriculture, Natural Resources Conservation Service.

References

Markon, C.; Gray, S.; Berman, M.; Eerkes-Medrano, L.; Hennessy, T.; Huntington, H.; Littell, J.; Trainor, S. 2018. Alaska. In: Reidmiller, D.R.; Avery, C.W.; Easterling, D.R.; Kunkel, K.E.; Lewis, K.L.M.; Maycock, T.K.; Stewart, B.C., eds. Impacts, risks, and adaptation in the United States: fourth national climate assessment. Vol. II. Washington, DC: U.S. Global Change Research Program: 1185–1241. http://doi.org/10.7930/NCA4.2018.CH26.

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. [N.d.]. Welcome to NRCS field office technical guide (FOTG). https://efotg.sc.egov.usda.gov/#/details. (10 March 2021).

Glossary

adaptation (to climate change)—Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects that reduces vulnerability, moderates harm, or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation (IPCC 2018).

adaptive capacity—The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2018). This concept may be applied to natural or human systems (Smit and Wandel 2006).

adaptive management—A decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes advances scientific understanding and helps adjust policies or operations as part of an iterative learning process (Walthall et al. 2012).

climate—Average weather conditions in a given location over time. The classical period for averaging climatic variables as defined by the World Meteorological Organization is 30 years. Climate influences a wide range of long-term activities and strategic decisions, from the types of crops grown to the design and construction of buildings, water delivery systems, and other infrastructure (Walthall et al. 2012).

climate change—Statistically relevant changes in the mean state of climate or in its variability and that persist over extended periods of time, typically decades, centuries, or longer. Changes may occur because of natural variations or a combination of natural variation and human-induced variation (IPCC 2018).

climate variability—The inherent fluctuations or cyclical changes within the climate system beyond that of individual weather events. Variability may be due to natural internal processes within the climate system or variations in natural or anthropogenic external forcing (IPCC 2018).

effects (of climate change)—A change that is a result or consequence of climate change. The positive or negative effects of climate change on agricultural production can be classified as either direct, indirect, or cumulative. Direct effects refer to the biophysical effects of changing abiotic climate conditions on crop and livestock growth, development, and conditions (Walthall et al. 2012). Indirect effects include biotic effects, such as those related to insect, disease, and weed pressure, as well as induced effects on input resources (land, water, soil) and market-mediated effects on input and output prices. Indirect effects of climate change may amplify or counteract the direct effects of climate change.

impacts (of climate change)—See “effects.”

invasive (species)—An organism that quickly spreads and causes ecological or economic harm in a new environment where it is not native.

mitigation—With respect to climate change, an intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC 2018).

resilience—The capacity of a system to absorb disturbance and reorganize while undergoing change to retain essentially the same function, structure, identity, and feedbacks (IPCC 2018).

risk—The potential for adverse consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values (IPCC 2018).

uncertainty—A state of having limited knowledge where it is impossible to exactly describe the existing state, a future outcome, or more than one possible outcome (Walthall et al. 2012).

vulnerability—The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2018).

weather—The specific condition of the atmosphere at a particular place and time. It is measured as parameters, such as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation (Walthall et al. 2012). Weather influences short-term activities and tactical decisions like crop planting, grazing, irrigation management, timing of manure and other nutrient applications, timing of pest suppression, harvesting, etc.

weed—An unwanted plant.

References

Smit, B.; Wandel, J. 2006. Adaptation, adaptive capacity and vulnerability. Global environmental change. 16(3): 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008.

The Intergovernmental Panel on Climate Change [IPCC]. 2018. Annex I: Glossary. In: Matthews, J.B.R., ed. Global warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Geneva, Switzerland: World Meteorological Organization. 32 p. https://www.ipcc.ch/sr15/chapter/glossary.

Walthall, C.L.; Hatfield, J.; Backlund, P.; Lengnick, L.; Marshall, E.; Walsh, M.; Ziska, L.H. 2012. Climate change and agriculture in the United States: effects and adaptation. Tech. Bull. 1935. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service, Climate Change Program Office.. 186 p. https://www.usda.gov/sites/default/files/documents/CC%20and%20Agriculture%20Report%20(02-04-2013)b.pdf. (24 March 2022).

Appendix: Natural Resources Conservation Service Alaska Soil Climate Handbook

Dennis Mulligan, Denise Miller, and Cory Cole[1]

Soils have a wide range of characteristics that influence their potential for agricultural development (for soil data also see the Web Soil Survey [USDA NRCS 2020]). Having a thorough understanding of soil properties can help producers ensure maximum agricultural benefits while preserving soil integrity.

Soil scientists use several classification methods to communicate these soil properties, such as by using soil taxonomy. Soil taxonomy is a hierarchal classification system of naming that allows a clear sorting process of soils based on the interrelationships of soil moisture and temperature coupled with existing morphological, physical, and chemical properties of a soil. The levels of soil taxonomy (from broadest to most descriptive) are order, suborder, great group, subgroup, family, and series. For this report, we focus on the broadest level of soil taxonomy—order.

Another method used by scientists to describe soil properties is the land capability class (LCC) rating system. Soil scientists use soil characteristics such as texture, available water capacity, and drainage class to determine the soil LCC rating. The LCC system categorizes soils into eight classes by the degree of soil limitation for crops; the greater the number, the more limited the soil (USDA NRCS 2020).

- **Class 1** soils have slight limitations that restrict their use. Alaska has no class 1 soils owing to the cold climate and short growing season.
- **Class 2** soils have moderate limitations that restrict the choice of plants or require moderate conservation practices.
- **Class 3** soils have severe limitations that restrict the choice of plants or require special conservation practices, or both.
- **Class 4** soils have very severe limitations that restrict the choice of plants or require very careful management, or both.
- **Class 5** soils are subject to little or no erosion, but have other limitations, impractical to remove, that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat.
- **Class 6** soils have severe limitations that make them generally unsuitable for cultivation and that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat.

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- **Class 7** soils have very severe limitations that make them unsuitable for cultivation and that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat.
- **Class 8** non-soil and miscellaneous areas have limitations that preclude commercial plant production and that restrict their use to recreational purposes, wildlife habitat, watershed, or aesthetic purposes.

Additionally, the LCC system is divided into four subclasses: e, w, s, and c.

- Subclass "e" represents erosion. It indicates soils with a high susceptibility to erosion or soils with past erosion damage as the dominant limitation affecting their use.
- Subclass "w" represents water. It indicates soils where excess water, in situations such as poor soil drainage, wetness, a high-water table or overland flow, is the dominant limitation affecting their use.
- Subclass "s" represents soil zone. It indicates soils that have soil limitations within the rooting zone, such as shallowness of the rooting zone, stones, low moisture-holding capacity, low fertility, or salinity or sodium content.
- Subclass "c" represents climate. It indicates soils where the climate, temperature, or lack of precipitation is the major hazard or limitation affecting their use.

Soils, climate, and northern latitude offer unique challenges to agricultural production in Alaska. The following sections discuss the soil orders and LCC ratings found in each of the main agricultural areas across the state.

Soils of South-Central Alaska

There are two soil survey areas in south-central Alaska where most agricultural activities occur: the Matanuska-Susitna (Mat-Su) Valley survey area and the Western Kenai Peninsula survey area (fig. A.1; USDA NRCS 2019a, 2019b).

The dominant soil orders in south-central Alaska are Spodosols, Inceptisols, Histosols, Entisols, and Andisols, with Inceptisols and Spodosols being the most suitable for agriculture (fig. A.2, table A.1).

Spodosols are the most dominant soil type in both surveys, comprising 44 percent of the soil survey in the Mat-Su area and 49 percent of soil in the Kenai soil survey area (table A.1). Although many areas of Spodosols are often used for agriculture, some contain relatively high amounts of volcanic ash materials and are less fertile when compared to Inceptisols. Spodosols are also strongly acidic and often require lime amendments to neutralize the soil to allow for crop growth.

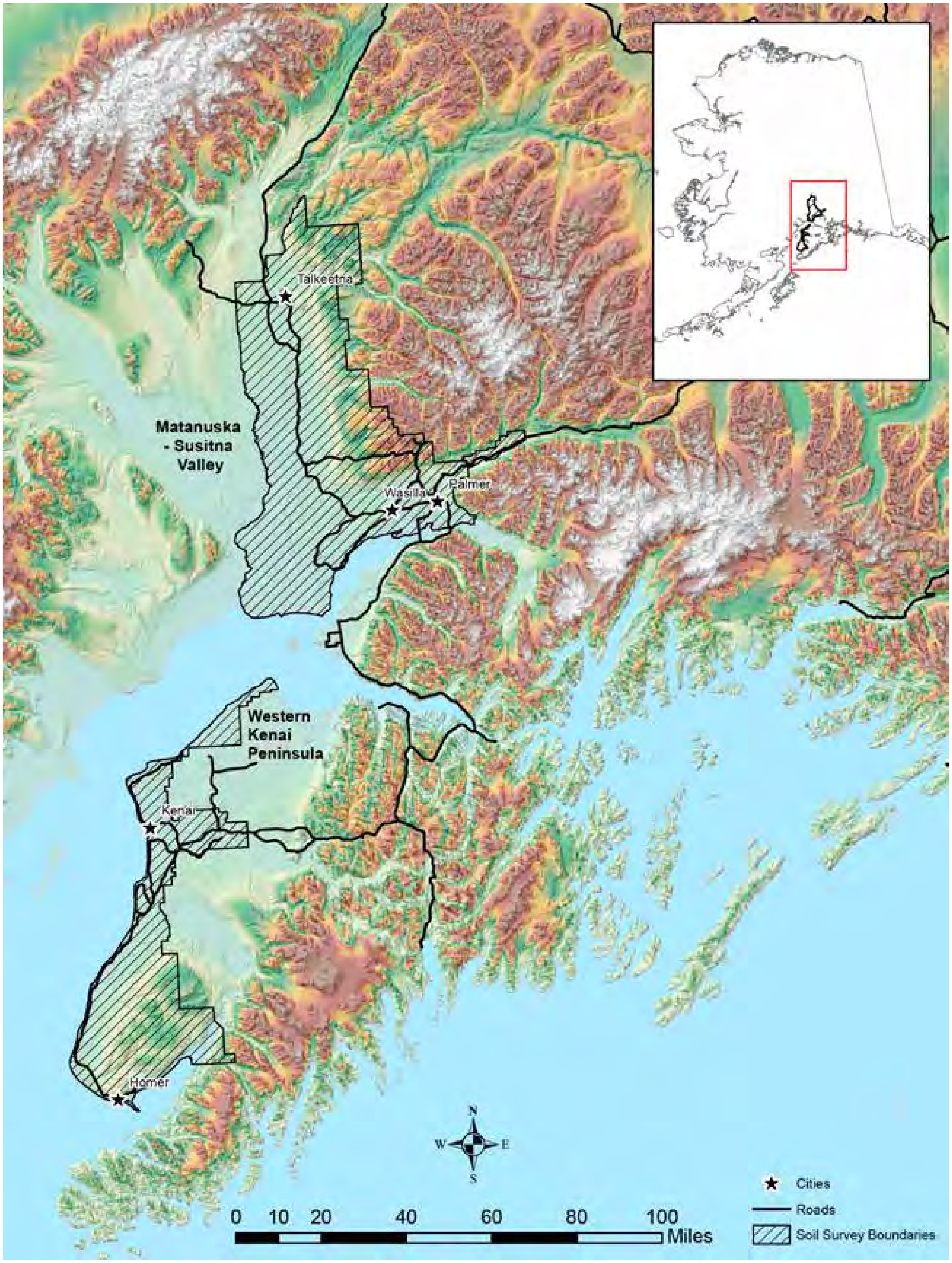


Figure A.1—Map of south-central Alaska showing a digital elevation model base and survey areas noted in black hatch marks for western Kenai Peninsula and Matanuska-Susitna Valley.

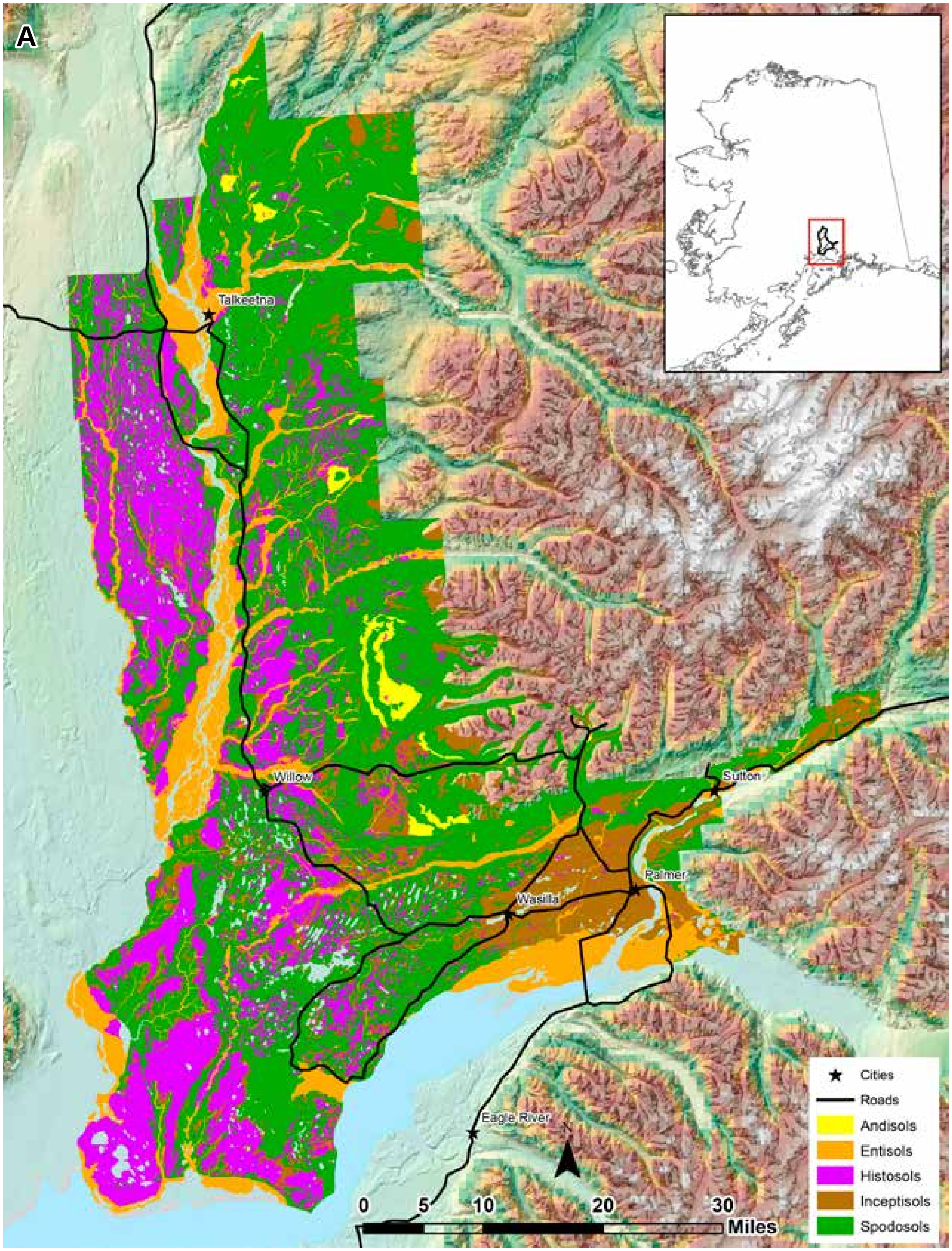


Figure A.2—Soil taxonomy order in the (A) Matanuska-Susitna Valley area and (B) western Kenai Peninsula survey areas (USDA NRCS 2019a, 2019b.).

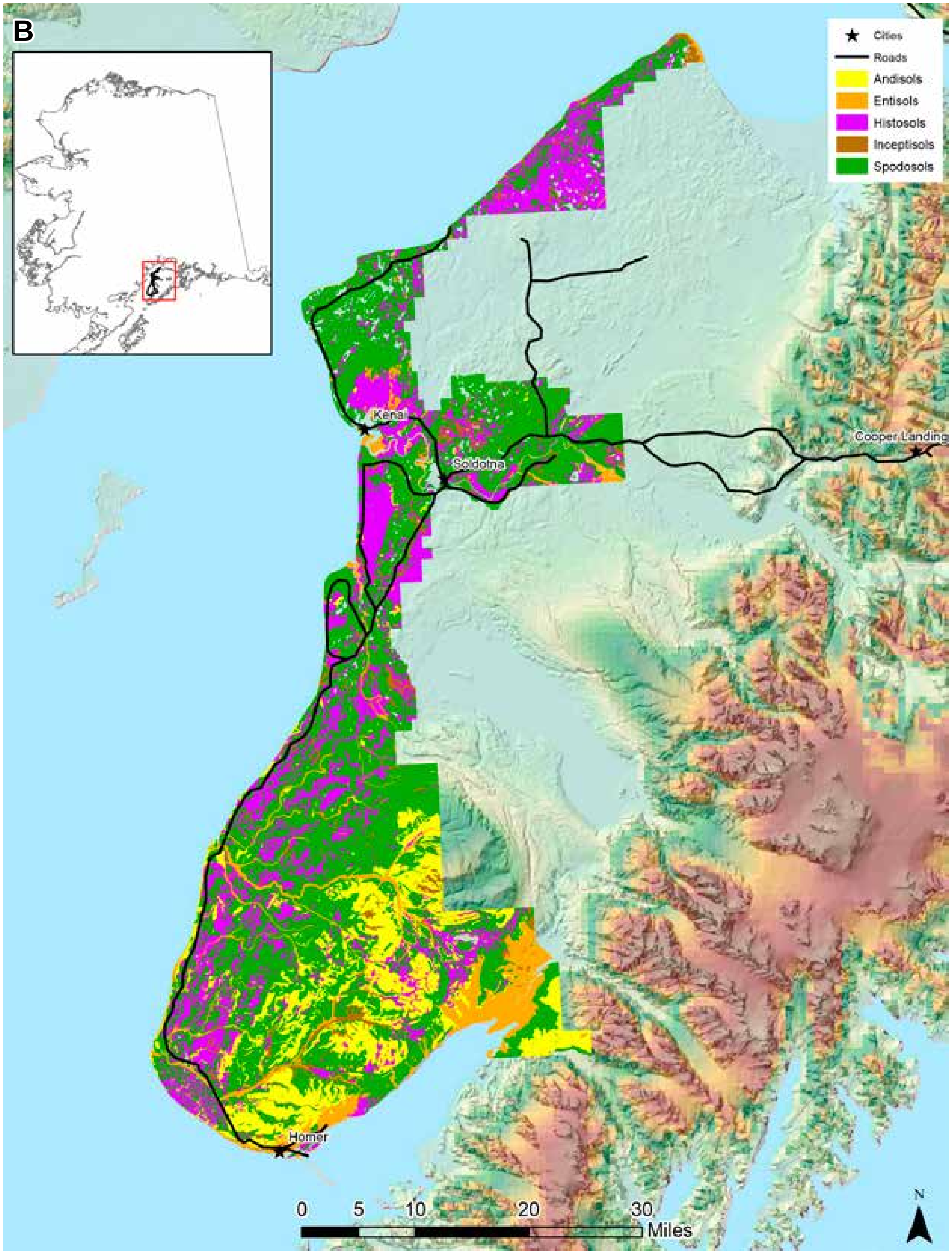


Figure A.2 (continued)—Soil taxonomy order in the (A) Matanuska-Susitna Valley area and (B) western Kenai Peninsula survey areas (USDA NRCS 2019a, 2019b.).

Table A.1—Soil order percentages for each soil survey area with specific dataset noted in parentheses

Soil order	Matanuska-Susitna Valley (AK600)	Greater Fairbanks (AK610)	Copper River (AK612)	Gerstle River (AK615)	Western Kenai (AK652)	Greater Nenana (AK655)	Greater Delta (AK657)
	Percent						
Andisols	3	NA	NA	NA	13	NA	NA
Entisols	11	25	10	31	7	13	15
Gelisols	NA	31	44	15	NA	33	20
Histosols	18	0.1	5	2	20	2	0.5
Inceptisols	15	28	23	49	5	46	54
Mollisols	NA	NA	14	NA	NA	0.2	0.3
Spodosols	44	NA	NA	NA	49	NA	NA
Null values	8	15	4	3	6	6	11

NA indicates soil order not present in the soil survey area.

Loess, or windblown deposits, with low volcanic ash content and near neutral pH make south-central Alaska's Inceptisols highly suitable for crop growth. Unfortunately, this relatively fertile soil type is not overly abundant in this region. In the Mat-Su area, Inceptisols cover about 15 percent of the area and are dominant between Wasilla and Palmer. In the western part of the Kenai Peninsula, Inceptisols are scattered and make up only 5 percent of the total area soil, with larger contiguous areas found on the northern tip of the peninsula.

Entisols in the south-central region are minor, covering 11 percent of the Mat-Su and 7 percent of the Kenai. Entisols can be used for agriculture, but wetness or flooding may be major limitations. Entisols are commonly found on alluvial deposits of floodplains and along rivers, including the Matanuska, Knik, Susitna, and Little Susitna Rivers in the Mat-Su Valley, and the Kenai and Fox Rivers on the western part of the Kenai Peninsula.

Organic-rich Histosols comprise 18 and 20 percent of the soils of both Mat-Su Valley and western Kenai Peninsula, respectively. Histosols in these regions are not suitable for growing crops due to wetness.

Andisols in this region have limited development and by definition contain volcanic ash. In the Western Kenai, these soils are routinely used for agriculture and comprise 13 percent of the area soil. They are found in the southern part of the Kenai Peninsula mostly. In the Mat-Su Valley, Andisols are only 3 percent of the soil and are severely limited for agricultural use due to wetness and erosion issues. The region covering south-central Alaska is one of the state's most productive agricultural areas despite having soils with limitations, according to the LCC ratings. There are no LCC class 1 or 2 soils in either the Mat-Su Valley or the western

Kenai Peninsula soil survey areas. In the Mat-Su area, class 3 and 4 soils comprise 24 percent of the soil and generally occur on broad glacial till and outwash plains (fig. A.3, table A2). These glacial materials are covered by loess in varying thickness. In the western Kenai Peninsula area, class 3 and 4 soils comprise 40 percent of the soil and occur on the glacial plain extending between the Kenai Mountains and the Cook Inlet (fig. A.4, table A2).

Class 5 soils in both survey areas are found along river floodplains as well as lake and muskeg margins, which greatly diminishes the agricultural value because of flooding or wetness. Class 5 soils comprise only 2 percent of Mat-Su area soil and nearly 15 percent of the Kenai area soil. Soils with severe limitations, such as those in class 6 and 7, are usually found on the steppes of the Chugach, Talkeetna, and Kenai Mountain Ranges. These soils comprise nearly 40 percent of Kenai soil and 66 percent of Mat-Su soil (table A.2). These soils suffer from very high erosion potential and are often shallow and rocky. Additionally, because they are geographically located at higher elevations, they experience limited growing seasons that are not suitable for most agronomic crops. Class 8 soils are non-soil areas such as water, beaches, and riverwash. They are typically of minor extent and have no agricultural value. This class of soils covers 8 percent of area in the Mat-Su and 6 percent of the Kenai.

Table A.2—Land capability class (LCC) percentages for each soil survey area with specific dataset noted in parentheses

LCC	Matanuska-Susitna Valley (AK600[a])	Western Kenai (AK652[b])	Copper River (AK612[c])	Greater Delta (AK657[d])	Greater Nenana (AK655[e])	Gerstle River (AK615[f])	Greater Fairbanks (AK610[g])
	Percent						
2	NA	NA	NA	29	5	1	12
3	14	30	NA	5	6	37	3
4	10	10	28	13	22	20	18
5	2	15	4	10	6	20	9
6	22	14	35	27	41	15	37
7	44	25	29	5	14	5	6
8	8	6	NA	11	7	3	15

NA indicates a land capability class that is not present in the soil survey areas.
[a] USDA NRCS 2019a.
[b] USDA NRCS 2019b.
[c] USDA NRCS 2019c.
[d] USDA NRCS 2019d.
[e] USDA NRCS 2019e.
[f] USDA NRCS 2019f.
[g] USDA NRCS 2019g.

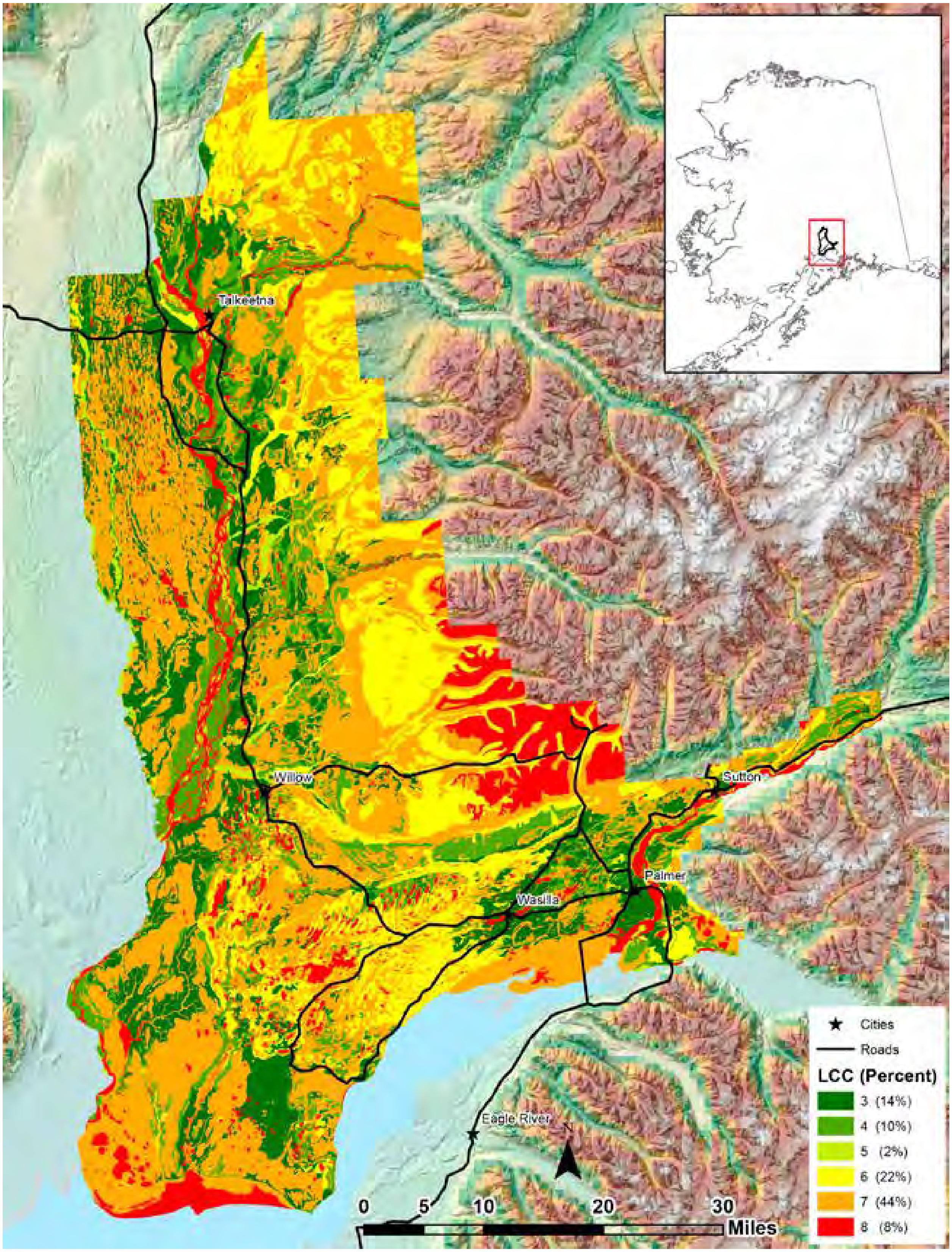


Figure A.3—Matanuska-Susitna Valley land capability class (USDA NRCS 2019a).

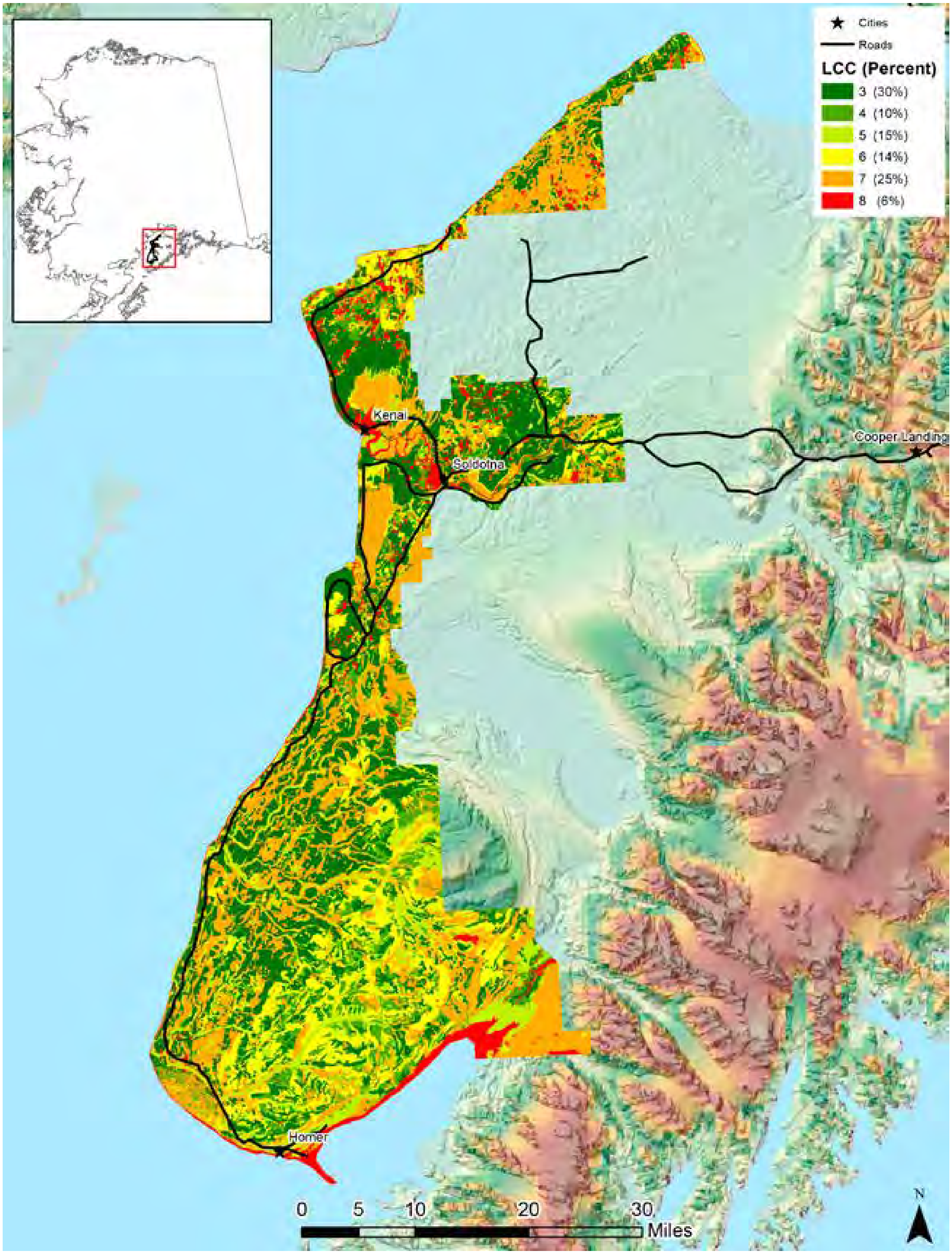


Figure A.4—Western Kenai Peninsula land capability class (USDA NRCS 2019b).

Soils of Interior Alaska

There are four soil surveys in the interior of Alaska that cover four areas heavily used for agriculture: the Greater Nenana, Greater Delta, and Gerstle River and Greater Fairbanks areas (fig. A.5; USDA NRCS 2019d, 2019e, 2019f, 2019g).

Dominant soil orders in interior Alaska are Inceptisols, Gelisols, Entisols, and Histosols. The dominant soils for agriculture are Inceptisols, Entisols, and sometimes Gelisols after thawing (fig. A.6, table A.1).

Inceptisols are by far the most abundant soil type in interior Alaska. In the Greater Delta survey area, they make up more than half the survey (54 percent). In the Gerstle River and Greater Nenana survey areas, they make up 49 and 46 percent of the soil, respectively. The Greater Fairbanks survey area consists of 28 percent. Inceptisols usually occur on loess-covered hillslopes and the broad glacial outwash fans skirting the Alaska Range. These soils are typically very good for agriculture. However, slope, depth to bedrock or gravel, and drainage can be limiting in some areas. Hilltop crests often have a thinner loess layer and can be too shallow for agriculture. Backslopes are often too steep. Footslope positions appear to be ideal for agriculture with thick loess deposits and gently sloping land. However, deeply buried permafrost with large bodies of ground ice is often present and can result in thermokarst pits, ponds, and mounds after the land has been cleared.

Gelisols are the next most abundant soil order in interior Alaska region soil surveys. These permafrost soils make up 33 percent of soil in the Greater Nenana survey area, 31 percent in the Greater Fairbanks survey area, 20 percent in the Greater Delta survey area, and 15 percent in the Gerstle River survey area. Permafrost is discontinuous in these soil surveys and is often found very near the surface, often between 30 and 50 cm (11.8 and 19.7 inches). The permafrost acts as a barrier to water movement, frequently resulting in a perched water table. When natural vegetation and the insulating mat of organic matter on the soil surface are removed by fire or are mechanically cleared, such as with tillage, the depth to reach permafrost increases or the permafrost may even disappear (Péwé and Holmes 1964). The lowering of the permafrost table after clearing may result in improved soil drainage. Clearing is not likely to improve soil drainage in areas of groundwater discharge nor in areas where the regional groundwater table is near the surface. Some alluvial formed permafrost soils can be developed for agricultural use because permafrost ice masses are not present in the gravelly substratum. Other permafrost soils may settle unevenly or be subject to thermokarst. On footslopes and valley bottoms, the silty mantle is very thick. The deep permafrost in these landscapes often has large masses of ground ice and differential subsidence, and thermokarsts often occur, thereby reducing agricultural suitability.

Entisols have limited soil development and are found in the alluvial deposits of floodplains along rivers. The Gerstle River area survey has the most Entisols at 31 percent, Greater Fairbanks at 25 percent, Greater Delta at 15 percent, and Greater Nenana

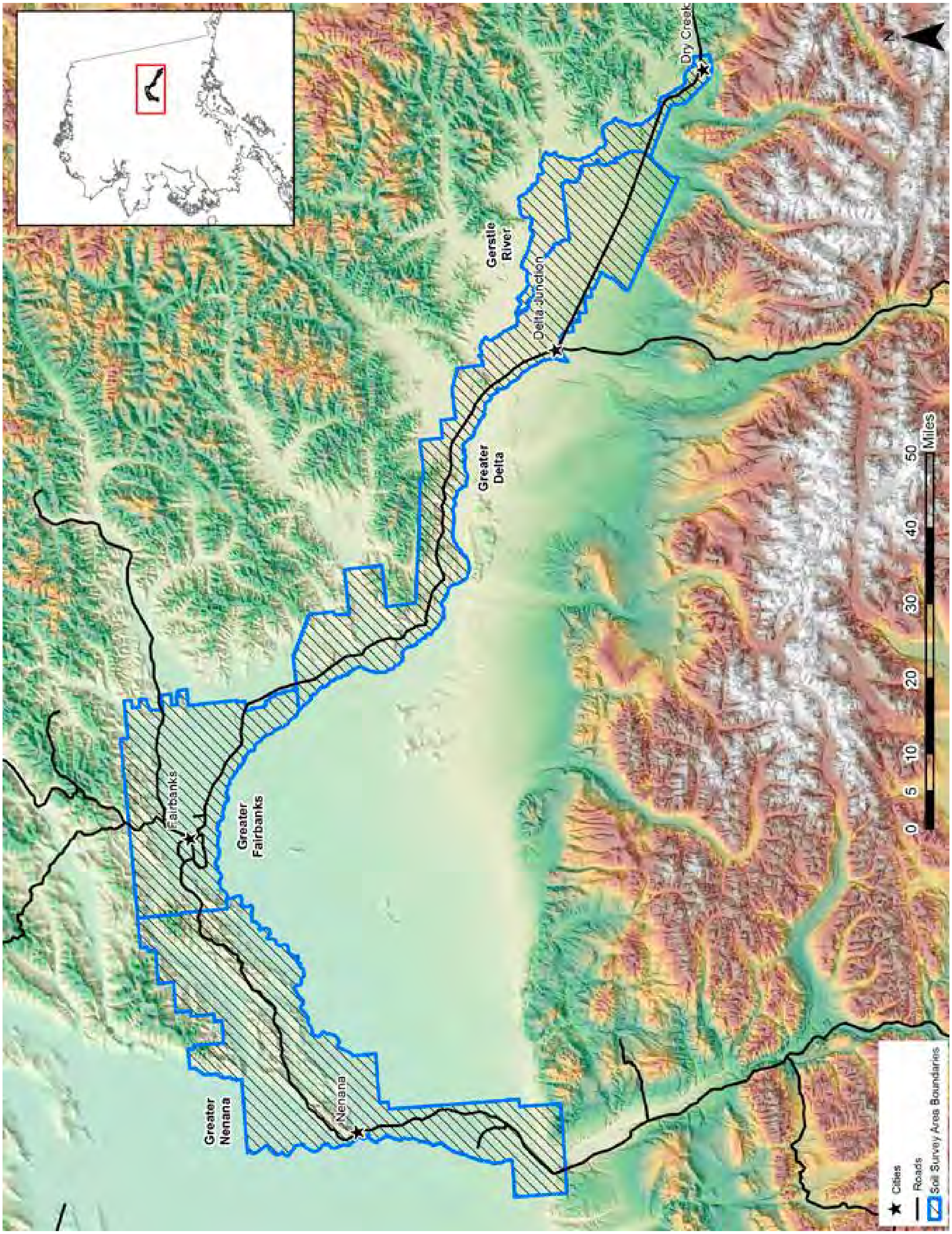


Figure A.5—Interior Alaska soil survey area noted with black hatch marks (USDA NRCS 2019g).

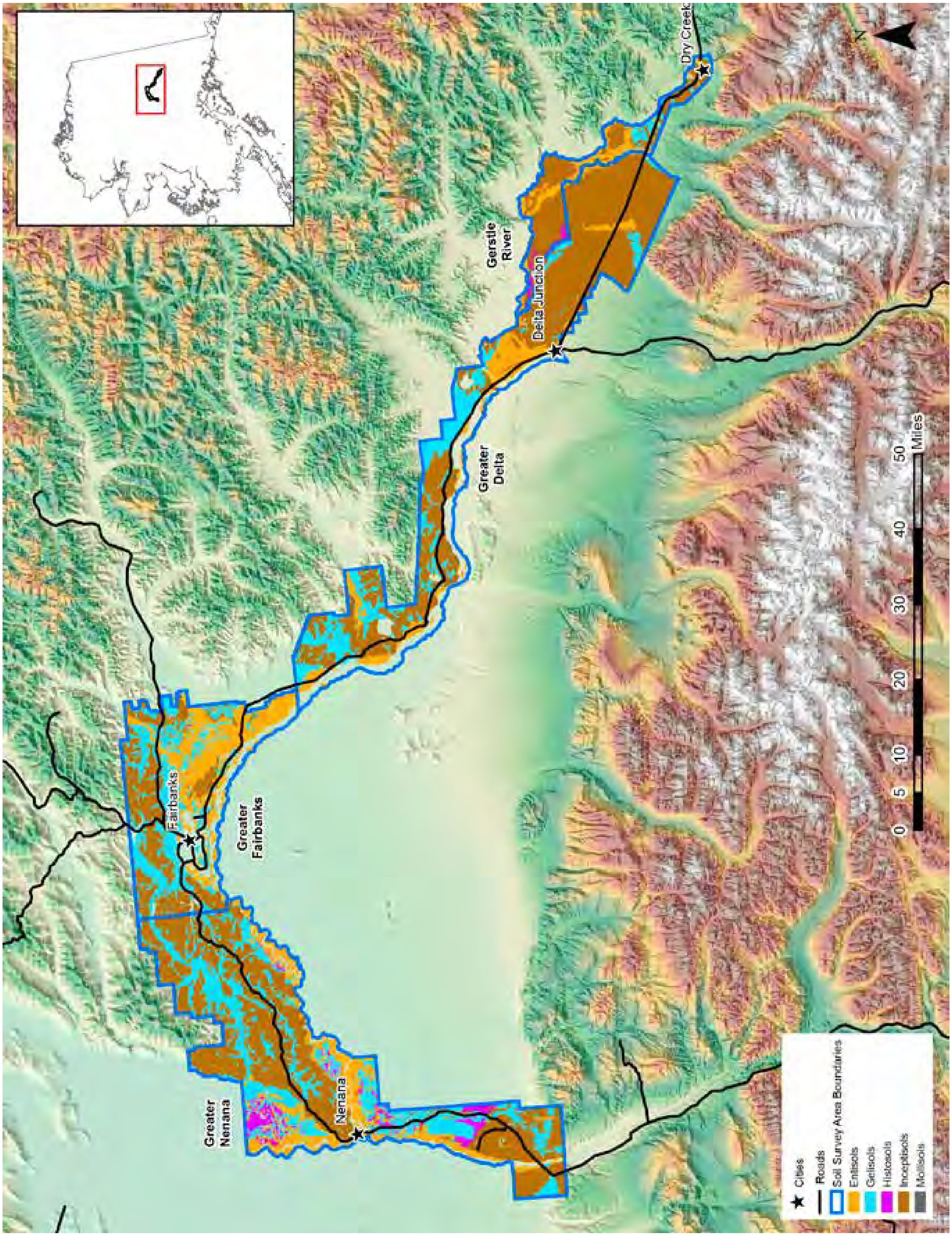


Figure A.6—Interior Alaska soil survey areas soil taxonomy order (USDA NRCS 2019g).

at 13 percent. Some of the Entisols in this region are highly productive agricultural soils, but wetness or flooding can be major limitations.

Although Histosols do occur in interior Alaska, they cover a very small area. The Greater Nenana and Gerstle River area soils each are composed of about 2 percent, whereas the Greater Fairbanks and Greater Delta areas are composed of <1 percent each. Usually if a soil has a thick enough organic mat in interior Alaska, it will have permafrost and therefore will be a Gelisol. These areas are also far too wet for agricultural production.

Mollisols are the smallest component in the interior soil survey areas. They comprise <1 percent of soils in the Greater Nenana and Greater Delta survey areas, and do not occur in the Greater Fairbanks or Gerstle River survey areas. Mollisols are commonly thought to be excellent agricultural soils; however, in interior Alaska, they are confined to south-facing river bluffs along the Tanana River and are far too steep to farm.

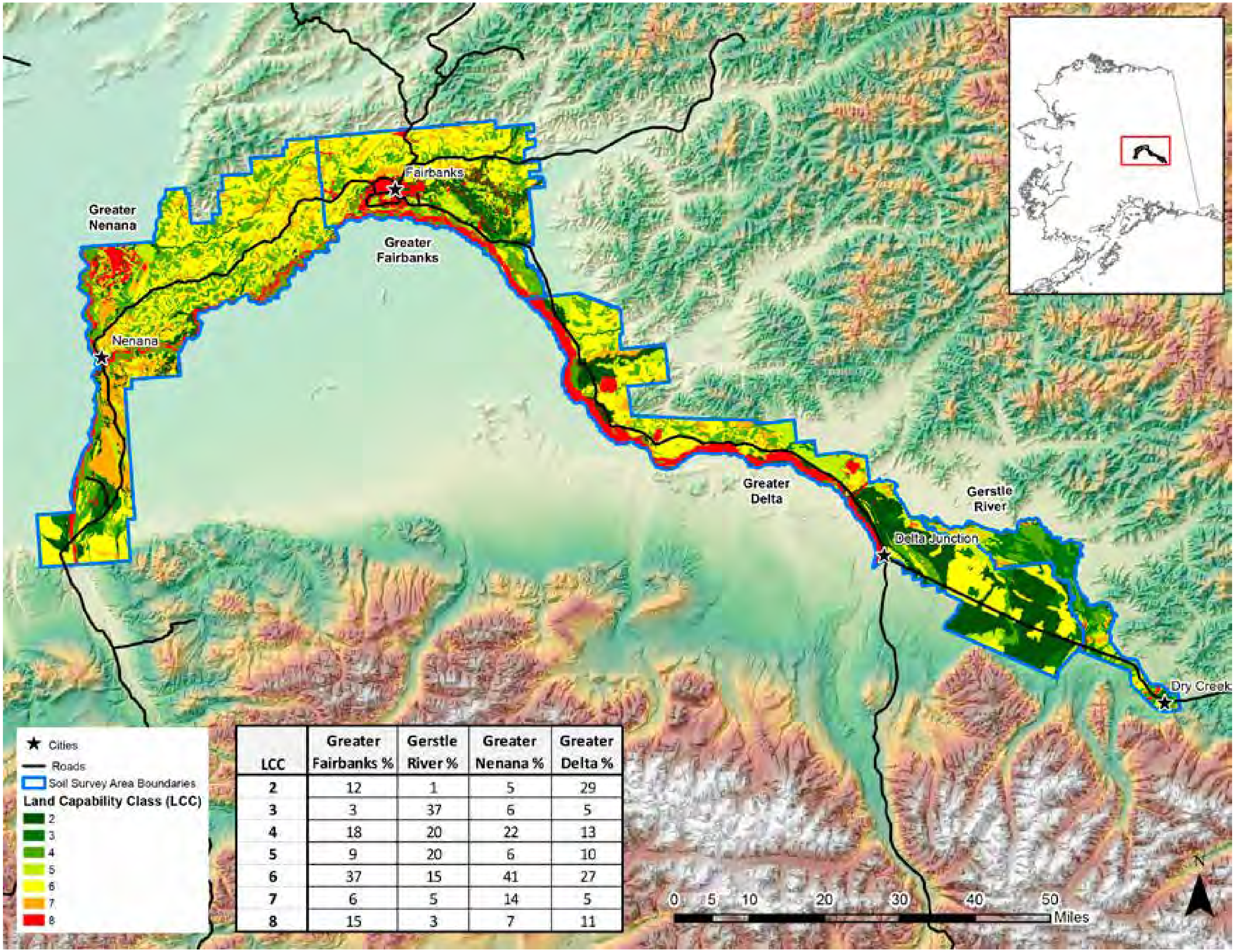
The agricultural zone around Delta Junction is one of the few locations in the state to exhibit LCC class 2 soils, which are only moderately limited by definition. Looking at the LCC ratings for interior Alaska (fig. A.7, table A2), there are class 2 soils present within the Greater Delta area soil survey at 29 percent, the Greater Fairbanks area at 12 percent, the Greater Nenana area at 5 percent, and the Gerstle River area at around 1 percent. Climate is the main limitation keeping these soils out of class 1. Cold temperatures and the short growing season limit the types of crops that can be grown in these areas.

Class 3 and 4 soils with moderate limitations make up 57 percent of soils in the Gerstle River area, about 28 percent in Greater Nenana, 21 percent in Greater Fairbanks, and 18 percent in the Greater Delta survey areas. Potential for erosion and wetness are the primary limitations, with secondary soil limitations such as depth to sand and gravel.

Class 5 soils with wetness issues have limited extent in most of the interior Alaska surveys. The Gerstle River survey area has the largest class 5 area (20 percent), which is likely because the survey is located almost entirely on a floodplain. The Greater Delta survey area follows with 10 percent, Greater Fairbanks at 9 percent, and the Greater Nenana at 6 percent.

Severely limited class 6 and 7 soils make up 55 percent of soils in the Greater Nenana survey area, 43 percent in Greater Fairbanks survey area, 32 percent in the Greater Delta survey area, and 20 percent in the Gerstle River survey area. Potential for erosion, shallow soil depths, and wetness are the primary limitations in these classes.

The class 8 non-soil areas for these interior Alaska soil surveys are highly variable. Class 8 coverage is largest in the Greater Fairbanks survey area (15 percent) due to the large urban zone and associated development features, including gravel pits and quarries. These soils make up 11 percent of the Greater Delta area because of several large lakes within the survey area. The Greater Nenana (7 percent) and Gerstle River (3 percent) class 8 non-soil areas are influenced by riverwash and some smaller waterbodies in the survey areas.



LCC	Greater Fairbanks %	Gerstle River %	Greater Nenana %	Greater Delta %
2	12	1	5	29
3	3	37	6	5
4	18	20	22	13
5	9	20	6	10
6	37	15	41	27
7	6	5	14	5
8	15	3	7	11

Figure A.7—Interior Alaska soil survey area land capability class (USDA NRCS 2019g).

Copper River Area

Soils in much of the Copper River survey area (fig. A.8; USDA NRCS 2019c) are formed in thick lacustrine deposits. These deposits can be very high in clay, often causing drainage problems even after the permafrost has been eliminated.

The dominant soil orders in the Copper River area are Inceptisols, Entisols, Gelisols, Mollisols, and Histosols (fig. A.9, table A1).

The most extensive soil order in this survey area is Gelisols at 44 percent. Gelisols occur on lake plain and glacial landforms where the parent material is usually a thin layer of loess over either glacial till or clayey lacustrine deposits. In the glacial till areas, Gelisols can be cleared to lower the permafrost table and improve drainage for agricultural use. In the clayey lacustrine deposits, the permafrost does recede; however, these soils may not drain because of slow water movement. They may also experience differential subsidence when thawed.

Inceptisols comprise 23 percent of the Copper River area soil survey areas and are usually made up of loess over clayey lacustrine deposits or gravelly glacial till. These soils are typically good for agriculture, but some sloping areas can be subject to erosion.

Entisols are found in the alluvial deposits of floodplains along rivers and in very clayey lacustrine deposits. These poorly developed soils make up 10 percent of the survey area soils. Entisols can be used for agriculture, however, they often have flooding or wetness limitations.

Mollisols make up 14 percent of soils in the area and occur in loess over clayey lacustrine deposits or loamy glacial till in this area. These soils are usually good for agriculture, but some sloping areas can be subject to erosion. Many of the Mollisol soils in the Copper River area are the cleared and thawed counterparts of permafrost soils.

Histosols cover the smallest area of any of the soil orders in this survey at just 5 percent. These soils form in depressions that are caused from the differential settling of thawing permafrost. Histosols are far too wet for agriculture. Looking at the LCC ratings for the Copper River area soil survey, there are no land capability class 1, 2, or 3 soils (fig. A.10, table A2). Class 4 soils with moderate limitations comprise 28 percent of soils in the area. Most of the limitations are due to the cold climate and erosion. Some areas on floodplains have soil limitations with gravel shallow in the soil profile.

Class 5 soils comprise 4 percent of the Copper River area and typically have wetness, flooding, or ponding limitations. Severely limited soils in classes 6 and 7 comprise 64 percent of soils in this survey area. The main limitations in the Copper River area are wetness and erosion potential in the more sloping areas.

There are no components designated as class 8. However, about 4 percent of the area soils has components identified as water, badlands, gravel pits, and rock outcrops.

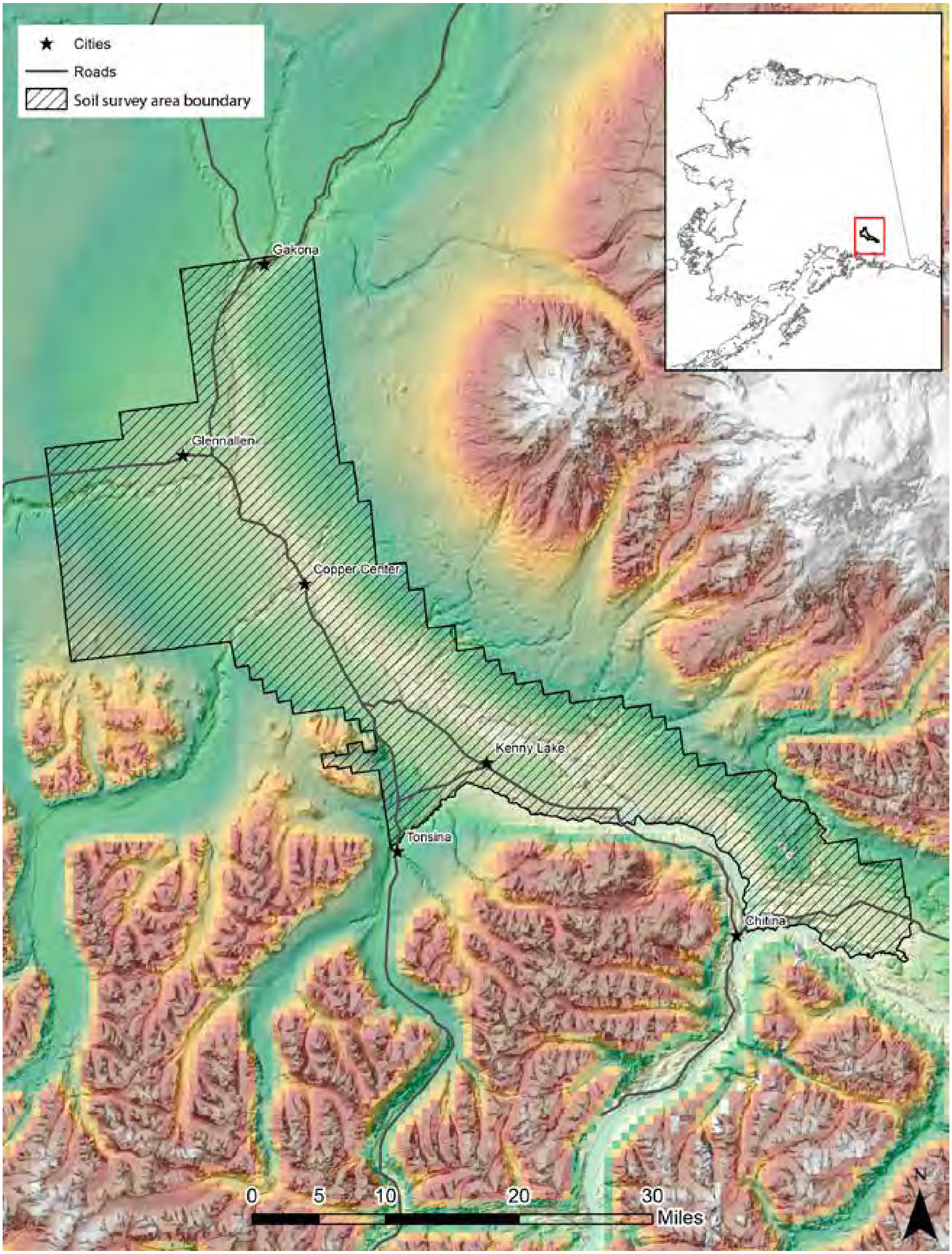


Figure A.8—Copper River soil survey area location noted with black hatch marks (USDA NRCS 2019c).

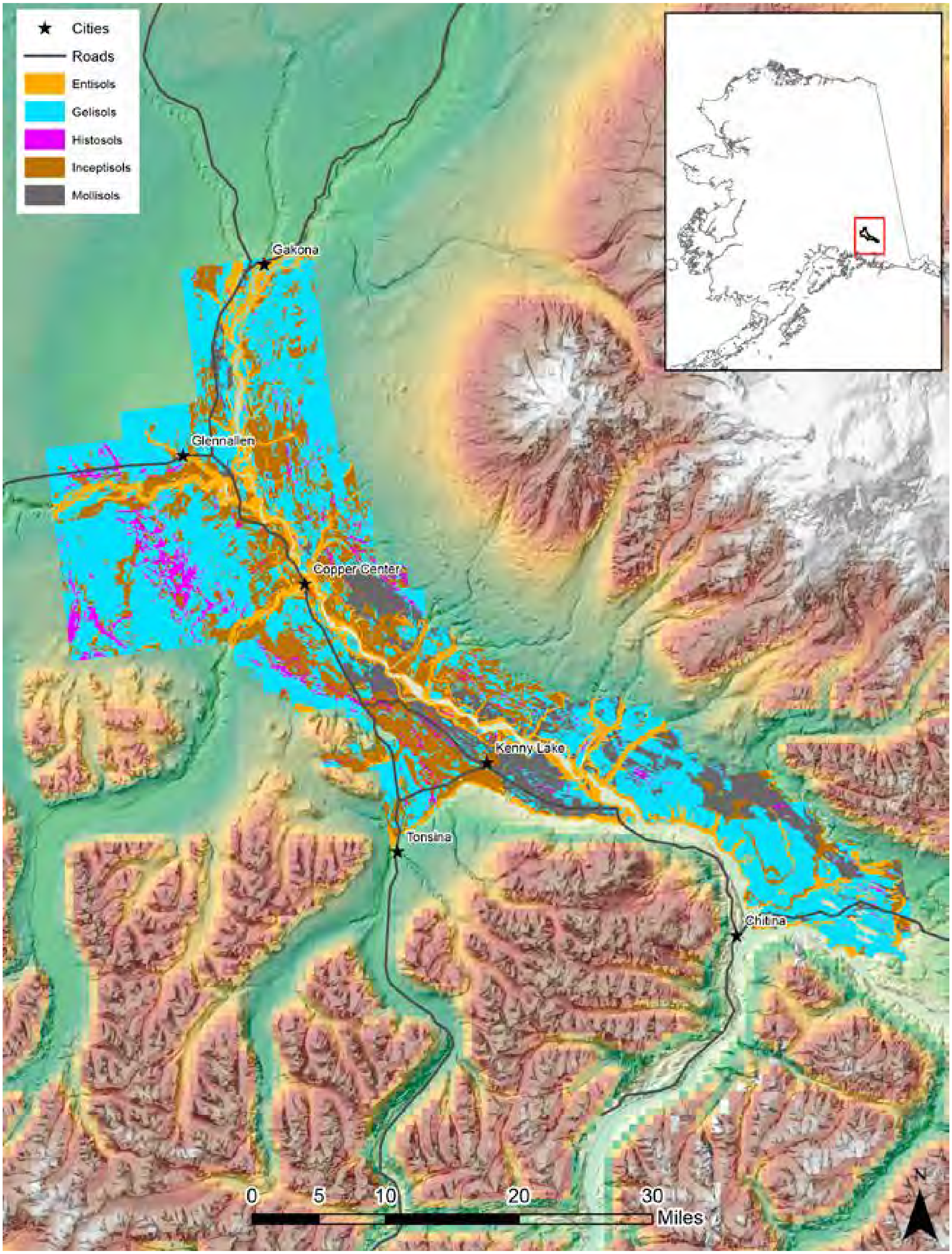


Figure A.9—Copper River area soil taxonomy order (USDA NRCS 2019c).

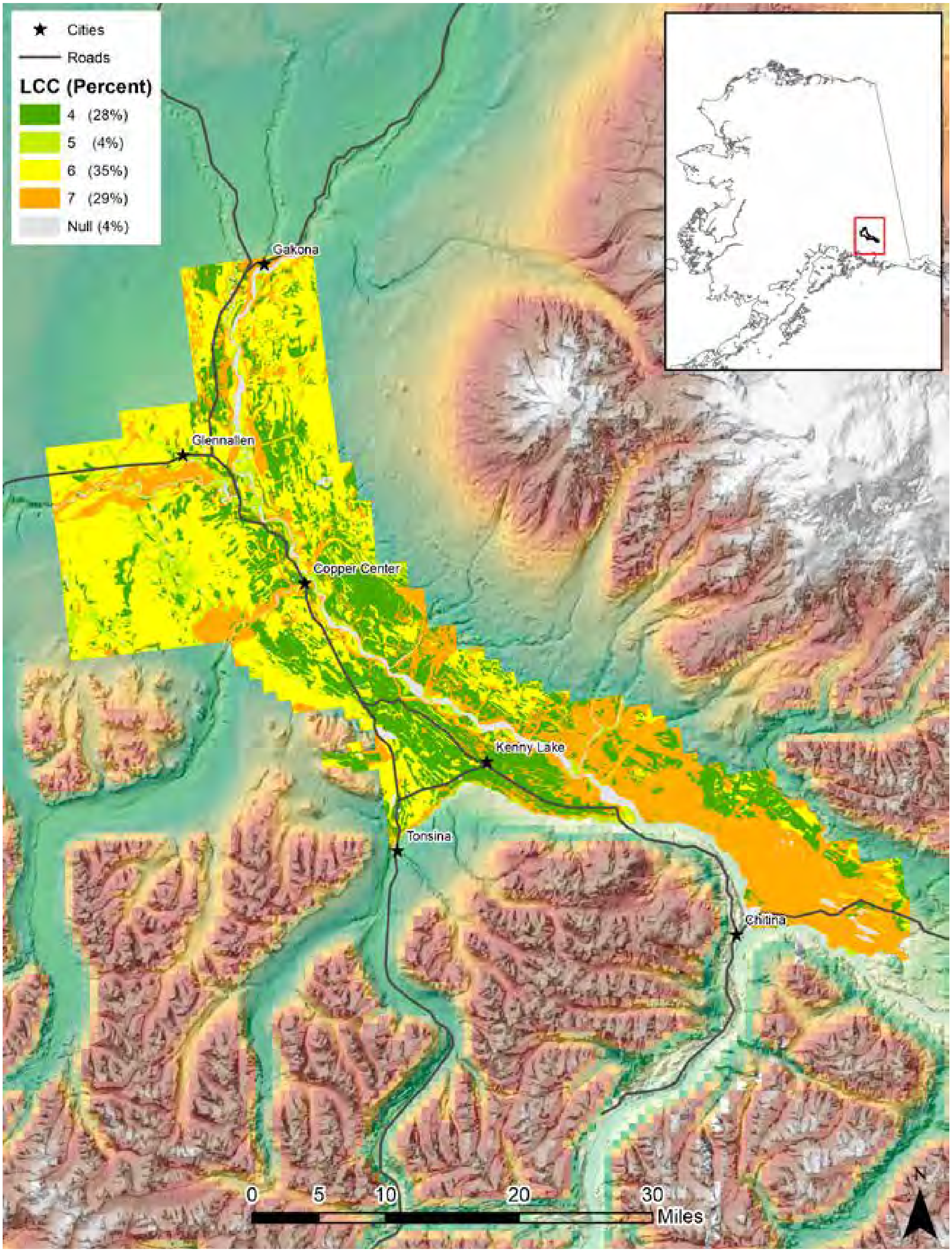


Figure A.10—Copper River soil survey area land capability class (USDA NRCS 2019c).

References

Péwé, T.L.; Holmes, G.W. 1964. Geology of the Mt. Hayes (D-4) quadrangle, Alaska [1: 63,360]. U.S. Misc. Geol. Investig. Map I–394. Reston, VA: U.S. Department of the Interior, Geological Survey.

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2020. Web soil survey. Washington, DC: Soil Survey Staff. http://websoilsurvey.sc.egov.usda.gov/. (22 April 2020).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019a. Soil Survey Geographic (SSURGO) database for Matanuska–Susitna Valley area, Alaska (AK600). [Database]. Spatial data, version 5, updated 5 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019b. Soil Survey Geographic (SSURGO) database for western Kenai Peninsula area, Alaska (AK652). [Database]. Spatial data, version 4, updated 5 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019c. Soil Survey Geographic (SSURGO) database for Copper River area, Alaska (AK612). [Database]. Spatial data, version 4, updated 22 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019d. Soil survey geographic (SSURGO) database for Greater Delta area, Alaska (AK657). [Database]. Spatial data, Version 4, updated 5 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019e. Soil survey geographic (SSURGO) database for Greater Nenana Valley area, Alaska (AK655). [Database]. Spatial data, Version 4, updated 5 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019f. Soil survey geographic (SSURGO) database for Gerstle River area, Alaska (AK615). [Database]. Spatial data, Version 5, updated 22 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019)

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2019g. Soil Survey Geographic (SSURGO) database for Greater Fairbanks area, Alaska (AK610). [Database]. Spatial data, version 5, updated 5 October 2019. Washington, DC: Soil Survey Staff. https://websoilsurvey.sc.egov.usda.gov/App/ WebSoilSurvey.aspx. (4 November 2019).

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