USDA Midwest and Northern Forests Regional Climate Hub: Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies

Photo Credit: (Betts, 2011)

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March 2015

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We acknowledge ICF International for its contributions to the Greenhouse Gas Profile.

Edited by: Terry Anderson, ARS

Suggested Citation: Hatfield, J., C. Swanston, M. Janowiak, R. Steele, J. Hempel, J. Bochicchio, W. Hall, M. Cole, S. Hestvik, and J. Whitaker, 2015: *Midwest and Northern Forests Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies,* T. Anderson, Eds., United States Department of Agriculture, 55 pp. http://climatehubs.oce.usda.gov/sites/default/files/pdf/Midwest%20Region%20Vulnerability%20Assessment%203_20_2015.pdf

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Letter from the Regional Leads

The Midwest Regional Climate Hub covers the States of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin and represents one of the most extensive and intensive agricultural systems in the world (Figure 1). The Northern Forests Climate Sub Hub shares this footprint and represents people working and living in these widespread northern forests, which store vast amounts of carbon even as they support industry, recreation, and cultural values. Diverse agriculture, grasslands and prairies, forests and woodlands, and urban areas form a mosaic across this landscape that defies any single approach to coping with the changing climate, but instead enables numerous approaches and opportunities.

Cropping systems across the Midwest are diverse despite the perception that the Midwest is solely a corn-soybean production system. Crops grown in the Midwest range from alfalfa to wheat, and from sweet corn and specialty crops to perennial crops. Each has its own sensitivity to weather within a growing season; however, the most sensitive stages are crop establishment and harvesting. The Midwest produces a large number of pigs, turkeys, dairy, beef, broilers, and layers. These livestock systems are also sensitive to the weather variations during the year and, in particular, hot weather during the summer. Overall, agriculture contributes almost $200 billion to the U.S. economy each year.

Forests cover a large expanse of the Midwest ranging from boreal forests around the northern Great Lakes to oak-hickory forests of the Ozarks. The Midwest is characterized by savannas and open woodlands, which mark a major transition zone between forest and grassland biomes within the U.S. Overall, forests cover some 87 million acres in the Midwest. The economic output of the Midwest forest industry is significant, totaling about $55 billion per year. This value does not include forest-related recreation such as hunting, fishing, hiking, skiing, camping, wildlife watching, off-highway vehicles, and many other pursuits. These activities take place throughout the Midwest in 10 National Forests, 3 National Parks, 4 National Lakeshores, 64 National Wildlife Refuges, hundreds of State and county parks, and in thousands of private and conservancy ownerships. Associated spending varies widely by State and recreation type. The state of Wisconsin estimated that annual forest-based recreationists spend approximately $2.5 billion within Wisconsin communities (Marcouiller & Mace, 1999). The state of Ohio, in a 2010 report, found that 62% of the state's recreational sites were located within or nearby forests (Ohio Department of Natural Resources, 2010).

Variations in weather and ultimately climate affect all agricultural and forest systems. They include temperature extremes, excess or deficit precipitation, severe storms, and wind. Reduction in snowpack or frozen soil can have significant effects on forest-associated economies. Many forests in the Midwest have seen a reduction in the number of days in which winter harvesting operations and transport can take place, or in which winter tourism associated with snowmobiling or silent sports has decreased. Extremes in spring weather can create distinct challenges in agriculture. Evaluation of the crop insurance claims for the Midwest show that the most frequent claim is excessive water and precipitation followed by drought. Producers are concerned about the effect of increasing spring precipitation on the workable field days in the spring. In Iowa, every inch of rain in April and May reduces the number of workable field days by 2.6 days. This is significant when coupled with the observation that the number of workable field days has decreased in the past 15 years, creating a problem for planting crops in the spring. This increase in spring precipitation increases the potential for soil erosion and is further exaggerated by the increase in storm intensity being observed across the Midwest. Animal operations are not immune to the changes in spring precipitation. Increased rain and storms add stress to animals and their young in outdoor field lots and pasture systems where they are greatly affected by cool, wet weather. All of these changes increase the pressure that agriculture and forest producers face in being able to conduct timely operations.

The Midwest Regional Climate Hub is working across a range of crops, forests, and livestock production systems to assemble the available information into tools and practices that can increase the resilience of these systems to climate change. At the foundation of this effort is the evaluation of practices that can enhance the soil and increase the water infiltration and water holding capacity because it has been found that crop productivity is directly related to the quality of the soil, of which water is the major limiting factor. Soils with more available soil water and enhanced soil structure show less variation among years due to variable rainfall and higher productivity. The shifting precipitation pattern and changing frequency of precipitation has increased the attention on the need for subsurface drainage to remove excess water in the spring and to apply irrigation to crops, especially specialty crops, during the late summer.

Crops and forests are under increasing pressure from weeds, insects, and diseases as a consequence of variable weather and a changing climate. Additionally, much forest management in the Midwest relies on natural regeneration of primary tree species, which is jeopardized in many boreal and drought-intolerant species. Therefore, understanding the implications of changing weather patterns and variability is critical to the effective management of agricultural and forest systems. Producers want tools that can help implement adaptation strategies to reduce these climate-related pressures and ensure the quality of production. Producers need information about the effects of climate change on production systems, which range from management of labor resources in specialty crop production, to market demand for nursery crops given the changing climate, to marketing of locally grown produce, and development of innovative management systems to increase profitability and product quality across all systems. The Midwest Regional Climate Hub is working to assemble information to serve the needs of producers and increase the value of our research information in educational and outreach efforts.

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1. Introduction

Agriculture is the dominant landscape enterprise across the Midwest and represents one of the most extensive and intensive agricultural areas in the world. Although this area is referred to as the Corn Belt, corn and soybean production occurs on 75 percent of the arable land with the remainder used to produce a wide variety of crops according the 2012 Census of Agriculture (National Agricultural Statistics Service, 2014a). Of the 127,784,828 acres of arable land in the Midwest, corn is produced on 53,986,449 acres and soybean on 43,888,216 acres.

Figure 1: Midwest Climate Hub and Northern Forests Climate Sub Hub. Legend: Cultivated (brown), Grassland (tan), Forest (green), Developed (red), Water (blue)

1.1. Description of the Region and Key Resources

The climate, geology, ecosystems, land use, demographics, and economies vary widely across the footprint of the Midwest Hub. There are nine distinct ecological provinces within the hub, with heavy concentrations of forest lands and industry around the borders of the hub in the Northwoods (eco-province 212), Central Hardwoods (eco-province 223), Central Appalachians (eco-provinces 221 and M221), and the Northeastern states (eco-provinces 211 and M211) (Figure 2). A broad swath of lands through the middle of the Midwest Hub (eco-provinces 251, 222, and 223) is intensively cultivated. The potential exposure and adaptive capacity to climate change vary across all the eco-provinces. The Northwoods forests may experience greater vulnerabilities in the many boreal species at the southern edge of their ranges, whereas the forests in the Central Hardwoods face the potential of increased fire and floods (S. D. Handler et al., 2014), and the Central Appalachian forests may experience increased channelization in the mountainous regions and late-season water stress in upland mesic forests. Common to all these ecosystems and agroecosystems is the greater likelihood of impacts from expanded pest and disease ranges.

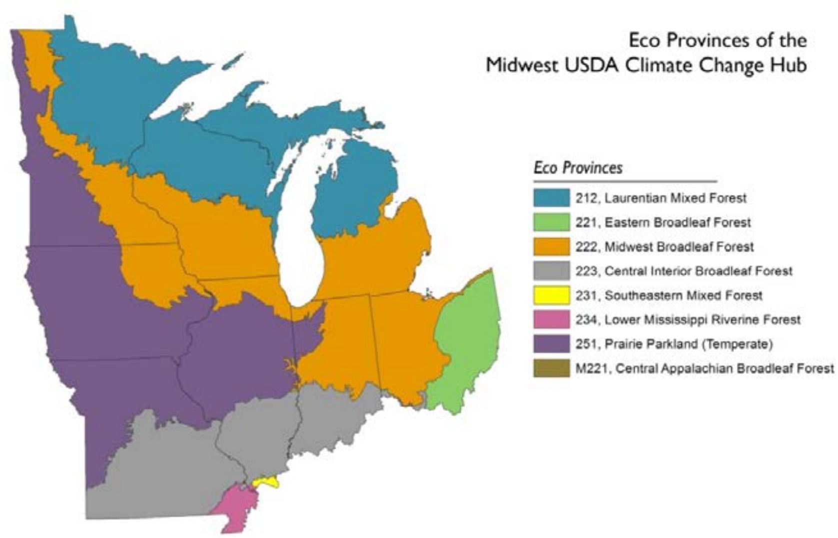

Figure 2: Eco Provinces of the Midwest Climate Hub

Climate change has the potential to significantly affect agriculture throughout this region with major consequences for the area covered by the Midwest region. This region includes the bulk of the traditional Corn Belt that stretches from Iowa and Minnesota east through Illinois, Indiana, and Ohio. Deep, fertile soils and sufficient, reliable rainfall have made this one of the most productive agricultural regions in the United States and the world. The region also includes a diverse range of other crops including vegetables, fruits, sugar beets, feed grains and hay, and ornamentals. Value-added operations such as wineries are becoming increasingly common, especially in areas near the Great Lakes and in higher elevation areas in the eastern portion of the region.

1.2. Demographics and Land Uses

One of the most intensive areas of agriculture in the world is in the Midwestern States of Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin. This area is not only critically important in meeting the grain and meat needs of consumers in the United States and throughout the world, it is also thus important to the U.S. economy. An inventory of current agricultural production across the Midwest reveals that of the $120 billion in sales, the largest production area is in corn and soybean; however, there is a significant economic value of nearly $5 billion from small grains, alfalfa, vegetables, perennials, and tobacco. Livestock, pig, cattle, dairy, poultry (layers and turkeys) contribute another large portion to the Midwest economy.

In the 2007 Census of Agriculture, these States had a market value of crop and livestock products sold of $76.989 billion (National Agricultural Statistics Service, 2009) with another $55 million contributed by the forest sector (S. D. Handler et al., 2014). Within the United States, Illinois, Iowa, and Minnesota ranked second, third, and fourth in the value of crops sold; Iowa ranked third in the value of livestock, poultry and poultry products; and Wisconsin ranked seventh in the value of livestock and poultry and their products. The economic value of the crop and livestock commodities in these States continues to increase because of rising prices. In 2007, 50,311,634 acres in the Midwest was planted in corn, followed by soybean with 35,280,401 acres, and forest area covering 87 million acres.

The soil resource of the Midwest is one of the most productive in the world; however, shifting precipitation patterns and intensity of storms threaten the long-term stability of this resource. Agricultural producers will have to implement adaptive management strategies to protect and enhance the soil along with crop and livestock management strategies to cope with climate change. The Midwest also encompasses forests that support local communities and provide clean water to millions of Americans.

1.3. General Climate Conditions, Extremes, and Past Impacts

The Midwest, being relatively far from the ocean, experiences wide extremes of both temperature and precipitation. In the winter, with no mountain ranges to act as barriers, bitterly cold air masses from the Artic can move unhindered southward into the region. The polar jet stream is often found near or above the region in the winter as well, bringing overcast skies, precipitation, and windy conditions. Summers in the Midwest are typically hot and humid due to a semi-permanent high pressure system in the subtropical Atlantic that draws warm, humid ocean air into the area (Kunkel et al., 2013). Annual precipitation varies from 20 inches in northwestern Minnesota to 50 inches in more southern regions. The Great Lakes have a moderating effect on the local climate, with near-shore locations being warmer in early winter and cooler in the summer than locations farther away (Kunkel et al., 2013). Major vulnerabilities in the Midwest region include floods, severe thunderstorms, summer drought, heat, flooding, heat waves, fluctuating Great Lake water levels, and winter storms (Kunkel et al., 2013).

1.4. Summary of National Climate Assessment Regional Climate Scenarios

The rate of warming in the Midwest has markedly accelerated over the past few decades. Between 1900 and 2010, the average Midwest air temperature increased by more than 1.5°F. However, between 1950 and 2010, the average temperature increased twice as quickly, and between 1980 and 2010, it increased three times as quickly as it did from 1900 to 2010. Warming has been more rapid at night and during winter. The Midwest growing season has lengthened by almost 2 weeks since 1950, due in large part to earlier occurrence of the last spring freeze. This trend is expected to continue, though the potential agricultural consequences are complex and vary by crop (Kunkel et al., 2013). Historical and recently observed climate trends for the Midwest region are provided below based on data from the National Weather Service's Cooperative Observer Network, supplemented with additional information from Kunkel et al.(2013).

Temperature

Average temperatures across the Midwest region have risen steadily over the last several decades, with average temperatures being consistently higher than the 1901–1960 average since 1990. The period since 2000 is the warmest on record. Seasonal changes in temperature have also been observed. The greatest changes in average temperature have been observed in winters and springs.

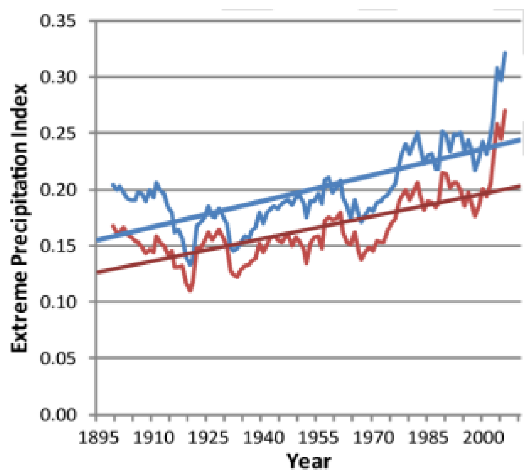

Figure 3: Time Series of extreme precipitation index for the occurrence of 1-day, 1-in-5-year extreme precipitation events. The annual time series and linear trend (straight line) are shown in blue. A time series for the months of May through September is shown in red. Analysis is average for the states of IL, IN, IA, MI, MN, MO, OH, and WI. Based on data evaluated in (Kunkel et al., 2013).

Precipitation

Extreme precipitation events are occurring more frequently in the Midwest. Currently, 85 percent of events are occurring during the summer period (May–September), and 90 percent of the annual trend is due to increases during this timeframe. Furthermore, the number of 1-day, once-in-5-year storms has increased by 4 percent per decade since the beginning of the 20th Century (Kunkel et al., 2013). Drought is also a threat to agriculture in this region because a majority of the land is not irrigated. In 2010, moderate drought was observed in some areas, whereas too much rain was observed in others as well as very high nighttime temperatures.

Growing Season

The growing season in the Midwest is now on average about 1 week longer than it was in the 1960s and 1970s. The last spring freeze is occurring earlier and the first fall frost is occurring later, with the relative timing shift of the last spring freeze being greater than the first fall frost.

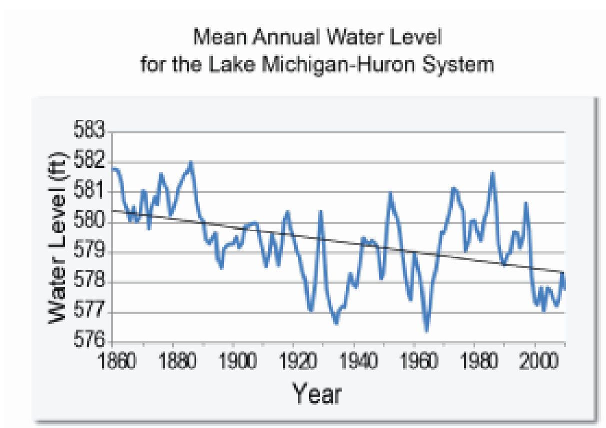

Figure 4: The Lake Michigan–Lake Huron system has shown a significant downward trend over the past 150 years (Kunkel et al., 2013).

Additional Climate Features

The Great Lake's water levels have fluctuated between 3 and 6 feet since the late 19th century. The Lake Michigan–Lake Huron system (see Figure 4) has endured a significant downward trend in water level over the past 150 years. Ice cover measurements on regional lakes indicate a negative trend in the duration of ice cover and percentage of total ice coverage (Kunkel et al., 2013).

Expected Changes

Mean annual precipitation is expected to increase in the far north of the region with a corresponding decrease in the southwestern corner of the region. Increases in precipitation in the winter, spring, and fall but decreases in the summer are predicted. More wet days (precipitation exceeding 1 inch) for the entire Midwestern region with increases up to 60 percent are also expected. Fewer dry days (precipitation of less than 0.1 inch) are simulated for northern areas and more dry days are expected for the southern portions (Kunkel et al., 2013).

2. Regional Agriculture's Sensitivity to Climate Change and Adaptation Strategies

Climate change poses a wide range of risks for agricultural production in the Midwest. For major corn and soybean growers in Iowa or Illinois, the main risks will likely come from water availability and management. The severe drought of 2012 greatly reduced yields in the western and central part of the region. This was followed by a dry winter but an unusually wet spring, which delayed 2013 planting. With greater extremes in weather being one of the major projected effects of climate change, providing better information to these growers to allow them to manage these risks has huge potential impacts on agricultural productivity. Smaller, niche growers face different but related challenges. Climate changes may close current production options, but open others.

2.1. Cropping Systems Overview of Risks, Vulnerabilities, and General Adaptation Strategies

More than 16,000,000 acres of pasture in the Midwest are used in combination of grazing livestock and hay production. The distribution of area across the Midwest planted with various crops is shown in Table 1. In addition to the intensive plant production across the Midwest, this region is an intensive animal production area with the animal population numbers recorded in the 2012 Census of Agriculture shown in Table 2.

The Midwest agricultural system is a diverse collection of crops and animal production systems and each production system has its own unique responses to climate and weather. There is variation in production among years attributable to variation in the weather each growing season as shown in Figure 5 for corn yield and Figure 6 for soybean. The variation in yields among years shows the weather events within specific years [e.g., 1988 and 2012 for corn and 1976, 1988, and 2003 for soybean with a slight drop in 2010 (excessive wet summer and hot summer) and 2012 (excessive drought)].

Table 1: Acres planted to various crops in the Midwest (National Agricultural Statistics Service, 2014b)

Commodity	Acres
Corn	53,986,449
Soybean	43,888,216
Hay and Alfalfa	10,358,742
Wheat	4,235,724
Sugar Beets	637,294
Annual Specialty Crops	
Asparagus	10,237
Beans	38,308
Cabbage	11,087
Carrots	10,383
Cucumbers	42,050
Onions	7,262
Peppers	4,401
Peas	94,970
Potatos	193,397
Pumpkins	21,295
Sweet Corn	239,032
Tobacco	4,212
Tomatoes	22,777
Watermelon	10,434
Perennial Specialty Crops	
Apples	64,625
Blueberries	22,897
Sweet Cherries	9.467
Tart Cherries	39,642
Cranberries	20,641
Grapes	23,583
Peaches	7,152
Plums	943
Raspberries	1,291

The variation in crop yield per acre is one measure of the impact of variation in the growing season weather conditions and another measure is the difference between the planted and harvested acres, which are referred to as lost acres, and the amount of lost production is estimated as a product of the lost acres times the average yield for that year. These data were computed for corn (Figure 7) soybean (Figure 8), wheat (Figure 9), and sweet corn (Figure 10).

Some years exhibit large losses in production area; these are typically those with excess precipitation. A large number of lost acres in soybean occurred in 1993, whereas the reminder of the record show no significant lost production area in corn, wheat, or sweet corn. There has been a decrease in the land area lost for corn production during the growing season with the progress in technology (e.g., seed treatments, drainage, improved planting equipment, and improved pest management practices); however, there has been a steady increase in lost acres over the last 10 years and an increasing economic impact of this lost area because of the continual increase in yield across the Midwest. Although the record shows a considerable number of lost acres devoted to wheat, this is small compared with corn and soybean acreage in relative amounts because there are fewer spring and summer extreme weather events to cause significant damage and reduce the harvested crop area. Another metric used to evaluate the impact of the growing season was an evaluation of the crop insurance claims for these four crops, and the total claims and the total crop insurance payments for corn (Figure 11), soybean (Figure 12), wheat (Figure 13), and sweet corn (Figure 14).

Table 2: Animal production in the Midwest (National Agricultural Statistics Service, 2014b)

Animal	Numbers
Cattle and Calves	17,825,236
Dairy Cows	5,695,982
Hogs and Pigs	42,684,828
Sheep and Lambs	14,123,673
Equine	711,588
Goats	403,565
Layers	146,505,736
Pullets	39,162,851
Broilers	84,087,693
Turkeys	44,985,526

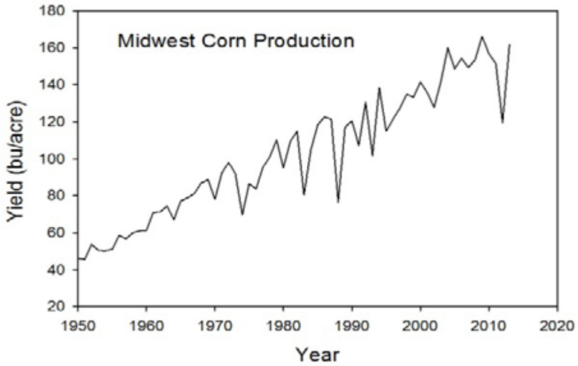

Figure 5: Corn yield for Midwest from 1950 to 2013

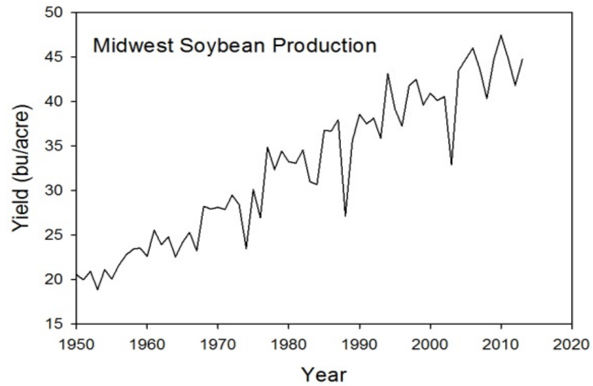

Figure 6: Soybean yield for Midwest from 1950 to 2013

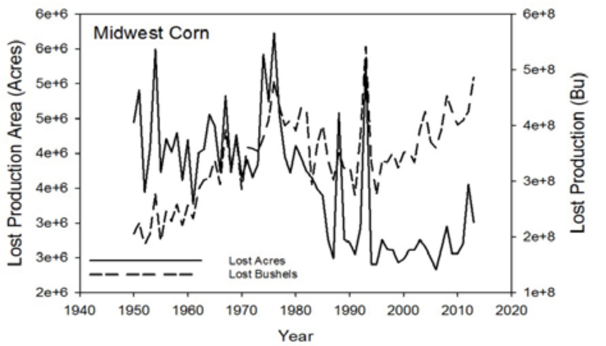

Figure 7: Lost acres (planted-harvested acres) and lost bushels (lost acres x average yield) for corn in the Midwest from 1950 to 2013

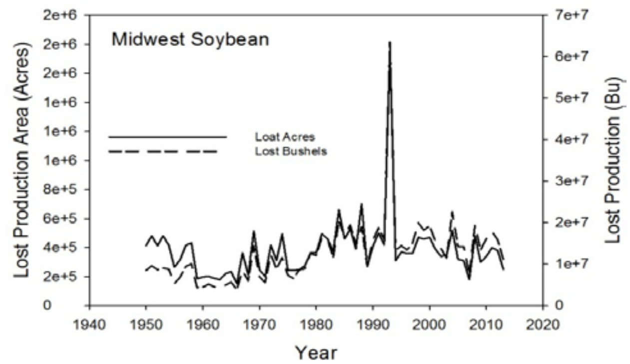

Figure 8: Lost acres (planted-harvested acres) and lost bushels (lost acres x average yield) for soybean in the Midwest from 1950 to 2013

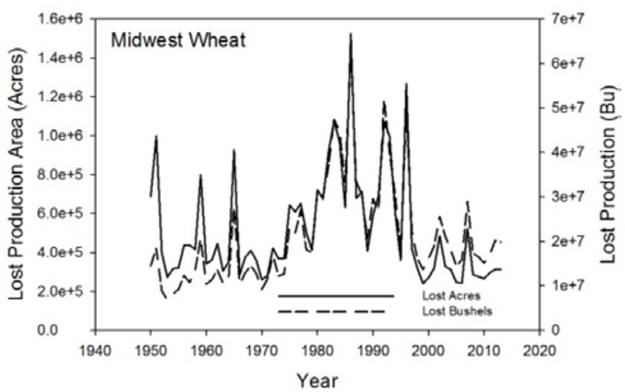

Figure 9: Lost acres (planted-harvested acres) and lost bushels (lost acres x average yield) for wheat in the Midwest from 1950 to 2013

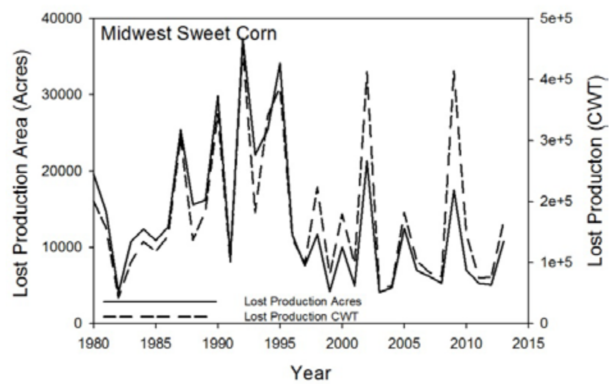

Figure 10: Lost acres (planted-harvested acres) and lost production (lost acres x average yield) for sweet corn in the Midwest from 1950 to 2013

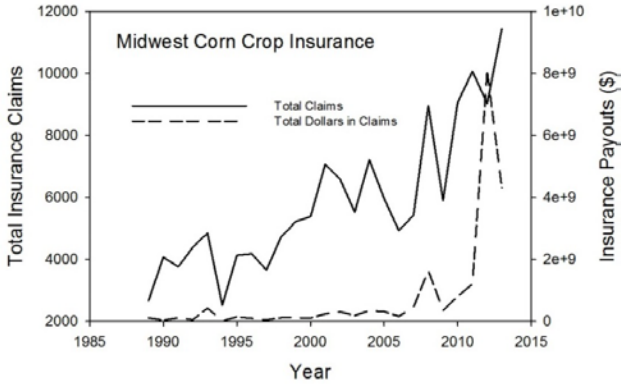

Figure 11: Crop insurance claims and insurance payouts for corn grown in the Midwest from 1989 to 2013

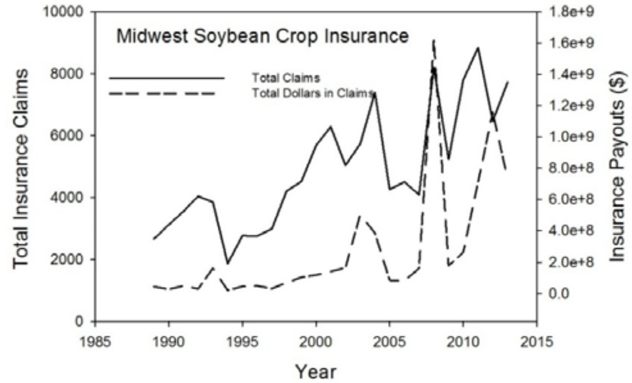

Figure 12: Crop insurance claims and insurance payouts for soybean grown in the Midwest from 1989 to 2013

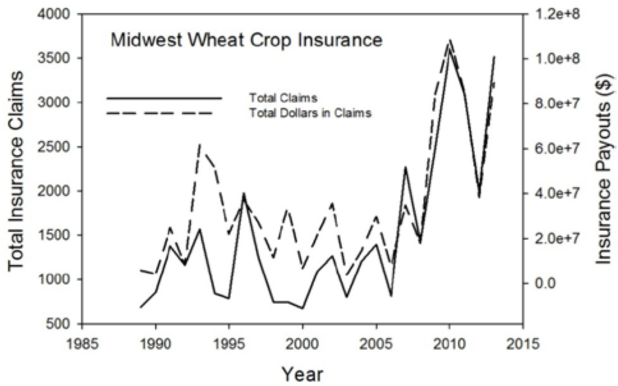

Figure 13: Crop insurance claims and insurance payouts for wheat grown in the Midwest from 1989 to 2013

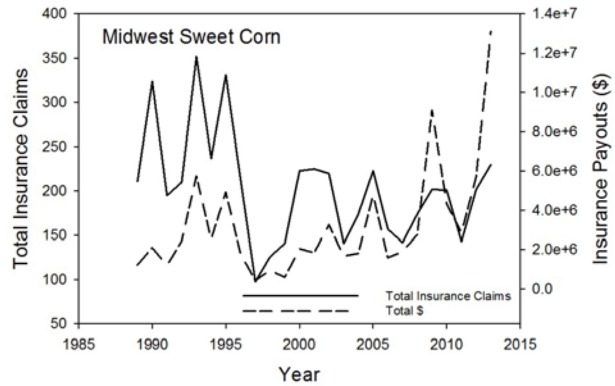

Figure 14: Crop insurance claims and insurance payouts for sweet corn grown in the Midwest from 1989 to 2013

Weather-related factors contributed the large majority of these claims in crop loss. Another notable observation in these data is a continual increase in insurance claims for each crop since 2000. This analysis reveals that weather is having an effect on production, which affects a producer's utilization of crop insurance to offset the production value. Producers use crop insurance in their production systems and an evaluation of the distribution of claims reveals the factors contributing to these claims.

2.2. Agricultural Ecosystem Drivers and Stressors

Agricultural systems vary in their response to changing weather and climate, and a number of factors in the growing season will affect crop distribution, management capabilities, economic viability, and quality of the grain, forage, or produce. These weather and climate factors will also affect livestock and their production. The projected changes in the climate for the Midwest have been detailed by Pryor et al. (2014) and the effects of climate change on agriculture in the Midwest have been detailed by Hatfield (2014).

Greater Extreme Precipitation and Seasonality Shifts

Precipitation is vital to agriculture and there are projections of slight average increases in total yearly precipitation with a shift toward more spring precipitation and less summer precipitation. The climate trend has been toward heavier precipitation with decreasing frequency. This creates the potential for more runoff from agricultural lands with inadequate protection from heavy precipitation (Nearing, Pruski, & O'Neal, 2004), which can lead to greater stream flow and volume and flash floods after heavy rains. The implications of the shifts in seasonality in precipitation will affect production because of inadequate soil water availability during the late summer when crops are producing fruit. The impact of this has been shown by Hatfield (2011): soils with low water capacity produce lower yields because of their inability to provide adequate water to meet crop demand during the grain-filling period.

Longer and Warmer Growing Seasons

Growing seasons have increased in length over the past decades and are now 9 days longer than they were in the mid-20th century. There has been a continued warming over this period of time with a trend toward warmer nights or higher minimum temperatures compared with maximum temperatures. These warmer temperatures have meant an increase in growing degree days, meaning that plants grow more quickly than they did in the past. Warmer temperatures also mean that the rate of water use by a plant increases because of the great water demand caused by an increase in saturation vapor pressure deficit. This translates into the potential for greater water deficits limiting growth in years with less rainfall or in soils with low water holding capacity. Warmer temperatures during the winter do not mean the probability for frost in the spring has changed; in fact, the last day of spring frost has remained relatively constant, creating the potential for more frost damage because plants may start to grow in the spring only to be exposed to frost damage on their flower buds. Warmer temperatures during the winter translate into the potential for overwintering of insects and an expanded range of insects across the Midwest. Warmer temperatures also increase the number of life cycles for insects during the growing season.

Temperature extremes are projected to increase along with warmer nighttime temperatures, and these will affect both livestock and crops because the extremes cause stress in both crops and animals. The warmer nighttime temperatures can upset metabolic activity and lead to reduced performance.

Increased Humidity

There has been an increase in the water vapor content and humidity in the atmosphere of the Midwest. This has been caused by more moisture flow from the Gulf of Mexico and leads to periods with excessive heat warnings due to a combination of high humidity and temperature. For animals, this leads to high thermal heat indices, which causes stress, which leads to reduced milk, meat, and egg production, and in some cases, death. Higher humidity increases the potential for disease outbreaks because conditions are more conducive to disease growth. This is especially true for fungal pathogens, including those that produce feed toxins. Climate change is expected to shift habitats and bring wildlife, crops, livestock, and humans into contact with pathogens to which they are susceptible and have not been previously exposed (Hoberg & Brooks, 2014).

Impacts on Agricultural Systems

The changing climate in the Midwest has several implications for agricultural production systems from grain to specialty and perennial crops, and from confined to natural environment animal production. Climate change and variability in growing season weather will place new stresses on these systems, which may require new adaptation strategies either to cope with or lessen their effects. Some examples of the climate effects on factors linked with agriculture are detailed below.

Workable Field Days

Greater spring precipitation decreases the number of workable field days across the Midwest and will place a constraint on producers being able to accomplish all of their spring operations in a timely manner. In the National Climate Assessment, Hatfield et al. (2014) reported that over the past 15 years and compared with the previous 15 years, there was a decrease of 3.7 workable field days in the April to mid-May period for Iowa. This effect has been observed across the Midwest with spring precipitation contributing to the collective effect of a loss of 2.6 workable field days per additional inch of precipitation in the April-to-June period (Anderson, Babcock, Peng, Gassman, & Campbell, 2015). Analysis of the potential impact of increased precipitation on the ability of producers being able to conduct their field operations will offer strategies to offset these impacts.

Soil Erosion

Increases in heavy precipitation and spring precipitation will lead to more soil erosion in field and around stream banks (Nearing et al., 2004). Conservation practices to protect soil from erosion will have to account for the shifts in precipitation intensity and more aggressive adoption of conservation practices.

Drainage and Water Management

Midwestern agriculture is one of the most intensively and extensively subsurface drained regions globally with approximately 40 percent of the arable land area being subsurface drained. The trend is for more pattern tile[1] to be installed at regular spacing in fields, which offers the potential to control water release from the field. Drainage from fields is a form of water management to conduct spring agricultural operations. This system of pattern subsurface drainage offers the potential for water management by releasing only the amount required for timely field operations while the remainder is retained in the soil profile for later use by the growing crop. However, to achieve this requires an accurate forecast of precipitation events to curtail the release of water from the profile and retain the optimal amount for crop water use in the growing season. Water management in a more general form will be required for improved crop production because crop productivity is directly related to the amount of water directly used by the crop.

Vulnerability Assessments for Agricultural Systems

Assessments of the vulnerability of agricultural systems can be conducted in a variety of ways. In this report we selected to convey this analysis as a function of the different segments of the crop calendar across all crops and livestock rather than each specific commodity. Feedback from Midwest producers indicate that this type of assessment is preferable to commodity assessments. Sensitivity of specific crops and livestock to weather and climate has been extensively described in Hatfield et al. (2011), Izaurralde et al. (2011), and Walthall et al. (2012).

Early Spring Agricultural Operations

Excessive precipitation in the early spring disrupts all agricultural and planting operations because the soil is wet. In drained areas excessive precipitation can lead to standing water in the field at planting, so those areas are not able to be planted with the remainder of the field. Wet soil conditions delay soil warming, so the seed may be planted into cool soil, which increases the potential for soil-borne diseases to attack the young seedlings. Wet soils have little capacity for water infiltration from subsequent precipitation events, leading to the potential for runoff and soil erosion. This effect is increased when the soils have little residue cover and lack of soil structure that causes the soil surface to lack the infiltration capacity to absorb precipitation. Increased soil erosion under the increased precipitation intensity and occurrence in the spring has the potential to increase soil degradation, flooding, and movement of nutrients and pesticides into nearby water bodies. Field operations (e.g., seed bed preparation or planting) in wet soils can lead to long-term compaction of the soil or degradation of the soil structure at the surface causing an increase in the potential for reduced infiltration of precipitation or decreased plant growth.

Warmer than normal temperatures will increase the rate of bud development and flowering in perennial plants and increase the potential for exposure to frost damage. This response was evident in 2012 across the Midwest when the temperatures were warmer than normal, which led to early flowering in many tree crops, but then a late frost destroyed the crop. Tart cherries in Michigan experienced a complete crop failure in 2012, and in many other areas, fruit crops suffered low yields because of frost damage to the flower buds.

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[1] The purpose of subsurface drainage is to lower the water table in the soil. There are a variety of patterns of subsurface drainage systems to choose from depending on the topography of the field. Some of the patterns include parallel, herringbone, double main, and random subsurface draining systems (Iowa State University Extension, 2010).

Excessive precipitation during the spring can affect animal operations, especially in open lots or pastures. Animals in open pens are subjected to mud and have difficulty accessing feed and water, causing lower performance in milk and meat production, and placing greater stress on the birth process and limiting access to dry conditions for newborn animals. Animals in pastures at calving or lambing times will be subjected to wet and cool conditions that may further increase the stress on newborn animals. This can lead to greater mortality among young animals because of their sensitivity to temperature extremes.

Late Spring and Early Summer Operations

Greater variability of weather during the early growing season affects plant development and exposes the plant to potential stress. Warmer than normal temperature increases the rate of plant development, which affects both quality and harvest operations of vegetables. For example, warmer temperatures speed the rate of development of asparagus, creating the need for early harvest. Because this crop is hand-harvested, variations in temperature among seasons creates a problem in knowing when to arrange for labor.

Small grain crops and early season vegetables can be exposed to frost damage in the late spring, which reduces yield. The increased variation of temperatures during this period will increase the variation in production and is often the cause for the lost acres for wheat production (Figure 9).

Excessive precipitation during the early growing season disrupts alfalfa harvest operations. Exposure to rainfall while the hay is cut and drying before it is baled reduces its quality and can also cause compaction and rutting in the soil by field equipment.

Excessive precipitation increases the potential for bacterial diseases of vegetable crops. Continual precipitation events lead to saturated soils. Excessive soil water stresses the plant and is one of the major causes of crop loss during the growing season. Saturated soils also increase the risk for nutrient leaching and runoff of sediment, nutrients, and pesticides. Manure applications in the spring can be vulnerable to runoff if the manure is applied to saturated soil with the likelihood of more precipitation within a few days of application.

Extreme temperature events or greater variation in temperature can expose animals to conditions that are not conducive to optimum production. Variations between cold and warm temperatures over short time intervals (e.g., days) can stress the animal leading to decreases in meat, milk, and egg production. Even though many of these animals are in confined building spaces, the adjustments of the building temperature may not be adequate to compensate for the changes in the ambient temperatures (Key, Sneeringer, & Marquardt, 2014).

Summer Growing Conditions

Extreme temperature events, mainly high temperatures during the day or night, cause stress in both plants and animals. These have been detailed by Hatfield et al. (2011) and Walthall et al. (2012). One of the most sensitive phenological stages to extreme temperature is the pollination phase when pollen is being produced to fertilize the ovule to produce the grain or fruit. Exposure to high temperatures just prior to flowering in many plants reduces yield, particularly if the plant is under stress due to lack of rainfall. High temperatures increase the rate of water use by the crop and in years when rainfall is limited yield will decrease due to lack of soil water to maximize crop production. This is further exaggerated in soils with limited water holding capacity as shown by Egli and Hatfield (2014; 2015) for corn and soybean across the Midwest. Variation in precipitation among years is the factor leading the variation in production as illustrated by corn and soybean production (Figure 5 and Figure 6). Degradation of soil that reduces its potential to store water induces more variation in crop production among years with variable precipitation. For high-value cash crops such as vegetables, water management with irrigation is being considered as a viable management option to reduce the negative effects on.

Variable precipitation induces variation in forage production in pasture areas (Izaurralde et al., 2011). Livestock producers with cattle or sheep on pasture adjust stocking rates or grazing patterns and even provide supplemental feed to ensure adequate feed supply to these animals. Reduced water supplies for livestock on pasture can occur because of the diminished amount of water in ponds.

Extremely high temperatures coupled with high humidity induces stress on animal systems. The development of the thermal humidity index (THI) demonstrates the vulnerability of animals to the combination of heat and humidity (Mader, Johnson, & Gaughan, 2010). Excessive heat during the night creates a stressful conditions for animals, which can lead to mortality if the conditions persist for multiple days. Dairy animals will reduce milk production and layers will reduce egg production when exposed to high nighttime temperatures. Animals in confined housing may be exposed to even higher extremes because of the inability of the building to provide sufficient cooling or ventilation to offset these temperature extremes. Plants are also subject to the effects of high nighttime temperatures by leading to an increase in the rate of plant development and shortening of the grain-filling period in corn and soybean, which causes a reduction in grain yield (J.L. Hatfield et al., 2011).

Variable precipitation affects harvest operations in vegetables and product quality. Precipitation coupled with high temperatures and high humidity will increase the potential for greater incidences of plant diseases and greater number of insect life cycles. The indirect effects of climate variation that include greater numbers and instances of insects and diseases requires better monitoring of these problems and rapid implementation of control measures.

Variation in weather conditions during the growing season will affect insect, disease, and weed populations. Better scouting for these populations will be required to avoid outbreaks that lead to economic loss. Development of tools that couple the economic thresholds (level of infestation of pests leading to significant economic impacts) with weather modules will be required to reduce the vulnerability to these indirect impacts.

Early Fall Conditions

Harvest operations may be disrupted due to variation in precipitation. Although the trend has been for less precipitation in the late summer/early fall period across the Midwest, the increased variation among years creates the potential for harvest periods with wet soil conditions (e.g., 2014 growing season). Variable conditions in the fall have the potential to lead to greater variation in crop maturity, which creates a condition in which harvest operations are disrupted and the need for grain drying before storage is expanded. Wet soil conditions during harvest create a potential problem because of the inability to move equipment through the field. Analysis of the number of workable field days for the fall will provide a potential risk assessment with climate variation across the Midwest.

Development of mycotoxins in corn relative to weather events creates a potential vulnerability to a changing climate. Initiation of these diseases in corn grain needs to be refined to be able to provide producers with potential management strategies to reduce this occurrence.

Variable precipitation and soil water supply increases the vulnerability of fall seeded crops (e.g., wheat and cover crops). Inadequate soil water will limit the growth of these plants and reduce their effectiveness in providing soil cover or nutrient uptake. Reduced fall growth in small grains limits their ability to survive over the winter and produce grain the next spring.

Post-harvest and Late Fall Conditions

Fall tillage operations are extensively conducted across the Midwest along with fall application of nutrients. Excessive precipitation during the fall limits the ability to perform these operations and when crop residue has been removed and tillage operations completed, precipitation can create erosion in the late fall and early winter before freezing. This portion of the growing season is increasingly vulnerable to the variation in weather among years from the viewpoint of environmental impacts from agricultural operations.

Variation in temperature with cool and warm periods can lead to potential problems in animals because of the wide range of conditions to which they are exposed. This degree of variation can extend into the overwintering period for animals in open feedlots or pastures.

Winter Conditions

Animal production is vulnerable to weather conditions over the winter, especially for those in open feedlots and pasture. Variations in temperature and precipitation will require monitoring of animals for adequate feed, water, and shelter.

This period is generally used by producers for analysis of the previous growing season and preparation for the next growing season. Variations in weather during the past growing season create uncertainty about the ability to adequately plan for the next growing season. This is potentially the most vulnerable part of the growing season because of the lack of analysis to help the producers understand the options for management and the key response variables to help in the decision-making process.

Summary

Midwestern agriculture is a complex and varied system of crop, fruit, and livestock production. Each commodity has its own unique response to environmental variables and risk response to those variables. To reduce the effect of climate variation in the future and weather variation in the next growing season, partnerships with commodity organizations and producers will be critical to filling the gaps in production systems.

3. Forest Systems: Overview of Risks, Vulnerabilities, and General Adaptation Strategies

Forests are a defining landscape feature for much of the Midwest, from boreal forests surrounding the northern Great Lakes to oak-hickory forests blanketing the Ozarks. Savannas and open woodlands within this region mark a major transition zone between forest and grassland biomes within the United States. Forests help sustain human communities in the region from ecological, economic, and cultural perspectives. These ecosystems are already responding to changing conditions, and climate change is anticipated to have a pervasive influence on forests in this region over the coming decades [vulnerability assessments for Midwest forests (Brandt et al., 2014; Butler et al., 2015; Stephen Handler et al., 2014; Stephen Handler et al., 2014; S. D. Handler et al., 2014; Janowiak et al., 2014; Lee, Penskar, Badra, Klatt, & Schools, 2012; Pryor et al., 2014; C. Swanston et al., 2011; C.W. Swanston & Handler, 2012; Wisconsin Initiative on Climate Change Impacts (WICCI), 2011)]. This paper does not attempt to establish new estimates of vulnerability or risk for the forestry sector; rather, it synthesizes recent information to provide a useful summary.

3.1. Forest Ecosystem Drivers and Stressors

Forest ecosystems each have particular ecological conditions or drivers that tend to support their existence. Climate change has the potential to alter many of these drivers.

Longer Growing Seasons

Growing seasons have extended across the Midwest during the last several decades (Andresen, Hilberg, & K., 2012). There is strong agreement that projected temperature increases will lead to longer growing seasons. Longer growing seasons have the potential to affect the timing and duration of ecosystem and physiological processes (N. L. Bradley, Leopold, Ross, & Huffaker, 1999; Dragoni & Rahman, 2012). Earlier springs and longer growing seasons are expected to cause shifts in phenology for forest species that rely on temperature as a cue for the timing of leaf-out, reproductive maturation, and other developmental processes (M. W. Schwartz, Iverson, Prasad, Matthews, & O'Connor, 2006; Walther et al., 2002). Longer growing seasons may also result in greater growth and productivity of trees and other vegetation, but only if balanced by available water and nutrients.

Shorter, Warmer Winters

Warmer winter temperatures are likely to cause changes in numerous winter processes. Snowpack is expected to decrease across the region by the end of the 21st century, and the region is projected to experience fewer days of soil frost by the end of the century (Notaro, Lorenz, Hoving, & Schummer, 2014; Sinha & Cherkauer, 2010). Although these conditions could increase water infiltration into the soil and reduce runoff, they may also lead to greater soil water losses from forests through increased evapotranspiration. This decrease in snow cover and frozen soil may affect a variety of ecosystem processes, including decomposition, nutrient cycling, and the onset of the growing season. Furthermore, altered seasonality in northern areas of the Midwest can lead to fewer winter operations for forest management activities (Rittenhouse & Rissman, 2015).

Increased Extreme Precipitation

Projected increases in heavy precipitation events are expected to increase total runoff and peak stream flow during the winter and spring (Cherkauer & Sinha, 2010), which may increase the magnitude or frequency of flooding. Increases in runoff following heavy precipitation could also lead to an increase in forest soil erosion (Nearing et al., 2004). The risk to forests from flooding, erosion, and related impacts will ultimately depend on local geological and topographic conditions that affect the size and character of the watershed, as well as interactions with infrastructure and land use.

Changes in Soil Moisture and Drought

Given that warmer temperatures and seasonal changes in precipitation are expected across the region, it is reasonable to expect that soil moisture regimes will also shift. Longer growing seasons and warmer temperatures may result in greater evapotranspiration losses and lower soil-water availability later in the growing season. There is substantial variation among model projections, however, and it is also possible that the region will experience an increase in precipitation sufficient to offset increases in evapotranspiration (Winkler, Arritt, & Pryor, 2012). Climate projections also highlight the possibility of reduced precipitation and increased moisture stress during summer months (Brandt et al., 2014; Stephen Handler et al., 2014; Stephen Handler et al., 2014; S. D. Handler et al., 2014; Janowiak et al., 2014). Overall, there is relatively low confidence in the projected future frequency of droughts across the central United States. For example, in the southern part of the Midwest, total soil moisture is projected to increase during winter and spring and decrease in the late summer and autumn (Diffenbaugh & Ashfaq, 2010; Mishra, Cherkauer, & Shukla, 2010). Although model projections vary for this region, most suggest an increase in drought duration and area (Mishra et al., 2010). This means that droughts may shift from affecting smaller areas over shorter time periods to covering regional landscapes for longer durations. Because many tree species are already functioning at their hydraulic limits, even a small increase in drought could lead to widespread decline and mortality (Choat et al., 2012).

Enhanced Fire Risk

At a global scale, the scientific consensus is that fire risk will increase by 10 to 30 percent due to higher summer temperatures (IPCC, 2007). There is little agreement on this trend across climate models for the early part of the 21st century (Moritz et al., 2012). By the end of the century, however, most national models project an increase in wildfire probability, particularly for boreal forests, temperate coniferous forests, and temperate broadleaf forests. In the Midwest, modeling suggests that increases in wildfire risk may be greatest in the southern Midwest (Heilman et al., in press). In addition to the direct effects of temperature and precipitation, increases in fuel loads from pest-induced mortality, or blowdown events could increase fire risk, but the relationship between these factors can be complex (Hicke, Johnson, Hayes, & Preisler, 2012). Forest fragmentation and wildfire management also make fire projections more uncertain for the region.

Intensified Biological Stressors

Changes in climate may allow some undesirable plant species, insect pests, and pathogens to expand their ranges farther north (Dukes et al., 2009) as the climate warms and the region loses some of the protection offered by a traditionally cold climate and short growing season. The abundance and distribution of some undesirable and invasive plant species may be able to increase directly in response to a warmer climate and also indirectly through greater invasion by plant and insect pests into stressed or disturbed forests (Ryan & Vose, 2012). Similarly, forest pests and pathogens are generally able to respond rapidly to changes in climate and also disproportionately in damage-stressed ecosystems (Weed, Ayres, & Hicke, 2013). Thus, a high potential exists for pests and pathogens to interact with other climate-mediated stressors. Unfortunately, we lack basic information on the climatic thresholds that apply to many invasive plants, insect pests, and pathogens. Furthermore, there remains a limited ability to predict the mechanisms of infection (in the case of pests and diseases), dispersal, and spread for specific agents, as well as which specific nonnative species, pests, or pathogens may enter the region during the 21st century.

3.2. Factors That Increase Risks to Ecosystems

Adaptive capacity is the ability of a species or ecosystem to accommodate or cope with potential climate change with minimal disruption (Glick, Stein, Edelson, & (editors), 2011). It is strongly related to the concept of resilience (Backlund, Janetos, & Schimel, 2008). Below, we summarize factors that could reduce or increase the adaptive capacity of forest systems within the region. Greater adaptive capacity tends to reduce climate change vulnerability, and lower adaptive capacity tends to increase vulnerability.

- **Low-diversity systems:** In general, species-rich communities have exhibited greater resilience to extreme environmental conditions and greater potential to recover from disturbances than less diverse ecosystems (Tilman, 1996, 1999). Consequently, less diverse forest types and ecosystems such as aspen, red pine plantations, or black ash swamps may be inherently more susceptible to future changes and stressors (Duveneck, Scheller, White, Handler, & Ravenscroft, 2014; C. Swanston et al., 2011). Genetic diversity within species is also critical for the ability of populations to adapt to climate change because species with high genetic variation are more apt to have individuals that can withstand extreme events and adapt to changes over time (Reusch, 2005).
- **Fragmented landscapes:** Species are generally expected to migrate more slowly than their suitable habitats will shift (L.R. Iverson, M.W. Schwartz, & A.M. Prasad, 2004; L. R. Iverson, M. W. Schwartz, & A. M. Prasad, 2004; McLachlan, Clark, & Manos, 2005). Migration may be further slowed or even blocked by fragmentation, in which previously contiguous forests and woodlands are divided into smaller, often unconnected units by agriculture and urbanization (Jump & Peñuelas, 2005; Scheller & Mladenoff, 2008). Humans may be able to assist in the migration of species to newly suitable areas to counteract the effects of fragmentation. Assisted migration is a contentious issue for some species, especially those of conservation concern (Pedlar et al., 2012; Mark W Schwartz et al., 2012).
- **Systems that are limited to particular environments:** Several species and forest types in the region are confined to particular habitats, whether through particular requirements for hydrologic regimes or soil types, or other reasons. Similar to species in fragmented landscapes, isolated species and systems face additional barriers to migration (Jump & Peñuelas, 2005). These systems face additional challenges in migration compared with more-widespread species with broad ecological tolerances.
- **Systems that are less tolerant of disturbance:** Systems maladapted to more frequent disturbance such as drought, flooding, wind, ice storms, or fire may be at higher risk because these events increase in a changing climate. Some of these systems may yet persist in the absence

of competitive invasive or native species, though perhaps with less vigor. Other systems may be tolerant of some types of disturbance but not others, such as lowland forests that may be able to withstand flooding but not drought or extreme high temperatures (Stephen Handler et al., 2014).

3.3. Tree Species and Ecosystem Shifts

As temperature and precipitation patterns continue to change, it is possible that large ecosystem conversions will accompany the changes. Ecosystems are complex assemblages of species, and so the response of individual species will strongly affect how ecosystems respond as a whole. Additionally, climate change effects will continue within the context of forest management, possibly including active and widespread adaptation efforts. Changes in broad ecosystem types will thus vary from one place to another on the basis of local management decisions and specific influences of site-level environmental factors.

Reduced Habitat for Northern and Boreal Species

Warmer temperatures are expected to be more favorable to individuals of northern and boreal species near the northern extent of their species' range and less favorable to those near the southern extent (L. R. Iverson & Prasad, 1998). Results from climate impact models project declines in suitable habitat and landscape-level biomass for northern species such as black spruce, white spruce, tamarack, jack pine, yellow birch, and paper birch (Stephen Handler et al., 2014; Stephen Handler et al., 2014; S. D. Handler et al., 2014; Janowiak et al., 2014). These northern species may persist in the region throughout the 21st century, although with declining vigor. Boreal species may remain in areas with favorable soils, management, or landscape features. Additionally, boreal species may be able to persist in the region if competitor species are unable to colonize these areas (L. Iverson, Prasad, & Matthews, 2008).

Altered Forest Composition

Species will respond individually to climate change, and this may lead to the dissolution of traditional community relationships (Davis, Shaw, & Etterson, 2005; Root et al., 2003). Past climatic changes resulted in large shifts in species composition (Davis, 1983; Williams, Shuman, Webb, Bartlein, & Leduc, 2004). Ecological principles and modeling studies indicate that forest communities may move across the region (Frelich & Reich, 2010; L. Iverson et al., 2008; Lenihan, Bachelet, Neilson, & Drapek, 2008) and that tree species may also rearrange into novel communities. Changes in forest composition could be accelerated or enhanced by major stand-replacing disturbance events or forest management.

Model results project that species currently near their northern range limits in the region may become more abundant and more widespread under a range of climate futures. At the same time, observed trends have suggested that forest species may be more prone to range contraction at southern limits and less able to expand ranges northward to track climate change (Murphy, VanDerWal, & Lovett-Doust, 2010; Woodall et al., 2013; Zhu, Woodall, & Clark, 2011). Most species can be expected to migrate more slowly than their suitable habitats will shift (L.R. Iverson et al., 2004; L. R. Iverson et al., 2004; McLachlan et al., 2005; Scheller & Mladenoff, 2008). Habitat fragmentation and dispersal limitations could further hinder the northward movement of southerly species despite the increases in available habitat. Pests and diseases such as emerald ash borer, beech bark disease, and Dutch elm disease are also expected to limit some species otherwise projected to increase, and the possibility also exists for nonnative plant species to take advantage of shifting forest communities and unoccupied niches if native forest species are limited (Hellmann, Byers, Bierwagen, & Dukes, 2008). Major shifts in species composition may not be observable until well into the 21st century because of the long timeframes associated with many ecosystem processes and responses to climate change.

Changes in Forest Productivity

One of the major implications of climate change is the potential for changes in forest productivity, which will be influenced by complex interactions among the degree of warming, ecosystem water balance, and disturbance events (Chiang, Iverson, Prasad, & Brown, 2008; Duveneck et al., 2014; He, Mladenoff, & Gustafson, 2002; Scheller & Mladenoff, 2005). There is evidence both worldwide and regionally that warmer temperatures and longer growing seasons are partially responsible for observed increases in forest growth and carbon sequestration during the past century (McMahon, Parker, & Miller, 2010; White, Running, & Thornton, 1999). Likewise, there is evidence that carbon dioxide fertilization has contributed to enhanced tree growth over the past two centuries (Cole, Anderson, Lindroth, & Waller, 2010; Franks et al., 2013; Norby & Zak, 2011) and potentially offset some of the effects of drier growing seasons (Franks et al., 2013; G. G. Wang, Chhin, & Bauerle, 2006).

Although the potential exists for forest productivity to increase under a changing climate, there are also several potential ways that productivity may be reduced. In particular, it is uncertain whether the timing and amount of future precipitation will be adequate for overcoming the greater evaporative demand of warmer temperatures. Episodic disturbances such as fires, wind events, droughts, and pest outbreaks may also reduce productivity in certain areas over different time scales. In addition, where tree species decline, lags in the migration of different species to newly suitable habitat may reduce productivity until a new equilibrium is reached.

3.4. Considerations by Ecoregion

Handler et al.(2014) described key vulnerabilities that climate change may present to the forest sector across the ecoregions of the Midwest, based on a review of available scientific literature, including both empirical studies of observed changes over the past several years and modeling studies that offer future projections under a range of future climates.

- Climate change will amplify many **existing stressors** to forest ecosystems such as invasive species, insect pests and pathogens, and disturbance regimes (very likely).
- Climate change will result in **ecosystem shifts and conversions** (likely).
- Many tree species will have **insufficient migration rates** to keep pace with climate change (likely).
- Climate change will amplify existing stressors to **urban forests** (very likely).
- Forests will be less able to provide a consistent supply of some **forest products** (likely).
- Climate change effects on forests will impair the ability of many forested watersheds to produce reliable supplies of **clean water** (possible).
- Climate change will result in a widespread decline in **carbon storage** in forest ecosystems across the region (very unlikely).
- Many contemporary and iconic forms of **recreation** within forest ecosystems will change in extent and timing due to climate change (very likely).

Additionally, the Laurentian Mixed, Broadleaf, and Prairie Parkland forest ecoregions in the Midwest have unique vulnerabilities to climate variability, which are described below.

Laurentian Mixed Forest

These projected changes in climate and the associated impacts and vulnerabilities will have important implications for economically valuable timber species, forest-dependent wildlife and plants, recreation, and long-term natural resource planning. Three recent vulnerability assessments describe potential climate change impacts for forests in the Laurentian Mixed Forest (Stephen Handler et al., 2014; Stephen Handler et al., 2014; S. D. Handler et al., 2014; Janowiak et al., 2014). Across these assessments, major conclusions are similar. One of the most consistent findings across the literature is the threat of climate change on forest ecosystems dominated by boreal species, such as spruce-fir and aspen-birch forests, which are consistently rated as the most vulnerable across numerous vulnerability assessments. Likewise, forests with particular hydrological requirements such as peatland forests, lowland conifer forests, and lowland and riparian hardwoods have generally been assessed as having higher levels of vulnerability due to potential changes in precipitation and hydrologic regimes. These impacts are magnified in areas were wetland forests are also dominated by boreal species.

Declines in the productivity or extent of these forest communities have the potential to dramatically alter other components of the forestry sector in the Northwoods. For example, the commercial importance of many of the tree species that are expected to decline has the potential to affect the forest industry (S. D. Handler et al., 2014).

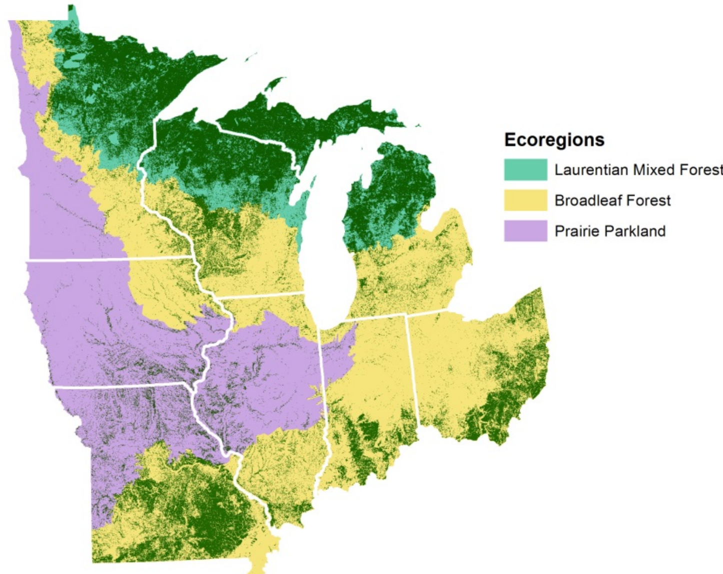


Figure 15: Midwest Forest Ecoregions

Shorter winter seasons may also reduce the feasibility of forest harvest operations in some areas (Rittenhouse & Rissman, 2015). Large potential shifts in commercial species availability may pose risks for the forest products sector if the shifts are rapid and the industry is unprepared. Likewise, wildlife species associated with northern climates and forests, such as the gray jay and the American marten, may also decrease as boreal conifer species and other key habitat features change.

The models indicate that climate trends may generally favor hardwood species across the landscape by the end of the century. Communities such as white pine and oak forests were perceived as less vulnerable to projected changes in climate (Stephen Handler et al., 2014; Stephen Handler et al., 2014; S. D. Handler et al., 2014; Janowiak et al., 2014). Results from forest impact models suggest that species such as bitternut hickory, black oak, bur oak, and white oak may have increases in both suitable habitat and biomass, and some deciduous forest types have the potential for productivity increases across the assessment area (Stephen Handler et al., 2014; Stephen Handler et al., 2014; S. D. Handler et al., 2014; Janowiak et al., 2014). There is already some evidence of temperate tree species crossing local ecoregions into boreal forest patches in response to warming in northern Minnesota and Wisconsin (Fisichelli, Peters, Iverson, Matthews, & Hoffman, 2013). For this reason, it is important to note that forest communities will not be influenced only by shifts in habitat ranges, but also by the ability of any species to actually migrate and establish in new areas (S. D. Handler et al., 2014). For the Boundary Waters Canoe Area in northern Minnesota, Xu et al. (2008) found that with increased wind and fire disturbance expected with climate change, forest composition change was influenced more by colonization of new species than competition among existing species. Similarly, simulations of forest response to climate change in northern Wisconsin found that species migration is negatively correlated with habitat fragmentation (Scheller & Mladenoff, 2008).

Eastern Broadleaf Forest

Climate change is likely to cause similar stress on forests in the eastern Broadleaf provinces as in the rest of the Midwest, including drought, forest pests and diseases, non-native species, and altered disturbance regimes (Stephen Handler et al., 2014). Oak decline is a major stressor throughout the continental portion of the eastern Broadleaf forest. This condition is correlated with drought periods (Dwyer, Cutter, & Wetteroff, 1995; Fan, Kabrick, & Shifley, 2006; J. Wang & Zhang, 2008). Species in the red oak group are particularly susceptible to decline and make up a large proportion of upland forests in this ecoregion. Decline begins with stressed trees that are then attacked by insects and diseases. If droughts become more frequent or severe, oak decline could worsen. A buildup of fine and coarse fuels could result from increased tree mortality, increasing the risk of wildfire in the area.

Existing forests may also have to compete with undesirable species under warmer future conditions. As one example, kudzu is an invasive vine that typically transforms invaded forests in the southeastern United States by quickly overgrowing and smothering even mature overstory trees, and its current northern distribution is limited by winter temperatures. Although kudzu is not currently widespread, it has appeared in southern Missouri and in scattered locations throughout Ohio. Modeling suggests the risk for kudzu invasion into the eastern Broadleaf ecoregions could be heightened under future warming conditions (B. A. Bradley, Wilcove, & Oppenheimer, 2010; Jarnevich & Stohlgren, 2009). The aggregate of the models suggests a medium risk for invasion for Missouri, Indiana, Illinois, and Ohio over the next century.

Forest ecosystem vulnerability assessments completed for two large regions within the Midwest suggest that some tree species and forest communities may benefit from climate change, whereas others may become more stressed and experience loss of suitable habitat. Specific stressors in the area that could be exacerbated by climate change include drought, wildfire, flooding, invasive species, and pests and disease. Although there is little agreement among climate models on changes in fire probability in the near term in the central U.S., there is a greater potential for wildfire probability by the end of the century (Heilman et al., in press; Moritz et al., 2012). Of nine community types assessed by Brandt et al. (2014) across southern Missouri, Illinois, and Indiana, mesic upland forests were considered to be the most vulnerable due to negative impacts on sugar maple and other dominant species, as well as a limited capacity to adapt to disturbances such as fire and drought. Fire-adapted communities such as woodlands, savannas, and glades were considered less vulnerable because they have more drought- and heat-adapted species and are better able to withstand large-scale disturbances. Bottomland forests had slightly higher vulnerability due to the possibility of shifts in flood dynamics. Another assessment of nine community types across Maryland, Ohio, and West Virginia (Butler et al., 2015) also found that mesic upland forests and large stream riparian forests were more vulnerable to climate change than fire-adapted communities. Projected changes in climate and the associated ecosystem impacts and vulnerabilities will have important implications for economically valuable timber species, forest-dependent wildlife and plants, recreation, and long-range planning.

Prairie Parkland

Fragmentation and parceling of forest ecosystems is more drastic in the Prairie Parkland than other ecoregions throughout the Midwest. For example, more than 90 percent of forestland in Iowa is currently divided into private holdings averaging less than 17 acres (Flickinger, 2010). Parceling frequently leads to fragmentation in forest ecosystems, even though land use change may not immediately follow ownership transfers (Haines, Kennedy, & McFarlane, 2011). Combined with extensive conversion of available land to agricultural monocultures, this ecoregion currently exists as a highly fragmented landscape for forest ecosystems. This condition raises the possibility that tree species in the Prairie Parkland ecoregion, especially those on upland sites, may be unable to successfully migrate to future suitable habitat, perhaps more so than other ecoregions in the Midwest.

Many of the forested areas in the Prairie Parkland are in low-lying areas along rivers. These forests are less fragmented than upland forests, but other stressors may be exacerbated by climate change contributing to their vulnerability. Changes in land use and infrastructure have altered the hydrology in these floodplain forests. A shift toward more heavy precipitation, which is already occurring in the Midwest, may lead to additional hydrological stress. Projections for changes in habitat suitability for floodplain forests are mixed, with projected declines in habitat suitability for elms, and projected increases for silver maple and boxelder (Landscape Change Research Group, 2014).

3.5. Forest Sector Adaptation Strategies

As an increasing amount of relevant scientific information on forest vulnerability to climate change becomes available, managers are searching for ways to realistically use this information to meet the more specific needs of on-the-ground forest management, including management plans and silvicultural prescriptions (C. I. Millar et al., 2012). The amount of information available on the anticipated effects of climate change on ecosystems is growing rapidly, putting high-quality scientific information within reach of most natural resource professionals (Seppälä, Buck, & Katila, 2009; Vose, Peterson, & Patel-Weynand, 2012). At this point in time, many professionals are shifting their requests for more information to requests for practical and efficient ways to focus and apply existing information. The application of this information can help them adjust management, conservation, and restoration priorities and activities to adapt forests to the changes in climate.

Principles of Forest Adaptation

A great deal of work has occurred to provide conceptual frameworks (C. I. Millar et al., 2012; Peterson et al., 2011), compile adaptation strategies (e.g., (Heinz, 2008; Heller & Zavaleta, 2009; Ogden & Innes, 2008)), and provide tools to support management decision making (e.g., (Cross et al., 2012; Morelli, Yeh, Smith, Hennessey, & Millar, 2012; Chris W. Swanston & Janowiak, 2012). The following principles can serve as a starting point for this perspective (Joyce et al., 2008; C. I. Millar, Stephenson, & Stephens, 2007; Chris W. Swanston & Janowiak, 2012; Wisconsin Initiative on Climate Change Impacts (WICCI), 2011):

- **Prioritization and triage:** It will be increasingly important to prioritize actions for adaptation on the basis of both the vulnerability of resources and the likelihood that actions to reduce vulnerability will be effective.
- **Flexible and adaptive management**: Adaptive management provides a decision-making framework that maintains flexibility and incorporates new knowledge and experience over time.
- **"No regrets" decisions:** Actions that result in a wide variety of benefits under multiple scenarios and have little or no risk may be initial places to consider re-prioritization and look for near-term implementation.
- **Precautionary actions:** Where vulnerability is high, precautionary actions to reduce risk in the near term, even with existing uncertainty, may be extremely important.
- **Variability and uncertainty:** Climate change is much more than increasing temperatures; increasing climate variability will lead to equal or greater impacts that will need to be addressed.
- **Integrating mitigation:** Many adaptation actions are complementary with actions to mitigate greenhouse gas emissions, and actions to adapt forests to future conditions can help maintain and increase their ability to sequester carbon.

Strategies, Planning, and Implementation

The Climate Change Response Framework was launched in the Midwest and northeastern United States in 2009 by the USDA Forest Service. It now works in concert with the USDA Regional Climate Hubs and continues to provide resources for forest adaptation. These resources are designed to translate largely broad-scale and conceptual information into tangible, actionable projects that can be used by forest managers and other natural resource professionals to advance their on-the-ground work (Chris W. Swanston & Janowiak, 2012). Among the resources are a menu of 50 adaptation strategies and approaches drawn from scientific literature and further vetted by regional forest managers and scientists. Dozens of tactical examples help to further ground these ideas. The Framework's *Adaptation Workbook* (www.adaptationworkbook.org)[2] provides a structured process that integrates climate pressures but is fundamentally based on users' original objectives, experience with local forests, and willingness to accept risk. It incorporates vulnerability assessment and adaptation strategies from the menu to ultimately identify adaptation tactics that align with landowner needs and are tied to long-term goals. When meeting original objectives appears impractical or too risky, the user may decide to reconsider the original objectives. This approach has been applied in more than 60 real-world forest management projects across numerous ownership types and ranging in size from stand-level silvicultural prescriptions to management plans covering thousands of acres (www.forestadaptation.org). The result across this wide range of users is a diversity of approaches to climate adaptation linked to equally diverse values and objectives.

Summary

Forests of the Midwest range widely in character and productivity, from the mixed boreal forests in the north to the dry woodlands in the south and the deciduous forests in the east. Likewise, ownership patterns, values, and expectations vary widely across these forests. Climate change will exert different pressures for ecosystem change in these forests, and correspondingly present the people who rely on Midwestern forests with a variety of challenges. Effective responses to rapid changes in the timing, intensity, and distribution of otherwise familiar stressors and ecosystem drivers can be most efficiently addressed as a community with diverse experience and resources. An active community of forest managers and landowners are devising practical responses to these challenges, and continued communication and shared learning within this community will best enable heathy and productive forests.

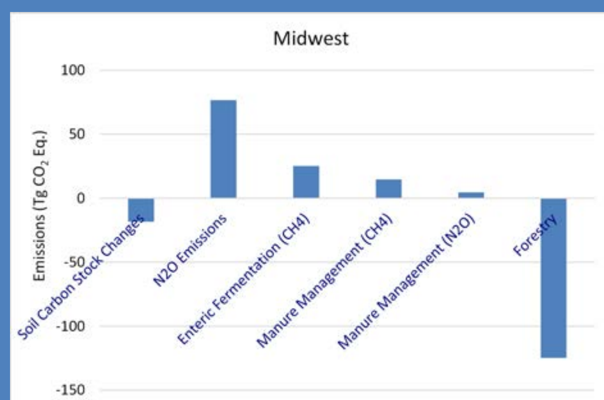
[2] The website will be available in May 2015.

4. Greenhouse Gas Emissions Profile and Mitigation Opportunities

Agriculture in the Midwest region (including crop, animal, and forestry production) has net greenhouse gas (GHG) emissions of approximately −20 teragrams[3] carbon dioxide equivalent (Tg CO_2 eq.) (i.e., a net storage of GHG emissions). In the region, crop-related nitrous oxide (N_2O) emissions are the largest contributor to GHGs at 78 Tg CO_2 eq., followed by methane (CH_4) from enteric fermentation (25 Tg CO_2 eq.), CH_4 and N_2O from manure management (20 Tg CO_2 eq.), and CH_4 from rice cultivation (less than 1 Tg CO_2 eq.). Forestry is the largest contributor to net carbon storage at −125 Tg CO_2 eq., followed by soil carbon stock changes at −18 Tg CO_2 eq.[4]

Midwest Region Highlights

- Corn, soybeans, beef cattle, poultry, and swine are the primary agricultural commodities produced in the Midwest.
- The highest source of GHG emissions is N_2O from croplands.
- Changes in carbon storage in 2008 offset GHG emissions resulting in a net sink.
- The greatest mitigation potential is available from changes in field tillage management practices.
- Retiring soils from cultivation and establishing conservation cover provides a good opportunity for additional carbon sequestration in the region.



Note: Rice cultivation is excluded from the chart because the emissions were less than 1 Tg CO_2 eq.

4.1. Soil Carbon Stock Changes

Carbon stock changes of major land use and management type for both soil types resulted in a net sequestration of −2.22 Tg CO_2 eq. in 2008. Specifically, cropland production changes on mineral soils sequestered 5.86 Tg CO_2 eq., changes in hay production sequestered 5.27 Tg CO_2 eq. and land removed from agriculture and enrolled in the Conservation Reserve Program sequestered 5.69 Tg CO_2 eq. In contrast, agricultural production on organic soils (which have a much higher organic carbon content than mineral soils) resulted in emissions of 14.6 Tg CO_2 eq.

Tillage practices contribute to soil carbon stock changes. Table 4 displays the tillage practices by type of crop for the Midwest Hub. Management practices that use reduced till or no till can contribute to increased carbon storage over time depending on site specific conditions.

[3] A teragram (Tg) is 10^{12} grams, which is equivalent to 10^9 kilograms and 1 million metric tons.
[4] Net carbon storage is the balance between the release and uptake of carbon by an ecosystem. A negative sign indicates that more carbon was sequestered than GHGs emitted.

Table 3: Midwest Estimates of Annual Soil Carbon Stock Changes by Major Land Use and Management Type, 2008

Land Uses	Emissions (Tg CO_2 eq.)
Net Change, Cropland[a]	−5.86
Net Change, Hay	−5.27
CRP	−5.69
Ag. Land on Organic Soils	14.6
Total[b]	**-2.22**

Source: USDA (2011)
[a] Annual cropping systems on mineral soils (e.g., corn, soybean, and wheat).
[b] Total does not include change in soil organic carbon storage on Federal lands, including those that were previously under private ownership, and does not include carbon storage due to sewage sludge applications.

Table 4: Tillage Practices in the Midwest Region by Crop Type (percent of acres utilizing tillage practice)

Crop Type	Acres[a]	No Till[b]	Reduced Till[b]	Conventional Till[b]	Other Conservation Tillage[b]
Corn	52,045,417	16.8%	22.7%	31.9%	28.6%
Sorghum	100,178	21.6%	15.9%	54.0%	8.5%
Soybeans	44,289,409	47.2%	13.3%	8.3%	31.2%
Wheat	4,646,299	15.2%	13.8%	40.6%	30.4%
Total	**101,081,303**	-	-	-	-

[a] Source: USDA (2011)
[b] Source: USDA ERS (2011)

4.2. Nitrous Oxide Emissions

In 2008, nitrous oxide (N_2O) emissions in the Midwest region totaled approximately 78 Tg CO_2 eq. Of these emissions, 71 Tg CO_2 eq. was emitted from croplands and 7 Tg CO_2 eq. was emitted from grasslands.[5] Because the Midwest region produces corn and soybean on the majority of its arable land, the majority of crop-related N_2O emissions in the region (more than 81 percent) are from the production of these two crops (National Agricultural Statistics Service, 2014c).

As indicated in Table 5, the majority of N_2O direct emissions are from corn crops. The quantity and timing of nitrogen-based fertilizer affects the rate of both direct and indirect N_2O emissions.[6] Table 6 indicates the percentage of national acreage that did not meet the rate or timing criteria as defined by Ribaudo et al. (2011). Timing criteria is defined in terms of best practices for quantity and timing of fertilizer application. Meeting the best practice rate criterion is defined as applying no more nitrogen (commercial and manure) than 40 percent more than that removed with the crop at harvest, based on the stated yield goal, including any carryover from the previous crop. Meeting the best practice timing criterion is defined as not applying nitrogen in the fall for a crop planted in the spring (Ribaudo et al., 2011). Acreages not meeting the criteria represent opportunities for GHG mitigation.

[5] Including both direct and indirect emissions; Table 5 includes only *direct* emissions from crops.
[6] Direct N_2O emissions are emitted directly from agricultural fields and indirect N_2O emissions are emissions associated with nitrogen losses from volatilization of nitrogen as ammonia (NH_3), nitrogen oxides (NOx), and leaching and runoff.

Table 5: Direct Nitrous Oxide (N_2O) Emissions by Crop Type

Crop Type	Direct N_2O Emissions ($Tg\ CO_2$ eq.)	% of Region's Cropland N_2O Emissions
Corn	29.66	54.5%
Soybean	14.72	27.1%
Hay	5.32	9.8%
Wheat	0.85	1.6%
Sorghum	0.02	<0.1%
Non-major Crops	3.82	7.0%
Total	**54.38**	**100.0%**

Source: USDA (2011)

Table 6: National Percent of Acres Not Meeting Rate and Timing Criteria (Percent of Acres)

Crop	Not Meeting Rate[a]	Not Meeting Timing[b]
Corn	35%	34%
Sorghum	24%	16%
Soybeans	3%	28%
Wheat	34%	11%

Source: Ribaudo et al.(2011)

4.3. Methane Emissions from Rice Cultivation

Methane emission from rice cultivation in the United States is responsible only for a small portion of total GHG emissions from cropped soils. In the Midwest, rice is grown only in Missouri and is not a major crop. Methane emission from rice cultivation was 0.4 Tg CO_2 eq. in 2008, which is relatively small compared with N_2O emission in the Midwest (approximately 54 Tg CO_2 eq.).

4.4. Livestock GHG Profile

Livestock systems in the Midwest focus primarily on the production of swine, beef and dairy cattle, sheep, poultry, goats, and horses. The region had more than 300 million head of poultry in 2008. The population of swine is the next-largest livestock population, with more than 41 million animals, followed by cattle (beef and dairy) with close to 20 million head (USDA, 2011). Nearly 80 percent of the cattle in the region is beef cattle. As with patterns in livestock production across the country, the primary source of GHGs from livestock is from enteric fermentation, digestive processes that result in the production of methane (CH_4) (referred to as enteric CH_4). In 2008, Midwest livestock produced 26.8 Tg CO_2 eq. of enteric CH_4.[7] Most of the remaining livestock-related GHG emissions are from manure management practices, which produce both CH_4 and N_2O.[8] In 2008, manure management in the Midwest resulted in 19.5 Tg CO_2 eq., considering both CH_4 and N_2O, with the majority attributed to CH_4 (USDA, 2011).

Table 7: Emissions from Enteric Fermentation in the Midwest, in Tg of CO_2 eq. and as a Percent of Regional Emissions

Animal Category	Tg CO_2 eq.	% of Region's CH_4 Enteric Emissions
Beef Cattle[a]	15.48	57.7%
Dairy Cattle[a]	9.76	36.5%
Goats[b]	0.02	0.1%
Horses[b]	0.53	2.0%
Sheep[b]	0.09	0.3%
Swine[b]	0.94	3.5%
Total	**26.82**	100.0%

[a] Source: USDA (2011)
[b] Source: Based on animal population from USDA (2011) and emission factors as provided in IPCC (2006)

[7] The enteric CH_4 emissions total for the region includes cattle and non-cattle.
[8] Livestock respiration also produces carbon dioxide (CO_2), but the impacts of ingesting carbon-based plants and expelling CO_2 result in zero-net emissions.

4.5. Enteric Fermentation

The primary emitters of enteric CH_4 are ruminants (e.g., cattle and sheep). Other livestock such as swine, horses, and goats also produce emissions, but in smaller quantities. The per-head emission of enteric CH_4 for dairy cattle is 40 to 50 percent greater than for beef cattle [e.g., 2.2 metric tons CO_2 eq. /head/year for dairy vs. 1.6 metric tons for beef in 2008 due primarily to their greater body weight and increased energy requirements for extended periods of lactation (EPA, 2014)]. However, in the Midwest region, because 80 percent of all cattle is beef cattle, the overall contribution to enteric CH_4 emission from beef cattle of enteric fermentation is much higher than for dairy cattle (USDA, 2011). Table 7 provides CH_4 emissions by animal type in 2008. As indicated, the majority of emissions are from beef and dairy cattle.

4.6. Emissions from Manure Management Systems

Manure management in the Midwest resulted in 14.9 Tg CO_2 eq. of CH_4 and 4.7 Tg CO_2 eq. of N_2O in 2008. Table 8 provides a summary of CH_4 and N_2O emissions by animal category. Swine waste accounted for 74 percent of CH_4 and 22 percent of N_2O emissions in 2008, and dairy waste accounted for 21 percent and 43 percent, respectively.

Table 8: 2008 Emissions from Manure Management in the Midwest, in Tg of CO_2 eq. and as a Percent of Regional Emissions

Animal		Methane		Nitrous Oxide	
Category	Population	Tg CO_2 eq.	Percent	Tg CO_2 eq.	Percent
Swine[a]	41,440,000	11.0	74.0%	1.0	21.7%
Dairy Cattle	4,396,333	3.2	21.2%	2.0	42.8%
Beef Cattle	15,239,958	0.3	2.3%	1.3	28.2%
Poultry	300,184,119	0.2	1.3%	0.3	7.2%
Horses[a]	2,113,122	0.2	1.1%	-	-
Sheep[a]	861,000	0.0	0.1%	-	-
Goats[a]	233,647	0.0	0.0%	-	-
Total	**363,468,179**	**14.9**	**100.0%**	**4.7**	**100.0%**

Source: USDA (2011)
[a] N_2O emissions are minimal and not included in this total.

The distribution of animal populations among different farm sizes varies across animal categories. Sixty-seven percent of dairy cattle are on operations with fewer than 300 head; although technologically possible, mitigation technologies such as anaerobic digesters are generally considered economically unfeasible for these small operations.[9] Conversely, the majority of swine exist on operations with more than 1,000 head where mitigation opportunities are less costly. Figure 16 provides a summary of CH_4 and N_2O emissions by animal category and baseline manure management practices.[10] The largest sources of CH_4 are anaerobic lagoons, deep pits, and liquid/slurry systems, primarily with dairy and swine waste. The largest sources of N_2O are beef dry lots. Figure 17 describes the proportion of beef cattle, dairy cattle, and swine managed using various manure management systems. The majority of beef waste is deposited on pasture, whereas dairy and swine waste is managed using a variety of systems, including anaerobic lagoons, deep pits, dry lots, and liquid/slurry systems.

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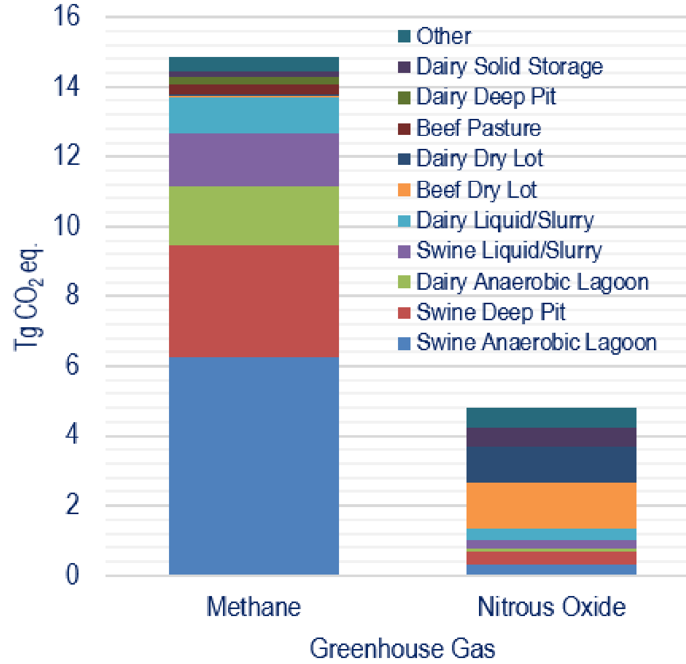
[9] Anaerobic digesters are lagoons and tanks that maintain anaerobic conditions and can produce and capture methane-containing biogas. This biogas can be used for electricity and heat, or it can be flared. In general, anaerobic digesters are categorized into three types: covered lagoon, complete mix, and plug flow digesters.

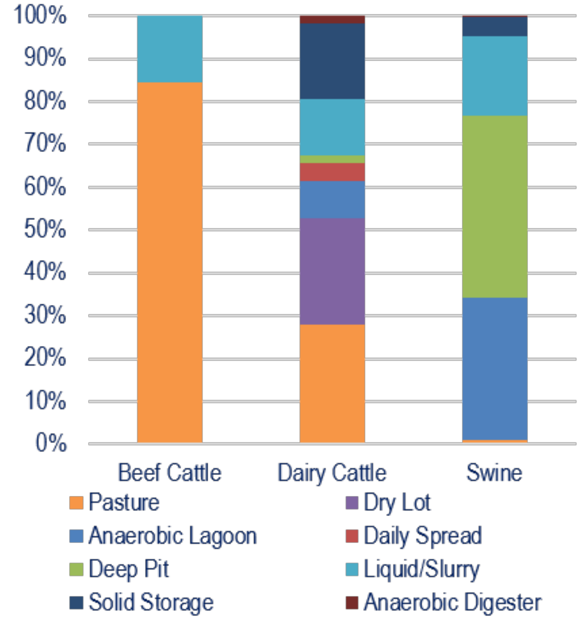
[10] Definitions for manure management practices can be found in Appendix 3-B in (ICF International, 2013).

Figure 16: 2008 CH_4 and N_2O Emissions from the Midwest by Animal Category and Management System (Tg of CO_2 eq.)



Source: EPA (2010)

Figure 17: Proportion of Beef Cattle, Dairy Cattle, and Swine Managed with Each Manure Management System



Source: EPA (2010)

4.7. Forest Carbon Stocks and Stock Changes

In the annual GHG inventory reported by the USDA, forests and harvested wood products from forests sequester 125 Tg CO_2 eq. per year in the Midwest; in addition, the 88.6 million acres of forest land in the Midwest maintain 27,286 Tg CO_2 eq. in forest carbon stocks.[11]

Managed forest systems in the Midwest focus primarily on the production of timber, in addition to serving as riparian buffers and wind breaks. Forestry activities represent significant opportunities for managing GHGs. Forest managers in the Midwest use a wide variety of silvicultural techniques to achieve management objectives, most of which will have impacts on the carbon dynamics. The primary impacts of silvicultural practices on forest carbon include

Table 9: Midwest Forest Carbon Stock and Stock Changes

Source	Units	Midwest
Net Area Change	1000 ha yr^{-1}	273
Non-Soil Stocks	Tg CO_2 eq.	12,602
SOC	Tg CO_2 eq.	14,684
Non-Soil Change	Tg CO_2 eq. yr^{-1}	-116[a]
Harvested Wood Products Change	Tg CO_2 eq. yr^{-1}	-9[a]
Forest Carbon Stock Summary (Tg CO_2 eq.)		
Non-Soil Stocks + SOC		27,286
Forest Carbon Stock Change Summary (Tg CO_2 eq. yr^{-1})		
Forest Carbon Stock Change		-125

Source: USDA (2011)
Negative values indicate a net removal of carbon from the atmosphere.

[11] Other GHGs such as N_2O and CH_4 are also exchanged by forest ecosystems. N_2O may be emitted from soils under wet conditions or after nitrogen fertilization; it is also released when forest biomass is burned. CH_4 is often absorbed by the microbial community in forest soils but may also be emitted by wetland forest soils. When biomass is burned in either a prescribed fire/control burn or in a wildfire, precursor pollutants that can contribute to ozone and other short-lived climate forcers as well as CH_4 are emitted (USDA, 2014).

enhancement of forest growth (which increases the rate of carbon sequestration) and forest harvesting practices (which transfers carbon from standing trees into harvested wood products and residues, which eventually decay or are burned as firewood or pellets). Other forest management activities will result in accelerated loss of forest carbon, such as when soil disturbance increases the oxidation of soil organic matter, or when prescribed burning releases CO_2 (N_2O and CH_4).

Forest management activities and their impacts on carbon storage vary widely across the Midwest with different forest types, ownership objectives, and forest stand conditions. However, silvicultural prescriptions exist for common forest types in the Midwest. For example, the USDA's Technical Bulletin *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory* (2014) provides this information for regions within the Midwest i.e., the northern Great Lakes States and Central regions (see Table 6-6 on page 6-59)].

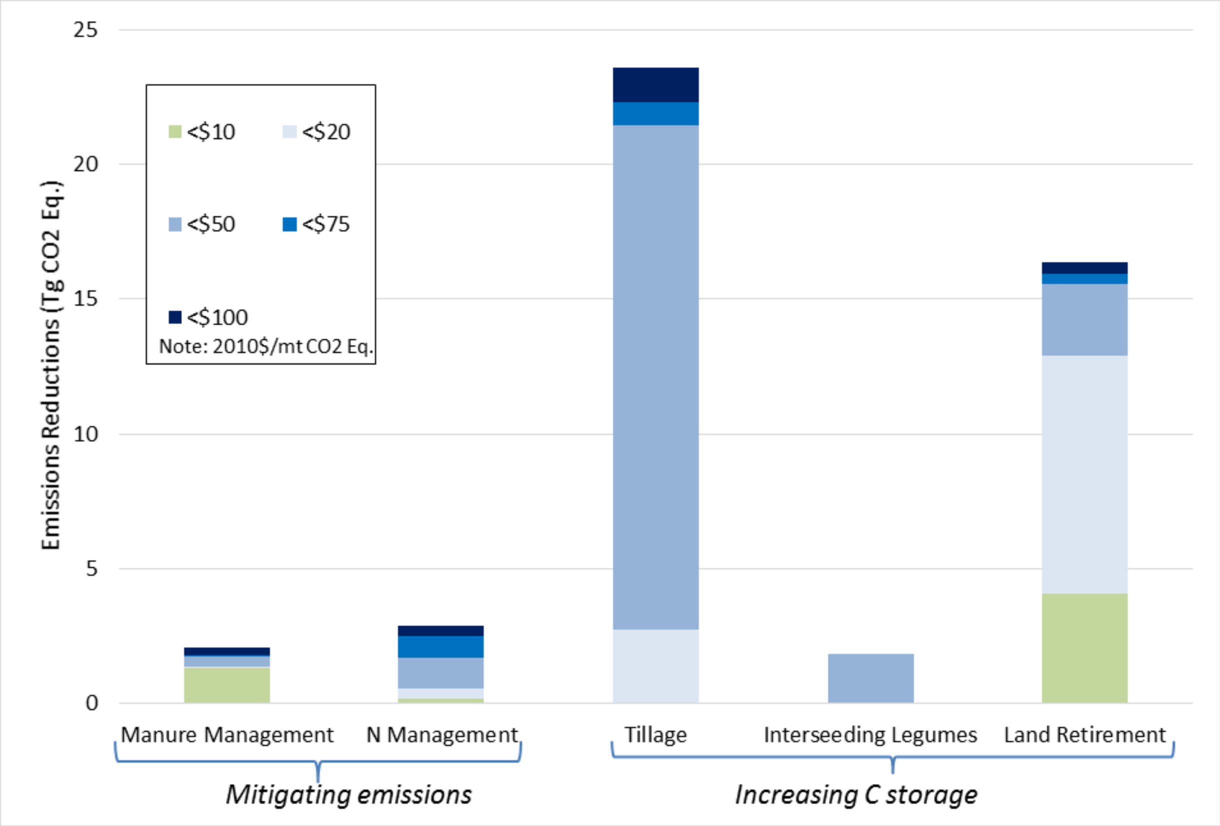
The USDA's *Forest Service 2010 Resources Planning Act Assessment* General Technical Report (2012) describes future projections of forest carbon stocks in the United States resulting from various vulnerabilities (e.g., less-than-normal precipitation, above-normal temperature) and other stressors (e.g., urbanization, other land development, demand for forest fuel and fiber). The RPA assessment projects that "declining forest area, coupled with climate change and harvesting, will alter forest-type composition in all regions." For example, the report notes that urbanization is the primary force behind projected losses of especially oak-hickory in the Midwest.

4.8. Mitigation Opportunities

Figure 18 presents the mitigation potential by sector for the Midwest. Each bar represents the GHG potential below a break-even price of $100/metric ton CO_2 eq.[12] A break-even price is the payment level (or carbon price) at which a farm will view the economic benefits and the economic costs associated with adoption as exactly equal. Conceptually, a positive break-even price represents the minimum incentive level needed to make adoption economically rational. A negative break-even price suggests the following: (1) no additional incentive should be required to make adoption cost-effective; or (2) there are nonpecuniary factors (such as risk or required learning curve) that discourage adoption. The break-even price is determined through a discounted cash-flow analysis such that the revenues or cost savings are equal to the costs.[13] The left two bars represent reductions from changes in management practices that mitigate GHGs. The right three bars represent increased carbon storage from changes in management practices. A total of 5 Tg CO_2 eq. can be mitigated at a break-even price below $100/metric tons CO_2 eq. Changes in land management practices can increase carbon storage by 42 Tg CO_2 eq. at a break-even price below $100/metric tons CO_2 eq. The color shading within a bar represents the mitigation potential or the potential increased carbon storage below different break-even prices indicated in the legend. For example, changes in tillage practices have the potential to contribute to 3 Tg CO_2 eq. of increased carbon storage for less than $20/metric ton CO_2 eq. (i.e., light green bar).

[12] Break-even prices are typically expressed in dollars per metric ton of CO_2 eq. This value is equivalent to $100,000,000 per Tg of CO_2 eq. or $100,000,000 per million metric tons of CO_2 eq.
[13] See ICF International (2013) for additional details.

Figure 18: Mitigation Potential in the Midwest Region, by Sector



- Most of the opportunity for reducing net GHGs emissions is from changes in field tillage practices (i.e., adopting long term reduced tillage practices).
- The second largest opportunity is by increasing carbon stock in land retirement practices, such as retiring organic and marginal soils.
- The highest potential reductions in emissions from manure management could be realized by installing complete mix digesters with electricity generation at swine and dairy farms, and installing improved separators at dairy farms with anaerobic lagoons.[14]

[14] The emission reduction excludes indirect emission reductions from the reduced use of fossil fuels to supply the electricity for on farm use (i.e., the emission reductions only account for emissions within the farm boundaries).

Agricultural Soils

For farms larger than 250 acres, variable rate technology is a relatively low-cost option for reducing N_2O emissions from fertilizer application.[15] Reducing nitrogen application can be a relatively low-cost option for all farm sizes. Transitioning from conventional tillage to no-tillage field management practices results in relatively large potential for carbon storage at low cost (i.e., the magnitude of the carbon storage potential is orders of magnitude higher than the potential to reduce N_2O emissions). Carbon gains can only be realized if no-till is adopted permanently, otherwise gains will be reversed.

Land Retirement

This category includes retiring cultivated organic soils and establishing conservation cover, retiring marginal croplands and establishing conservation cover, restoring wetlands, establishing windbreaks, and restoring riparian forest buffers. Organic soils are very rich in carbon (approximately 14.3 metric tons CO_2 eq. per acre) and provide the greatest opportunity for sequestering CO_2 in the Midwest.

Manure Management

The GHG mitigation opportunities for manure management with the lower break-even prices are primarily for large swine and dairy operations due to economies of scale for investments in capital equipment. The greatest CH_4 reductions can be achieved on swine operations with greater than 5,000 swine by transitioning anaerobic lagoons, liquid/slurry systems, or deep pits to complete mix digesters. For large dairy operations (i.e., with 1,000 head of cattle or more), transitioning from anaerobic lagoon systems to improved solid separators or complete mix digesters offer the greatest mitigation potential.

Enteric Fermentation

Emissions from enteric fermentation are highly variable and are dependent on livestock type, life stage, activity, and feeding situation (e.g., grazing, feedlot). Several practices have demonstrated the potential for efficacy in reducing emissions from enteric fermentation. Although diet modification (e.g., increasing fat or protein content, providing higher quality forage) and providing supplements [e.g., monensin, bovine somatotropin (bST)] have been evaluated for mitigation potential, the effectiveness of each option is not conclusive.

[15] Variable rate technology (VRT), a subset of precision agriculture, allows farmers to more precisely control the rate of crop inputs to account for differing conditions within a given field. VRT uses adjustable rate controls on application equipment to apply different amounts of inputs on specific sites at specific times (Alabama Precision Ag Extension, 2011).

5. USDA Programs

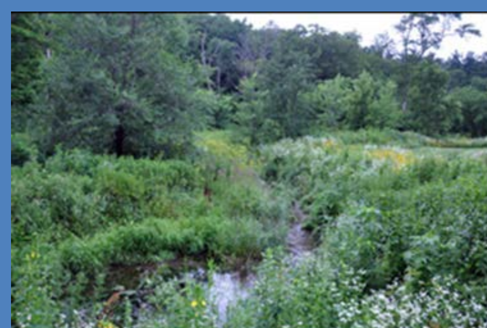
The recently published USDA Climate Change Adaptation Plan[16] presents strategies and actions to address the effects of climate change on key mission areas including agricultural production, food security, rural development, forestry, and natural resources conservation. USDA programs administered through the Agriculture Research Service (ARS), Natural Resources Conservation Service (NRCS), U.S. Forest Service (USFS), Farm Service Agency (FSA), Rural Development (RD), Risk Management Agency (RMA), and Animal and Plant Health Inspection Service (APHIS) have been and will continue to play a vital role in sustaining working lands in a variable climate and are key partner agencies with the USDA Climate Hubs. In the Midwest, Hub partner agencies are also vulnerable to climate variability and have programs and activities in place to help stakeholders respond to climate-induced stresses.

5.1. Natural Resources Conservation Service

The anticipated impacts of climate change on private lands in coming years and decades will necessitate that NRCS place additional emphasis on actions that explicitly address climate change. NRCS is already well positioned to address (via adaptive strategies) soil quality, landscape stability, extreme weather events, climate variability, natural disasters, and other issues. The point at which existing systems are transformed will vary depending on the interaction of climate change and variability of factors such as land use, land fragmentation, water availability, and energy costs. NRCS can work with a variety of research and development partners and affected producers to identify 1) land use alternatives, 2) land management systems, and 3) conservation priorities necessary to protect natural resources.

Staff members in NRCS field offices across the United States provide the technical link between research and application for the climate hubs. NRCS is the primary Federal agency that supplies conservation assistance on a voluntary basis to private citizens through its Conservation Technical Assistance (CTA) Program. NRCS has staff located in nearly every U.S. county thereby well-positioning it to provide outreach and support, and to implement conservation measures to increase resiliency to climate change and

Program Highlight: Driftless Area Landscape Initiative



The Driftless Area Landscape Initiative (DALCI) will directly target soil erosion and wildlife habitat in the four-state (Illinois, Iowa, Minnesota, Wisconsin) Driftless area. The diverse numbers of threatened and unique species in the DALCI offer opportunities to restore critical and rare habitat, increase grassland acreage, and improve water quality. This initiative increases resistance and resilience to climate change while addressing the unique needs of this distinctive, historic, and vulnerable landscape (NRCS, 2015).

[16] The 2014 USDA Climate Change Adaptation Plan includes input from eleven USDA agencies and offices. It provides a detailed vulnerability assessment, reviews the elements of USDA's mission that are at risk from climate change, and provides specific actions and steps being taken to build resilience to climate change. Find more here: http://www.usda.gov/oce/climate_change/adaptation/adaptation_plan.htm

reduce GHG emissions as a member of the regional climate change hubs.

The soil resources of the Midwest are the underpinnings of all agricultural and forest productivity. In the Midwest, the NRCS focus is to maintain soil quality through holistic conservation farm plans that minimize erosion, improve water quality, improve the overall health of the soil, increase biodiversity, conserve soil moisture, and improve the resiliency to climate change of working lands.

NRCS is uniquely positioned to provide information on climate change adaptation and resiliency to local producers and landowners through a grassroots structure and partnership with local soil and water conservation districts. These districts supported by NRCS have offices in nearly every county in the Midwest and are staffed by experts who have technical relationships with many of the landowners and producers in their districts.

NRCS maintains the *Field Office Technical Guide* and is the primary scientific resource for the conservation of soil, water, air, and related plant and animal resources. These technical guides are localized so that they apply specifically to the geographic area for which they are prepared. Many of the conservation and engineering practice standards provide technical assistance to help producers adapt to the effects of climate change. Examples of these are conservation tillage and crop rotation systems, prescribed grazing to improve pastures, and manure management.

NRCS supports adoption of these practices and more through financial programs such as Environmental Quality Incentives Program (EQIP), Conservation Stewardship Program (CSP), and Agricultural Conservation Easement Program (ACEP).

Additionally, research information on climate effects on agricultural and forest production is becoming increasingly available through other USDA agencies, universities, and other natural resource agencies. This information is being made available through seminars, webinars, and online resources.

5.2. United States Forest Service

The Forest Service approach for adapting to climate change encompasses 1) climate-specific strategies across the agency and 2) direct program-by-program efforts to integrate climate-related policies and guidance where climate change is one of many drivers of change to be considered in sustaining forest and grassland ecosystems.

- Managing for northern and boreal tree species at the southern edge of their current range will become more challenging as their current habitat becomes less suitable (and moves northward) and reestablishment in a warmer climate becomes more difficult. In the Midwest and Northeast, balsam fir, spruce, and paper birch are particularly vulnerable tree species.
- Fish and wildlife species that rely on cold water streams and boreal forest habitats may be particularly vulnerable to climate change.
- Warmer temperatures and increases in tree mortality could increase the efforts required to prevent or contain wildfires.
- Many invasive species, insect pests, and pathogens could benefit from a longer growing season and milder winters, increasing the amount of effort to control them or remove dead and dying trees.
- Increases in heavy precipitation events could place additional stressors on infrastructure, such as roads and culverts, and require greater effort to prevent erosional losses during harvest.
- The large amount of private land and fine-scale fragmentation of forest landscapes will make it challenging to implement climate change adaptation.

The Forest Service's Eastern Region measures its climate change response through the Climate Change Performance Scorecard. Since 2011, each National Forest and Grassland has used a 10-point scorecard to report accomplishments and plans for improvement on ten questions in four dimensions: organizational capacity, engagement, adaptation, and mitigation. By 2015, each is expected to answer yes to at least seven of the scorecard questions, with at least one yes in each dimension. The goal is to create a balanced approach to climate change that includes managing forests and grasslands to adapt to changing conditions, mitigating climate change, building partnerships across boundaries, and preparing employees to understand and apply emerging science.

The Forest Service's Northern Institute of Applied Climate Science (NIACS) is a collaborative effort among the Forest Service, universities, and forest industry to provide information on managing forests for climate change adaptation, enhanced carbon sequestration, and sustainable production of bioenergy and materials. As a regional, multi-institutional entity, NIACS builds partnerships, facilitates research, and synthesizes information to bridge the gap between carbon and climate science research and the information and management needs of land owners and managers, policymakers, and members of the public. A major effort coordinated by NIACS is the Climate Change Response Framework, an integrated set of tools, partnerships, and actions to support climate smart conservation, and which provides a collaborative approach to incorporate climate change into forest management. The Framework covers six regional projects in the Midwest and Northeast: Central Appalachians, Central Hardwoods, Mid-Atlantic, New England, Northwoods, and Urban. Each regional project interweaves four components: science and management partnerships, vulnerability assessments, adaptation resources, and demonstration projects. More information is available at www.forestadaptation.org.

As part of the Forest Service's Research and Development arm, scientists at the Northern Research Station are deeply involved in research to understand the processes and extent of global climate change and their probable/possible effects on forest ecosystems. Covering the Northeast and North Central regions, the station is focused on answering questions such as: What processes in forest ecosystems are sensitive to physical and chemical changes in the atmosphere? How will future physical and chemical climate changes influence the structure, function, and productivity of forest and related ecosystems, and to what extent will forest ecosystems change in response to atmospheric changes? What are the implications for forest management and how must forest management activities be altered to sustain forest productivity, health, and diversity? More information is available at www.nrs.fs.fed.us/disturbance/climate_change/.

The Forest Service Northeastern Area, State and Private Forestry division serves private landowners through a number of programs. The Forest Stewardship Program (FSP) helps private forest landowners develop plans for the sustainable management of their forests. In addition, the Forest Legacy Program (FLP) and the Community Forest and Open Space Conservation Program (CFP) support the retention of private forests. The mission of the division's Forest Health Protection program is to protect and improve the health of America's rural, wildland, and urban forests. More than 250 specialists in forest entomology, forest pathology, invasive plants, pesticide use, survey and monitoring, fire suppression and control, technology development, and other forest health-related services provide expertise to forest land managers throughout the nation. Cooperative forestry programs assist forest landowners with programs that encourage conservation practices.

5.3. Farm Service Agency

With 8 State and 626 county offices throughout the Midwest, the Farm Service Agency is the face of USDA to producers who participate in the conservation and energy, commodity crop, disaster assistance, and farm loan programs it manages. Virtually all Farm Service Agency programs affect producers' ability to adapt to and even mitigate the effects of climate change:

- The Conservation Reserve Program (CRP), among the largest voluntary conservation programs in the world, provides incentives to producers to take marginal or vulnerable cropland out of production for 10–15 years to improve soil health, effectively eliminate erosion, enhance water quality, and create wildlife habitat. Under the Agricultural Act of 2014 (the 2014 Farm Bill), grassland can also be enrolled in and maintained under CRP.
- The Biomass Crop Assistance Program (BCAP) provides incentives to producers to establish, cultivate, and harvest eligible biomass for heat, power, bio-based products, research and advanced biofuels.
- The new Price Loss Coverage (PLC) and Agricultural Risk Coverage (ARC) programs, along with the Marketing Assistance Loan (MAL) and other existing programs, help to mitigate the price and yield risks that producers face, which maintains farm incomes and keeps farmers on the land.
- The Noninsured Crop Disaster Assistance (NAP), Livestock Forage Disaster (LFP), Livestock Indemnity (LIP), and other programs provide emergency assistance to producers when drought and other disasters affect agricultural production.
- The Direct and Guaranteed Loan Programs provide many farmers and ranchers the opportunity to obtain the credit they need to begin and continue their operations, particularly when obtaining commercial credit is difficult. Under 2014 Farm Bill, the ability to help beginning and socially disadvantaged producers has been enhanced.

The programs described above are all available to producers to help mitigate and/or adapt to the effects of climate change. The CRP and BCAP programs both provide an opportunity for producers to sequester carbon for overall climate change. Additionally, other programs could be developed to provide financial incentives to producers to capture and store carbon from the atmosphere.

Climate change has the potential to greatly increase demand for Farm Service Agency programs, which may increase costs to the Federal government.

Regional CRP priorities such as HELi (Highly Erodible Land initiative) work to take the most vulnerable land out of production. Currently, HELi does not have adequate acres assigned in the Midwest—Iowa, for example, currently does not have any acres available to producers. Climate change could increase demand for these types of targeted CRP priorities. There is also focus in the Midwest on CRP pollinator habitat due to the decline in pollinator populations. It is not clear how climate variability will affect pollinator populations.

5.4. Rural Development

Rural Development supports rural communities through loans, loan guarantees, and grants. For some Rural Development programs, the agency holds liens or other security interests in facilities and related infrastructure in areas that could be affected by hydrological changes and sea-level rises resulting from impacts such as inundation and erosion. Additionally, many climate change models predict greater frequency and severity of weather events such as tornados and hurricanes, which can damage utility facilities and infrastructure. Climate change therefore represents a risk to these agency assets and the communities they serve. Rural Development administers services through the Rural Housing Service, Rural Business-Cooperative Service, and Rural Utilities Service.

Rural Housing Service

The Rural Housing Service (RHS) administers programs that provide financial assistance (loans and grants) for quality housing and community facilities for rural residents within the region and throughout the Nation.

RHS will implement the following prevention measures in an effort to reduce the effects of climate change and become more resilient to adverse effects predicted to be incurred by flooding, storm surges, hurricanes, tropical storms, and other severe weather that could adversely affect structures funded through RHS programs:

1) RHS will continue to provide training to staff on proper siting of facilities/infrastructure for the life-of-structure (30 to 50 years in some cases) in locations where the effects of climate change will not adversely affect the facility or the surrounding environment.
2) RHS will also continue to consider the effects of sea level rise, other potential flooding, and severe weather effects into long-term planning.
3) RHS will continue to provide funding for the following programs, which have been designed to lessen the need for fossil fuels, promote renewable energy, and increase energy efficiency in an effort to reduce the effects of climate change:
    - Multi-family Housing Energy Efficiency Initiative
    - Multi-family Housing Portfolio Manager, Capital Needs Assessment/Utility Usage
    - Energy Independence and Security Act compliance (affects new construction of single family housing)
    - Climate Action Plan installation of 100-MW capacity onsite renewable energy Multi-Family Housing by 2020.

Rural Business-Cooperative Service

The Rural Business-Cooperative Service (RBS) administers programs that lessen the need for fossil fuels, promote biomass utilization, renewable energy, and increase energy efficiency within all of the Climate Hub Regions. The Rural Energy for America Program lowers the demand on base plants by investing in energy efficiency and renewable energy. Lower base load demand conserves water and helps to reduce greenhouse gasses that contribute to climate change. Renewable energy investments can provide extra resiliency by distributing energy resources.

RBS is investing in alternative fuels, renewable chemicals, biogas, wastewater conservation, and harvesting combustible lumber from forest thinning for advances biofuel.

Rural Utilities Service

The Rural Utilities Service (RUS) administers programs that provide clean and safe drinking water and sanitary water facilities, broadband, telecommunications, and electric power generation and transmission/distribution within all of the Climate Hub regions.

The following programs or measures will help address resiliency and lessen the impact of droughts, floods and other natural disasters and increase energy efficiency:

- **National Rural Water Association (NRWA) Grant—**A**n** energy efficiency program designed to promote energy efficient practices in small water and wastewater systems. Covers energy assessments, recommends energy-efficient practices and technologies, and provides support in achieving recommendations.
- **Memorandum of Agreement between the Unites States Environmental Protection Agency and the United States Department of Agriculture – Rural Development Rural Utilities Service – Promoting Sustainable Rural Water and Wastewater Systems.** The goals of this MoA are to increase the sustainability of drinking water and wastewater systems nationwide to ensure the protection of public health, water quality, and sustainable communities, to ensure that rural systems have a strong foundation to address 21st century challenges, and assist rural

dwellers to implement innovative strategies and tools to allow them to achieve short- and long-term sustainability in management and operations.

- **Emergency Community Water Assistance Grants (ECWAG)—**Assist rural communities that have experienced a significant decline in quantity or quality of drinking water due to an emergency, or in which such decline is considered imminent, to obtain or maintain adequate quantities of water that meets the standards set by the Safe Drinking Water Act. Emergencies are considered to include incidents such as drought, earthquake, flood, tornado, hurricane, disease outbreak, or chemical spill, leakage, seepage.
- **Electric Program—Energy Efficiency and Conservation Loan Program (EECLP)** The program is "for the purpose of assisting electric borrowers to implement demand side management, energy efficiency and conservation programs, and on-grid and off-grid renewable energy systems." Goals include 1) increasing energy efficiency at the end user level; (2) modifying electric load such that there is a reduction in overall system demand; 3) effecting a more efficient use of existing electric distribution, transmission, and generation facilities; 4) attracting new businesses and creating jobs in rural communities by investing in energy efficiency; and 5) encouraging the use of renewable energy fuels for either demand side management or the reduction of conventional fossil fuel use within the service territory.
- **Principles, Requirements, and Guidelines (PR&G)**—Application of the revised PR&G in the near future to RUS water and wastewater program planning will include consideration of, among other factors, effects on and impacts of climate change.
- **Rural Development Climate Change Adaptation Planning Document—**This document, from June 2012, would apply to all three Rural Development agencies. The plan was prepared to in support of Departmental efforts to respond to EO 13514 (Federal Leadership in Environmental, Energy, and Economic Performance) as well as DR 1070-001. The planning document discusses increased efforts at risk assessment, and identifies five specific actions related to climate change planning and adaptation.

Engineering Design Standards and Approved Materials—The RUS electric program envisions greater incorporation of climate change-related impacts as it revises its standards and materials for RUS-financed infrastructure. Already, some borrowers (e.g., in coastal areas and the Great Plains) have received agency approval for 'hardened' electric poles and lines.

5.5. Risk Management Agency

The Risk Management Agency (RMA) provides a variety of actuarially sound crop and livestock related insurance products to help farmers and ranchers manage the risks related to agricultural production. Coverage is provided against agricultural production losses due to unavoidable natural perils such as drought, excessive moisture, hail, wind, hurricane, tornado, lightning, insects, etc. In 2013, the Federal crop insurance program provided U.S. agricultural producers with more than $123 billion in protection for agricultural commodities. These policies provide financial stability for agricultural producers and rural communities, and are frequently required by lenders.

Because climate change is an ongoing process, the risk environment for agricultural production will also be undergoing constant change (e.g., some perils may occur with greater or lesser frequency and/or severity). Climate change will also promote adaptive responses by producers such as adoption of new production practices, planting of new varieties, or shifting the locations of farming operations.

RMA continually strives to improve the effectiveness of its programs by refining insurance offers to recognize changes in production practices; and where appropriate, adjusting program parameters (e.g., premium rates, planting dates, etc.) within each county to recognize structural changes to the risks of growing the crop in those areas. In that regard, RMA monitors climate change research and, to the extent that climate changes emerge over time, updates these program parameters to reflect such adaptation or other changes. RMA also updates loss adjustment standards, underwriting standards, and other insurance program materials to ensure that they are appropriate for prevailing production technologies.

The ability to consistently produce high crop yields may be most affected by climate variability. However, the crop insurance program is inherently responsive and self-adjusting to the potential for climate variability. As the climate does become more variable, ample indemnification will be made to insureds as losses occur. If a higher degree of yield variability becomes the new norm, existing low rates might eventually approach those typically found in the southern United States. If the climate does not become more variable, existing low rates may be relatively stable into the near and intermediate future.

In Iowa, Minnesota, and Wisconsin, weather and climate influence which crops and varieties are planted to reach maturity before a killing frost. This choice influences yield potential. Highly variable weather such as torrential rain, unusually hot/dry weather, early fall or late spring frost, can have a large influence on crop yields and crop insurance indemnities.

As climate zones migrate toward the poles, RMA will be asked to provide new county crop insurance programs in more northerly areas while some programs may need to be eliminated in more southerly counties. For example, northern Michigan may potentially increase its planted corn acreage, whereas commercially grown green peas may no longer be a viable crop in Illinois[17]. RMA's 10 regional offices are in an ideal position to identify and analyze emerging crop production trends and respond accordingly to meet producers' needs and mitigate unwanted risk exposure to taxpayers at large as everything changes.[18]

5.6. Animal and Plant Health Inspection Service

The Animal and Plant Health Inspection Service (APHIS) is responsible for protecting and promoting U.S. agricultural and forest health, regulating certain genetically engineered organisms, enforcing the Animal Welfare Act, and carrying out wildlife damage management activities. APHIS is constantly working to defend U.S. plant and animal resources from agricultural and forest pests and diseases. Once a pest or disease is detected, APHIS works in partnership with affected regions to manage and eradicate the outbreak. In its new Strategic Plan for 2015, APHIS lists seven goals:

1. Prevent the entry and spread of agricultural pests and diseases.
2. Ensure the humane treatment and care of vulnerable animals.
3. Protect forests, urban landscapes, rangelands and other natural resources, as well as private working lands from harmful pests and diseases.
4. Ensure the safety, purity, and effectiveness of veterinary biologics and protect plant health by optimizing our oversight of genetically engineered (GE) organisms.
5. Ensure the safe trade of agricultural products, creating export opportunities for U.S. producers.
6. Protect the health of U.S. agricultural resources, including addressing zoonotic disease issues and incidences, by implementing surveillance, preparedness and response, and control programs.
7. Create an APHIS for the 21st Century that is high-performing, efficient, adaptable, and embraces civil rights.

[17] Press Release on Crop Insurance and Prevented Planting in Iowa, Minnesota and Wisconsin: http://www.rma.usda.gov/fields/mn_rso/2014/cipp.pdf

[18] Press Release on Final Planting Dates: http://www.rma.usda.gov/fields/mn_rso/2014/springcrops.pdf and RO List of offices: http://www.rma.usda.gov/aboutrma/fields/rsos.html

APHIS works to achieve these goals through the actions of several mission area program staffs and support units. The text below discusses the APHIS programs and their respective responsibilities, as well as expected vulnerabilities due to climate and measures in place to minimize risks from these vulnerabilities. As an agency with nationwide regulatory concerns, APHIS programs are typically national in scope and application.

Animal Care (AC). Animal Care's mission is to protect animal welfare by enforcing the Animal Welfare Act and the Horse Protection Act. AC protects animals and their owners by supporting FEMA-led emergency pet evacuations necessitated by disasters such as hurricanes.

APHIS Animal Care's nonstatutory mission to support FEMA for the well-being of household pets during disasters is vulnerable to climate change. More storms and more severe storms are predicted as the climate warms and consequently activities in this mission area may increase. Animal Care's statutory mission to ensure the welfare of animals used in commerce, exhibition, and research may change as well. For example, the availability of water may change the economics of these industries resulting in a decrease in activities in certain parts of the country.

Animal Care sponsors and participates in planning and exercise activities together with FEMA, Emergency Support Function (ESF) #11, States, nongovernmental organizations, and other response partners to strengthen the nation's capacity to respond to natural disasters. These efforts should help reduce the impact of disaster and help people recover more quickly.

Biotechnology Regulatory Services (BRS) - To protect plant health, Biotechnology Regulatory Services (BRS) implements the APHIS regulations for genetically engineered (GE) organisms that may pose a risk to plant health. APHIS coordinates these responsibilities along with the other designated Federal agencies as part of the Federal Coordinated Framework for the Regulation of Biotechnology.

None of BRS' actions are directly "vulnerable" to climate change. However, because climate change would likely affect the distribution of some agricultural crops and other plants, BRS actions related to conduct of inspections of field trials for GE plants could be affected. Therefore, if growing areas for regulated GE plants shift, BRS would need to conduct inspections in those new locations.

BRS has in place a flexible staffing plan and practice—not all of its staff are centrally located; they are set up to provide mobile inspection service to wherever GE crops are growing in field trials. Additionally, BRS receives reports each year from those holding permits for conducting field trials. BRS uses this information to plan inspections throughout the life cycle of the field trials.

Plant Protection and Quarantine (PPQ) - PPQ is responsible for safeguarding and promoting U.S. agricultural health. PPQ is constantly working to defend U.S. plant and forest resources from agricultural pests and diseases. Once a quarantine plant pest or disease (one not previously found in the U.S. or if found, is under official control) is detected, PPQ works in partnership with affected regions to manage and eradicate the outbreak. PPQ has three strategic goals:

1. Strengthen PPQ's pest exclusion system,
2. Optimize PPQ's domestic pest management and eradication programs, and
3. Increase the safety of agricultural trade to expand economic opportunities in the global marketplace.

In the face of an increasingly variable climate and more erratic weather conditions, PPQ will continue to play a central role in responding to risk and managing vulnerabilities. In this capacity, PPQ operates primarily on a national level with regional emphasis as needed to address and divert pest incursions.

PPQ is tasked with assessing risk and predicting where an invasive plant pest may be introduced, establish, and spread; these assessments are often based on climatic conditions and host availability from a national perspective. As climate changes, host distribution and landscape conditions deviate from what is considered normal. PPQ assessments are based on available data that often reflect past conditions. As climate changes, the relevance of these data may lessen our ability to accurately predict and understand risk.

Some of the challenges in predicting future risk under climate change require a shift from analyzing mean responses (e.g.. a temperature increase of 2 to 3 degrees on average), and instead focus on trying to understand how pest invasiveness and establishment potential change with increased weather variability and increased extreme events. For example, several years of warmer than normal weather can allow the development of invading pest populations and their spread to new areas. Once arriving in new areas, if such pest populations can secure warmer microclimates to survive the winter, they can become more prevalent earlier the following season. Anticipating global trade shifts in response to climate change is another challenge, as is the subsequent risk of new crop pests and diseases associated with them.

PPQ Science and Technology is partnering with other agencies, universities, and the climate hubs to increase our capacity to obtain, analyze, and implement data models that inform climate change-specific policies and pest programs. We have increased our capacity to perform pest risk modeling at regional, national and global levels with new platforms. These platforms are designed to project climate change scenarios onto the landscape to model geographic shifts in climatic suitability and host availability. We are also applying phenological models that can be used to analyze how climate change and increased weather variability might affect temporal sequencing of pest development and subsequent population response.

Veterinary Services (VS) - VS is responsible for regulating the importation and interstate movement of animals and their products in order to prevent the introduction and spread of foreign animal diseases of livestock. If a foreign animal disease were to be detected in the United States, VS is responsible for responding to the outbreak, in coordination with States, tribes, and producers. VS also regulates the licensing of veterinary biologics, such as vaccines.

VS is involved with reviewing and reporting on the distribution and spread of vectors that can transmit a variety of animal diseases. Possible climate-mediated changes in dispersal and redistribution of arthropod vectors (e.g., midges, mosquitoes, ticks) and their ability to transmit economically important pathogens [e.g., bluetongue virus (BTV), epizootic hemorrhagic disease virus (EHDV), and Japanese encephalitis virus (JEV)] from existing areas where the pathogen is established to new locations, could result in significant increases in morbidity and mortality to livestock, wildlife, and people, along with a reduced ability to market animals from affected areas.

VS currently does passive and active surveillance for diseases spread by vectors including cattle fever (babesiosis), EHDV, vesicular stomatitis virus and BTV, and monitors reports and studies of other vector-borne diseases. The regional prevalence and distribution of vectors and subsequent infections provides an opportunity to characterize environmental relationships within a given region to determine risk factors for infection related to specific climatic conditions associated with disease outbreaks. Using predictive climate models to identify environmental risk factors could help guide surveillance and disease prevention efforts if the geographic ranges of vectors and pathogens expand as expected. Potential research activities (work not currently underway) could include:

- Identifying environmental risk factors associated with the occurrence of BTV, EHDV, cattle fever and other pathogens in the United States at a regional scale, using climate and land cover models to characterize present environmental conditions in endemic areas.
- Estimating potential changes to infection risk of BTV, EHDV, cattle fever and other pathogens to livestock (sheep and cattle) and wildlife (white-tailed deer, pronghorn) based on climate change scenarios applied to the ecology of geographic areas currently supporting vector transmission of these pathogens.
- Using climate models and scenario analyses to identify new geographic areas likely to undergo environmental changes leading to an increased risk of infection with selected pathogens.
- Estimating economic impacts of potential vector and pathogen range expansion to livestock and wildlife industries.

Climate change can affect vector and pathogen distributions throughout the United States, bringing collaboration opportunities between VS and all of the USDA Climate Change Hubs.

Policy and Program Development (PPD) - PPD performs economic, environmental and other analyses to support the actions of the APHIS programs.

PPD analyses would be more robust over time if they were better able to incorporate economic and environmental impacts of climate change to relevant agricultural systems and ecosystems. Validated forecasts for how a changing climate is likely to impact the distribution of production areas for various commodities, as well as anticipated needs for commodity movements at an international and domestic scale, can inform our economic analyses. This information, along with information on pollinators' water and other resources; as well as effects on low-income, minority, and Tribal communities, will better inform our environmental analyses.

PPD is incorporating climate change into many of its environmental compliance [e.g., National Environmental Policy Act (NEPA)] documents and is leading an agency-wide effort to develop guidance for addressing climate change in our NEPA documents.

Wildlife Services (WS) - The mission of APHIS Wildlife Services (WS) is to provide Federal leadership and expertise to resolve wildlife conflicts to allow people and wildlife to coexist. WS conducts program delivery, research, and other activities through its regional and State offices, the National Wildlife Research Center (NWRC) and its field stations, as well as through its national programs.

As climate changes, so may the breeding and wintering ranges of birds, which might affect aviation safety. Airports and military installations should be prepared to address new challenges associated with changes in bird ranges. Also, species' migration strategies may change. As an example, we have developed migration models for osprey in relation to military aircraft movements. These very well could become outdated as climate and therefore migration strategies change.

Proper habitat management is crucial to successful management of wildlife hazards to aviation. Distribution of plant species that grow on airports and military installations may change in the future. Thus, habitat management strategies may also need to adapt to a changing climate.

WS NWRC is gathering data on species and habitat distribution, so it should be able to detect changes in species ranges, migration/movement patterns, and therefore adjust its habitat management strategies.

WS NWRC is researching alternative land covers that could be used at airports and military installations in the Midwest and across the United States; staff members are determining which habitat types could be viable options in new areas as conditions change.

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