

Sustainable Agriculture for Alaska and the Circumpolar North: Part II. Environmental, Geophysical, Biological and Socioeconomic Challenges

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ABSTRACT. Local agriculture, food security and food supply are limited in Alaska, as well as in much of the circumpolar North. These limitations stem from a suite of challenges that have never been well characterized, categorized, or wholly defined. We identify these challenges as being environmental, geophysical, biological, or socioeconomic in nature, noting that some challenges are interrelated. Additionally, Alaska is expansive, and growing conditions are highly variable across different regions and microclimates of the state. Environmental challenges to Alaskan agriculture are generally linked to high latitude and include strong seasonality, a short growing season, cold temperatures, and unpredictable frosts. Geophysical challenges are characterized by a high percentage of soils that are wet and cold or low in natural fertility. Biological challenges include cultivar adaptability and selection; the control of various pests, weeds, and diseases; and decreased microbial activity in cold soils, which can allow pesticides to linger and slow mineralization of organic fertilizers. Socioeconomic challenges to farming in Alaska are especially limiting and may categorically represent the strongest hindrances to agriculture. They often overlap or interact with many of the identified agro-ecological and biogeographic challenges. Major socioeconomic issues can be a relatively low financial incentive or reward for farmers; inconsistent or limited markets; the high cost of land, infrastructure, and inputs; zoning challenges; a lack of cooperatives; and for rural farmers, time conflicts with more traditional means of subsistence food acquisition. These challenges collectively represent factors that limit agriculture in Alaska, and they provide a basis and justification for developing more sustainable solutions.

Key words: agriculture, Alaska, challenges, climate, circumpolar, farming, soils, subarctic, sustainable, socioeconomic

RÉSUMÉ. En Alaska, l'agriculture locale, la sécurité alimentaire et les approvisionnements en vivres sont limités. C'est également le cas d'une grande partie du Nord circumpolaire. Ces limitations découlent d'un ensemble de défis qui n'ont jamais été bien caractérisés, catégorisés ou entièrement définis. Nous estimons que ces défis sont d'ordre environnemental, géophysique, biologique ou socioéconomique, et que certains des défis sont interreliés. De plus, l'Alaska est d'une grande étendue, et les conditions de croissance varient énormément d'une région à l'autre et d'un microclimat à l'autre de l'État. De manière générale, les défis environnementaux inhérents à l'agriculture alaskienne ont trait à la haute latitude, ce qui comprend une importante saisonnalité, une courte saison de croissance, des températures froides et des gelées imprévisibles. Pour leur part, les défis géophysiques sont caractérisés par un fort pourcentage de sols humides et froids, ou encore, de sols dont la fertilité naturelle est faible, puis les défis d'ordre biologique ont trait à l'adaptabilité et à la sélection des cultivars, à la lutte contre divers organismes nuisibles, les mauvaises herbes et les maladies, ainsi qu'à une activité microbienne réduite dans les sols froids, ce qui permet aux pesticides de rester plus longtemps et ralentit la minéralisation des engrais organiques. Quant aux défis de nature socioéconomique, ils imposent des restrictions particulièrement fortes en Alaska, au point où ils pourraient même catégoriquement représenter le plus grand obstacle à l'agriculture. Dans bien des cas, les défis se chevauchent ou ont une action réciproque sur un grand nombre d'enjeux agroécologiques et biogéographiques. De plus, les grands enjeux socioéconomiques peuvent prendre la forme de récompenses financières relativement faibles pour les agriculteurs, de marchés irréguliers ou limités, du coût élevé de la terre, des infrastructures et des intrants, d'obstacles inhérents au zonage, d'un manque

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de coopératives et, dans le cas des agriculteurs ruraux, de conflits d'emploi du temps avec les moyens de subsistance plus traditionnels d'acquisition de la nourriture. Collectivement, ces défis représentent les facteurs qui imposent des restrictions à l'agriculture en Alaska, et ils constituent les fondements et la justification nécessaires au développement de solutions plus durables.

Mots clés : agriculture, Alaska, défis, climat, circumpolaire, agriculture, sols, subarctique, durable, socioéconomique

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INTRODUCTION

Very little of Alaska's food demand is met by local agriculture, and its year-round food supply is insufficient (Alaska State Senate, 1976; Drew, 1977; UAF CES, 2006; Conenstein, 2010; Helfferich, 2010; Helfferich and Tarnai, 2010; Stevenson et al., 2014a). Its communities are supported by some local farming and gardening (Fig. 1), but food imports are playing an increasingly major role in sustaining life in the North (Stevenson et al., 2014a). The disparity between Alaska's levels of food demand and local production is very generally linked to challenges inherently associated with farming at high latitudes and with geographic isolation from infrastructure and markets in the lower 48 contiguous states. Socioeconomic challenges are often more limiting to Alaskan agriculture than field-based challenges, although some overlapping areas are difficult to separate. Our aim is to identify, categorize, and characterize challenges to commercial and subsistence agriculture in Alaska and other northern regions. In this process, we use a review of published data and information, as well as analyses of new data.

Past, present, and future aspects of food security and resilience in the North, including Alaska's current dependence upon imported agricultural goods, have been discussed at length (Stevenson et al., 2014a). Sustainable circumpolar agriculture has previously been defined to include food production occurring above 55° N (ARDC, 1974; Stevenson et al., 2014a) while also fitting the legal United States Department of Agriculture (USDA) definition of sustainable agriculture (U.S. Code Title 7, Section 3103). Briefly, sustainable agriculture is characterized as an integrated production system that will satisfy human food and fiber needs, enhance environmental quality and the natural resource base, make efficient use of resources, and, where appropriate, integrate natural biological cycles and controls. It sustains the economic viability of farm operations and enhances quality of life. Farmers are defined as the persons who engage in the act or business of agriculture, including any local cultivation of fruits, vegetables, root crops, fodder (grasses, grains, forage), dairy products, poultry, livestock or shellfish.

ENVIRONMENTAL CHALLENGES

It is all very well to talk about these wonderful Alaskan summer days and the long hours of sunshine. It sounds

nice in the steamship folders and the various Chamber of Commerce literature. But to the poor homesteader it is merely pure bunk; the days are long alright but they are filled with fog and rain rather than sunshine.

Matanuska Valley homesteader (1917)
(in Wilson, 1978)

The environmental factors that influence crop growth and yield in Arctic and Subarctic regions are tied to larger physical forces operating at a global scale, including the earth's tilt, Coriolis forces and global air and ocean currents. These forces are then manifested regionally in photoperiod, climate, weather events, cloud cover, precipitation and humidity (Fig. 2). Physical factors, such as topography and land formations (e.g., mountains, hills, and valleys), land and water cover, and other landscape variables further influence northern microclimates. Major environmental challenges to sustainable agriculture in Alaska and the circumpolar North are generally linked to high latitudes and include strong seasonality, a short growing season, relatively cold temperatures, and unpredictable frosts.

Solar Challenges and Influences

The effects of long summer days on plants in high-latitude regions are often positive and can produce exceptionally large crops. Fully mature crops can also be produced in a relatively short time. In areas where relatively cold temperatures overlap with the growing season, long days are a prerequisite for yield formation for most field crops.

At the summer solstice, Fairbanks (64.84° N, 147.72° W) receives almost 22 h of direct sunlight, and the city of Palmer (61.60° N, 149.12° W) in the Matanuska Valley receives between 19 and 20 h of sunlight. In contrast, Oregon, Washington, and California, three states that export many agricultural products to Alaska, receive from 14 to 18 h of direct sunlight at the summer solstice. The rate of daily photoperiod increase around the spring equinox is much more rapid at higher latitudes, but the tradeoff is that the daily loss of daylight is equally as rapid around the fall equinox.

The influences of photoperiod and light intensity can vary significantly among different crops and cultivars. In some crops, such as lettuce, a 50% increase in day length from 16 to 24 h can increase dry mass substantially, sometimes doubling weight and having other positive effects (Koontz and Prince, 1986; Kitaya et al., 1998). Strawberries exhibit

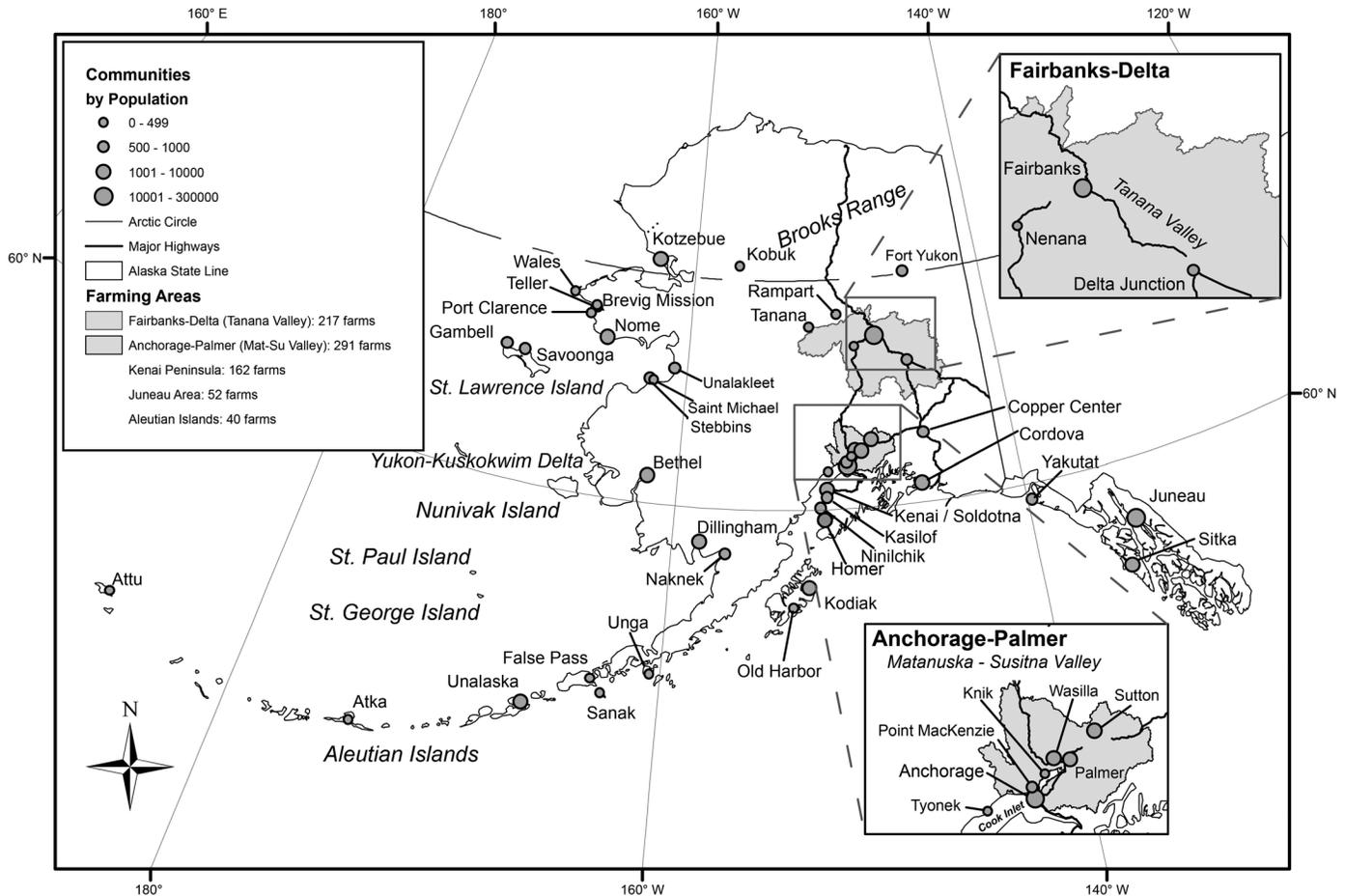


FIG. 1. Map of some current and historic communities and major farming areas of Alaska. The USDA Agricultural Census data from 2007 reported 291 farms in the Anchorage/Matanuska-Susitna area, 217 farms in the Fairbanks/Delta/Nenana area, 162 farms in the Kenai Peninsula area, 52 farms in the Juneau/Southeast area, and 40 farms in the Aleutians/Western Alaska area (USDA, 2014).

a strong response to day length among various cultivars, with some that are well adapted for short or long days and some that are day-neutral. Other influences, such as temperature, can interact with day length and result in increased, decreased, delayed, or faster fruit and flower production in strawberries (Serçe and Hancock, 2004). The relationship between photoperiod, daily light integral, and the number of days to flower initiation in certain plants has been elucidated. For instance, a study of the herbaceous plant *Primula vulgaris* has shown that long day lengths result in fewer days to flower (Karlsson, 2002), yet the complexity of the interactions between various environmental factors, including light, suggests that effects are not always additive. To date, few seed companies specialize in northern seeds, but for those that do, the selection for adaptability to northern light conditions, among other factors, is important.

A major challenge arising from the long days in Alaska and other high-latitude regions is that of bolting, particularly in crops such as lettuce, cabbage, or spinach. Bolting is the failure of a plant to properly form a head because of excessively rapid stem (seed stalk) elongation or leaf twisting. Bolting is exacerbated by overexposure to long days and warm temperatures. The process expends a plant's

entire energy reserve for seed production and leaves the plant tissues tough, woody, and either tasteless or bitter. High irradiance, elevated temperatures, and extended day lengths can predispose lettuce transplants to bolting after planting (Dennis and Dullforce, 1974; Klapwijk, 1979). Bolting can occur in biennial plants, making them complete a two-year life cycle in a single year.

It is ultimately not the intensity of solar radiation that causes bolting, as solar radiation is fairly low in Alaska, but the long period of exposure each day due to increased day length. Susceptibility to bolting can vary among cultivars, although some “bolt-resistant” varieties exist. While bolting is a challenge in some vegetables, some farmers are able to take advantage of it and grow a two-year seed crop in a single year.

Additional challenges associated with high-latitude photoperiods have been more recently demonstrated in legumes and agronomic crops (Van Veldhuizen and Knight, 2004). Subarctic photoperiods can be problematic for timing of flowering in soybeans, which germinate and grow well in Alaska. They do not flower until 10 h of darkness are present in mid-August, which does not leave plants enough time to develop or reach maturity before the first



FIG. 2. Challenges to sustainable agriculture in Alaska.

killing frost. For non-adapted varieties of winter rye, a long day length can cause rapid growth in seedlings, resulting in a low buildup of root reserves and consequently a low winter survival rate (Klebesadel, 1969).

Climate and Weather

Alaskan farmers and gardeners experience a short growing season and conditions that are often harsh or unreliable. Alaska's climate is driven by multiple factors that have the potential to influence the success of agriculture, including latitude, variable topography, proximity to oceans, the presence of multiple pressure systems, and the impacts of cyclical climatic events (Benson et al., 1983; Stafford et al., 2000; Polyakov et al., 2003).

The existence of both short-term and long-term climatic cycles and patterns and the interplay between them have recently been reviewed and discussed (Bone et al., 2010; Stevenson et al., 2012). Specifically, the regional effects of the Siberian and Arctic high-pressure systems and Aleutian low-pressure systems influence daily temperature (Martyn, 1992; Overland et al., 1999). The El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) work at longer timescales and can affect temperature across the state (Bond and Harrison, 2006; Masuda et al., 2006; Combes and Di Lorenzo, 2007). ENSO is a tropical Pacific atmosphere-ocean phenomenon that is responsible for the shorter 1–2 year El Niño and La Niña events, which generally transfer heat from tropical zones to higher latitudes (McLean et al., 2009). In El Niño winters, there is a more

persistent flow from the North Pacific into Alaska that results in warmer winters across most of the state (Graham, 1994; Renwick and Wallace, 1996). The PDO works at still longer timescales, representing a 20–30 year cycle between warm and cool sea surface temperatures in the North Pacific (Papineau, 2001), with oscillations between warm and cool temperatures occurring over relatively short durations (Mantua et al., 1997; Chavez et al., 2003). Multiple short- to medium-term climatic cycles and patterns interactively govern the weather patterns affecting agriculture in northern environments.

Not all of Alaska is climatically suited for agronomic crops. Growing seasons may be too short to allow for maturation of crops in some areas, and rainfall patterns during the growing season can restrict planting and harvesting of crops in others. Alaska's two major road-accessible agricultural regions experience somewhat varying climates because of their differences in latitude, topography, and proximity to oceans. The Interior region (Delta Junction/Fairbanks), ranges between 63° and 65° N, and is several hundred miles from any of the oceans. It experiences a continental climate with both winter and summer temperature extremes for the state. On occasion, Interior Alaska can experience temperatures near –51°C in winter and near 32°C in summer. The Matanuska-Susitna Valley, the other major agricultural region of Alaska, is located just north and east of Knik Arm (Cook Inlet) and experiences slightly milder summer and winter climates because it is near the ocean. However, the region receives less sunlight, experiences cloudier days, and is windier than the Interior.

Excessive winds are not uncommon in the growing season as large masses of air are funneled through the surrounding mountains.

Optimum temperature curves and net photosynthesis vary among plants (Gijzen, 1995). In cool areas, nutrient assimilation elevates along with temperature because of increased activity in the light reaction and through carboxylation. Yet, dark respiration and photorespiration also increase, decreasing net CO₂ uptake. Net photosynthesis decreases in response to exceeding a crop's optimum temperature. There can be a few days per year in Alaska when excessively high temperatures become an issue for agriculture. When not well maintained, crops under plasticulture (plant and soil coverings used for temperature regulation and season extension) can sometimes become excessively warm, which can cause light reactions to be less efficient and enzyme activities to decrease, thereby affecting plant quality.

Weather can strongly influence the production of fodder and other forage crops in Alaska. For example, a wet fall in 2012 followed by a hot, dry summer in 2013 led to a recent hay shortage around the state and in several parts of the Pacific Northwest. The Alaskan shortage was economically damaging to hay farmers, who struggled to fill orders. Horse owners were left struggling to find enough hay to feed their animals, and any hay that could be obtained was substantially more expensive.

Frost heaving and cold weather are hazards for crops in Alaska. In the Matanuska Valley, damage due to frost heaving was observed in plants after numerous freeze-thaw cycles (Smith, 1975). Soil freeze-thaw events in Interior Alaska can occur more frequently in spring than in fall and are influenced by snow cover. Crop death may occur when soil temperature at the depth of the crown node, a temperature-sensitive plant organ several centimeters below the surface (Boatwright et al., 1976), approaches lethal levels. Delta Junction, in particular, can experience persistent winds, resulting in thin snowpacks and soil temperatures that dip well below the lethal temperature for grains and legumes for extended periods of time. Cultivars can vary in cold hardiness, and snow management on agricultural fields can also influence the frequency of soil freeze-thaw events and the occurrence of lethal winter temperatures. Low-lying areas are particularly susceptible to unseasonable frosts and cold winds. In high-latitude areas, cold winds are often associated with cold air flowing through mountain passes or off glaciers. Some of Alaska's best soils and productive farmlands are in wind paths containing loess deposits that winds have left.

In Alaska and other high-latitude areas, such as Norway, ice cover can result in considerable winter damage to certain overwintering forage crops. In Norway, the absence of snow cover in some winters and areas with poorly drained soils can cause substantial soil freezing that leads to winter crop damage (Sveistrup and Igeland, 1995; Larsen, 1996; Valberg, 1996; Arnoldussen and Sveistrup, 1997). Furthermore, compaction of wet soils through the use of heavy

machinery has shown the potential to decrease overwintering resilience and reduce yields in Norway (Haraldsen et al., 1995 cited in Arnoldussen and Sveistrup, 1997). Frozen soils may make it hard to get into the field in spring because of poor soil drainage. The thawing subsoil releases water, which sub-irrigates crops above.

It can be difficult for farmers to anticipate timing of the last frost in the spring and the first frost of the fall. The early safe-planting date varies with latitude. For instance, gardeners in Southeast Alaska can often safely plant outdoors three weeks earlier than those in the Fairbanks area. In Fairbanks, during the decade 1994–2004, the number of frost-free days varied from as few as 83 in 1994 to as many as 134 in 2001, a difference of 51 days (weather station data compiled and reported to the University of Alaska Cooperative Extension Service). During this same period, the rate of first frost varied from 19 August to 24 September, and last frost varied from 6 May to 5 June. Sharratt (1992) evaluated trends in growing-season length and first spring and last fall freeze dates at eight climate stations that recorded data across Alaska from 1924 to 1989. While the growing season did not change during the 65-year study period in half the locations, it increased in length in the other half. However, a shortening of the growing season observed between 1940 and 1970 at several stations was generally associated with a later occurrence of the last spring freeze.

Circumpolar agriculture is likely to be affected by impending changes in climate, but specific effects will depend on the region, the direction and degree of regional change, and the overall level of predictability of weather events. It is important to note that while several areas of the state are becoming warmer and drier, others are becoming cooler or wetter, or both (Alessa et al., 2011; Stevenson et al., 2012). As warming in some regions of the state could cause further permafrost melting, freshwater ponds and lakes may drain into thawed soils (Osterkamp, 2007), leading to a decrease in freshwater and possible contamination of water depending on sediment chemistry (Alessa et al., 2008). Additional challenges that climate change could pose for sustainable agriculture in the North are changes in the abundance or type of pests, diseases, and invasive species and reduced regional winter survival rates of perennials due to warm spells that may cause perennials to break their dormancy (ACIA, 2004: Key Finding 3). Ultimately, northern environments contain multiple levels of uncertainty that are driven by specific weather patterns, climatic cycles, and seasonal extremes, in comparison with more temperate latitudes. Assessments of climate trends in Alaska for the purpose of predicting effects on agriculture must use a sound scientific approach, including a careful choice of time series, reference dates, and statistical methods (Stevenson et al., 2012).

Water and Irrigation

Water stress occurs frequently during the growing season in the Subarctic, and soil water content, precipitation,

water balance, humidity, and yield relative to evapotranspiration have received prior attention. Sharratt (1994) showed that irrigation can reduce water stress and bolster crop production in nearly 50% of all years. Despite Alaska's abundance of freshwater and relatively low overall withdrawal for agricultural purposes (Kenny et al., 2009; Alessa et al., 2011), not all Alaskans have easy or affordable access to sufficient water.

In some situations, water can be a factor that limits farm size. Sufficient water is a prerequisite for an irrigation system, such as drip or trickle irrigation, an essential part of plasticulture and greenhouse production systems that allow Alaskan farmers to extend the season and produce crops that would otherwise not be viable. Many farmers, although they may live on the road system, may not have access to city water or an economical well. Around Fairbanks, many farmers do not live within the city limits, where land is more expensive, so they cannot take advantage of city water systems. For instance, the Calypso Farm and Ecology Center near Fairbanks irrigates two to five acres using rain and snowmelt catchment ponds and gutters. Fairbanks area farmers can either drill a well, have water delivered, or set up a rain or snow water catchment system. Weddleton et al. (2006) found that well depths range from 30 to 183 m, and that variation in yield and water quality (e.g., arsenic, iron) from wells can be quite variable. Depending on the crop grown, not all farms require irrigation. The decision of whether to irrigate usually doesn't factor into whether a farm in Alaska is operating sustainably, but for many locations farmers can increase yields and reduce risk if they irrigate.

GEOPHYSICAL CHALLENGES

Soil Quality and Distribution

In 1899, C.C. Georgesson, USDA Special Agent in charge of Alaska Investigations, made note of the impact that unaerated and undrained soils can have on agriculture:

the young plants languished, turned yellow, and died... due to the soil and not the climate. It points a warning at those who begin with raw ground not to expect too much nor to become discouraged if it seems unproductive at first. It may possibly also account for the condemnations of some of those who say that "Alaska is no good for farming." The explanation lies in the fact that the raw, water-logged soil is too acid for the growth of most cultivated plants, and is unproductive until sweetened by aeration and drainage.

(quoted in MSB, 1983)

Soils play a crucial role in crop productivity, and the native soils of some regions, including the Arctic, are not always naturally well-suited to agriculture. In this paper, we consider that soils ideal for agriculture must be at least

46 cm (18 in) deep, have a loamy texture, not be overly wet, flood infrequently (< once in 10 years), have slopes no steeper than 7%, and experience limited wind erosion (Restad and McNicholas, 1983).

Soil moisture content presents a serious challenge in many areas of Alaska. For instance, soils in the rainy Southeast panhandle can often become too wet during the growing season, while those in other areas of Alaska can become too dry. Soils at high latitudes are relatively cold, and the temperature affects plant growth. Cold soils can affect the uptake of nutrients, especially phosphorus, and slow microbial activity, decreasing the mineralization of organic matter and the release of nitrate. Cold soils also offer less frost protection in the fall.

Seed germination for vegetables in spring typically requires soils to warm to temperatures above 4.5°C. Some field crops, however, are seeded on soil containing frost and emerge because their threshold is lower. The vertical temperature gradient means that shallower seeding will be benefited by warmer soil temperatures near the surface. Freezing and thawing are principal factors affecting weathering of seasonally frozen soils. For this reason, many vegetables are initially seeded and grown in a greenhouse before transplanting into the field as the soil warms. Some early-season crops, such as varieties of potato, carrot, and pea, can withstand cooler spring temperatures.

A constraining factor in Alaskan agriculture is the reduction of microbial activities and mineral weathering in seasonally frozen soils (Husby and Wooding, 1985), although microbial activity can be very pronounced as soils begin to thaw (Edwards and Cresser, 1992). The release of available nutrients from these processes occurs for only a few months per year in many high-latitude areas. The result is lower natural fertility and a higher fertilization requirement, particularly in continuous cropping systems, which have no fallow period in which soils can accumulate or store nutrients. Grain crop residues left on the soil surface undergo virtually no decomposition during the seven months of winter in Alaska's Interior. If these residues are incorporated into the soil in spring just prior to seeding the new crop, the microorganisms that feed on them will end up competing with the grain crop for available nutrients in the first two months of the growing season, a phenomenon known as nutrient immobilization (Husby and Wooding, 1985).

Organic Fertilization

A key point of consideration in Alaskan agriculture is that of soil amendments. Inorganic fertilizers are typically less expensive than commercially available organic fertilizers, and they are already in a form that can be used by plants. Options for integrating local, organic fertilizers into Alaskan agriculture exist (Stevenson et al., 2014b), albeit with some limitations and considerations.

Livestock manure can be used to incorporate organics into field crops at high latitudes, but feeding and housing

animals year-round can be prohibitively expensive and onerous. The specific challenges of raising livestock sustainably in Alaska requires further consideration before this option is widely adopted (Ikerd, 2011). Fish-based fertilizers are commercially or privately available in Alaska, but the conversion of these or other organic fertilizers to a nutrient form that plants can absorb and assimilate is slowed by reduced microbial activities in cold soils.

Composting can supply some needed nutrients, but this method of fertilization is typically limited to less than half of the year when temperatures are above freezing and compostable resources are not covered in snow. Cover crops might offer another opportunity to fertilize sustainably, but Alaska's growing season is short, and it may be difficult to grow a cover crop in the same year before or after a commercial crop is grown.

Frozen Soils and Permafrost

Frozen subsoils in spring can bring complications to farming that last well into summer, even in locations where summer ambient air temperatures are suitable for growing. Many sites that appear arable may actually contain ice lenses or blocks that impede vertical drainage. Such soils can remain wet throughout the summer without warming to a level that is ideal for agriculture.

Permafrost is defined as a layer of subsurface soil or rock that remains frozen (below 0°C) for multiple years (NSIDC, 2012). In locations where it occurs close to the surface, permafrost can impede both water percolation and warming of the soil surface to the temperatures preferred by some agricultural crops. Permafrost can underlie an entire area, or it can be discontinuous or absent. While the domestic water supply for consumption can be impeded by permafrost, adequate sources of surface water are often available for irrigation above the permafrost.

Soil Types, Distributions, and Limitations

Understanding the types of soil, their distribution, and associated agronomic limitations is important to unlocking agricultural potentials in Alaska. Alaska has five major soil climate regions, or Land Resource Regions (USDA NRCS, 2004, 2006): the Southern, Aleutian, Western, Interior, and Northern Alaska regions (Fig. 3), each with distinctive soil and site characteristics (Stevenson et al., 2014a: Fig. 2a, b). In the Southern and Western regions, well-drained soils suited to agriculture are leached of soil nutrients and acidic. These conditions may be attributed to the regionally high annual precipitation, which can exceed 2500 mm in the Southern region (PRISM Climate Group, 2010), and to cool temperatures and relatively high summer precipitation throughout the Western region.

The Aleutian region, including the Cook Inlet watershed, contains some of the best agricultural soils in the state: upland soils of the Matanuska Valley near the Knik and Matanuska Rivers, which are neutral or slightly acid,

are enriched annually from active loess deposition (Clark and Kautz, 1998). Soils with suitable site and soil properties for cultivation include soils within the orders and suborders of Spodosols-Cryods and Inceptisols-Cryepts. The Cook Inlet Lowlands are 38% Spodosols and 23% Histosols (USDA NRCS, 2004). Leaching of chemical nutrients is significant in Spodosols, but adding manure or organic fertilizer that breaks down more slowly can mitigate this problem (Brady and Weil, 1996). Most well-drained, upland soils of the region are acidic and leached of nutrients and require significant soil amendments to increase fertility and make them suitable for agriculture. Wet soils associated with topographic depressions and soils with shallow depth to gravelly drift are the primary physical limitations to agriculture within this region.

The Interior region, dominated by a strong continental climate, has the largest extent of soils suited to agriculture in Alaska: soil orders and suborders include Gelisols-Orthels, Gelisols-Turbels, and Inceptisols-Cryepts (Fig. 3) although it lies within the zone of discontinuous permafrost (Péwé, 1975). Elsewhere within this climatic region are significant areas of soils on flood plains with a suitably thick surface mantle of loamy alluvium suited to cultivation.

The Northern region, north of the Brooks Range summit, is Arctic in nature, with cool summers and severely cold winters. Short summers, with frosts and snow possible in all months, severely restrict agricultural activities within this region. However, the village of Kobuk has previously reported productive vegetable growth in the region using commercial fertilizer (Dearborn, 1979).

The wide range of soil characteristics throughout Alaska implies that regionally specific strategies for managing soils will need to be developed. Some soils may be too coarse to hold enough water or inorganic nutrients, while others may have impervious layers. Some of the most used soils in Alaskan agriculture have moderate potash content, but are often deficient in organic matter, nitrogen, and phosphates. Surface layers are usually acidic, and subsoils are high in calcium and magnesium (Mick and Johnson, 1954).

The USDA Land Capability Classification System was designed to rank the relative agricultural suitability of soils across the nation (USDA NRCS, 2012). This system ranks soil components within soil map units on an eight-point scale, one being the best and eight the least suitable for agriculture. Because of the short growing season and limited diversity of crops suited for cultivation, no Class I soils are recognized in Alaska. The U.S. Department of Agriculture Natural Resource Conservation Service (USDA-NRCS) does, however, recognize soils within Land Capability Classes 2, 3, and a portion of 4 as suitable lands for agriculture (Fig. 4). Several of the local Soil and Water Conservation Districts and borough governments in Alaska have recognized this group of soils as Farmlands of Local Importance, thus providing some statutory protection.

Physiography, climate, hydrology and soil texture are the more important site and soil characteristics that determine an area's suitability for cultivation. Since comprehensive

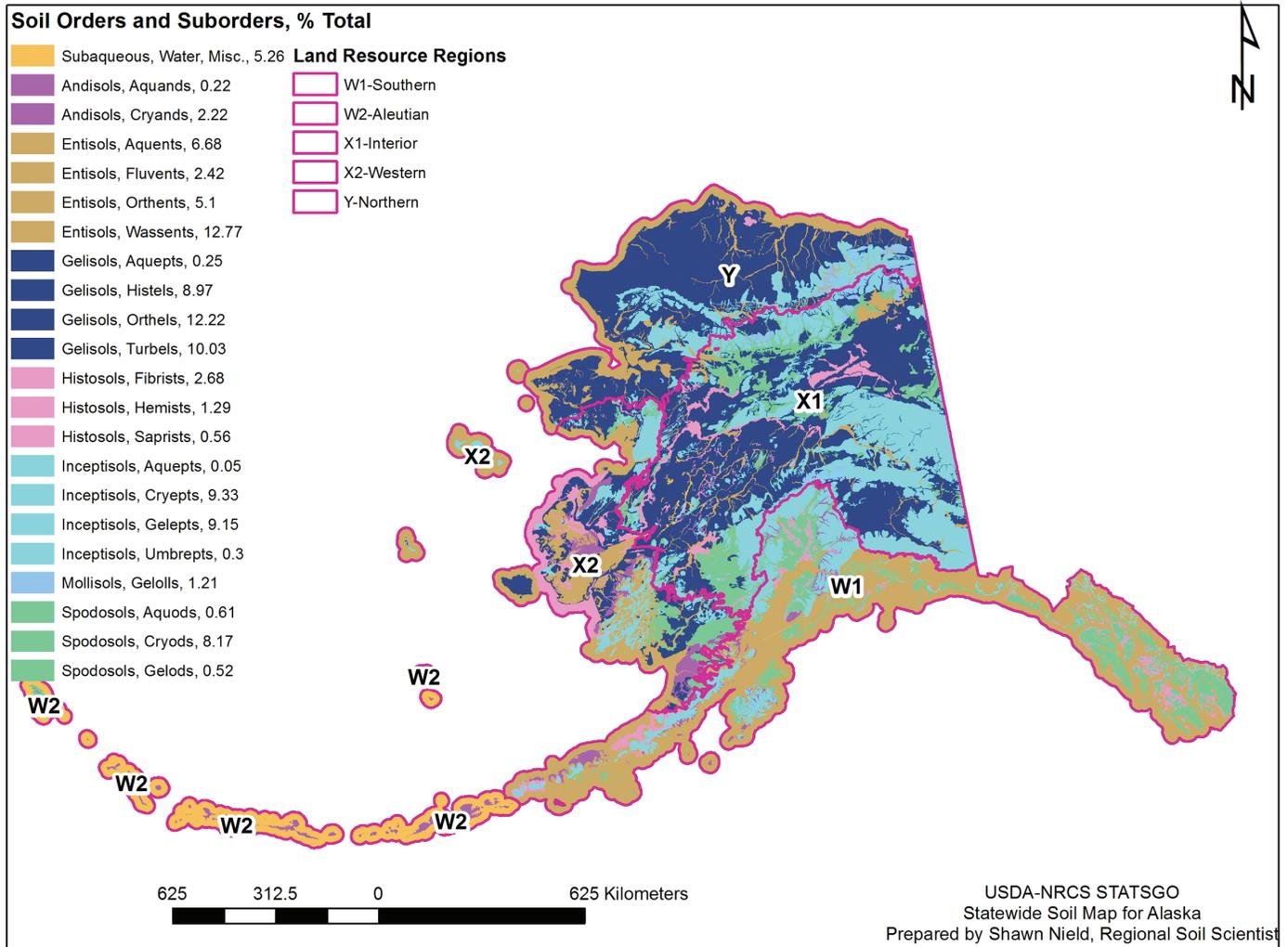


FIG. 3. Soil regions and major soil taxonomic orders and suborders of Alaska. The Land Resource Region codes identify the five major regions of Alaska: W1-Southern, W2-Aleutian, X1-Interior, X2-Western, and Y-Northern. Sources: USDA-NRCS Draft Statewide Soil Map (STATSGO), 2011 and USDA NRCS (2006).

climatic data are often unavailable in certain regions, the Land Capability Classification for Alaska uses index crops as a surrogate for growing degree days and frost-free season. Those index crops include barley, potatoes, and hay. In order for a soil to receive the highest Land Capability Class 2, the climate must be able to support all three index crops. Should it only support two of the three index crops, the best assignment that is attainable is Class 3. Should the climate of an area support only one of the three index crops, then Class 4 is the best possible class attainable.

Areas with no agricultural soils identified include non-vegetated areas and steeply sloping mountains, as well as the Arctic, where climate severely restricts the growth of forage and grain crops. The 0%–10% and 10%–30% categories generally include narrow mountain valleys, where agricultural soils are limited to mountain foot and toe slopes of less than 20%. Small areas of flood plains and stream terraces are also suited to agriculture within this group. The 30%–60% and 60%–90% categories include large areas of gently sloping plains and hills with relatively large contiguous areas of soils with slopes less than 20%.

Figure 5 shows the distribution of the site and soil characteristics that are the primary limitations to agriculture. The slope limitation is assigned where slopes exceed 20%. Soils with a water table within 50 cm of the surface are assigned a wetness limitation. A textural limitation is assigned where the surface mineral layer is more than 15% rock fragments. Soils with a flooding hazard probability of more than once every 100 years have been assigned a flooding limitation. A climate limitation has been assigned for areas where the growing season is very short or non-existent.

Regional climatic differences factor into whether certain crops can be consistently grown year after year. Interior and parts of Southcentral Alaska have climates favorable to most climatically adapted crops, including barley, cole crops, potatoes, and hay. Land Capability Classifications of 2 to 4 are possible in these regions (Fig. 4). This list is shorter in Southern and Western Alaska, where rainfall patterns, cloudy summer days, and cooler summer temperatures limit the total number of growing degree days available for cultivated crops (Fig. 5). Rainfall patterns, including high precipitation in late summer, limit harvest and

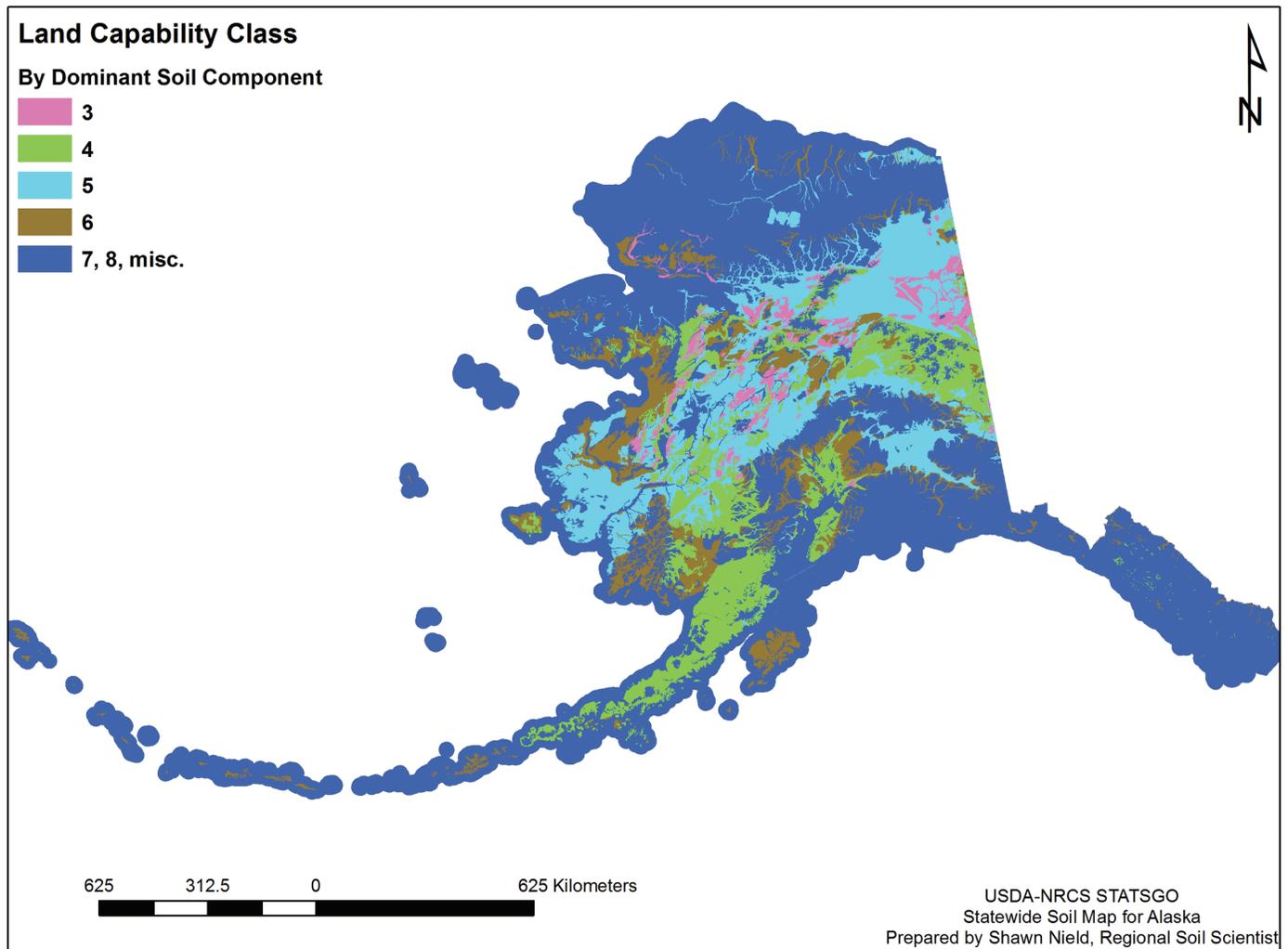


FIG. 4. Distribution of land capability classification groups for Alaska. Sources: USDA-NRCS Draft Statewide Soil Map (STATSGO), 2011 and the USDA NRCS (2012). Although Land Capability Class 2 soils do occur in Alaska, they do not form contiguous units of significant extent to display at the published map scale.

drying of grain and hay and restrict field operations. Land Capability Classifications of 4 are the best possible in these regions. Elsewhere, in Interior and Southcentral Alaska above about 350 m elevation, midsummer frost and short growing seasons restrict the growth of most grain crops and generally limit agriculture to hay and pasture, and the best possible Land Capability Classification is 4. Northern Alaska, which is generally not well suited to agriculture because of the severe climate, may be able to support localized agriculture with the best possible Land Capability Classification of 5.

Site and soil properties are used to determine land suitability for agriculture based on the Land Capability Classification. Suitable sites have slopes of less than 20% and water tables below 50 cm during the growing season. They are also found where the surface 25 cm of mineral soil has a loamy soil texture with less than 15% rock fragments. The best sites are also not flooded or experience flooding only rarely. Generally speaking, in order to meet the best Land Capability Class in Alaska (2), a site must occur in a climatically favorable region that has adequate growing degree

days and frost-free season to grow all index crops, meet the site and soil properties described earlier in this paragraph, and have a slope of less than 7%. Above this upper limit of 7% slope, soil water erosion becomes a major issue, and row cropping is not sustainable in terms of soil health. Conservation tillage practices in subarctic Alaska designed to address erosion and soil quality are described in detail in Stevenson et al. (2014b).

In general, the best sites for agriculture in Alaska can be determined by taking into account maps of agricultural potential, land classification, and climatic and geophysical challenges. However, land capability classes are assigned on a very large scale, and often within these large zones numerous regions can be found where soil properties and microclimates allow crops to prosper unexpectedly.

BIOLOGICAL CHALLENGES

Biological factors most strongly impacting agriculture in Alaska and other high-latitude locations can include cultivar

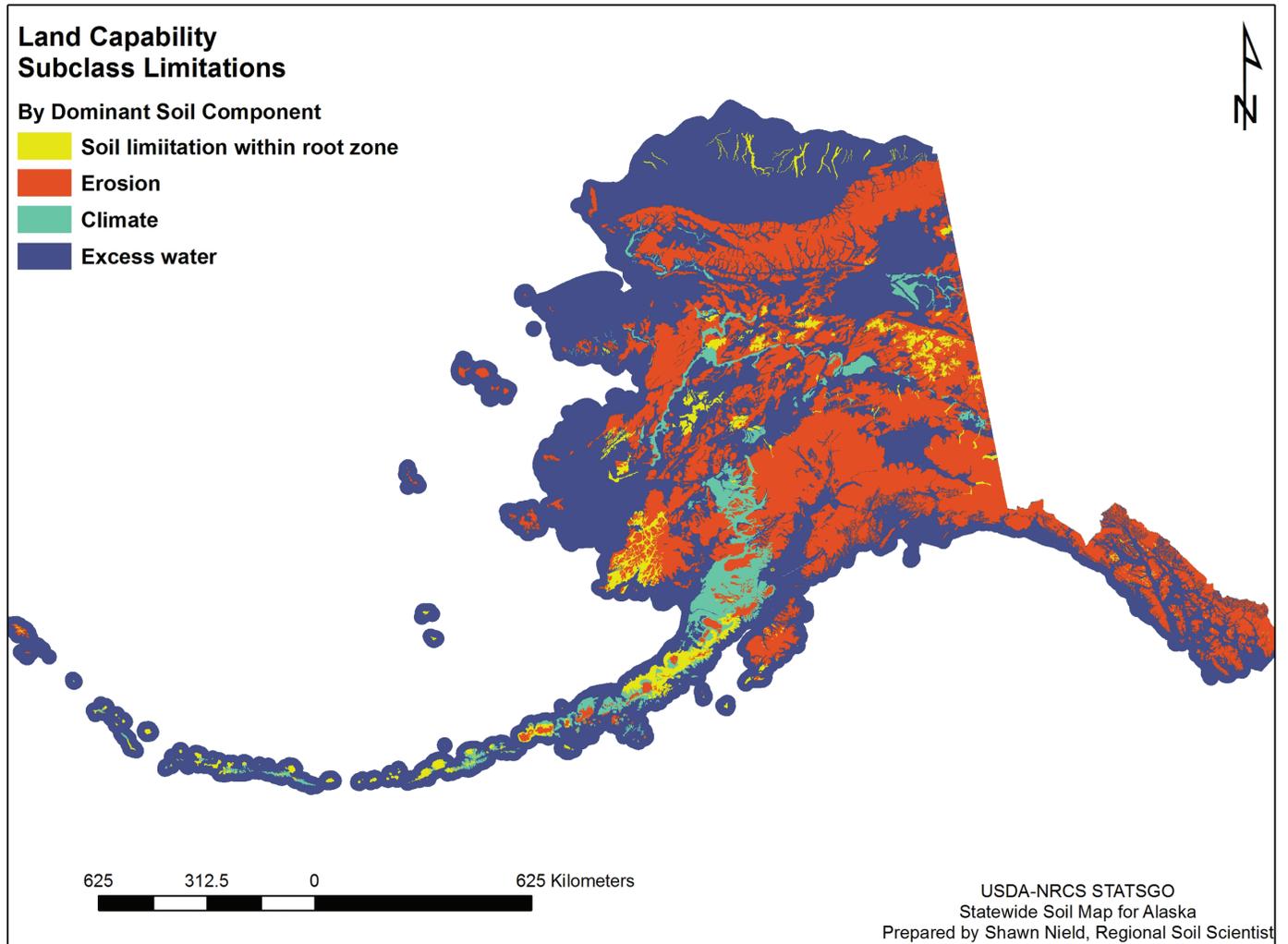


FIG. 5. Some environmental and geophysical limitations to agriculture in Alaska based on land capability subclasses. Subclasses include susceptibility to erosion, excess water, soil limitations within the rooting zone, and soils for which the climate (temperature or lack of moisture) is the major hazard. Sources: USDA-NRCS Draft Statewide Soil Map (STATSGO), 2011 and the USDA NRCS (2006).

development and selection, overwintering, latitude of adaptation, physiological age, drought stress, animal pests and disease, weed infestation, and plant pathogens (Fig. 2).

Crop and Cultivar Development and Selection

Vegetable, floral, and agronomic crops and cultivars for Alaska have been reviewed in prior publications, which have provided plant variety, source, maturity, yield, and other information (Wooding et al., 1975; Roberts, 2000; Van Veldhuizen and Knight, 2004; Holloway et al., 2006; Matheke et al., 2008; Seefeldt and Vandre, 2010; Smeenk, 2010). Long-term scientific experimentation, monitoring, and experience have demonstrated that high-latitude limits to agriculture depend heavily on the gene base (ARDC, 1983). The challenge for northern regions is to find crops and cultivars that are at the same time sustainable producers, palatable, marketable, and able to tolerate cool soils, long days, a short growing season, and ideally unseasonable frosts. For instance, few grains will tolerate high

winds, excessive rains, and midsummer frosts. Some northern crops are productive without season-extension techniques, while others fare better or require their help in mitigating the vagaries of regional and seasonal climatic variability (discussed in Stevenson et al., 2014b).

Because of Alaska's large size and the significant variation in optimal cultivars and crops, it can be challenging to identify the most productive crop or cultivar for a particular area. Agriculture Experiment Stations historically operated throughout the state in Sitka, Kodiak, Kenai, Rampart, Copper Center, Fairbanks, and Palmer; however, only the Palmer and Fairbanks stations remain in operation today. For Interior and Southcentral Alaska, crop and cultivar research can often be easily transferable, but for Arctic and coastal communities, it is not.

Farmers may wish to select cultivars that will maximize yield or cold hardiness. Numerous varieties exist for most fruits, greenhouse/high tunnel vegetables, and garden vegetables, such as potato, snap beans, peas, cabbage, or lettuce. For example, many varieties of potato have been tested and

rated by maturity and yield for Southcentral and Interior Alaska (Seefeldt and Vandre, 2010; Smeenk, 2010). Cool-season crops can be seeded directly into outdoor soils in spring. In all but the warmest areas of the state, most warm-season crops are productive only if season-extension techniques or greenhouses are used.

The majority of Alaska's agricultural land base is used to produce agronomic crops (e.g., perennial hay and grain), but potatoes, vegetables, and livestock are also well represented. On a cash basis, Alaska crop production is dominated by greenhouse and nursery crops, followed by vegetable crops and then hay. Some crops are adapted to a wide range of climatic and geographic locations, while others thrive only in selected locations. The performance and characteristics such as yield, fiber, protein and nutritional content of barley, wheat, oats, and other grain crop varieties are well documented (Wooding and Knight, 1973; Husby and Wooding, 1985; Dofing, 1992; Van Veldhuizen and Knight, 2004).

Fodder and grain crop varieties have been bred specifically for Alaska. Average yields of perennial forages range from 0.9 to 1.3 tons per acre, and better-managed farms often exceed 2 tons per acre per year (Quarberg et al., 2009a). Barley (*Hordeum vulgare*) and multipurpose oats (grain or forage) are the first and second most common cereal grains produced in Alaska, respectively, but winter wheat has not proven to be successful in Alaska because it requires a long growing season (Quarberg et al., 2009b; Tarnai, 2009; Hartman, 2010).

High-latitude farms provide a relatively small market to larger seed companies, and there are few incentives for developing specialty seeds for cold climates. Some of the productive varieties that work well in Alaska are at the end of their product cycles in the major production regions in the continental United States. Unfortunately, U.S. seed companies do not usually maintain selected varieties when Alaska growers represent the only market. Some operations, such as the Denali Seed Company in Anchorage, have been able to provide some seeds that are better suited to subarctic and Arctic conditions by relying upon and catering to Alaskan gardeners to help determine which varieties best fit Alaskan conditions.

Overwintering, Latitude of Adaptation, and Physiological Age

Just before winter, perennials harden off, a process in which they begin storing food in their roots to sustain them until the next season of active growth. Year after year, they undergo this physiological change in autumn in response to decreasing photoperiods before the first frost. Different hardiness systems and zone maps have been developed for Alaska (see summary in Roberts, 2000). Pre-winter hardening and sufficient nutrients are important factors that contribute to the health of perennial grasses that overwinter below the snow. Even if a cold-shocked plant remains alive, its early growth may be suppressed for several days during

regeneration of a healthy root system and new leaves. Winter survival of perennial plants, including fodder crops, in the Far North depends on how well adapted cultivars are to various climatic zones and microclimates, but it is also a function of temperature, planting, and snow cover. Very low overwintering ambient temperatures, the length of winter, and desiccation (when plants are not covered by snow) present serious challenges to northern agriculture, although subterranean and subnivean temperature measurements give a more realistic measure of actual exposure.

Crop breeding programs for forage and grain crops around the circumpolar North have helped to develop new varieties for improved yield, disease resistance, efficient fertilizer use, and crop quality. As strains constantly become better adapted to particular geographic locations and as quality and yield improve, older varieties are replaced with newer ones. The effects of planting date, seeding-year development, winter survival, and subsequent seed and forage production potential have been well studied in crops in Alaska. For example, date-of-planting studies referred to by Van Veldhuizen and Knight (2004) showed that for an agronomic crop, any planting date after the middle of May can result in delayed maturity, low yields, and low-quality grain, even for the varieties best adapted to Alaska.

Klebesadel (1992) showed that in trials involving timothy (*Phleum pratense*) and early planted northern and southern-adapted ecotypes of red clover (*Trifolium pratense*) and alfalfa (*Medicago sativa*), the more southern-adapted cultivars were generally more productive than northern cultivars in that region. However, early planted northern-adapted seedlings of timothy, Kentucky bluegrass (*Poa pratensis*), and red fescue (*Festuca rubra*) showed stronger winter survival and greater next-season production than the more southern-adapted ecotypes. Clipping legumes short near the end of season did not allow them to hold the snow cover against the force of occasional winter winds, resulting in complete winter kill due to insufficient snow cover, which has been found to be necessary to protect crops from cold and wind (Klebesadel, 1992). Klebesadel (1994) demonstrated the effects of plant date and latitude of adaptation on the phenological development and winter survival of legume cultivars in Alaska.

Physiological age is known to influence the performance of seed tubers. It is a biological parameter determined by chronological age and by exposure to environmental conditions at a given latitude (Reust, 1986; Struick and Wiersema, 1999). One of the most interesting and controversial issues in northern agriculture is that of the so-called "northern vigour" effect, an unsupported theory that suggests that vegetatively propagated crops (usually seed potato) produced in more northern latitudes are superior to material produced farther south (Canada-Saskatchewan Irrigation Diversification Centre, 1998; an effect has also been suggested in strawberry: ICDC, 2007). "Northern Vigour™" is a trademark of the Saskatchewan Seed Potato Growers Association, but the descriptive term, "vigour,"

presumably refers to a difference in the seed tuber's initial rate of sprouting (emergence), yield, or grade (Canada-Saskatchewan Irrigation Diversification Centre, 1998; Struik and Wiersema, 1999). Studies of vigour are numerous, but conclusions are contrasting (Wahab, 1993; Struik and Wiersema, 1999; Johansen et al., 2002; Knowles et al., 2003). Some studies have concluded that scientific documentation for a northern vigour effect is altogether lacking (Knowles et al., 2003; Johansen et al., 2008). Despite Canadian claims of a vigour effect (Canada-Saskatchewan Irrigation Diversification Centre, 1998; ICDC, 2007), a consensus of peer-reviewed studies that fully assert its presence or efficacy is lacking. It is plausible that if seed potatoes at high latitudes were exported farther south to a warmer climate, there might be an effect of yield increase based on a younger physiological age. Unfortunately, northern vigour is often claimed to be something else (e.g., superiority in sprouting, growth vigour, and yield) that does not fit completely with physiological age theories. In Norway, northern vigour, physiological age, dormancy and performance of seed potato have been well studied, especially in regard to environmental or external influences such as temperature, day length, or pre-sprouting regime (Johansen and Nilsen, 2004; Johansen, 2011; Johansen and Molteberg, 2012).

Crop Protection

Animal Pests: Alaska is far away from large agricultural regions, and the pressure of common agricultural insect pests is lower than in other areas. However, their presence has been substantial enough to warrant decades of research. The bulk of animal pest research addresses insects, such as aphids or flies, which are common in the circumpolar North (Johansen, 1999; Johansen and Meadow, 2006; Pantoja et al., 2010b) and have affected Alaskan agriculture.

Pest research in Alaska is of interest since it is expected that populations will fluctuate with changes in climate (Whitfield, 2003). The Arctic Climate Impact Assessment (2005) suggests that indirect effects of climate change on high-latitude agriculture could include an increase in the occurrence and densities of insect pests, diseases, and weeds. This suggestion points to the critical role of temperature and moisture for the spread of many plant diseases (Gitay et al., 2001); the risk of increased crop damage in northern Europe (Carter et al., 1996; Maxwell et al., 1998); and an increase in species that lead to infestations in North American agriculture, as well as in the severity of such infestations, with less severe winters (Shriner et al., 1998).

At present, the biology of agricultural insect pests in the circumpolar region is unknown or poorly understood (Pantoja et al., 2009, 2010a, b). The continued development of a sustainable agricultural industry in Alaska depends on the effective management of insect pests and the implementation of integrated pest management programs to reduce pesticide use and possible contamination. Agricultural use of insecticides is currently fairly minimal, but changes in climate and the arrival of new pests could change this.

Information on taxonomic identity, biology, population dynamics, and geographical distribution of insect pests is particularly important in the development of integrated pest management (IPM) programs for subarctic regions.

There is a need to understand the biology and ecology of insect pests in the North, especially for plant hardiness zones not found in the conterminous United States. Entomologists from the USDA Agricultural Research Service and the University of Alaska Fairbanks have previously summarized work on turnip maggots (Washburn, 1969, 1975; Bleicher, 1984), beekeeping in Alaska (Washburn, 1961, 1974), the resurgence of Alaskan cutworms (Washburn, 1971), the use of insecticides in Alaska (Chamberlain, 1949; Washburn, 1973), and the warble-fly problem in Alaska reindeer (Washburn et al., 1980).

Except for those on grasshoppers, the reports on economically important insect pests in Alaskan agriculture are limited or outdated (Pantoja et al., 2009, 2010a, b). A few regional reports provide information on Alaskan insects, but host plant association information is limited. Documentation of the occurrence and distribution of crop diseases in Alaska is also limited (Lefebvre, 1950; Logsdon, 1955, 1956; Sprague, 1955; Logsdon and Strobel, 1960), and pests and disease are often linked. Furthermore, little is known about the potential for insect transmission of diseases to agricultural crops.

Despite the publication of a few agronomic studies (Chamberlin, 1949; Dearborn, 1983) and taxonomic studies (Beirne, 1956; Hamilton, 1997), little is known about the taxonomic identity, population dynamics, distribution, ecology, and biology of leafhoppers affecting agricultural crops in Alaska. In the major potato production areas of Alaska, 41 leafhopper species associated with agricultural settings have been identified (Pantoja et al., 2009), 20 of which are specifically associated with potato. In the United States, Canada, and Europe, wireworms (Coleoptera: Elateridae) are important pests of vegetables, small grains, and potatoes (Onsager, 1975; Toba, 1981; Toba and Campbell, 1992; Horton and Landolt, 2001, 2002; Crozier et al., 2003), and in Alaska, their damage to potato was noted as early as 1949 (Chamberlin, 1949) as well as more recently (Dearborn, 1983). Coccinellids, commonly referred to as lady beetles, are more commonly associated with biological control of pest species; they have a wide distribution and occur in high numbers in agricultural habitats. Hagerty et al. (2008, 2009) published the first long-term survey of coccinellids associated with Alaskan agricultural crops, reporting 13 species in association with agricultural crops of the Tanana and Matanuska-Susitna River valleys of Alaska. Distributional data are available on Lepidoptera for Canada or for North America (Danks and Downes, 1997), and some specimens are reported as far north as Point Barrow (Roberts, 2000). Alaskan records for geometrid moths are indicated on maps by McGuffin (1967–87). Landolt et al. (2007) provided information on the biodiversity of Lepidoptera in Alaska and data on species composition and population dynamics needed to develop IPM programs against

this group. Root maggots, an important pest of turnips, present a challenge to growers in Alaska (Washburn 1953, 1969; A. Pantoja, unpubl. data). Growers use crop rotation, protective covering (row fabric) over the entire planting, or barrier cones around individual plants to prevent root maggot-fly oviposition on plants. Grasshoppers are known to damage hay and grain crops, as well as compete with livestock for pastures (Davies, 2007). The factors leading to grasshopper outbreaks are not well understood; in many regions, populations appear to be limited by food quantity and quality. However, in spite of the short growing season and limited food sources, populations of Alaskan grasshoppers are seldom, if ever, food-limited (Fielding and Defoliart, 2007, 2010; Fielding, 2008). These grasshoppers are adapted to high latitudes; however, embryonic development is highly temperature-dependent (Fielding, 2008; Fielding and Defoliart, 2010).

Weeds: Weeds present a substantial challenge to commercial and subsistence farms at high latitudes, just as they do elsewhere. The Alaska Natural Heritage Program maintains the Alaska Exotic Plants Information Clearinghouse (AKEPIC) Database, an exhaustive review of Alaska's weeds and their identification, tracking, distribution, and invasive rankings of weeds (AKEPIC, 2008). The database includes both annual weeds such as chickweed (*Stellaria media*) and lambsquarters (*Chenopodium album*), which are frequently controlled by cultivation, and perennial weeds such as horsetail (*Equisetum fluviatile*) and cotton sedge (*Eriophorum vaginatum*). Conn and Werdin Pfisterer (2010) showed that some weed seeds in Alaska can remain viable after almost 25 years of burial, although many species do not. Moose (*Alces alces*) and other native herbivorous wildlife can act as transport vectors of non-native weeds lining roadsides into farming areas (Seefeldt et al., 2010).

Plant Pathogens and Microbial Hindrances: Horticulture in Alaska accounts for nearly 70% of farm marketing cash receipts (Benz et al., 2009), yet research on plant diseases in Alaskan agriculture has been limited. Reports of plant viruses in Alaska grown crops have been restricted to potatoes (Campbell, 1988), barley and oats (Robertson and Brumfield, 2000; Robertson, 2003), carrots (Robertson, 2007), rhubarb (Robertson and Ianson, 2005), and clover (Robertson and Brown, 2010). A few reports refer to viruses on ornamental plants (Robertson et al., 2009) and on native plants, including lupine (Robertson, 2004; Robertson and French, 2007), larkspur (Robertson, 2001), and twisted-stalk (Robertson, 2005). Current baseline data on disease status, incidence, and severity are needed to direct future research efforts in agronomic settings and manage plant diseases at the farmer's level.

Reduced Microbial Activity and the Persistence of Pesticides: The rate at which pesticides undergo biodegradation by soil microbes is intimately tied to soil temperature, among other factors. This link means that in northern regions, pesticides will persist longer in colder soils, and planting too soon after application can reduce crop rates substantially (Eberle and Gerber, 1976). The effects of cold

soils on herbicide degradation and damage to subsequent crops of small grains and canola have been well studied. Herbicides have been found to persist for relatively long periods of time in subarctic soils and to cause damage to subsequent crops (Ranft, 2008; Frutiger, 2009; Ranft et al., 2010).

The use of pesticides in Alaska is complicated by the high cost of shipping, the paucity of products labeled for use in the crops grown in the state, and the interaction between the short growing season, cold soils, and possible pesticide injury to the crop (and possibly, subsequent crops). Herbicide use on Alaskan crops and the interaction of season and crops has received prior attention (Conn and DeLapp, 1984; Conn and Knight, 1984; Conn, 1986, 1990; Farris and Conn, 1987); however, further research is needed to study pesticide use and contamination levels in Alaska and elsewhere in the circumpolar region.

Challenges in Raising Livestock and Poultry at High Latitudes

While livestock production in the North can be affected by the cold, it is often more limited by non-climatic factors, such as availability of processing facilities and access to superior genetics, rather than directly by climate (ACIA, 2005). Production and availability of inexpensive, reliable feeds are major constraints to animal agriculture at high latitudes (ACIA, 2005). Cold temperatures outside the thermal neutral zones of livestock and poultry can reduce body condition and market returns, although this is less of an issue for indigenous animals, such as reindeer, or animals that can be kept in heated facilities.

From 2001 to 2006, 85% of meat from hoofed animals was imported into Alaska from outside sources, and an average of only 2% of all red meat has typically come from Alaska-raised beef and pork (Paragi et al., 2010). Paragi et al. (2010) reported that from 2001 to 2005, less than 1% of red meat produced in Alaska came from reindeer. The history and present status of reindeer herding in Alaska has been discussed previously, in detail (Stevenson et al., 2014a).

Climatologists forecast warmer and drier conditions in the Interior in coming years with increased frequency of wildland fires. These conditions could shift forest composition from spruce toward deciduous trees, or even produce a biome shift to grassland savanna with scattered trees. Hence, in the long term, the potential for livestock production in Alaska may improve if adequate precipitation or irrigation allows forage and grain production (Paragi et al., 2010).

SOCIOECONOMIC CHALLENGES

The agro-ecological and biogeographic challenges discussed in the sections above cannot be studied in isolation from the socioeconomic and cultural challenges to farming

in Alaska. These areas can have considerable overlap and at times are inseparable. Socioeconomic challenges to high-latitude farming (Fig. 2) may be the most arduous and limiting factors influencing sustainable farming in Alaska. The level of food self-sufficiency and sustainability in the state depends largely on the desire of individuals to pursue agriculture for subsistence or for profit and on their capability and knowledge. Additionally, state and federal policies can influence the development of a sustainable agriculture system in Alaska.

Production, per se, is not the biggest challenge to growers in the North. The socioeconomic issues related to marketing, consumer preferences, competition with global markets, subsidized inexpensive food, and limited social support services for producers are the most challenging and pertinent issues facing Alaska's local growers (for a historical perspective, see Francis, 1967; Shortridge, 1976). As noted previously, Alaska (in contrast to other circumpolar entities) has been fairly immune to food or supply boycotts through past wars or standoffs (Stevenson et al., 2014a). Furthermore, if crop diseases break out in one area of the United States that supplies Alaska with food, another unaffected area can usually provide it.

Alaska's population has increased from approximately 73 000 in 1940 to almost 10 times that number in 2010 (U.S. Census Bureau, 1940, 2010). Yet, the number of farms in the state as of 2012 (762; USDA, 2014) was not substantially different from the number of farms in the 1940s (Shortridge, 1976; Stevenson et al., 2014a). Although average farm size and productivity have not remained static during this period of time, the small number of farms in Alaska is, in part, related to the low return gained in response to the time and effort required to produce marketable products.

There is a growing concern that Alaska's food system is vulnerable and over-dependent on outside distribution systems (Alaska State Senate, 2012; AFPC, 2014). Additionally, there is concern for the health of Alaskans and a realization of the economic opportunities lost for the state because it lacks local agriculture. A growing cadre of Alaskan farmers and agriculture professionals believes that feeding more of the state with locally produced foods is possible, even off the road system (Stevenson, 2009; Stevenson et al., 2014b), and that considerably higher levels of food self-sufficiency and sustainable production are attainable goals. Even if a stronger agricultural presence did not improve food security, it would lead to greater overall economic development within the state. However, Alaska must also overcome significant socioeconomic challenges. And as one of the least populous states, it has little influence to deal with these concerns at the federal level.

Economic Challenges

Several of the larger economic challenges to commercial agriculture in Alaska are identifiable. First, there is the low level of financial reward for the labor involved. Next,

intensive management efforts and high capital investment are required. Additionally, a high level of economic risk is taken on in the operation of an agricultural business. Few farmers have become wealthy from growing in Alaska, as there is only a fair payback for all the investment, risk, and work. The average net cash farm income from farms in Alaska was \$11 271 in 2012 (USDA, 2014). It seems logical, then, that part of the reason there are so few farms in Alaska is that they return so little money for all the difficulty it takes to produce crops. There are simply more lucrative and seasonally consistent jobs in Alaska than farming. That is not to say that there are no rich farmers in Alaska, but these have often been successful in other areas of business and now farm for various reasons, not primarily for financial gain.

Maximum prices on produce and other crops are usually set by outside forces (e.g., "Seattle price + freight cost"). While Alaska has a strong contingent of customers that buy the quality products sold in farmers' markets at prices significantly higher than those found in the grocery stores, they are not the majority of the population. The economics get even more challenging when a crop is sold on the wholesale market. The Alaska Grown program is one of the few incentives for wholesale buyers to pay any premium for crops grown in Alaska over their imported counterparts. In many areas, farmers' markets have begun to sell out, and demand may be exceeding supply.

Alaska as a whole has a limited sales market with its largest population centers in Southcentral Alaska. The Anchorage area is served by over 15 farmers' markets, but many other communities may not provide a market sufficient to support local agriculture. In essence, growing may be relatively easy compared to the challenge of selling for a profit. A certain level of marketing sophistication may be needed to achieve greater improvements.

It is challenging for local growers to compete with food imported to grocery stores even though some supermarkets are beginning to sell more Alaskan products. Alaska's farmers must pay retail costs for shipping in supplies to grow their entire crop, while their grocery store competition pays wholesale shipping rates on just the edible portions of the crop. In other words, Alaska's farmers pay to ship in supplies for growing the crop itself, along with roots, stems, and even any diseased and unmarketable vegetables. Grocery stores ship in large volumes of marketable crops, and shipping with other products in the store can also lower their overall costs.

Next, farmland in Alaska is expensive and availability is limited. The Alaska Rural Rehabilitation Corporation (ARRC), a non-profit organization in the Matanuska-Susitna Valley, provides farm loans to prospective farmers throughout Alaska. Its manager has stated that for a beginning farmer without outside income, the best agricultural lands on the road system are simply too expensive to turn a profit (S. Gallagher, ARRC, pers. comm. 2011). If prospective farmers can achieve a tax-deferred exchange and can buy the land, they can often afford to farm, but

the cost of clearing new land is also high. Furthermore, development pressure on some of Alaska's most productive land is incredible. For instance, much of the farmland in the Butte-Wasilla corridor is valued at \$5000–\$20 000 per acre because of its value for housing lots. Land and zoning challenges to agriculture are rooted in the ratio of crop productivity to land cost. Unless done on a small scale, the likelihood of agriculture paying off such high land prices is low. Those who wish to farm sustainably in Alaska likely do so for other reasons than just for profit (Ikerd, 2011), but as defined by Congress, economic viability is an essential component of sustainable agriculture (FACT, 1990).

As populations near urban centers expand, the development of lands with good agricultural potential may become threatened. Land capability classifications must be taken into account in zoning discussions to maximize the protection of suitable agricultural lands. Paragi et al. (2010) report that public discussions on the protection of lands suitable for food production have been held to explore new zoning models in view of potential loss of productive agricultural land to residential or industrial development near urban centers.

Several productive areas identified in this paper as having prime agricultural land are not currently available lands. Many are federal, state or Native-owned lands. The State of Alaska possesses some agricultural projects in various locations, which means that the land is restricted to agriculture only. The State Division of Agriculture cannot lend on housing on these properties, and other standard lending institutions don't lend on the property. The ARRC and the USDA Farm Service Agency are the only two entities that lend for the construction of housing on restricted state agriculture lands. Since the projects began in the 1980s, the values have increased tremendously from their original purchase prices. Lewis and Thomas (1982:178) previously noted that Alaskan agricultural development is tied to the disposal of government-owned land: "If agriculture is to develop according to the United States farm production model, then large quantities of agricultural land must be sold to private citizens. Past federal policy in Alaska has not led to this outcome and thus the present-day development efforts spring from state government leadership."

The cost and availability of infrastructure limit sustainable agriculture development in Alaska. At a 2010 conference for Western Sustainable Agriculture Research and Education, farmers and other stakeholders were asked, "What will be needed to create stronger local food systems that are less reliant on imports from elsewhere?" (WSARE, 2010:1). Rebuilding or improving infrastructure (e.g., processing, canneries, etc.) and developing cost-effective storage facilities were both identified as important needs.

Infrastructure is often a chicken-and-egg issue in Alaska (e.g., there isn't much of a used implement market for entry-level farmers because there are so few implements in the state since there are so few farmers in the state...). Likewise, it is difficult to have a local farm supply store when there might be only 10 farms within 200 miles of it. For

instance, if a part for a tractor or a planter belonging to a farmer in a small outlying community had to be ordered and brought in by plane, it might actually make better economic sense to order it from an online dealer in Chicago or Dallas rather than to call up a dealer in Fairbanks. While the total cost in this scenario may be cheaper to the farmer, it would not support any in-state building of agricultural infrastructure or agricultural businesses (it would support freight and shipping businesses). There are few local suppliers of greenhouses, plastics, enclosures, tools, mechanized equipment, seeds, and fertilizer (organic or conventional). The lack of locally available infrastructure, supplies, and inputs could be inhibiting sustainable agriculture development in Alaska, and these issues were identified as areas needing research in the 2010 conference on sustainable agriculture in Alaska (WSARE, 2010).

Next, Alaska has almost no processing infrastructure or businesses to which farmers can sell raw agricultural products (Stevenson et al., 2014a), nor do farmers have a strong history of forming cooperatives to add value to their basic products. Until the development of some mobile slaughter facilities for reindeer, the lack of infrastructure to bring meat products to market was extremely challenging for this sector of Alaskan agriculture. A lack of infrastructure and facilities continues to cripple farming in the state. Furthermore, energy for fueling mechanized equipment and heating and lighting greenhouses is a major issue for Alaskan farms. The development and integration of affordable alternative energies on farms could spur greater sustainable development of agriculture in Alaska.

Predicting costs and making informed economic decisions are additional challenges to Alaskan farmers that are crucial to overcome. As an example, in deciding upon an irrigation system, the direct and indirect costs need to be considered in addition to the specific need. The different techniques available (solid set pivot systems, trickle tape in rows, rainwater catchments and cisterns, etc.) vary considerably in cost. A \$100 000 pivot may need a 20-year amortization period, whereas a \$500 drip system in a high tunnel could pay for itself in the first season. However, irrigation systems that don't represent a significant capital investment often end up requiring a significant labor investment. Furthermore, the infrastructure, operations, and maintenance are legitimate expenses for a farm and are allowable tax write-offs. In essence, the expenses reduce the amount of income on which a farmer pays taxes. For instance, if a farmer spends \$1000 per year on irrigation and is in the 15% tax bracket he saves \$150 that year on taxes. However, he still spent \$1000 in saving that \$150. Most of the various government cost-sharing programs that would help to purchase irrigation equipment would actually increase the farmer's tax obligation since these funds are often treated as income. These examples highlight the important role of agro-economic education for farmers, which could extend to developing Alaska-specific systems along with clearer references that would provide explanations of investments, tax breaks, and returns.

Cultural Challenges

Local, sustainable production of vegetables, forage crops, fruits, and other foods could make circumpolar states more self-reliant and less dependent on outside food sources. We previously discussed how some rural Alaska villages have embraced, practiced, or tolerated local farming and gardening (Stevenson et al., 2014a). Further expansion could foster greater rural economic development, make fresher and higher-quality produce more available, and increase the likelihood that dietary choices will improve and increase food security for rural areas.

One of the challenges for sustainable agriculture development, particularly in remote locations in Alaska, is a lack of access to agricultural education. There are few educational opportunities for beginning farmers and ranchers in the number of outlying communities that exist in Alaska. The University of Alaska Cooperative Extension Service has a limited number of staff specializing in agriculture and a small travel budget for travelling to remote communities (Rader et al., 2012). During the Western Sustainable Agriculture Research and Education statewide stakeholder conference mentioned above, training for beginning farmers and gardeners was identified as an important need for creating stronger local food systems that are less reliant on imports from elsewhere (WSARE, 2010). With only 762 farmers in Alaska and less than 30 American Indian or Alaska Native farmers, those who hope to farm sustainably are likely to be beginning farmers (USDA, 2009a, 2014). Seasonal employment such as construction and firefighting, and traditional subsistence activities, including hunting and fishing, are usually a higher priority than farming or ranching (Rader et al., 2012). One aspiring Inupiaq farmer, Chad Nordlum (2012) stated,

I am not a farmer. I grew up in Kotzebue, Alaska. Farmers do not come from Kotzebue. Snow mobile racers, dog mushers and fisherman come from Kotzebue, but not farmers. Hunting and gathering are the traditional ways of the Inupiaq people but the Inupiaq have always been adaptable... I have never been on a working farm. Although I am not a farmer now, I do hope to be someday.

Because Alaska Native communities have historically acquired foods by hunting, fishing, and gathering, and still do so today, there is a need to understand how a new or increasing influence of agriculture might affect villages and households. For instance, how does the concept of tending the crops as a business mix with going to fish camp for several weeks in the middle of the growing season? Furthermore, is the community status of “farmer” one to which entrepreneurs wish to aspire? Graves (2005) has shown that a decline in the emphasis on Alaska Native men’s responsibilities for hunting and fishing can affect household resiliency. The impact includes a reduction in men’s perception of their overall position within their families

and communities, feelings of alienation, and even depression linked to alcoholism. How might someone who is a subsistence or commercial farmer perceive his role within the family and community, or how might a family or community view this new farmer? Would the role be perceived positively, perhaps embraced as a substitute avenue for leadership and food provision, like that of a hunter or fisherman? Or would it be perceived as an inferior or less valued role in the family and community? How might communities across different regions of the state view the activities of new or aspiring farmers? The answers to these questions remain unclear, but it is likely that a greater availability of fresher, local foods for purchase would be appreciated in remote locations.

Community agricultural professionals are hopeful that the integration of sustainable agriculture into some subsistence-based communities will continue to occur without hindering the preservation of traditional sociocultural practices or boundaries. If so, it may help to improve overall food security in villages, elevate local involvement in food, and improve health through increased physical activity and the offering of more local healthy food choices.

Food Costs

Fazzino and Loring (2009) reviewed food costs for 20 Alaskan communities and reported that meals for a family of four can cost 250% of what a family in Portland, Oregon, would pay (UAF CES, 2009). They also cited anecdotal reports that in many remote communities (often low-income areas, but also “regional centers” such as Fort Yukon), food prices sometimes reached 600%–1000% the cost of food in the lower 48 contiguous states (e.g., in 1995, a gallon of milk sold for up to \$15; Reed, 1995). There is no doubt, then, that one positive effect of increasing the overall level and efficiency of production would be to make food choices more affordable—although there is the looming question over whether this can ever be achieved for all of Alaska.

Although some Alaskan produce can be slightly cheaper than the same imported product, locally grown and sold produce in some specific regions of Alaska (e.g., Fairbanks) can be more expensive than the same item grown outside of that local area and imported (Meadow, 2009). Local growers in places like Fairbanks have a hard time competing with the prices of larger companies like Food Service of America, which distributes produce to markets in Alaska and in other states. Yet, foods grown and sold locally can be fresher and can be produced in varieties that are more flavorful but don’t ship well. The purchase of these foods supports the local economy and small businesses. A review of economic assessments, data, and analyses for specific regions and communities of Alaska is needed to compare costs of imported and local agricultural products and to present a more comprehensive understanding of these issues.

As important as the cost of locally grown produce are the perceptions and preferences of consumers and their

willingness to pay for it. A single study of Alaskan consumers' perception of organic produce (not necessarily locally grown) highlighted the importance of healthfulness and quality of that produce (Swanson and Lewis, 1993), but did not examine the price premium consumers were willing to pay.

Agricultural economies throughout America are generally considered strong at present. Current food costs throughout the United States are comparatively low, with less than 10% of family income spent on food (as noted in Consenstein, 2010). In Alaska, however, many residents consider food costs high because they know that food is cheaper in the lower 48 states. Paragi et al. (2010:37) have stated, "We expect it will remain difficult to engage the rural and urban public or government in serious discussions about agricultural policy until the price of food becomes a substantially larger (even prohibitive) proportion of annual income for Alaskans, or until major disruptions in transportation increase the frequency and magnitude of local and regional food shortages."

For many Alaskans, the price of food has become prohibitive already. Ideally, local, sustainable agriculture on a larger scale, accomplished by overcoming the challenges listed above, will lead to greater production of local foods that are competitive with those shipped in from other areas. For commercial agriculture, the goal is to have local crops that are profitable and worthwhile for farmers to grow and which are marketable at a competitive price relative to imported foods. For subsistence farming and gardening, goals are different, but ultimately rest in greater food security or self-sufficiency that meets personal needs or tastes.

Social and Policy Challenges

Stakeholders in Alaskan agriculture have historically faced challenges in communicating with legislators in a unified voice, partnering with agencies, and presenting recommendations. However, the recent passage of bills and resolutions (e.g., Alaska Senate Bill 24, 2012; House Concurrent Resolution 1, 2013) to promote a state food resource development working group that can work in partnership with stakeholders on the Alaska Food Policy Council and with state agencies (Alaska State Senate, 2012; Alaska State Legislature, 2013) is a change in the right direction. The details of this progress are described further by Stevenson et al. (2014b).

At the federal level, the success of sustainable agriculture in Alaska is strongly influenced by U.S. policies and funding on statewide priorities. Because of its small population and even smaller agricultural base, Alaska finds that its needs and priorities are dwarfed by those of the lower 48 states. Some agencies, such as the Sustainable Agriculture Research and Education Program, base their policies on regional needs assessment; however, many U.S. agencies set policies and programs on a national level rather than on a state or even regional level.

Funding priorities have also dictated research priorities that often are not directly aligned with the needs of Alaskan farmers. For agriculture to develop more sustainably, research will need to be more closely aligned with the needs of farmers throughout Alaska, and it must be available and easy to find electronically (WSARE, 2010; Rader, 2011). Agriculture, in general, is challenging in Alaska, and agriculture research in the State has often focused on what is possible, without regard to whether a practice is sustainable.

CONCLUSIONS

Sustainability has long been a tenet of northern agriculture, whether it is using all available materials or operating at a scale that is manageable and economical. So-called "non-sustainable" practices are often too expensive to implement or may not even be practical in northern environments. In view of the high costs of living in Alaska and the percentage of food that is imported from lower latitudes, it is likely that more communities will gravitate towards initiating, practicing, or improving sustainable agriculture. Identifying challenges to high-latitude agriculture and sustainable farming practices in the North ultimately facilitates discussion of the corresponding solutions required to maintain sustainable lifestyles.

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