CHAPTER 1

Sustaining Agriculture in a Changing Climate

Climate change is upon us, and agriculture is inextricably involved. Fundamental to our identity as a species, crucial to the health and well-being of our communities, the way that we eat fuels the 21st-century challenges that threaten our way of life. How can we resolve this dilemma? The path that we have taken as a species shapes the possibilities of our future.

For the last ten thousand years, we have been on a long walk out of the Earth's wild places, onto the farm and into the city. In the slow evolution from foraging to agriculture, humanity took up, quite unconsciously, the work of nature. We took on the work of cultivating plants and animals, of caring for them and guiding their evolution. With this change in the way we related to the ecosystems that sustained us, we changed ourselves, and we changed the Earth.[1]

Agriculture emerged as our dominant food acquisition strategy rather late in our history as a species. For millions of years, bands of *Homo sapiens* adapted to the available food resources produced by the native ecosystems in which they lived. Satisfying this basic need to eat drove the evolution of a wide diversity of foraging strategies shaped largely by local ecological conditions.

Archeological evidence suggests that by the end of the last ice age, about twenty thousand years ago, humans had evolved a comfortable way of life based on foraging for food. In diverse ecosystems across the Earth, humans, like all animals, were part of the native food web. Food foraging sustained stable human populations for millennia, but about ten thousand years ago, something changed. All over the Earth, human population began to grow. Wherever that happened, you find agriculture.

Early Systems of Agriculture

Agriculture can be defined as the cultivation of deliberately bred crops and livestock for food, fiber and other materials. It evolved as a distinctly human form of food acquisition during the Neolithic Period (10,000–2000 BCE), as foraging cultures slowly came to rely on one of three distinct forms of early agriculture.

In the desert grasslands of the world, ecosystems too dry for the cultivation of plant foods, humans first hunted and then domesticated grazing animals—sheep, goats, cattle and camels—to sustain themselves. This led to the evolution of *pastoralism* as an efficient means of food acquisition. In the wetter forest ecosystems, humans first only gathered wild foods, but eventually began to care for some of the plants they favored. These *horticulturalists* made use of the diversity of edible plants and small forest-dwelling animals—swine, poultry and guinea pigs—and managed gardens of favored plants and animals in clearings rotated through their forested homelands. In just a few unique places, where the right combination of natural resources came together—plants, animals, land, water—a third form of early agriculture evolved. *Sedentary agriculture* emerged in the great river valleys of savanna ecosystems inhabited by a diversity of plants that produced edible fruits, seeds and vegetables, as well as large herds of grazing animals. Sedentary agriculturalists created the first permanent farms producing domesticated grains and livestock on land kept fertile by yearly flooding.

Even though these three forms of agriculture evolved in very different ecological circumstances, they share a number of characteristics. First, all are embedded in local ecosystems and dependent to a great degree on ecological processes to provide water, nutrients, pest suppression,

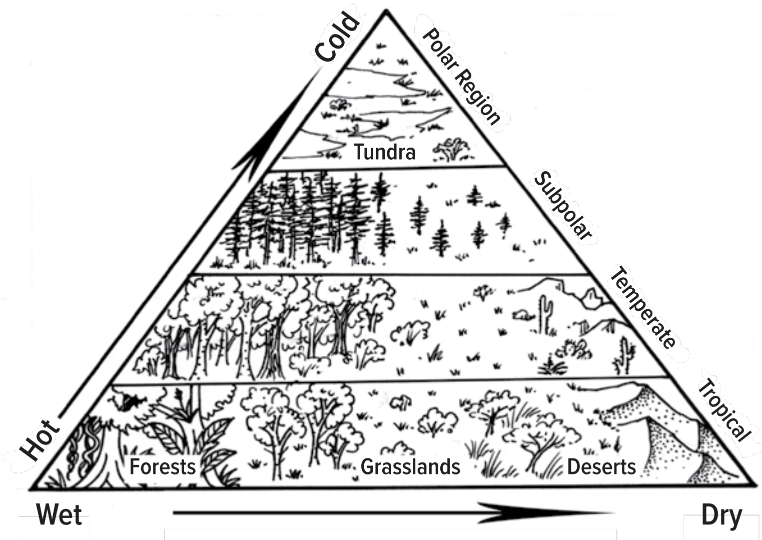

FIGURE 1.1. Major Terrestrial Biomes. The land-based ecosystems of the earth can be grouped into four major biomes—tundra, forest, grasslands and desert—based on dominant vegetation and climate. Pastoralism evolved in grasslands, shifting horticulture evolved in forests, and sedentary agriculture evolved in both temperate and desert regions with access to manageable water supplies. Credit: Sherri Amsel

waste disposal and other services needed to successfully produce edible plants and animals. Early farmers increased food production in these systems in two ways. They could care for favored plants and animals by improving growing conditions, providing food and reducing the risk of predation. And they could improve the yield and quality of the food produced by the species under their care through careful selection for desired qualities and yield. But in every essential way, these early systems of agriculture were adapted to ecological resource limits.

All these early systems of agriculture took advantage of the many benefits that animals provide to food production. Most importantly, animals are an efficient strategy for producing food from plants that are inedible to humans, for gathering and storing foods, and for utilizing food wastes. The ruminant animals—sheep, goats, cattle, camels—convert inedible grasses and forbs into high-quality meat, milk and eggs for human consumption, while others—dogs, swine, poultry—can consume a wide variety of foods and make great garbage collectors. Animals are excellent "biological silos" for storing excess production. Ruminants are particularly useful as buffers in extreme conditions because they can survive for long periods without food. At this point in the development of agriculture, animals were not yet used for traction.[2]

All of the early agricultures created an energy profit—more food energy was produced than energy invested in production—although none came close to the energy profit estimated for foraging of forty food calories produced for every calorie of labor invested.[3] The energy profit in pastoral and horticultural systems has been estimated at about eleven food calories harvested for every calorie of labor invested. Because sedentary agriculture required more intensive management, it is the least profitable of the early agricultures, reaping about eight calories for every labor calorie invested.

Foraging and the early farming systems that followed it propose very different solutions to the same basic question facing all animals: How best to allocate the available time and resources to acquire food? All things being equal, animals (including humans) tend to solve this effort-allocation problem by maximizing the capture of calories, protein and other desired foods in a way that yields the most return with the greatest certainty in the least time for the least effort.[4] Moderate, reliable returns are usually preferred over fluctuating high returns. It turns out that, for a long time, foraging was a good solution to the effort-allocation problem facing early humans. But climate change changed everything.

At the end of the last ice age, between ten and twelve thousand years ago, agriculture began to replace foraging as a food acquisition strategy in many regions. Rapid warming and increasing climatic variability caused ecological disturbances that changed the effort-allocation equation. Climate change led to shifts in the ranges of plants and animals, changing the mix of available food species and causing plants and animals that could not adjust to the new climate conditions to disappear.

At the same time, lowland and coastal areas were being flooded by rising seas fed by the melting of massive continental glaciers. Archeological evidence suggests that during this time foraging cultures throughout the world began to broaden the number of plants and animals they used for food and started to cultivate favored plants and animals. The first evidence of warfare dates from these challenging times as well. People across the globe shifted from food gathering to cultivating crops and livestock during this time, though some foraging cultures persist to this day.[5]

Ultimately, the effort-allocation problem boils down to a question of managing five basic natural resources: land, water, labor, plants and animals. Pastorialists focused on managing livestock because grasslands have few native edible plants and shifting, uncertain rainfall; however, grasslands have a lot of grass and mobile grazing animals whose milk, blood and meat provide sustenance to humans. Horticulturalists did not have benefit of large domesticable animals, but had large expanses of forest filled with edible plant foods and plentiful rainfall, and they focused on cultivating native edible plants and small woodlands animals. Sedentary agriculturalists had benefit of a diversity of edible grasses and other edible plants as well as domesticable animals, and they developed agricultural systems that used both. All three forms of early agriculture increased food supplies, causing human populations to rise, but it was sedentary agriculture that ignited the human population explosion that continues to this day.

The first clear evidence of fully developed systems of sedentary agriculture emerged in several locations in Asia about six thousand years ago. The sedentary agriculturalists inhabiting the Fertile Crescent were originally pastoral cultures that kept livestock and foraged wild foods, including native grasses. These native grasses flourished under the changing climate conditions, offering pastoralists a new food source and encouraging innovations in the tools and technologies needed to cultivate wild grains as a dietary staple. The people of the Fertile Crescent domesticated the abundant native grasses and developed the first grain crops—early forms of wheat and barley.

By 3000 BCE, the sedentary agriculturalists had increased agricultural productivity by using natural resources—particularly land and water—more intensively. The development of irrigation works supported huge increases in yield and stabilized production. Animal power provided labor, and animal manures were used as fertilizers to replace nutrients taken from the soil in harvested crops. This intensification of sedentary agriculture produced large surpluses of food but cut the energy profit of agriculture in half—from eight to four food calories for every labor calorie invested[6]—because of the additional work required to build, maintain and power the production system with human and animal labor. Intensive sedentary agriculture was so productive that fewer people were required for food acquisition, freeing up some to devote all of their time to other pursuits. This release of human resources from food production sparked the development of the first cities and gave birth to human civilization as we know it. All because of climate change.

American Agriculture

Up until about a hundred and fifty years ago, sedentary agriculture really had not changed all that much since Neolithic times. Neolithic farmers domesticated just about every animal and plant that could be domesticated. These early agriculturalists developed irrigation, used animal manures as fertilizers, rotated grain and legume crops and used pesticides. Over the last five thousand years, in every favorable biome, regardless of culture, the basic elements of intensive sedentary agriculture remained the same.

Contemporary American farmers and gardeners will recognize the practices used by Roman farmers in about 200 CE. To enhance soil fertility, the Romans cultivated grain crops like spelt, barley and wheat in rotation with alfalfa and mixed cover crops of beans, vetch, chickpea and clover. They managed sheep, goats, pigs and cattle on pasture and gathered hay from wild grasslands and acorns from oak forests to feed their livestock in winter. Roman farmers terraced their fields to reduce soil erosion, limed and fertilized their soils with livestock manure and monitored soil quality based on color, smell, taste, stickiness and compactness.

When Europeans arrived on the American continent, it was fully settled by Native Americans using foraging as well as all three systems of early agriculture.[7] In the eastern forests, some Native Americans depended mostly on foraging and others on horticulture, but many used both to their advantage. The Midwest and Great Plains were home to sedentary agriculturalists who managed crops in floodplains and hunted buffalo moving through their lands, as well as pastoralists who followed the buffalo throughout the year. Foragers, pastoralists, horticulturalists and sedentary agriculturalists all called the Far West home. Throughout the continent, these three early agricultural strategies, supplemented with foraging and trade, were used to create local, place-based ecological solutions to the problem of food acquisition.

1.1. Native American Farming Cultures

Prior to European contact, Native Americans farmed using sophisticated systems of crop production involving common agricultural practices such as irrigation, terracing and crop rotation, fertilization, and breeding. The Mohawk, Cherokee, Mandan and Hohokam are representative of farming cultures in the North American Northeast, Southeast, Northern Great Plains and Southwest.

The Mohawk inhabited much of what is now New York State. These shifting horticulturalists lived in villages, each featuring a large communal-style longhouse made from wood harvested while land was cleared for crop production. Mohawk women farmed forest gardens planted with the staple crops of corn, squash and beans—known as the "three sisters"—as well as pumpkins and tobacco. They processed crops and stored them for use over winter, gathered wild fruits and other plants, and tapped sugar maples for syrup. Mohawk men hunted deer and other wild game and fished to supplement crop production. When soil nutrient depletion caused crop production to decline in the forest garden, the village would move to a new location and establish a new garden and longhouse.[8]

The Cherokee originally inhabited a large region of the southern Appalachians including the Carolinas, northern Georgia and Alabama, southwest Virginia and the Cumberland Basin of Tennessee and Kentucky. They settled along major rivers in permanent villages and towns of homes and public buildings constructed with wood and stone and protected by wooden palisades. Sedentary agriculturalists, the Cherokee tended large communal fields of corn and beans on the outskirts of each village. These fields were managed

FIGURE 1.2. A Mandan Farmer Cultivating Maize and Squash with a Bone Hoe.
Credit: Clark Wissler

in a three-year rotation that included one year of corn and beans followed by two years of fallow. Each household also grew sunflowers, pumpkins and squash in smaller gardens located in fertile floodplains. The harvests from communal fields were shared with every family in the village. To supplement crop production, Cherokee women foraged wild fruits and other plants and men hunted deer and small game in the forested woodlands.[9]

The Mandan lived in permanent settlements along the banks of the Missouri River and two of its tributaries in present-day North and South Dakota. Their villages featured large, round, earthen lodges some forty feet in diameter surrounding a central plaza. The Mandan farmed, gathered, hunted and actively traded goods with other Great Plains tribes. Mandan women farmed small fields of corn, beans, sunflowers, tobacco, pumpkins and squash in fertile floodplain soils. Harvests were processed and stored for winter use and for trade. Mandan men hunted bison, deer and small mammals to provide meat and other material goods.[10]

The Hohokam lived along the Gila and Salt Rivers systems in what is now Arizona. One of several Southern farming peoples, they are distinguished by their construction of a major system of irrigation canals that spread over several hundred miles. The Hohokam used the canals to irrigate fields of corn, squash, beans and cotton. This irrigated agriculture was highly productive, allowing the harvest of two or sometimes three crops on the same land each year. Hunting wild game and gathering wild fruits and other plants provided important additions to their diet. Crops were processed and stored for use during the long dry periods each year when they could not be cultivated. The Hohokam and other Southwest farming cultures developed other innovations to increase agricultural yields. They developed improved corn and bean varieties that were well adapted to the extreme growing conditions typical of their region and used water conservation practices like terraces and check dams to capture and store water during heavy rains or flooding, and to trap silt to create deep fertile pockets of soil in the landscape.[11]

European colonists settling in North America faced the same ecological conditions as Native Americans, but brought with them the knowledge, experience and technology of intensive sedentary agriculture as practiced in Northern Europe. They faced three key challenges when they arrived on the eastern coast of America: climate, forests and soils. The climate was mostly warmer and wetter that their homelands, the land was predominately forested, and the soils were infertile. A blending of New World and Old World agricultural knowledge offered the best solution to the food acquisition problem.[12]

Europeans settling in the eastern forests practiced *horticulturalism* to create a distinctly new form of American agriculture. They usually cleared about 25 percent of their land and left the rest in forest. A typical rotation of the time was corn, wheat and pasture, with the length of each grain crop determined by corn yield. When corn yields fell, typically after two or three years, wheat was grown until yields fell, and then cultivated fields were planted in pasture or allowed to revert back to forest. Corn came first in the rotation because high grain yields could be produced in the rough ground of newly cleared fields by planting corn in hills, along with beans and squash. Cattle and hogs free-ranged in the forests and were rotated through pastured areas. Milk cows were typically kept close to the house and taken out to graze every day in improved pastures held in common. Cattle and hogs were fed some grain when there was excess, particularly right before slaughter.

Using this blend of Old and New World agriculture, eastern farms produced enough food for the family, plus some excess to barter or sell. Wheat, cattle and hogs were the principal commercial products, along with small quantities of butter and cheese made from excess milk produced by the family cow. Colonists bartered for or purchased specialty foods like sugar and salt, as well as manufactured goods they could not produce on the homestead. This system was productive for a time, but soils were soon degraded by the continuous production of grains, the low quantities of manure applied to cultivated fields and the short period of forest fallow.

As New Englanders pushed west over the Appalachian Mountains looking for new land, they took this new American agriculture with them and settled into the more fertile soils of the Midwest. Corn remained the grain of choice for human and livestock consumption. Because of limited transport options and prevailing market demands, wheat, beef and pork remained the most common commercial products. As cheaper Midwestern grain and livestock began to flow to markets to the east, farmers in the East switched to more perishable products like fruits, vegetables and dairy to remain profitable and to supply expanding urban markets nearby.

While small family farms were typical of agriculture in the Northeast and Midwest, an early form of industrial agriculture, powered by human labor, shaped the culture of the South. Most southern farms were family farms of less than 100 acres producing subsistence crops and livestock plus some tobacco and cotton for trade; however, large plantations producing commodity crops for export on 1,500 to 2,000 acres dominated commercial agriculture in the South. During the early colonial period, plantations in Maryland and points south along the Atlantic coast produced tobacco, indigo and rice for European markets, using first indentured servants and then African slaves. By the late 1700s, the Industrial

Revolution in England created a new market for American cotton. Southern planters, short on land and labor, pushed over the southern Appalachians to settle on new lands in the lower Mississippi region. By the early 1800s, more than one million African slaves worked the cotton, rice, tobacco and cornfields of the South in a system of industrial agriculture that dominated the South until the Civil War.

The western expansion of America through the mid-1800s offered both challenge and opportunity to agriculture. Climatic conditions in the Great Plains and arid West forced settlers to replace corn with more drought-resistant grains like winter wheat and sorghum, and swine with sheep and cattle. Even with these adjustments, conditions remained challenging, and sedentary agriculture in the region was very difficult. Many settlers found that pastoralism was better adapted to the climate of the American West and turned to raising cattle on the western prairies. Settlers who moved on to the Pacific Northwest and California found the moderate climate and fertile soils of the region excellent for the production of wheat and had developed a thriving industry exporting the grain to national and international markets by the 1850s.

The Rise of Industrial Agriculture

Industrial agriculture began to take its modern form in the mid-nineteenth-century wheat fields of California. The moderate Mediterranean climate, large flat valleys, plentiful water supplies, isolation from large population centers and access to major seaports set the stage for the continued development of mechanized commodity agriculture in America.

California agricultural investors understood that to be competitive in distant markets, they had to keep production costs low and provide consistent, high-quality products. The topography and climate of California's Central Valley facilitated the development of large-scale mechanization. Continuous waves of immigration supplied the low-cost hired labor needed on these large commercial farms, and San Francisco offered low-cost wind-powered transport to destinations worldwide. Wheat producers invested in affiliated industries—agricultural inputs, processing and marketing—and a vertically integrated, export-oriented commodity wheat industry emerged in the the Central Valley of California by the mid-1860s. This form of industrial production was fundamentally different from the small-scale, labor-intensive, owner-operated farms producing wheat in other parts of the country.

1.2. California's Central Valley

A unique mix of landscape, natural resources and climate support the incredible productive capacity of California's Central Valley, one of the most productive agricultural regions on Earth. Stretching over 450 miles from Redding in the north to Bakersfield in the south and covering about twenty thousand square miles, the valley produces a wide range of crops—more than two hundred and fifty at last count—and is home to nine of the top ten most productive agricultural counties in the nation.[13] The region's Mediterranean climate (hot, dry summers and cool, wet winters), a three-hundred-day growing season, rich floodplain soils, a level landscape and abundant water, plus easy access to national and global markets, allowed for the development of the most intensive agricultural production in the United States. Using less that 1 percent of the nation's farmland, Central Valley farmers produce 25 percent of the nation's food supply and 40 percent of its fruits, nuts and other table foods.[14]

The Central Valley is made up of two different valley systems that meet just east of San Francisco: the Sacramento Valley to the north and the San Joaquin Valley to the south. The Sacramento Valley is cooler and wetter with less productive soils but more abundant groundwater and more surface water resources, which it shares with the much drier and warmer San Joaquin Valley through a system of federal and state water projects.

Agriculture is threatened throughout the Central Valley by development pressures, more frequent droughts, reduced winter snowpack and increased competition for water. However, the more productive San Joaquin faces the most critical challenges. Groundwater levels in much of the region have dropped 120 feet or more in the last 150 years,[15] increasing the costs of pumping groundwater, causing massive land subsidence in some areas during the twentieth century (Figure 2)[16] and possibly increasing the risk of earthquakes along the San Andreas Fault.[17] More than half a million acres of cropland have been degraded by the buildup of salts from irrigation waters,[18] another two hundred thousand acres are challenged by drainage issues, and farms are competing intensely for imported surface water supplies with urban, industrial and environmental management uses. Some in the region are calling for the retirement of land in agricultural production as a sustainable solution.[19]

In 1870, California was a leading US producer of wheat and barley and was exporting these grains to Australia, China and Great Britain. By 1890, two decades of continuous grain production with little use of crop rotation, fertilizers or fallow had degraded soils and promoted high weed populations. Grain yield and quality had also begun to decline, and by the end of the century, California had abandoned wheat as a commercial crop. But the industrial structure created to produce the grain was easily adapted to other high-value crops. By 1910, California industrial agriculture had shifted focus to fruit and vegetable production, invested in the necessary irrigation infrastructure and developed the associated industries to pack, process and transport fresh and processed fruits and vegetables to national and international markets.

The Pacific Northwest climate and landscape was also well-suited to grain, fruit and vegetable production, but lacked the transport and irrigation infrastructure to develop a productive commercial industry. Railroads reached the region in the 1880s, and irrigation shortly thereafter, and a commercial agriculture sector swiftly developed in the region.

By 1920, California and Washington led the nation in fruit production. Washington was the number one apple producer, a position it holds to this day. California contributed significant quantities of apples, pears, cherries, peaches to the domestic supply and produced virtually all of the almonds, apricots, walnuts, olives and lemons grown in the United States, as well as substantial proportions of grapes and figs (80 percent), prunes and plums (70 percent) and oranges (57 percent).

Significant agricultural developments in the rest of the United States during the latter part of the 1800s encouraged the development of the fed cattle industry—a third major industrialization of American agriculture. The settling of the Great Plains and the mechanization of grain production increased wheat and corn supplies, while the invention of refrigerated railcars encouraged cattle feeding facilities and allied industries—slaughter, packing and distribution—to locate near major railheads in Chicago and Kansas City. The first grain distribution companies formed at this time. Initially these companies simply managed grain supplies, but they soon began to market US grain internationally and eventually developed into an industrial food-processing sector. By the end of the 1800s, the Midwest had emerged as the nation's leading corn and swine producer, while agriculture in the East adjusted to new competition from California fruits by shifting to fresh vegetables and dairy for regional consumption.

All of the best agricultural land in the United States was settled by 1920, closing the option of moving west as a way to increase production. Growing international demand drove US agricultural development through the remainder of the twentieth century. The solution to the need for increased production was to intensify agriculture—to produce more, on less land, with less labor. Over the next fifty years or so, with the help of a national system of publicly-funded land grant colleges, agricultural research stations, the Cooperative Extension Service and American agribusiness, American agriculture fully industrialized.

This process involved a massive transformation—from human and animal power to fossil fuel power, from a focus on subsistence to a focus on commercial production, from pasture-based livestock production to confined livestock production and from a regional market orientation to an international market orientation. During this period—roughly the middle of the twentieth century—the responsibility for the American food supply was transferred from a multitude of small-scale, diversified family farms and ranches to a small number of large-scale, highly specialized industrial farms and feedlots. In the eastern states, farming declined because of development pressure and because the region's small farms could not compete with foods produced in the West, where access to cheap energy, irrigation, new technologies and a national transport system made possible through public subsidy reduced the costs of production and increased yields on millions of acres.

Industrial agriculture solved the problem of managing land, labor, water, crops and livestock to produce food in a completely revolutionary way—by replacing labor and land with fossil fuels and abandoning subsistence as a fundamental purpose of agriculture.[20] Over the last century, the industrialization of the US food system drove a consolidation and regional specialization of the agriculture that continues to this day.

The Geography of the US Food Supply

America's plate is filled to overflowing with industrial food produced at home and sourced around the world.[21] California leads the nation in food production and processing, but specific areas within the Pacific Northwest, the Midwest, the Great Plains and the Southeast contribute significant volumes of just one or two kinds of products to the US food supply. Imports, primarily from Mexico, Canada, Chile, Central America and Asia, fill seasonal gaps in domestic production or provide a type or quality of product not produced domestically such as fresh vegetables in winter or tropical fruits year-round. Trade in food and other agricultural products has been important to America since colonial times, but the global movement of food, particularly perishable produce, has increased dramatically since the early 1980s, when the necessary technology and transportation systems were developed (see Figure 1.3).[22]

Fruits and Vegetables

California has long been the nation's leading producer of fruits, nuts and vegetables. With ample supplies of water for irrigation, California's ideal climate has supported an incredibly diverse and productive agricultural industry that has come to dominate US fruit, nut and vegetable production. Over the last decade, California has produced about 90 percent of all nuts, 70 percent of all processed vegetables and 50 percent of all fresh vegetables grown in the US each year. Other leading fresh vegetable producing states, Florida, Arizona, Georgia and Washington, together with California accounted for about 75 percent of US domestic fresh

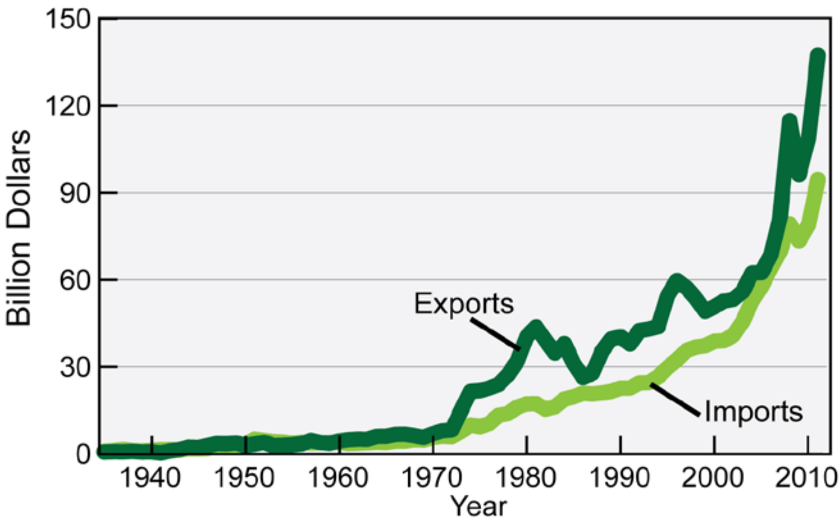

FIGURE 1.3. Trends in US Agricultural Imports and Exports. US trade began to grow after 1980 as changes in technology and trade policies opened markets and made it possible to transport perishable goods long distances without a significant loss of quality. Climate is an important factor in the global production and movement of food and agricultural materials. Through seasonal weather effects and other associated impacts, climate change will increase uncertainty in the global food system. The graph shows US imports and exports during the period 1935–2011 in adjusted dollar values. Credit: USGCRP

vegetable production in 2012. About 25 percent of the vegetables consumed in the US are imported, mostly from Mexico and Canada.

Together, three Pacific states—California, Washington and Oregon—produce much of the US-grown fruit supply: virtually all of the apricots, avocados, nectarines, pears, boysenberries and raspberries; more than 95 percent of the nation's strawberries and sweet cherries; more than 75 percent of the apples, prunes and plums; 70 percent of the peaches and nearly half of all US-grown blueberries. Imports contribute almost 50 percent of the US consumption of fresh fruits, with Mexico, Chile and Costa Rica the major suppliers.[23]

Grains and Beans

Wheat is the principal food grain produced in the United States and is the third-largest grain crop by value, behind corn and soybeans.[24] Different types of wheat are grown in different regions of the United States. Bread wheat accounts for almost 70 percent of total US wheat production and is grown in the Great Plains. Kansas, Oklahoma and Texas together account for about 75 percent of total US production of bread wheat in 2012. Wheat used for cakes and cookies accounts for about 20 percent of total US wheat production and is produced east of the Mississippi River. The white wheat used to make pasta and cereal makes up the remainder of the US total and is grown in the Pacific Northwest, Montana and North Dakota. The United States is a major supplier of wheat and wheat products to global markets and has held the largest share in global trade for many decades. About half of the US wheat crop is exported each year.

The production of corn and soybeans, the nation's top two grain crops by value, is centered in the Midwest, with Iowa leading the nation in production of both crops in 2012. Although only 2 percent of the corn produced in the US is directly eaten by people, it is an important livestock feed and is also processed into a multitude of food and industrial products including starch, sweeteners, corn oil, beverage and industrial alcohol and fuel ethanol. In 2012, about 8 percent of US production was exported, mostly for use as livestock feed. Soybeans are crushed to produce soybean meal and soybean oil. The meal is used as livestock feed while soybean oil is used for human consumption, accounting for more than half of all the vegetable oil consumed in the United States.[25] The United States is the world's largest exporter of soybeans, exporting about half of the US grown supply each year.

US rice production accounts for less than 2 percent of the world total, but it is important in global trade because most rice is consumed where it is produced. In recent years, about half of US production has been exported. Arkansas is the nation's leading producer of rice, accounting for about 50 percent of US production and together with Louisiana, Mississippi, Missouri and Texas produced almost 80 percent of US rice production in 2012.

Dry edible beans are produced in the Pacific Northwest and the Northern Great Plains. Pinto, navy, black, garbanzo and red kidney are the principal dry beans produced in the United States, with North Dakota leading the nation in production for more than 20 years. In 2012, North Dakota, Idaho and Washington produced more than 50 percent of the total US production of dry edible beans.

Meat, Seafood and Dairy

America's beef production is centered in the south-central and western Great Plains. This region is home to three of the top five calf-producing states and processes about 70 percent of all US-grown beef. Although calves are produced on farms and ranches throughout the United States, most of them spend the last months of their lives in feedlots in Texas, Nebraska and Kansas, which together produce nearly 60 percent of the nation's fed cattle. About 12 percent of the US beef supply is imported as meat and livestock to assure a continuous supply of fresh beef throughout the year. Canadian imports contribute to the total US supply of grain-fed cattle, while Mexico supplies calves for US feeding operations during seasonal lows in domestic calf production.

US pork production is centered in the Midwest, home to nine of the top ten hog-producing states that together produced about 70 percent of total US pork production over the last decade. Iowa is the hog-producing capital of the nation, producing about a quarter of the country's pork each year. Although pork imports amount to just 4 percent of domestic consumption, Canada is a large supplier of feeder pigs to the United States, sending more than 5.6 million our way in 2012. The United States is the largest exporter of pork and pork products globally, with exports averaging 20 percent of commercial pork production over the last decade.[26]

American poultry production is centered in the Southeast. Georgia is the nation's leading producer of chickens and along with Arkansas, Alabama, North Carolina, Mississippi and Texas produces about two-thirds of the nation's supply. The United States is the world's largest turkey producer and largest exporter of turkey products. Turkey production is centered in the Midwest and the Southeast, with each region accounting for about 40 percent of national production in 2012. The United States is the world's largest producer and second-largest exporter of poultry meat, exporting about 20 percent of US poultry meat and 14 percent of turkey meat in 2012.

While the United States' seafood consumption is far behind that of poultry, pork and beef, it adds up to nearly five billion pounds each year, second only to China.[27] In 2011, about half the seafood consumed in the US was wild-caught, and the other half farmed. About 9 percent was produced domestically and the rest imported, mostly from Asia but also from Chile, the European Union and Canada. Asia accounted for 89 percent of world aquaculture production by volume in 2010, with China by far the largest producer.

The United States is the single largest producer of cow's milk in the world. About half of the milk supply is processed into cheese, another third into fluid milk and cream products and the remainder into dairy products such as butter, ice cream and milk powders. California and Wisconsin have led the nation in dairy production since the 1980s. For

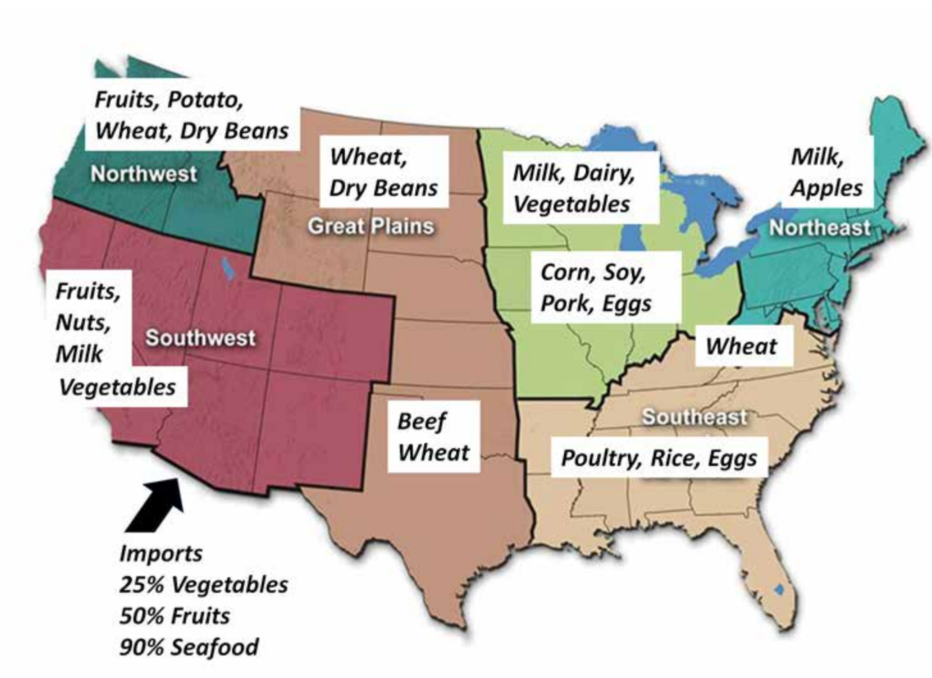

FIGURE 1.4. The Geography of Food Production in the United States. The regional specialization of food production emerged as a result of natural resource capacity and public investment in built resources such as irrigation and transportation networks. Regional production characteristics based on the 2012 Agricultural Atlas and USDA-ERS 2012 production data. Map Base Source: USGCRP

the last decade, they have together produced about one-third and one-half of the national supply of milk and cheese, respectively. Milk and dairy product imports to the United States are dominated by specialty cheeses from Europe and milk powders from New Zealand. About 13 percent of the US milk supply was exported in 2012.

Sustainability Challenges to the US Food System

Over the last century, the US food system has evolved to rely on large-scale, vertically integrated monocultures to produce, process and deliver food and other agricultural products to consumers in the United States and beyond. The success of the US industrial food system has been achieved through a focus on land- and labor-efficient production of commodities in a national system characterized by monocultures, geographic specialization and increasing concentration in all phases of the food system. For example, since 2000, oligopolies (4-firm control of at least 50 percent of market) have emerged in the US food system in agricultural inputs,[28] grain distribution,[29] food processing[30] and grocery retailing.[31] In 2007, just 2 percent of US farms and ranches accounted for more than 50 percent of all US agricultural sales and from 60 to 70 percent of the sales of high-value crops (vegetables, fruits, nuts, nursery and greenhouse products), hogs, dairy, poultry and beef.[32]

This industrial system of food production solved the age-old resource allocation problem for American consumers by offering those with the financial means a diverse selection of low-cost foods of consistent quality and year-round availability. Ironically, we seem to have returned to our ancestral roots—while we used to forage in the forests and grasslands of the world, now we forage in the supermarket. In both cases, a vast biological or bio-industrial machinery is at work behind the scenes. While the industrial food system operates out of sight and out of mind for most Americans, the simplicity of foraging at the local full-service grocery masks a variety of environmental and social harms that are increasingly undermining the sustainability of the US food system.

The environmental, social and economic harms produced by the US industrial food system have raised concerns since the early days of mechanization in the mid-1800s and are widely recognized today.[33] The linked 21st-century challenges of climate change and resource scarcity bring a new urgency to concerns about the sustainability of the US industrial food system.[34] The resource degradation associated with industrial production practices coupled with the geographic specialization and concentration of American agriculture degrade the nation's adaptive capacity, while the interactions between energy, water and land use in the US will likely amplify climate change effects[35] and significantly increase the vulnerability of the US industrial food system to climate change. Although the application of vulnerability assessment and adaptation planning to US agriculture and food systems is only just now getting underway, sustainable agriculture has been widely recognized as a promising strategy for the development of integrated solutions to the climate change challenges ahead.[36]

1.3. The Interaction of Water, Energy and Agriculture Amplifies Climate Change Effects[37]

The extraordinary drought and heat waves that spread across the United States in 2011 and 2012 hit particularly hard in Texas. The summer of 2011 was the warmest and driest summer on record (Figure 1.5). The associated heat wave kept temperatures above 100 degrees Fahrenheit for more than a month. These extreme climatic events set off a cascade of interacting effects among the region's energy, water and land resources.

High temperatures increased demand for cooling, which increased water withdrawals for electricity generation. Heat, increased evaporation, drier soils and drought also led to higher water demands, this time for irrigation, placing further stress on dwindling supplies. At the same time, low-flowing and warmer rivers could not provide enough cooling water for the power companies to supply the higher demands for electricity from consumers. The impacts on land resources and land use were dramatic. The drought cost Texas farmers and ranchers about a quarter of their normal income. Increased tree mortality in the region provided fuel for wildfires that burned

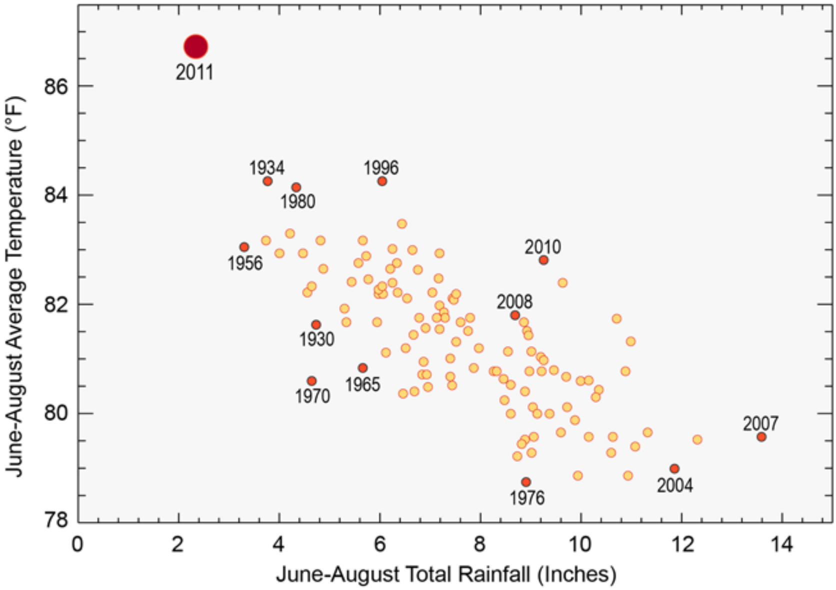

FIGURE 1.5. Texas Summer 2011: Record Heat and Drought. The dots on this graph show average summer temperature and total summer rainfall in Texas from 1919 through 2012. The dark dots illustrate the extremes in temperatures and rainfall observed over this time period. The record temperatures and drought during the summer of 2011 (large dark dot at upper left) represent conditions far outside those that have occurred since the instrumental weather records began. An analysis has shown that the probability of such an event has more than doubled as a result of human-induced climate change. Credit: USGCRP.

3.8 million acres and destroyed nearly three thousand homes. Because water shortages threatened more than 3,000 megawatts of generating capacity—enough to power one million homes—water was rationed to farms and urban areas to preserve water for energy production.

Sustainable Agriculture: A Resilient Agriculture?

New demands from a dynamic global economy, continued decline in the quality and availability of natural resources, and the unprecedented challenges of climate change are just beginning to take their toll on the US food system. While the challenge is daunting, we have a wealth of knowledge and experience to begin working on a new, more resilient solution to the age-old resource allocation problem. Much of this knowledge can be found in the principles and practices of sustainable agriculture.[38]

Compared to industrial production systems, sustainable production systems tend to enhance the resilience of the food systems within which they reside. Sustainable farmers and ranchers typically manage much greater biodiversity, employ more people in better jobs and circulate more dollars in the regional economy.[39] The diversified production systems typical of sustainable farms and ranches reduce the need for fossil fuel energy, water, pesticides and synthetic fertilizers and typically produce less waste.[40] Sustainable farms and ranches have high quality soils and tend to enhance environmental well-being in the communities where they are located.[41] Sustainable agriculture also offers an unprecedented opportunity to mitigate climate change while increasing agricultural productivity worldwide through the use of regenerative agricultural practices.[42]

There are successful sustainable producers engaged in food systems all across the US. These farmers and ranchers offer models of locally adapted food production, processing and distribution that cultivate ecological, social and economic well-being on their farms and ranches and in their communities. They have been successful largely without the scientific, technical and financial support provided to producers using industrial methods. Throughout the ecological and social diversity of the American landscape, on farms large, medium, and small, sustainable producers and their supporters have been busy for decades laying the foundation for a more sustainable and resilient American food system.

How are sustainable producers managing the challenges of farming in a changing climate? What kinds of changes have they perceived and how are they adapting to those changes? What practices do they use to cultivate resilience to climate change on their farms and ranches and in their communities?

1.4. Defining Sustainable Agriculture

Congress defined sustainable agriculture more than twenty years ago in the Food, Agriculture, Conservation, and Trade Act of 1990:

- the term sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term:
- satisfy human food and fiber needs
- enhance the environmental quality and the natural resource base upon which the agricultural economy depends
- make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls
- sustain the economic viability of farm operations
- enhance the quality of life for farmers and society as a whole

This definition explicitly acknowledges the multiple dimensions of sustainability—ecological, social and economic—and provides specific design criteria for sustainable agriculture systems.

The focus on ecological health and community well-being as the basis of agricultural productivity clarifies a fundamental difference of philosophy between sustainable and industrial agriculturalists.[43] The industrial philosophy of agriculture views the production of agricultural products as no different from the industrial production of other goods. The farm is a factory, the land an assembly line. The farmer is a factory worker, managing purchased energy and materials to produce high volumes of low-cost commodities. A narrow focus on economic efficiency drives increasing geographic specialization, concentration and vertical integration in the US food system.

The agrarian philosophy of agriculture takes a broader view of the potential contributions of agriculture to society. This view recognizes that agriculture has the capacity to produce many ecological and social goods in addition to supplying sufficient food and fiber. Agriculture has the capacity to restore and conserve natural resources like soil, water and air. Healthy soils can help to replenish groundwater supplies and clean up surface waters, and crop diversity can reduce the need for fertilizers and pesticides, which are the largest source of water pollution in the United States. Rural communities benefit from the social and financial capital created by a focus on producing high-quality goods for regional markets. Urban communities benefit from the social and financial capital produced by regionally owned production, processing, distribution and marketing, as well as better access to nutrient-dense foods and improved environmental quality.

Voices from the Field

From the summer of 2013 through late winter 2014, I spoke about these issues with twenty-five award-winning sustainable producers from across the United States. We talked about some of the most challenging aspects of sustainable management on their farm or ranch, and about changes in the weather. The producers shared with me how they think about managing for resilience to climate effects and how confident they are that they can manage those effects in the coming years. Many also shared their concerns about the path the US food system has taken over the last fifty years and their frustrations with the scientific, economic, regulatory and policy barriers to sustainable food in this country.

All of the producers I interviewed have been farming in the same location for at least twenty years, many for thirty and some for forty years or more. Many are the third or fourth generation on the farm or ranch they now own and operate, so they have benefit of family memories and stories of weather long ago to inform their perceptions of the weather they have experienced through the years.

These farmers, growers and ranchers own successful agricultural businesses that operate, for the most part, outside of the industrial food system. Most have never participated in federal agricultural subsidy, production insurance, disaster or conservation programs. Most have been nationally recognized for their excellence in sustainable farm and ranch management. All are innovative leaders and compelling advocates for sustainable agriculture and food systems.

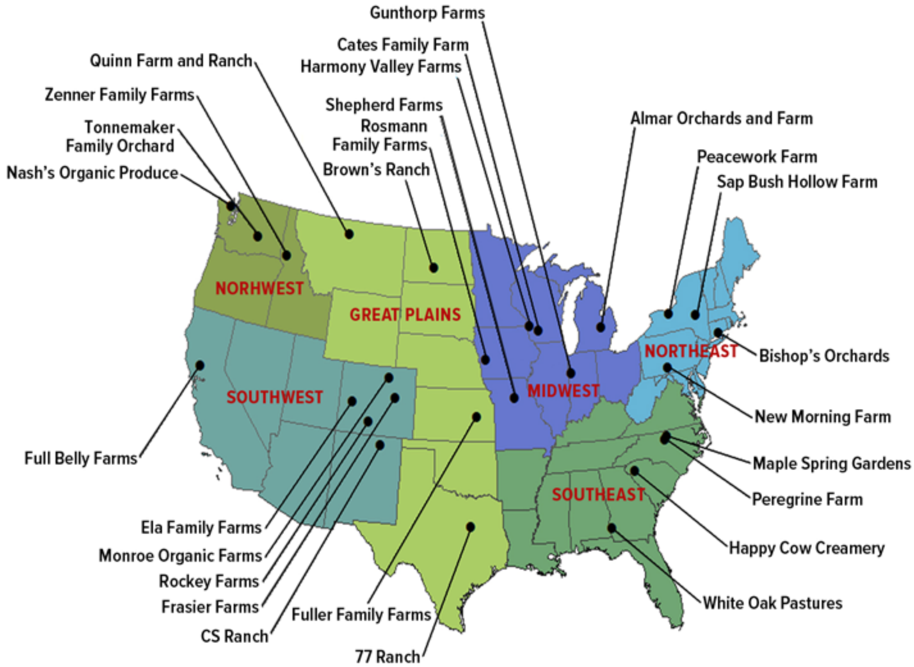

FIGURE 1.6. Featured Farm and Ranch Locations. This map shows the name and location of the farms and ranches owned by the 25 sustainable producers who contributed to this book through their participation in an hour-long semi-structured telephone interview conducted July 2013 to March 2014. Credit: Cherie Southwick and David Abernathy, GIS Crew, Warren Wilson College, Asheville, NC.

Vegetables, Fruit, Pork, Poultry and Grain in the Northwest

Farmers in the Northwest have enjoyed relatively moderate climate change effects over the last two decades, although warmer winters, declining snow pack and wetter springs and falls have complicated vegetable and grain production.

Nash Huber produces organic vegetables and fruits, food and feed grains, pork and poultry, and cover crop seed on 450 acres of irrigated prime farmland in Washington's North Olympic Peninsula. Warmer winters, wetter falls, more unpredictable weather in summer and more variable extremes have challenged farm management since about 1995. In response, Nash has purchased more tractors, tools, processing equipment and combines to take advantage of increasingly narrow windows of time when conditions are right for fieldwork.

Kole Tonnemaker and his brother Kurt are the third generation to own and operate the 126-acre Tonnemaker Hill Farm, home to 60 acres of orchards, 20 acres of vegetables and 40 acres of hay, all produced under irrigation and all certified organic. Although Kole can't say that he has seen a big change in seasonal weather patterns, in the early 1990s, he decided to add vegetables to the farm's crop mix to buffer farm income from the risk of fruit crop failure in the region's highly variable spring weather.

Russ Zenner has been farming in the Palouse Region of Idaho near the Washington–Idaho border in Genesee for more than 40 years. Russ manages 2,800 acres of dry-land direct-seeded crops in a three-year rotation of winter wheat, spring grains and spring broadleaf crops. Recent changes in seasonal rainfall patterns have got Russ thinking about redesigning the crop rotation to increase crop diversity and the proportion of fall-seeded broadleaf crops.

Vegetables, Fruit, Beef, Lamb and Grain in the Southwest

Many farmers and ranchers in the Southwest region have experienced changes in weather that have increased the challenges of maintaining the productivity of their farms and ranches.

Paul Muller co-owns and operates Full Belly Farm, a 400-acre diversified organic farm located in the Capay Valley of Northern California where more than 80 different crops including vegetables, herbs, nuts, flowers, fruits, grains and livestock are raised on a diverse landscape mosaic. Although water conservation has always been a management focus, heavier rainfall, longer dry periods and continuing drought have encouraged more thinking about sustainable water management. Changes underway include a switch to more drought-tolerant cover crops, the addition of cover-crop mulches to conserve soil moisture and upgrading to more water-efficient drip and microsprinkler irrigation systems.

Jacquie Monroe and her husband Jerry are the third generation to own and manage Monroe Family Farms, located east of Denver. The 200-acre farm produces 100 different vegetables and all the pasture, hay and feed grains needed to produce pasture-based meats (beef, pork and lamb) and eggs on the farm. Changing weather patterns have reduced water supplies, requiring investment in more efficient irrigation systems and a plan for adjusting crop production area to fit projected seasonal water availability.

Steve Ela is a fourth-generation fruit grower at Ela Family Farms located near Hotchkiss in the "frost-free" fruit-growing region of Colorado's Western Slope. Steve manages 100 certified organic acres planted with 23 varieties of apples and 29 varieties of pears, peaches, cherries, plums and tomatoes. More variable weather, reduced snowpack, more extreme weather and a lengthening growing season have required some significant changes in production practices to maintain farm productivity and profitability. Steve has installed more efficient drip irrigation, added new frost protection and has shifted to longer season apple varieties and more frost resistant peaches.

Brendon Rockey and his brother Sheldon are the third generation to grow potatoes on the 500-acre Rockey Farms, located in the San Luis Valley of Colorado. Dwindling water supplies and failing groundwater levels motivated Brendon to experiment with cover crops and companion planting to try and reduce water use. Brendon improved farm profitability with the new cropping practices through a 50 percent reduction in water use and decreasing or eliminating fertilizer and pesticide applications while maintaining yields and improving crop quality. Brendon can't say that the current drought is a sign of climate change; he is just working to make his farm as resilient as possible to whatever the future may bring.

Mark Frasier has managed the 29,000 acre Woodrow division of Frasier Farms for more than 30 years. The third generation on the ranch, Mark buys stocker cattle and raises calves produced on the ranch to run nearly 5,000 head when fully stocked. Mark has not noticed a change in weather patterns during his lifetime, but credits planned grazing with the resilience of his operation to the weather extremes typical in the short grass prairie region of eastern Colorado.

Julia Davis Stafford is a fourth-generation co-owner and operator of the CS Ranch, located in northeastern New Mexico on 130,000 acres. Julia has worked together with her family to manage the ranch's cow-calf and stocker enterprises for more than 30 years. For much of the ranch's history, the cowherd has numbered between 2,500 and 3,000 head, but continuing drought over the last 15 years has forced the family to destock the ranch. Julia is concerned that eventually the ranch will be unable to maintain profitability if cattle numbers continue to fall, creating widespread impacts to the livelihoods of ranch owners, employees and local businesses.

Vegetable, Beef, Lamb, Poultry, Grain and Beans in the Great Plains

Farmers and ranchers in the Great Plains, a region of weather extremes, have been challenged by warmer temperatures, more extreme rainfall in the north and more extreme drought throughout the region.

Gabe Brown has been producing cattle, feed and food grains on 5,000 acres of native rangeland, perennial forages and no-till cropland near Bismarck, North Dakota, for more than 30 years. Gabe thinks the most effective climate risk management tool he has available is the capacity of the ranch's healthy soils to buffer the more variable rainfall and temperatures increasingly common today.

Bob Quinn owns and manages 4,000 acres of organic land producing certified organic food grains in a full tillage dryland production system near Big Sandy, Montana. More weather extremes and dry fall conditions have required some changes to his crop mix and fieldwork scheduling, but warmer winters have created new fruit growing opportunities.

Gail Fuller is the third generation to farm at Fuller Farms, a 2,000-acre family farm located in east-central Kansas near Emporia. Gail manages a large variety of cash crops, cattle, sheep and poultry in a highly diversified and integrated dryland production system. More variable weather encouraged Gail to increase the diversity of his grain rotation by adding cover crop cocktails so that his soils could hold more water between rains.

Gary Price uses planned grazing to manage a cow-calf and stocker operation on the restored native range that dominate the landscape on his 2,500-acre 77 Ranch, located near Blooming Grove, Texas. The ranch also includes 200 acres of cropland, 90 acres of improved pastures and

40 acres of small stock ponds and natural lakes. Gary has reduced herd size and replaced some grains with forage crops to provide supplemental feed for his cattle in response to extreme drought conditions.

Vegetables, Fruit, Nuts, Beef, Pork, Poultry and Grains in the Midwest

In a region well-known for extremes of weather, rapid temperature swings, more variable rainfall, more very heavy downpours and catastrophic flooding have challenged many Midwest producers.

Ron Rosmann produces certified organic feed and food grains, beef, pork and poultry on the 700-acre Rosmann Family Farms located in west-central Iowa. More frequent and intense weather extremes since about 2000 have required more careful livestock management during periods of extreme temperature swings, and there are new weed-management challenges in the grain fields that seem to be related to a lengthening growing season.

Dan Shepherd has grown pecans, buffalo, gamma grass seed and grains at Shepherd Farms near Clifton Hill in north-central Missouri, but now he manages about 300 acres of mature pecans on the 4,000-acre farm. Although Dan has not noticed any clear trends in changing weather patterns, the last decade has included several weather-related firsts in his 44 years on the farm: total crop loss from a spring freeze in 2007, levee breaches in 2008 and 2013, and a prolonged 3-year drought from 2011–2013.

Greg Gunthorp is a fourth-generation hog farmer who finishes cattle, swine and poultry on pasture at Gunthorp Farms near LaGrange, Indiana. He processes the beef, pork and poultry that he raises on-farm in a USDA-inspected facility that he built on the farm and sells it through an on-farm store and into local wholesale markets. Greg has not perceived any significant changes in weather during the twenty-five years he has managed the farm, other than perhaps a slight increase in extreme events.

Richard de Wilde owns Harmony Valley Farm, a 200-acre diversified vegetable farm located near Viroqua in southern Wisconsin that sells certified organic produce, berries and beef through direct and wholesale markets. He realized that there "is no normal anymore" after back-to-back, 2,000-year flood events ended the 2007 growing season two months early and destroyed early summer crops in 2008. He credits his local community and the farm's CSA members with providing crucial support during recovery from the catastrophic flooding.

Dick Cates and his wife, Kim, own Cates Family Farm, a 900-acre grass-fed beef farm near Spring Green in southern Wisconsin. In 1990 Dick transitioned the farm to rotational grazing practices to restore the farm's native oak savannah landscape and improve profitability. Over the last 10 to 15 years, Dick has reduced stocking rates, increased hay reserves and is thinking about adding an irrigation system to the farm in response to more variability and extremes in weather.

Jim Koan produces organic apples in a 150-acre orchard, as well as vegetables, grains, pasture-raised hogs and value-products on the 500-acre Almar Farm and Orchards in eastern Michigan. The fourth generation to own the farm, Jim has managed it for more than 40 years. Since about 2000, warmer winters and more variable springs have increased the risk of crop failure, and imported apples have taken a bite out of profits. Jim reduced production risk and improved profits by diversifying into value-added apple products, including apple-finished pork, apple cider vinegar and an award-winning hard cider.

Vegetables, Fruit, Beef, Pork, Lamb and Poultry in the Northeast

Some farmers in the Northeast have been challenged by more variable weather, heat waves, more heavy rainfall and extreme weather events and an increase in plant disease.

Jim Crawford has produced a diverse mix of organic vegetables and small fruits—about 50 different kinds—on 45 acres at New Morning Farm in south-central Pennsylvania for 44 years. About 15 years ago, more variable temperatures, more heavy rainfall, summer drought and a growing number of novel plant diseases began to complicate vegetable and fruit production on the farm. Jim has adapted by shifting soil preparation to the fall, protecting soils and crops from excessive rainfall with plastic mulch and hoophouses, and increasing use of OMRI-approved pesticides.

Elizabeth Henderson has grown organic vegetables at Peacework Organic CSA for more than 25 years near Newark, NY, on prime farmland under a conservation easement. Hotter summers, more heavy rainfall and drought, and novel diseases have required some adjustments to the farm's management practices, including the addition of irrigation, changes to fieldwork hours and adjustments to crop succession timing.

Jim Hayes has been raising livestock since 1979 at Sap Bush Hollow Farm west of Albany, New York. Jim produces beef, lamb, pork and poultry on 160 acres of pasture using an integrated rotational grazing system. More dry periods and drought, more frequent and stronger winds, and extreme weather have challenged farm operations and required new infrastructure such as drainage systems, a raised barn, reinforced pasture shelters and solar power.

Jonathan Bishop is a fourth-generation co-owner and field operations manager at Bishop's Orchards in Guilford, Connecticut, a 320-acre diversified fruit and vegetable farm supplying multiple direct markets, including a full-service grocery on the farm. Although Jonathan hasn't seen any long-term changes in weather patterns, a number of severe storms over the last few years have confirmed for Jonathan the resilience benefits of scale, experience and crop diversity.

Vegetables, Fruit, Milk, Beef, Pork, Lamb and Poultry in the Southeast

Farmers in the Southeast report increased challenges from more frequent summer droughts and heat waves and more frequent and intense weather extremes of all kinds.

Ken Dawson and his family have been producing vegetables, cut flowers, culinary and medicinal herb starts and small fruits since 1981 at Maple Spring Gardens, located northwest of Durham, NC. To maintain productivity in recent years, Ken has had to adapt his cropping practices to increasing extremes of weather and warmer summer temperatures. He has stopped growing some crops and has adjusted seasonal planting schedules to avoid new disease challenges and to achieve continuous vegetable harvests through the growing season.

Alex Hitt and his wife Betsy grow vegetables and flowers for wholesale and direct markets at Peregrine Farm located just west of Chapel Hill, North Carolina. More intense heat waves and drought in summer, combined with a reduced summer water supply, have got Alex thinking about putting more focus on vegetable production in the spring and fall and reducing crop production in mid-summer.

Tom Trantham owns and manages Happy Cow Creamery, a 90-cow grass-based dairy farm and creamery located south of Greenville, South Carolina. Dryer summers and more intense summer thunderstorms over the last decade have not presented any challenges on the farm, largely because Tom's use of annual forage crops in a diverse rotation makes it easy to adjust to changing weather conditions throughout the year.

Will Harris is the fourth generation to own and operate White Oak Pastures, a pasture-based livestock farm located about 90 miles from the Gulf of Mexico in southwest Georgia. Livestock produced on White Oak Pasture's 2,500 acres of non-irrigated pastures are processed on farm in state-of-the-art zero-waste USDA-inspected beef and poultry processing plants. Will thinks hotter summers, more extreme drought and competition for water have begun to challenge livestock management on his farm. If dry periods and droughts continue to intensify in coming years, Will believes he will have to find a way to irrigate his pastures in a region marked by increasing competition for limited groundwater resources.

The Climate Change Challenge

Agriculture has proven to be a robust food acquisition strategy with an incredible record of adaptation over more than five thousand years of human experience. During that long period of time, every time population pressures have intensified, we have found a way to increase food production in nearly every biome on the planet capable of supporting agriculture.

We have increased food production through two complementary strategies. We can grow more food by cultivating more acres, an *extensification* of agricultural production. The settlement of the Midwest and Great Plains was a major extensification of American agriculture. The production of grains and beef increased dramatically during this period even though the yields of crops and livestock per acre of land remained the same. Even today, American agriculture still makes use of an extensive land base to produce some products like beef calves, cattle and lamb.

The other strategy is to grow more food by increasing crop and livestock yields, an *intensification* of agricultural production. This approach uses land more intensively and requires major changes in agricultural management. These changes could involve the selection of high-yielding plants and animals, or working to prevent conditions that reduce yields like pests or disease. They may involve bringing additional resources, like water or nutrients or pesticides, to the land to address a condition that is limiting the growth of crops or livestock. Industrial agriculturalists have used this strategy to greatly increase production without adding to the agricultural land base through the development of tools and technologies that can produce a substantial increase in yield per acre, although often at a reduced energy profit: irrigation, improved crops and livestock, fertilizers, pesticides, antibiotics and confined animal production.

These two approaches worked well for us for a very long time. It is no wonder that many in the US industrial agricultural community—farmers, growers, ranchers, researchers, technical advisors, extension policymakers, agribusinesspeople—are upbeat about our capacity to adapt agriculture to climate change; however, their confidence may be misplaced.

Prime agricultural land is dwindling, and human population is growing, limiting our options for the further extensification of food production. Industrial agriculture degrades the ecological, economic and social foundations of human well-being and fuels global warming, limiting the intensification of production as a solution. And it is easy to forget that agriculture—all of agriculture, from its first beginnings in Mesopotamia ten thousand years ago to the satellite-controlled tractor fertilizing genetically engineered crops in Iowa last week—evolved during a period of unusual climatic stability and with the benefit of a wealth of human, natural and technological resources.

As we face the climate change challenge, we do not have the benefit of a stable climate. We do not have access to unlimited natural, financial, scientific or technological resources. The natural resource base upon which agriculture depends is oversubscribed, and much of it is highly degraded. And the very system that we depend on for food fuels the pace and intensity of climate change. As a species dependent on agriculture for our survival, we have entered uncharted territory.

Ten thousand years ago, in many parts of the world, our ancestors evolved from food foragers to shifting horticulturalists and pastoralists to sedentary farmers in response to a suite of challenges not unlike those we face today. Population pressures were building, natural resources were declining, and changing climatic conditions reduced the productivity of the food acquisition strategies our species had used for at least two hundred thousand years. Agriculture emerged as the most successful solution to the resource allocation problem, and agricultural peoples soon dominated the planet. We face an unprecedented challenge, but it is a challenge that our species has navigated at least once before. What kinds of knowledge, tools and experience can help guide us to a sustainable and resilient future?

Never before in our history as a species have we known so much about how our planet works or how much our own well-being depends on the well-being of healthy ecosystems. Never before have we had such an ability to envision a sustainable and resilient path into our changing world. How will we solve the problem of food acquisition in a world shaped by the unprecedented challenges of resource scarcity and climate change?

This is the climate change challenge.

1.5. Resource Scarcity Limits Industrial Solutions

Will Harris owns and operates White Oak Pastures, a pasture-based livestock farm in southwest Georgia near Bluffton. Will's father managed operations through the mid-1900s, and he changed with the times—shifting from pasture-finished to finishing cattle on purchased feeds—to keep White Oak Pastures up to date. Will continued those practices when he took over the farm in the 1970s, but became disenchanted with them and in 2000 began transitioning the farm to sustainable pasture-based livestock production.

Will shares these thoughts about the differences between industrial and sustainable agriculture:

"You know, most of the people that operate in this high animal welfare/high environmental sustainability farming model are younger people who came to it from somewhere else. Not many of them are like me, or only a small percentage—former monocultural, commoditized, centralized, industrialized farmers—but I'm one of them. And I'm like a reformed prostitute, you know, I've got the zeal of the convert.

"I love the debate that I get into occasionally, probably a little bit more than most, because I am one of the good old boys. They say, 'You know, the way you farm won't feed the world versus the way we farm. We're feeding the world,' and I love it when they say that, because they say, 'You just can't produce enough.'

"When they say that, I try not to smile, and I say, 'Okay, let's have that debate, but before we have that debate, I want us both to stipulate that neither farming system will feed an endlessly increasing population.' The Earth has got a carrying capacity, and once you get beyond that carrying capacity, neither one of them is going to feed the world.

"And most of them will stipulate that. They don't want to, but they eventually will. And I say, 'Okay, well, I'll go ahead then and capitulate right up front that if we're going to run out of acres first, you win. You can feed way more people than I can if acres are the only limiting factor. If we've got unlimited water, unlimited petrol fuel, unlimited antibiotics that don't create pathogen-resistance, unlimited fertilizer resources…you win.

"But now if the limiting factor becomes water, I'm probably going to win, because I don't use as much water as you do. If the limiting factor becomes petrol fuel, I win, because I don't use as much of it as you do. And if the limiting factors become phosphates and potash and these other depleting resources, I win, because I don't use as much as you. And antibiotics and pesticides, and so on…I win just about any way we do it other than acreage."