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MIchigan Climate Assessment 2019: Considering Michigan's Future in a Changing Climate

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Michigan Climate Assessment 2019

Considering Michigan's Future in a Changing Climate

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Preface

The Michigan Climate Assessment is a document meant for policy makers to inform them on the state of climate change in Michigan. Global climate change is often the focus of the discussion on climate change, but people often refer to the weather, climate, and impacts locally. The U.S. government publishes a National Climate Assessment, the most recent of which was published in 2018 (https://nca2018.globalchange.gov/). However, this focuses on global climate change and impacts on seven regions within the continental U.S., Alaska, Hawaii, and U.S. territories. State climate assessments are an effort to bring climate change to a local level. At the time of writing only California and Vermont had created state climate assessments. Michigan climate assessment follows the structure of Vermont's climate assessment.

The Michigan climate assessment is edited by two Eastern Michigan University (EMU) professors, Drs. Thomas Kovacs and Kimberly Barrett. Drs. Kovacs and Barrett led a semester-long course, ENVI 305 Topics in Environmental Science and Society, which is a required course within the Environmental Science and Society (ENVI) program and satisfies the EMU general education intensive writing requirement. The chapter authors are teams of students charged with choosing a topic of one of Michigan's vulnerable sectors to climate change. For each sector, they summarized the important physical, social, economic, and policy impacts and their relationship with the expected change in Michigan's climate. The chapters conclude with recommended adaptations, opportunities, and resiliencies. Prior to these chapters is a summary of Michigan's changing climate.

Chapter 1 Michigan's Changing Climate

Thomas Kovacs

Global and Michigan Climate Change

This chapter is a summary of how Michigan's climate has changed over the past nearly 65 years and how it is expected to change over the 21st century. Estimates of Michigan's future climate change are based on a statistical downscale of 16 different global climate models (GCMs) (Hayhoe, 2013). GCM output has resolution that is too coarse to understand climate change at the state level. For example, for the state of Michigan the GCM output would average over both land and the Great Lakes providing a level of change that is not representative of changes that will be observed over land. Statistical downscaling techniques incorporate data from recent climate change and their correlation with GCM output to provide a resolution that more closely approximates the high-resolution observational climate data. Projections for the Great Lakes states are available from the Great Lakes Integrated Sciences and Assessments (GLISA) Great Lakes regional change maps (GLISA, 2020).

Estimates of change already experienced over the past nearly 65 years are based on data from the National Climate Data Center in cooperation with the Great Lakes Integrated Sciences and Assessments (GLISA) in partnership with the office of the Michigan State Climatologist (GLISA 2019). Only climate stations that had data between the years of 1951-2017 were chosen. Those stations were then clustered into four different regions with each region represented by 4-6 surface climate stations.

The combination of climate data and statistical downscaled climate projections provides a picture of the climate change that Michigan has already experienced over the past 65 years with the projected changes expected over the next 55 years. The changes already experienced provides a reference in the discussion of each vulnerability sector discussed in each of the remaining chapters. The future projections provides a reference for the severity of the changes expected over the next 55 years, which spans the lifetime of many of Michigan's current young residents.

Global Context of Michigan's Changing Climate

Climate change in Michigan occurs in an environment of global climate change. These global climate changes will also affect Michigan because ecosystems, recreation, and tourism shift into Michigan, and water, agriculture, and energy demands change. People may also immigrate to Michigan from warmer climates that become uncomfortable or impossible to live and work because of high temperatures and flooding that frequently inundates coastal land.

Climate change occurs when an area, locality, region, or the entire globe experiences a change in the long-term means (defined as 30 years by the World Meteorological Organization) of any weather parameter. Temperature is the weather parameter most discussed and its increase over the past 150 years is the definition of global warming. The burning of fossil fuels accounts for a large majority of the global warming the Earth has experienced (IPCC, 2014). The burning of fossil fuels increases the concentrations of carbon dioxide and methane in the atmosphere (Figure 1-1). Carbon dioxide and methane are greenhouse gases in that they absorb the Earth's emission while not absorbing solar radiation leading to an increase in the amount of energy absorbed at the surface. As these greenhouse gases increase in concentration in the atmosphere the mean global temperature increases (i.e. global warming).

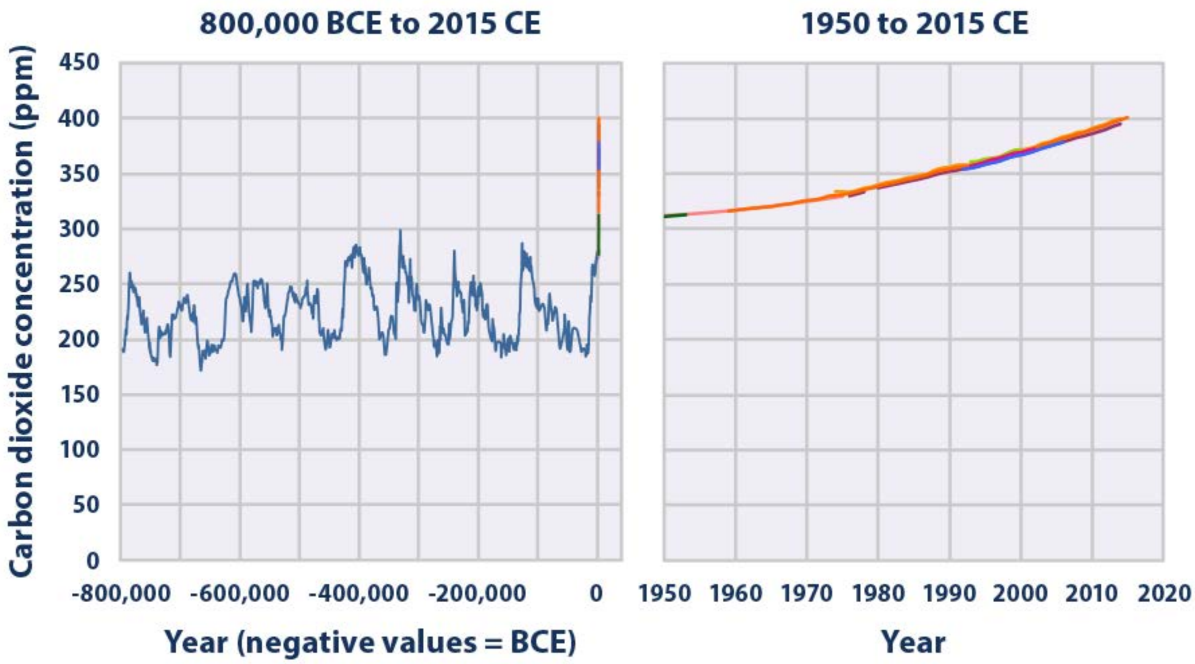

Figure 1-1 Carbon dioxide concentration from 800,00 BCE to 2015 CE from ice core data and from 1950 to 2015 CE from measurements at Mauna Loa. From EPA (2016)

Surface and satellite-based sensors have both independently observed global warming. Surface data shows that the global mean temperature has increased by about 1 ^{o}C over the past 100 years (Figure 1-2). Global warming is generally larger for higher latitudes due to decreasing snow cover, which would normally reflect sunlight back to space. The reduced snow cover because of warming temperatures allows more sunlight to be absorbed. Largely because of this, Michigan’s mean temperature has increased slightly faster especially in the Upper Peninsula.

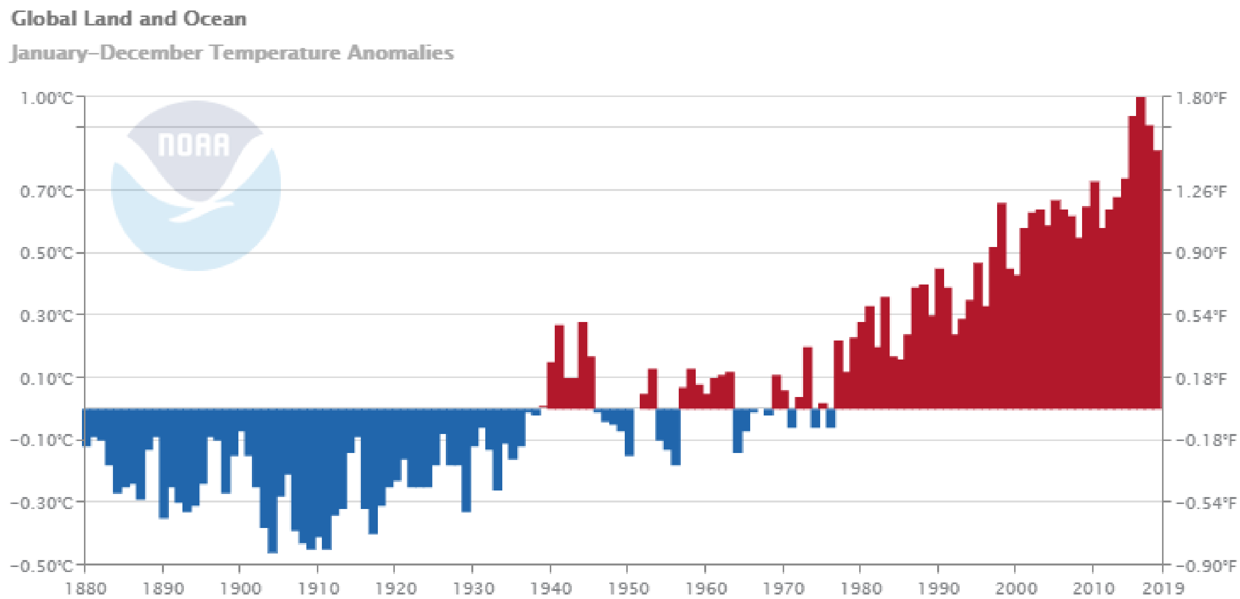

Figure 1-2 Global mean annual temperatures from 1880-2018 plotted as an anomaly to the 1901-2000 mean. From NOAA National Centers for Environmental Information (2019)

Increasing global temperatures has also melted glaciers and caused the ocean water to expand leading to an increase the ocean's mean sea level (Figure 1-3). Increased mean sea level causes coastal flooding and land inundation that can make living and working impossible. Displaced businesses, increased insurance losses, and lost property values can negatively affect the economy for the entire country including Michigan. Although Michigan would not be directly affected by sea level rise, the increase in disaster costs affects taxpayer money and insurance costs. Furthermore, impacted businesses and energy production can cause inflation or loss of services.

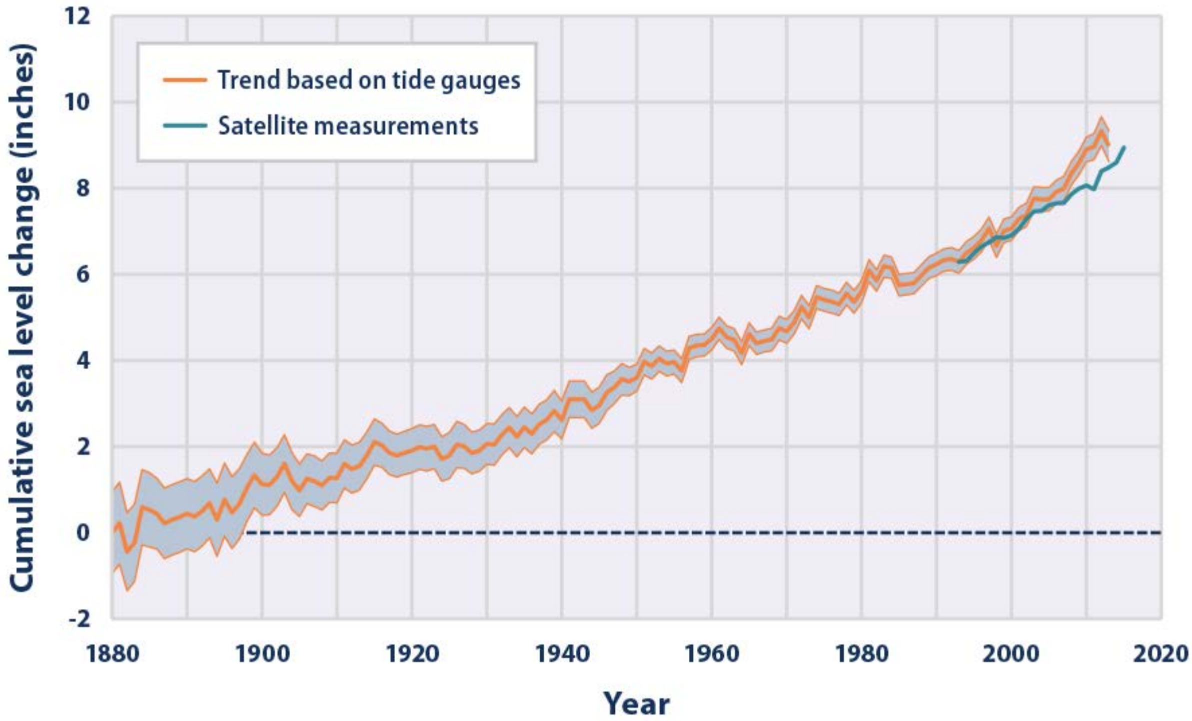

Figure 1-3 Cumulative sea level increase since 1880 observed by tidal gauges (yellow) and satellite measurements (blue). The gray envelope around the tidal gauge data are uncertainties (estimates of standard error of the mean) in the measurement. From EPA (2016b)

Past and Future Change in Michigan Temperature

As previously mentioned, the increase in mean temperatures has been accelerated in Michigan because of loss of snow cover. However, because the state is surrounded by water, the increase has been somewhat lower than states farther west at the same latitude. Figure 1-4 shows the increase in mean temperatures for the past 65 years. The temperature increase was largest in the Upper Peninsula (1.6 ^{o}F) and lowest in the southwest part of the Lower Peninsula (0.7 ^{o}F). These patterns are expected to continue into the next 55 years, but with an accelerating nearly fourfold increase. The Upper Peninsula is expected to increase up to 6 ^{o}F and the southwest Lower Peninsula is expected to increase up to 5 ^{o}F. Not shown in Figure 1-4 is the seasonal changes in the past 65 years, which are largest in the winter and spring except in the Upper Peninsula where it was fall and winter.

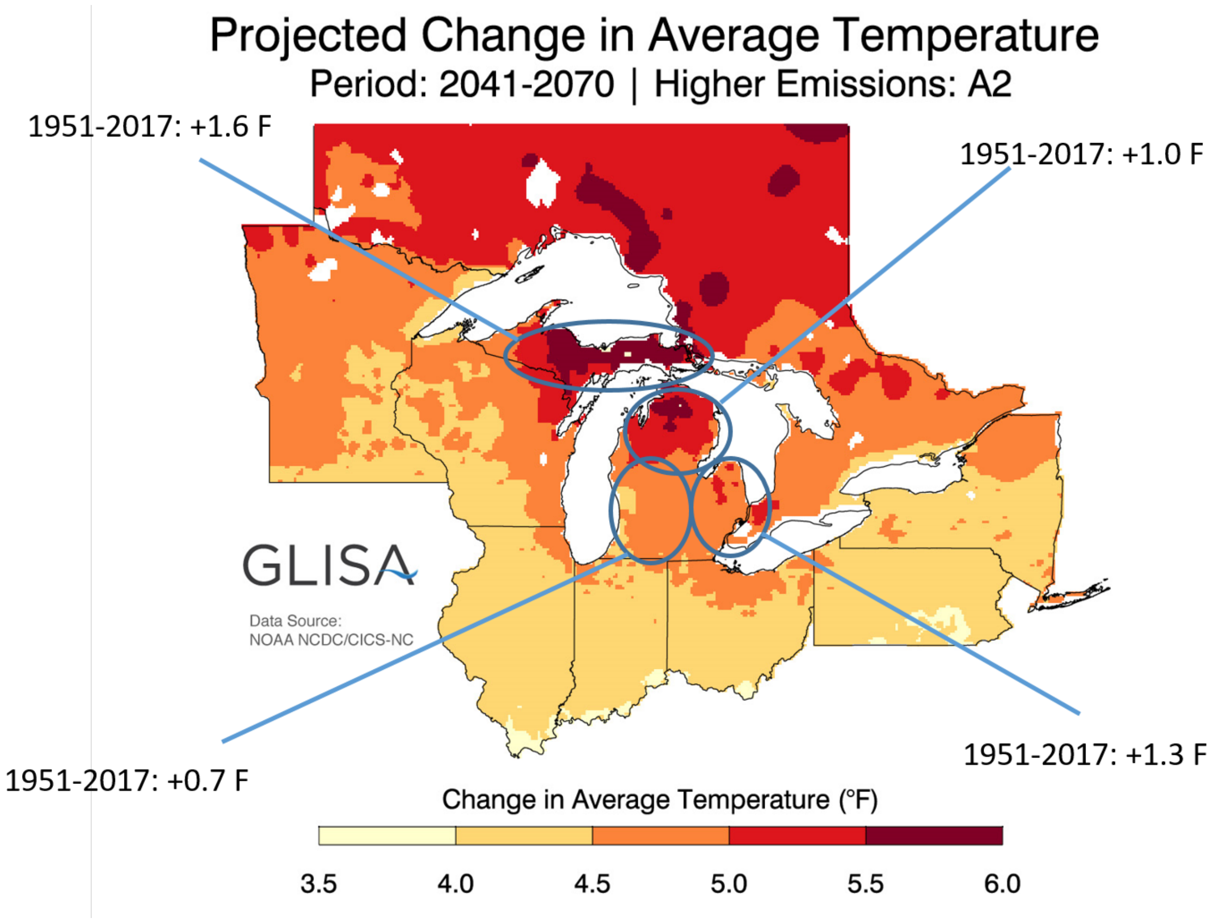

Figure 1-4 Projected change in average temperature expected for the period 2041-2070. The scale at the bottom (GLISA 2020) gives magnitude of the change. Also provided are the calculated changes for the same statistic over the period 1951-2017 for the four regions defined in the text within Michigan. From GLISA (2019)

Two of the largest impacts of temperature to Michigan is excessive heat and the effect on the growing season. Figure 1-5 shows the past and projected number of days over 90 ^{o}F. Over the past 65 years, the number of days has decreased by as little as 2 days in the Upper Peninsula and as much as nearly 6 days in the southwest part of the Lower Peninsula. This pattern is inconsistent with the upward trend of the mean temperatures. Partially explaining this pattern is that summer temperature increases were the lowest and low temperatures increased significantly more than high temperatures. Along with rising lake temperatures these are all consistent with a more humid climate, which reduces the seasonal and daily temperature range. Therefore, it is possible that much of the added energy in Michigan's climate system raises humidity more than summer and daytime temperatures.

Future projections are somewhat opposite of what has been experienced over the past 65 years. In the period 2041-2070 the number of 90 ^{o}F days are expected to increase the most in the southern lower peninsula (+ 50 days per year) and least in the upper peninsula (+ 30 days per year). This pattern is likely because a larger part of the high temperature distribution is already close to 90 ^{o}F in the southern Lower Peninsula.

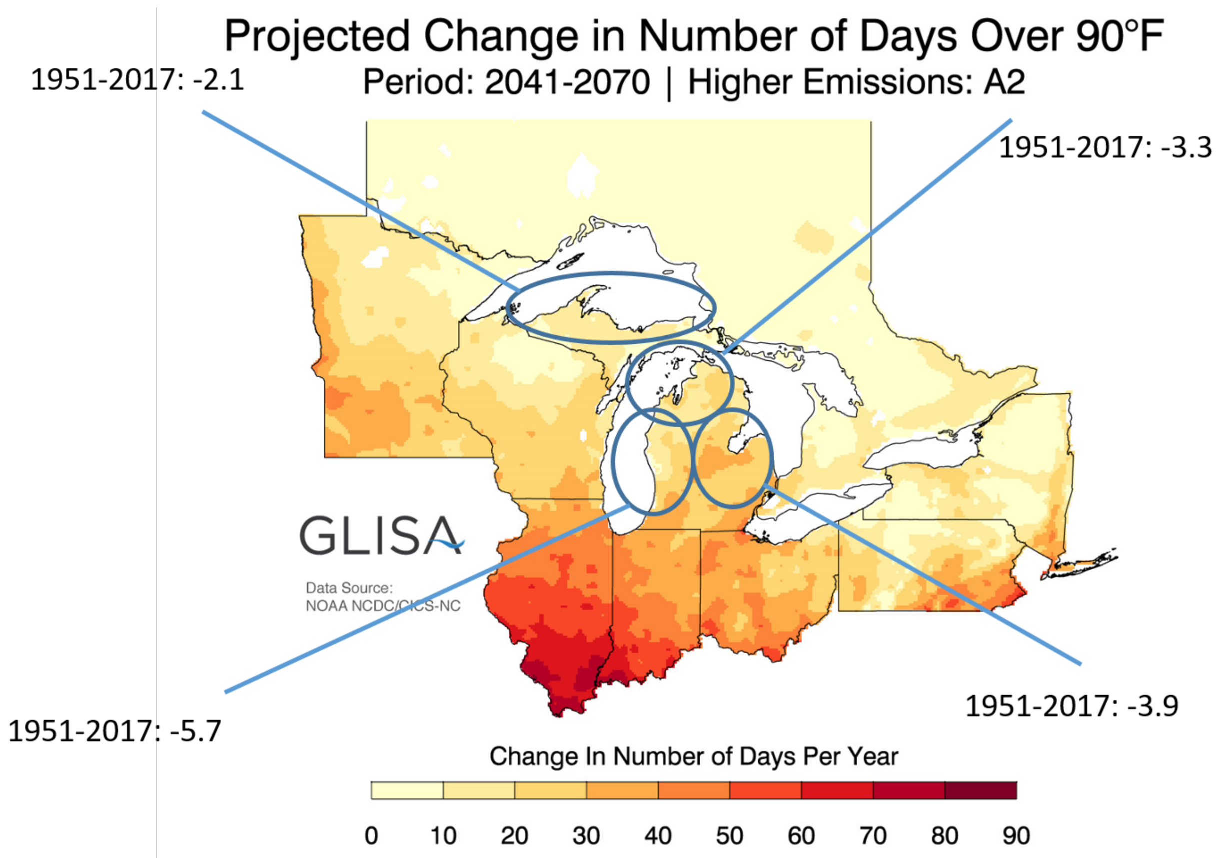

Figure 1-5 Projected change in the number of days over 90^{o} F expected for the period 2041-2070. The scale at the bottom (GLISA 2020) gives magnitude of the change. Also provided are the calculated changes for the same statistic over the period 1951-2017 for the four regions defined in the text within Michigan. From GLISA (2019)

The growing season is more impacted by temperatures near the freezing level. Figure 1-6 shows the past and projected number of days under 32 ^{o}F. Over the past 65 years, the number of days has decreased by as little as less than a day in the southwest Lower Peninsula and as much as nearly 17 days in the southeast part of the Lower Peninsula. The reason for this pattern is uncertain. The pattern for the future 55 years shows a consistently large increase in all regions ranging from 25 to 35 fewer days of temperatures under 32 ^{o}F. This pattern is observed in the frost-free seasonal length shown in Figure 1-7. The frost-free season starts on the last frost of the calendar year and ends with the first frost in the fall. Frost-free season length is impacted by the number of nights below 32 ^{o}F, but is also impacted by the variance in nighttime temperatures. With less variance, which one would expect with more humidity, the frost-free season length has been and is expected to be much longer. The frost-free season has increased nearly 20 days in all regions except the southwestern Lower Peninsula. Over the next 85 years, an increase by as much as 40-70 days is expected through nearly all of Michigan especially the northern Lower Peninsula and much of the eastern Upper Peninsula.

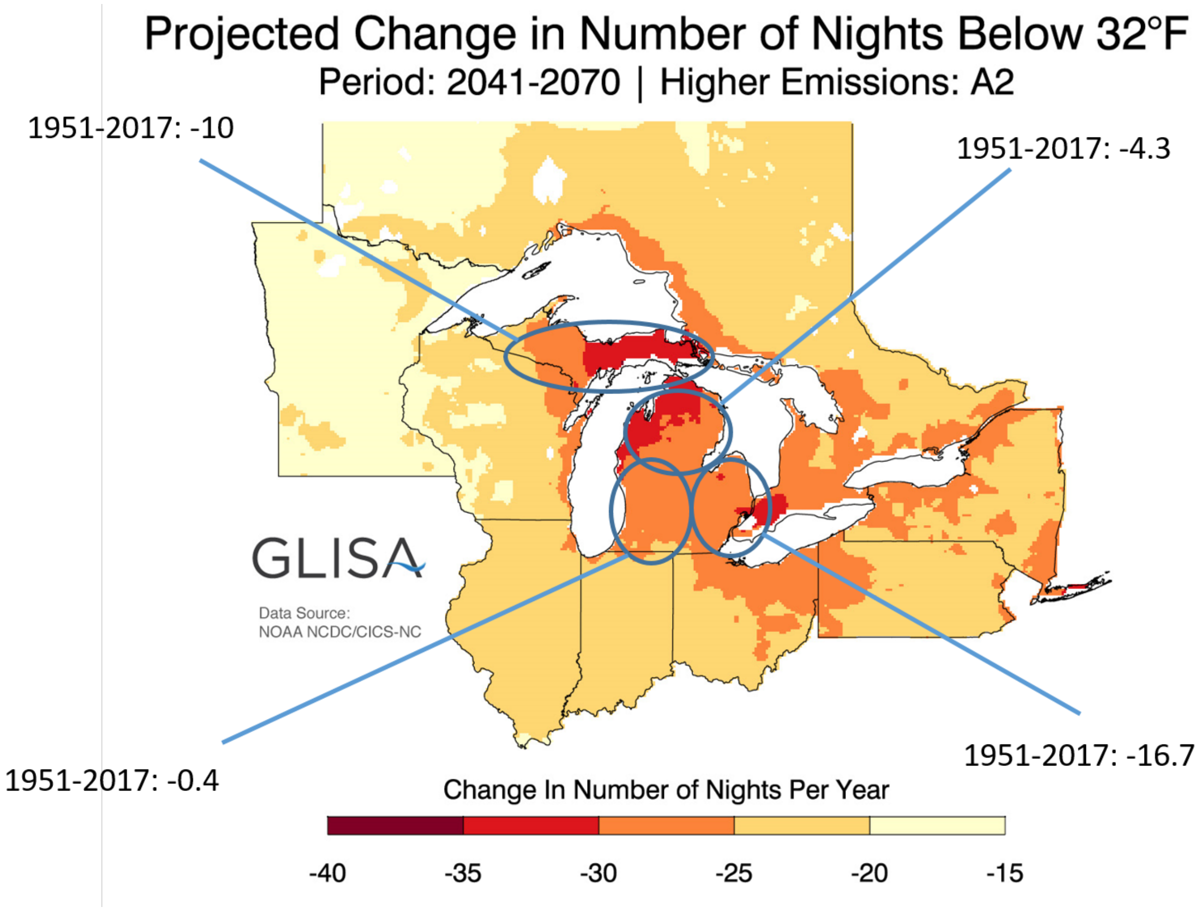

Figure 1-6 Projected change in the number of nights below 32° F expected for the period 2041-2070. The scale at the bottom (GLISA 2020) gives magnitude of the change. Also provided are the calculated changes for the same statistic over the period 1951-2017 for the four regions defined in the text within Michigan. From GLISA (2019)

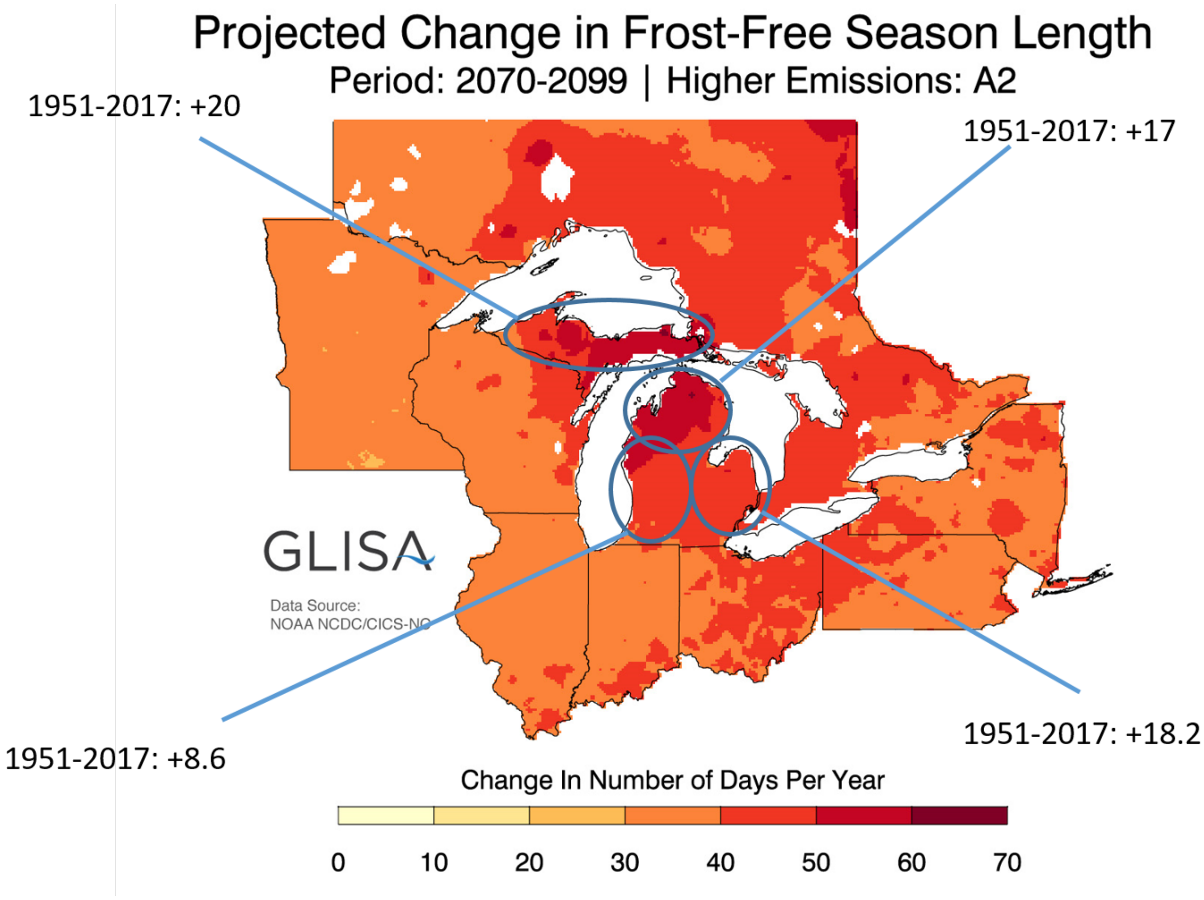

Figure 1-7 Projected change in frost-free season length expected for the period 2041-2070. The scale at the bottom (GLISA 2020) gives magnitude of the change. Also provided are the calculated changes for the same statistic over the period 1951-2017 for the four regions defined in the text within Michigan. From GLISA (2019)

Past and Future Change in Precipitation

Total annual precipitation has increased by as little as 1.5 inches in the Upper Peninsula to as much as 6.2 inches in the southern Lower Peninsula (Figure 1-8). That trend is expected to continue into the future at about the same rate of increase. Not shown in Figure 1-8 is that the largest increases in precipitation has occurred in the transitional seasons of fall and spring. The importance of increases in these seasons is in flooding and the increased development of mold and fungus and related plant diseases. With less sunlight in these seasons, the extra precipitation cannot dry, increasing soil and plant moisture and runoff.

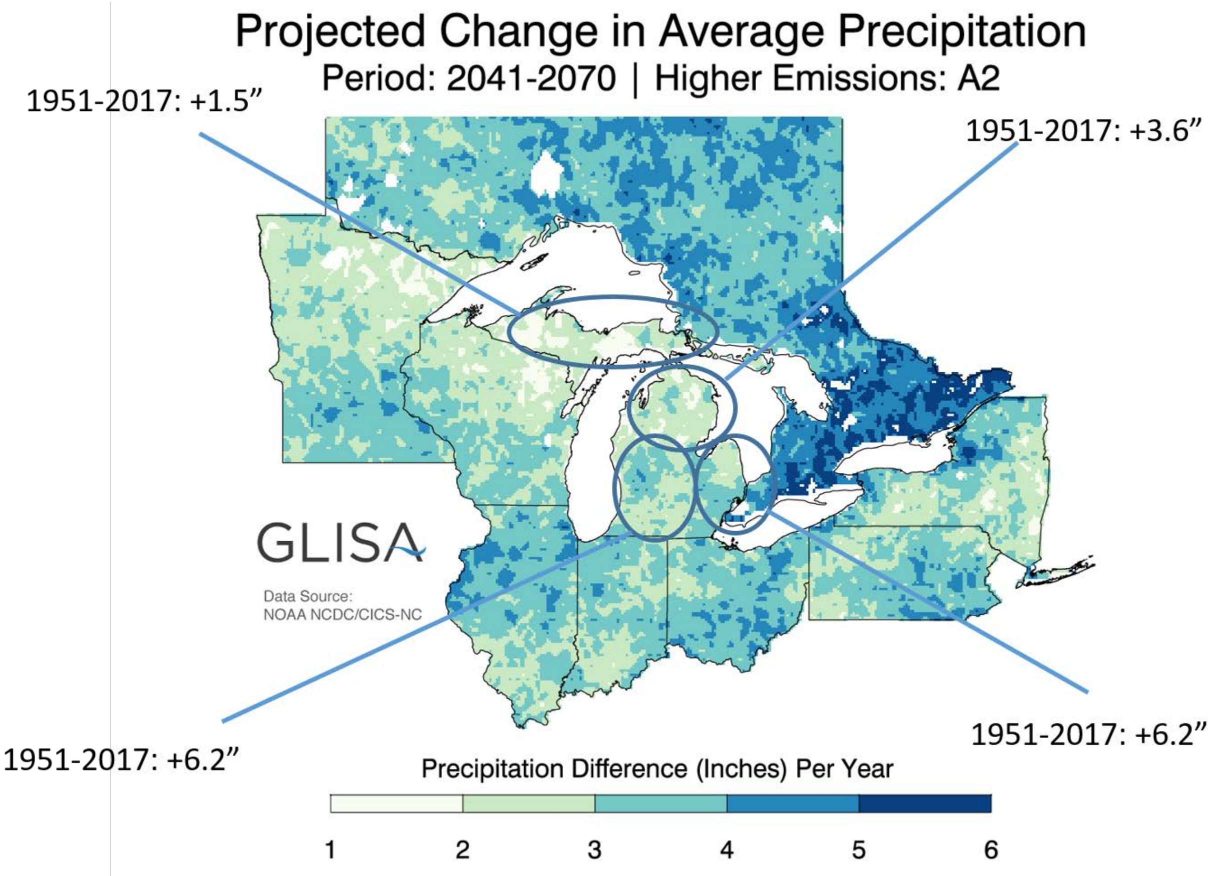

Figure 1-8 Projected change in the average precipitation expected for the period 2041-2070. The scale at the bottom (GLISA 2020) gives magnitude of the change. Also provided are the calculated changes for the same statistic over the period 1951-2017 for the four regions defined in the text within Michigan. From GLISA (2019)

Also related to flooding is the number of heavy precipitation days. Heavy precipitation days are those days experiencing a precipitation amount greater than the top 2% of events for a particular region. The past changes were small with a slight, but non-significant increase and are not shown. Future projections are for an increase in heavy precipitation events by as much as two such events per year mostly in the eastern parts of the lower and upper peninsulas (Figure 1-9).

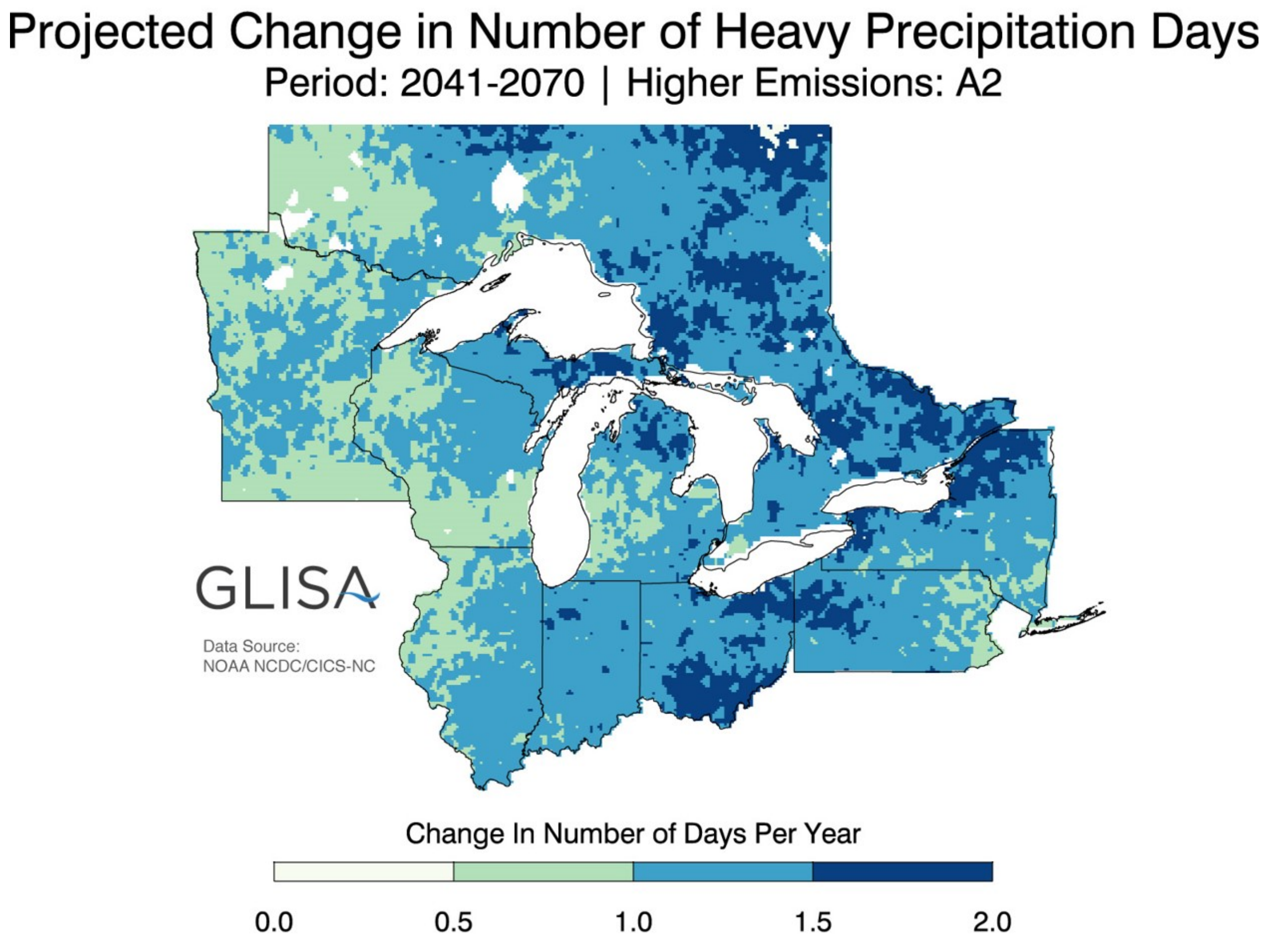

Figure 1-9 Projected change in the number of heavy precipitation days expected for the period 2041-2070. The scale at the bottom (GLISA 2020) gives magnitude of the change. Also provided are the calculated changes for the same statistic over the period 1951-2017 for the four regions defined in the text within Michigan. From GLISA (2019)

It may seem counterintuitive for an area to have more floods and droughts, but Michigan is expected to have both. Even though Michigan is expected to have more precipitation, that precipitation is expected to fall in fewer rain events with more time between precipitation events. Figure 1-10 shows that the projected number of consecutive dry days are expected to increase by up to two days in the next 65 years.

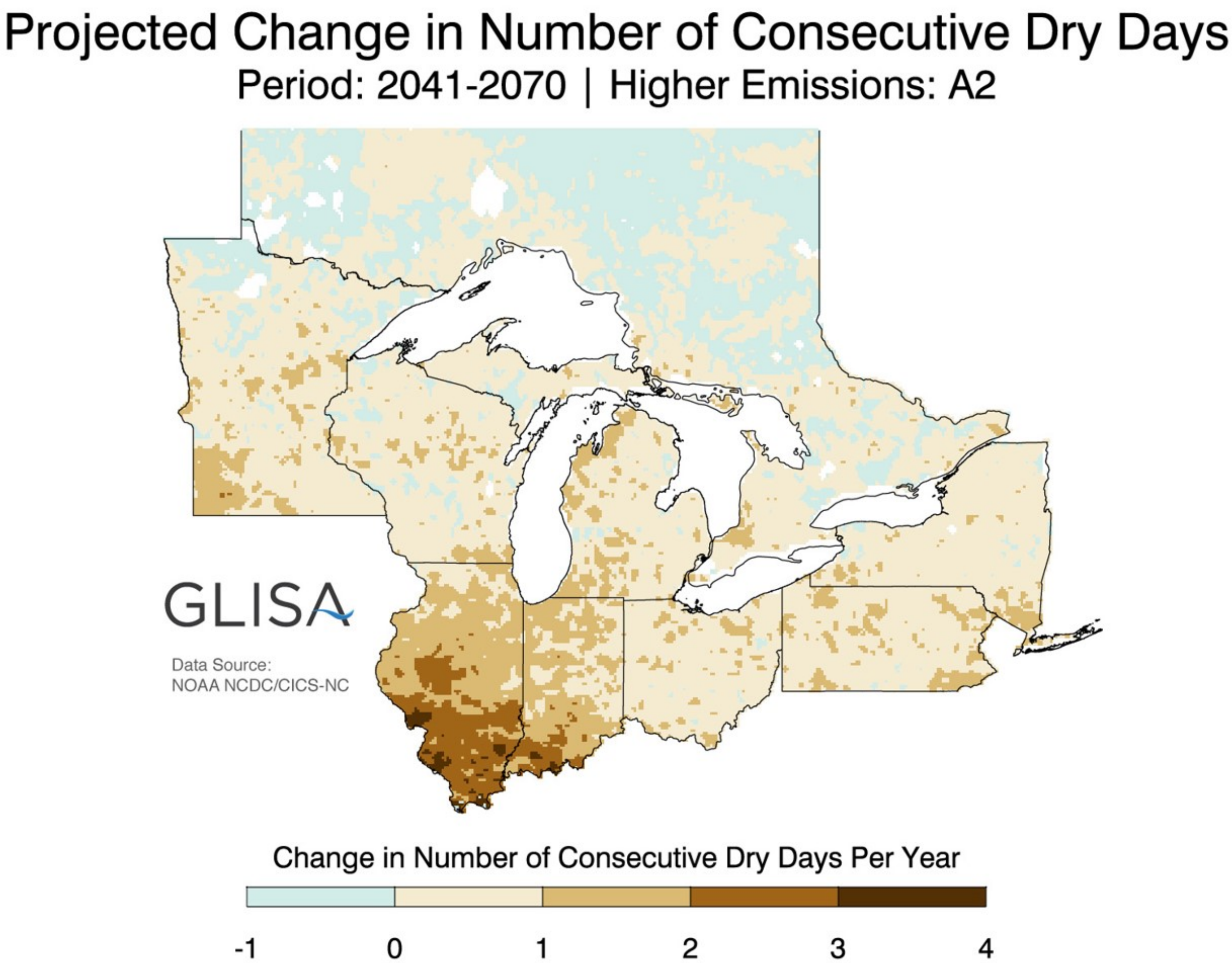

Figure 1-10 Projected change in the number of consecutive dry days expected for the period 2041-2070. The scale at the bottom (GLISA 2020) gives magnitude of the change. Also provided are the calculated changes for the same statistic over the period 1951-2017 for the four regions defined in the text within Michigan. From GLISA (2019)

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Chapter 2 Ecosystems

Kenneth Glynn and Leah Higgins

Key Messages

- Species range will shift as temperatures warm and ecosystems change, which is particularly damaging to species unable to shift northward due to geographic barriers.
- Freshwater ecosystems are anticipated to experience warming water, declining dissolved oxygen concentrations, and sedimentation from increased precipitation rates, reducing fish and mussel biodiversity.
- The species composition of MI forests is changing because of climate change and an increased risk of invasive species. The composition of tree species is shifting from those that are cold tolerant to those that are heat-tolerant from rising average temperatures. Invasive species, such as the emerald ash borer and hemlock woolly adelgid, are killing native species and thriving from patterns of early budding associated with climate change.

- A change in species composition is likely to alter forest ecosystem health and productivity. These rapid/sudden changes can have cascading negative effects on all organisms within the ecosystem and can therefore negatively affect the services humans receive from them, such as timber, freshwater, and carbon sequestration.
- MI forests contribute largely to the economy of the state both from the timber industry and from recreation and tourism.
- Increased global average temperatures paired with changes due to altered plant community make-up is likely to have both interactive and divergent impacts on grassland ecosystem functioning and biodiversity.
- An increase in annual temperatures will trigger shifts in grassland biodiversity through plant species loss, shifting species dominance, and by favoring invasive species.
- Some plant and animal species will not be able to keep up with the rate of change, which will result in a transformation of grassland landscapes over the course of the century.

Introduction: The Importance of Biodiversity

Species in a given ecosystem require a certain area or volume of space in order to survive or thrive, called the ‘species-area relationship’ (Rosenzweig, 2003). A decrease in a species area, then, can have drastic effects on population and species survival. Average regional temperature increases, changes in precipitation patterns, changes in seasonal weather patterns, and changes in seasonal temperature extremes are expected to occur because of climate change (The Great Lakes Integrated Sciences and Assessment Center, n.d.). Each consequence will affect the size, shape, and latitude of existing species-area relationships, muddling the current ecosystem relationships that individuals in a species rely on (Sexton et al., 2009).

These ecosystem changes, more often than not, will result in the degradation of biodiversity as they increase the risk and rate of species invasions and species extinction both locally and globally. Given that an ecosystems functioning is highly reliant on its biodiversity, negative impacts to biodiversity result in a reduction in the goods and services they provide for humanity. The functional characteristics, distribution, and abundance of the organisms that make up an ecosystem depend heavily on ecosystem properties and functioning as well (Tilman et al., 2006).

Ecosystem services are goods and services which human society receives from healthy, functioning ecosystems (Daily et al., 1997). A common example is the oxygen humans breathe is put into the atmosphere from forests, grasslands, and other terrestrial ecosystems. Biodiversity loss is known to reduce the quantity and quality of ecosystem services at a global scale (Cardinale et al. 2012). Ecosystem services specific to Michigan ecosystems is discussed in-depth in subsequent sections.

Species may exhibit a role in a particular ecosystem that is unknown and therefore not reflected in a model, or an invasive species' ecological niche may differ between the niche occupied prior to and post-invasion (Fernández & Healy, 2015). Niche shifting after a climatic event is largely unpredictable, which will likely force reactionary conservation practices in place of planned, proactive ones.

To understand ecosystem services and reactionary conservation practices that might become a necessity in the future, consider forests. Forests act as a carbon sink, meaning they can capture and store the carbon we knowingly emit in excess everyday through the burning of fossil fuels. Therefore, protecting and even increasing the size of existing forests might be a viable solution to help counteract climate change. Michigan presents an opportunity to put forth forest conservation initiatives because the state contains such a large expanse of forestland and is largely dependent upon the timber industry. The species composition of Michigan forests is also changing because of increased average temperatures and spreading invasive species, and may therefore increase the need for conservation implementation now and in the future.

Temperate Forests

The value of a forest ecosystem is hard to quantify because they are often intertwined with many organisms and ecological processes that function as a cohesive unit. Despite this challenge, what remains clear is that increasing average temperatures, variable amounts of precipitation, and patterns of frost-free springs correlated with climate change, are altering both the species composition of forests and the processes that all organisms rely on for survival, including us. Michigan forests present a special case for examining these changes associated with climate change because such a large portion of the state is comprised of forest. Approximately 19.6 million acres of forestland exist in Michigan and 18.6 million are considered timberland (Pugh et al., 2009). Michigan's economy is heavily reliant on the services its forests provide, therefore an assessment of how these services are likely to change in the future, is essential.

Climate change impacts on temperate forests

***Increased risk of invasive species*.** Of all the problems associated with climate change, an increased threat of invasive species is among the most detrimental to forests. Many invasive plant and animal species thrive in warmer climates and benefit from patterns of early budding associated with increasing average global temperatures. For example, in Michigan growing seasons continue to lengthen from an average increase in temperatures in the winter and spring, resulting in less frost and early budding of plants. This might seem like a benefit for crops and agriculture, but it presents an opportunity for invasive plants and animals to outcompete native species. For example, Michigan forests have become infested by numerous invasive plants such as buckthorn, honeysuckle, and autumn olive that are more heat tolerant than native species. These invasive shrubs take advantage of the decrease in frost by budding before native species. The natives that grow close to the forest floor get crowded out, do not receive proper amounts of sunlight, and ultimately are inhibited from proper germination (Brym et al., 2011).

Many invasive animals that persist in Michigan forests also take advantage of this change in frost and growing season. Among the most notable in recent years are the emerald ash borer and the hemlock woolly adelgid. The emerald ash borer is an invasive insect that has decimated ash tree populations in Michigan, and all throughout the eastern United States, in the last decade. This invasive insect is capable of killing a full-grown ash tree in three to four years and a smaller/younger tree in less than two years (DeSantis et al., 2013). Millions of ash trees have disappeared and attempts to manage and control this species have been futile. Rising average temperatures are anticipated to increase the range and spread of this species across the United States (Iverson et al., 2016). Another more recent invasive species that has become problematic for Michigan forests is the hemlock woolly adelgid. This invasive insect has only recently been discovered in Michigan (in 2015), but has the potential to cause untold damage to hemlock tree populations across the state. It feeds on the sap of hemlock trees, cutting off its supply of vital nutrients, ultimately killing it. These insects first arrived in New York and were originally believed not to be threatening, due to the insects' lack of resistance to cold northern temperatures. However, the insect has begun spreading westward, already decimating hemlock tree populations in southern states (Salk et al., 2011). As climate change continues to increase average temperatures across the United States, it also increases this pests' habitable range, thus presenting a major threat to hemlock tree populations not only in Michigan but also across the country.

***Shifts in forest composition*.** Invasive species are undoubtedly harmful to the welfare and success of native species, but the harm they impose presents broader, more threatening, consequences. All of the species listed above, both plant and animal, have the propensity to alter the species composition of the forests they reside in. In other words, invasive species that inhibit the success of and/or eliminate native species can change the ways in which the ecosystem functions (i.e. its productivity and the services it provides). For example, the hemlock trees threatened by the hemlock woolly adelgid are common along the western shoreline of Michigan and serve an important role in maintaining the stability of the landscape. If these trees disappear, it is likely that the shoreline will experience increased soil erosion, thus potentially eliminating habitat of native species and causing untold damage to infrastructure. Climate change is continually creating more optimal temperatures and environments for invasive species. If invasive species in Michigan forests continue to displace natives, it will result in a decline in not only the biodiversity of native species, but also of the ecosystem services Michiganders rely on from these forests.

Michigan forests are also slowly changing species composition independent from the pressure of invasive species. It is common knowledge that climate change is increasing average global temperatures, but less common is knowledge about how ecosystems such as forests are adapting and changing to these increasing temperatures. Michigan is one of the northernmost states in the U.S. Therefore, its forests are comprised of species that are adapted to life in periodically cold climates. Increasing temperatures are placing selective pressures on these species, ultimately resulting in a shift in the presence of cold-tolerant species (e.g. maple and birch) to more warm-tolerant species (e.g. oak and pine) (Knott et al., 2019). These changes are slow and hard to quantify as most tree species have long life cycles and take many years to establish. We cannot, therefore, say with any certainty how long this change is species composition will take or even that these species will one day entirely replace one another. Nonetheless, what we can say with certainty is that plants and animals alike are uniquely adapted to the habitats they reside in. An increase in average global temperatures has noticeably altered the timing in which trees begin budding. This affects the presence of pollinators, disrupts migration patterns (e.g. birds and insects), and leaves these tree species susceptible to predation, pathogens, and disease (Winkler et al., 2018). Michigan, being a state that supports large expanses of forest, will likely feel the impact of this change disproportionately as it largely benefits from the ecosystem services the forest provides.

Changes to Michigan forest ecosystems; ecosystem services and productivity

Ecosystem services of Michigan's forests. As stated prior, Michigan's forests are expected to experience some level of change in the future if current warming trends continue. The severity of this change is of great concern to the future health and productivity of the forest, and to Michiganders who wish to continue benefiting from the services it provides. One such service is outdoor recreation and tourism. As invasive species decimate native tree populations, they leave large expanses of forest riddled with dead trees (Irland et al. 2001). These dead trees are hazardous, as well as unaesthetic, and present a serious problem for the forest management sector. Large numbers of dead trees in areas such as state parks make outdoor recreation activities, such as camping, hiking, and snowmobiling, much more hazardous for tourists and residents alike. The cost of managing these dead trees can be high, as it takes an entire team of skilled workers to survey, identify, and remove them safely and efficiently. The state of Michigan spends millions of dollars every year on invasive species management and research. These mitigation strategies are often temporary solutions and only delay the inevitable spread of invasive species like the emerald ash borer and hemlock woolly adelgid. Therefore, we can only anticipate that the cost of managing theses invasive species, and the harm they inflict, will likely increase in the future as average temperatures continue to rise and frost-free springs become more frequent, thus promoting their success and survival.

Another important ecosystem service worth noting that Michigan's forests provide, is timber. Michigan has a long history of logging and its economy is still largely dependent on its supply of timber products. According to the USDA, in an assessment of timber product output and use published by the U.S Forest Service in 2014, Michigan's timber industry employs approximately 25,000 workers and produces an output of $7.3 billion in timber products (Haugen et al., 2014). As increasing average temperatures and frost-free springs alter species composition in Michigan forests, both from a shift of cold tolerant to warm-tolerant species or from the spread of invasive species, they are also changing the quantity and abundance of available wood products. For example, most timber in Michigan comes from hardwood species such as maple, birch, beech, ash and hemlock, as well as pine and cedar. Ash trees populations have all but vanished from the state and hemlock trees are likely to follow the same path if their invasive predators are not managed. A change in average temperatures is also expected to replace cold-tolerant species like maple and birch, with warm-tolerant species such as hemlock, pine, and cedar. Michigan's foresters in near future will have to not only deal with removing large expanses of dead trees, but also a change in the type of timber products they provide (Irland et al., 2001; Geisler et al., 2016). This has the potential to affect the timber industry and Michigan's economy, in terms of supply and demand, productivity, and output of timber products. However, what remains evident is that the industry will be subjected to change, and change as we know, can be beneficial or detrimental.

The logging industry has itself been responsible for changing the health, stability, and productivity of Michigan's forests in the past. Indigenous tribes, such as the Potawatomi and Anishinaabe, heavily relied on the forests of Michigan to support their way of life. As settlers in the 19th century began extensively logging and clear-cutting the landscape, they unknowingly polluted waterways, contaminated and removed wetlands, degraded once fertile soil, and created stagnant pools that ultimately bread mosquitos and spread malaria (Barton, 2018). The forests have slowly recovered as land management and conservation practices have improved and the impacts of deforestation are better understood. However, the land that once supported these indigenous tribes was never returned to its original state, and these native peoples have since been forced to live on reservations. The crops that these tribes once consumed are becoming increasingly difficult to cultivate as average increasing temperatures alter growing seasons and increase the likelihood of predation and disease from pests and pathogens. These people have not only had their land degraded and taken away from them, but they are likely to be disproportionately affected by the negative consequences attributed to climate change. It is unknown how these tribes will adapt, being that they are forced to live on restricted plots of land that may no long support their traditional way of life. Mitigation strategies must take into account those that are disproportionately affected by climate change.

Freshwater Ecosystems

Michigan is, in a sense, defined by the Great Lakes. Four of the Great Lakes surround Michigan's two peninsulas and determine Michigan's borders. All five —Superior, Huron, Michigan, Ontario, and Erie—come together to form the Great Lakes basin. The five lakes combined hold about 21% of the globe's surface water (Facts and Figures about the Great Lakes, 2019). Michigan contains an estimated 11,000 inland lakes and 36,000 miles of streams (Inland Lakes & Streams DEQ, n.d.).

Industrialization and resource extraction are the two largest contributors to degradation of the Great Lakes system since European colonization and Native American displacement. Overfishing, in conjunction with other exploitations, has likely permanently altered ecosystem functioning in the Great Lakes themselves and within inland lakes and streams (The Great Lakes, An Environmental Atlas and Resource Book, 1995). Climate change is expected to exacerbate these harms. Rising average water temperature and lower dissolved oxygen levels will affect various species in the Great Lakes basin, generally negatively. Harmful algae blooms, linked to nutrient runoff, will likely be amplified by warming of lake water. Sedimentation from increased precipitation will likely harm mussel species. Shifting of suitable habitat will lower some species populations, and allow other species to become invasive as their range of suitable habitat shifts northward (Rahel & Olden, 2008). Specific effects to the Great Lakes, inland lakes, streams and rivers, and vernal pools are discussed in the following.

Great Lakes

Biodiversity threats to the Great Lakes varies, but a few overall trends are expected. Changes in the stratification of temperature in lake water can further limit the dissolution of oxygen into lake water. The coldest, deepest layer, called the hypolimnion, is the most oxygenated of all water layers, and will de-oxygenate as temperatures increase (Cooperative Lakes Monitoring Program, 2008). A study by Kramer et al., (2015) found that larger lakes experience the largest changes in stratification when temperature rises. If actual temperature rise causes significant stratification, the Great Lakes are at a greater risk than smaller inland lakes (Kraemer et al., 2015).

Few fish are found in the hypolimnion of the Great Lakes (Vadeboncoeur et al., 2011). The forage fish that are present in the deep pelagic zone, however, are known to be the primary food for the popular sportfish, lake trout and Chinook salmon in Lake Huron. Historical disturbances from invasive sea lamprey and rainbow smelt have already reduced biodiversity in this particular lake community, threatening the nutritional intake of lake trout and Chinook salmon (Roseman & Riley, 2009). Few fish are found in the hypolimnion of the Great Lakes

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A second concern is damage from higher rates of harmful algae blooms. Harmful algae blooms are predicted to increase in volume and seasonal length, creating dead-zones that reduce habitat space. Harmful algal blooms (HAB's) from cyanobacteria are predicted to occur more often and with greater concentration of bacteria as temperatures rise, because warm water is excellent habitat for blue-green algae (Chapra *et al.*, 2017). Earlier warm seasons, as predicted by GLISA (n.d.) allow for earlier blooms, lengthening the time a HAB has to grow (Wood et al., 2016). Once a bloom collapses, that area of water is extremely deoxygenated, and toxins released from the bacteria may be present also (Paerl & Otten, 2013). Dead-zones, as these post-collapse areas are named, can be deoxygenated to the extent that other living creatures entering the zone risk death.

Inland lakes

Inland lakes species will be affected by seasonal ice-cover changes and increasing average temperature. Cold-adapted fish, like lake trout, are at a relative disadvantage due to temperature rises and consequent changes in oxygen. Negative effects from reduction of oxythermal habitat include lower spawn and survival rates, and spawn rates may be further limited by changes in ice-cover patterns year-to-year (Guzzo & Blanchfield, 2016).

Walleye have been negatively affected by the interaction between deforestation and warming lake water within the Canadian province of Ontario. Deforestation results in less fallen trees at the edges of inland lakes, which in turn reduces the low-light habitat area, which walleye require, and the warming of lakes from climate change further limits their range. Together, these pressures had a definite reduction of walleye biomass in the study area (Gutowsky et al., 2018). Similarly, a study by Zuiden and Sharma (2016) in the same area finds that, despite having divergent temperature preferences, walleye populations are reduced by nearly one-third when smallmouth bass are also found in a given lake. Temperature changes alone adversely affect cold-adapted fish, and this ecological pressure combines with others to reduce these fishes' populations.

Streams and rivers

Temperature increases. The nature of stream shape and topography creates a narrow space for animals to inhabit.~~species-area relationship~~ Therefore, as climate change alters these ecosystems' temperature and dissolved oxygen levels, cold-water adapted species seek refuge by travelling upstream to cooler waters. A 40-year projection by Michigan State University Fish and Wildlife researchers Carlson et al. (2015) projects an increase of 0.19-5.94 degrees Celsius for 30 cold-water Michigan streams due to climate warming. As average temperatures rise, the range of warm-adapted fish expands upwards. Downstream species are predicted to migrate upwards and displace headwater species due to the relationship between headwater and temperature. Ultimately, this displaces and causes competition between southward fish populations and northward fish populations. Coldwater stream fishes are at the greatest risk of having suitable habitat eliminated or colonized (Buisson et al., 2008).

Sedimentation from precipitation events. NOAA anticipates increased severity of precipitation events under the current climate pathway (Frankson & Kunkel, 2014). Sedimentation of the water, called browning, occurs when precipitation runoff causes terrestrial sediment to enter bodies of water and suspend before settling. Browning can be likened to high levels of dust in the air: it damages fishes' and other aquatic species ability to breathe and at severe levels can result in suffocation (Weyhenmeyer et al., 2016). As suspended sediment settles, build-up on the riverbed can suffocate native mussels and further decrease mussel biodiversity in rivers and streams (Clubshell Fact Sheet 1997, Northern Riffleshell Fact Sheet 2018, Rayed Bean Fact Sheet 2012, Snuffbox Fact Sheet 2018).

Vernal pools. Vernal pools are small pools found in forest areas that form in the spring due to snowmelt and seasonal rainfall. Amphibians, salamanders, and invertebrates are greatly benefitted by vernal pools, as these shallow pools provide an area to breed (Calhoun et al., 2014). In addition, vernal pool biodiversity was found to correlate positively to tree diversity in the surrounding area, pointing to vernal pools as hubs for biodiversity (Previant & Nagel, 2014). Increased precipitation and longer periods of consecutive dry days, as predicted by Frankson & Kunkel (2014) as well as The Great Lakes Integrated Sciences and Assessments Center (n.d.), is likely to influence the formation of vernal pools. Hart and Gotelli (2011) compared invertebrate population for common mosquito and midge larvae under forty-nine different precipitation scenarios. The findings indicated variation between the ecological needs of the two species, and that the combination of seasonal precipitation patterns and increased average temperature will likely alter the population distributions of aquatic invertebrate species.

Invasive Species Proliferation

Cisco in the Great Lakes basin

Cisco species were historically extremely abundant in the Great Lakes region, but decreased in diversity, range, and population due to invasive species introduction, pollution, and overfishing (Christie, 1974). Today, the U.S. Fish and Wildlife Service list blackfin cisco, deepwater cisco, longjaw cisco, and shortnose cisco as extinct on the list of Extinct Species (2018). Kiyi cisco, found only in Lake Superior, bloater cisco, and shortjaw cisco have had their range shrink to the northern Great Lakes of Superior, Huron, and upper Michigan (Derosier et al., 2015). In the neighboring and geographically similar state of Wisconsin, Sharma et al. (2011) found that lakebound and stream-bound cisco populations might decrease up to 70% due to shifts from changing water temperature and water stratification, as well as the compounded effect of invasion from rainbow smelt. The Great Lakes basin has already lost many unique cisco species, and is likely to lose more.

Zebra mussel and native mussel interaction

Endangered species, in particular, face multi-faceted limiting factors, and it is not always clear how ~~the~~ climate change will affect these already vulnerable groups. Currently, four Michigan mussel species—clubshell, northern riffleshell, rayed bean, and snuffbox—are listed as endangered, in part due to the influx of zebra mussels into the Great Lakes basin. As filter-feeders, mussels, including the zebra mussel, contribute to water quality by filtering water as they eat (Clubshell Fact Sheet, 1997; Northern Riffleshell Fact Sheet, 2018; Rayed Bean Fact Sheet, 2012; Snuffbox Fact Sheet, 2018). Gallardo and Aldridge (2013) modelled the effects of warming water on two mussel species in Europe, finding that invasive zebra mussels displaced native mussels. In multiple climate scenarios, zebra mussels were found to expand their range upwards and increase in concentration, with losses in the native mussel's population and range (Gallardo & Aldridge, 2013). As discussed in the introduction, biodiversity is critical to the long-term resiliency of a given ecosystem. InvasiveZebra mussels, aided by climatic effects, will displace native mussels and ecosystem resiliency will be reduced.

Hydroelectric dams as a mitigation strategy

As discussed above, the warming of lake and stream water can displace existing ecosystems and species, and make space for better-adapted invasive species. Warming of Michigan Lakes and streams is predicted to increase the spread of invasive species in Lakes Ontario and Erie, and in the northern watersheds Nipigon, Black Sturgeon, and Dog. Forecasts indicate halving of invasive species population in upstream catchments by the construction of semi-passable hydroelectric dams (Malles et al., 2015). Though hydroelectric dams are not particularly beneficial for native species movement either, multi-disciplinary discussion persists on improving the technology and knowledge that permits construction of selective fishways, or fishways that permit only certain species to pass through (Silva et al., 2018). If constructed correctly, hydroelectric dams that limit movement of invasive species only may prove to be a benefit to protecting Michigan's ecosystems.

Effects on Human Society

Fishing

Commercial and recreational fishing are important aspects of Michigan's economy and culture. In 2016, upwards of $16,500,000 were generated by commercial fishing of the Great Lakes. All of the fish species discussed prior were commercially caught and contributed to these 2016 economic gains (Great Lakes Landings by Lake, 2019).

Commercially caught yellow perch. A fish representative in assessing climatic effects on fishing is the yellow perch. Spawn rates of the yellow perch, and the species' ability to forage is compromised by climate change effects. Yellow perch have spawn rates connected to low eutrophication levels in shallow coastal zones, so the year-to-year population is adversely affected by increasing water temperatures (Parker et al., 2012). In warmer waters, yellow perch eggs are smaller on average, producing smaller offspring (Farmer et al., 2015). Deoxygenation of the lowest lake layer prevents yellow perch from predating on the invertebrates that live on the lakebed (Roberts et al., 2009). Yellow perch accounted for 1,280,000 pounds of commercially caught fish in 2016 (Great Lakes Landings by Lake, 2019). As increased temperatures and deoxygenation reduce yellow perch population, and the populations of similar fish, commercial fisheries may be unable to meet demand.

Inter-state recreation. Recreational fishing may decrease as preferred fish species decline and less preferred or undesired fish species, such as invasive species, propagate. Econometric modelling predicts that the presence of culturally undesired fish species, such as the invasive Asian Carp, causes decrease in inter-state travel for fishing (Ready et al., 2018). As invasive species are benefitted by climate change or new invasive fish arise from climatic changes, recreational fishing may decline and have significant economic and cultural impacts.

Reduction in ecosystem services for municipal taps

Biodiversity provides an important ecosystem service by filtering water and consequently improving water quality. Cardinal (2011) finds that water quality is linked to having diverse algal species. Thus, decreases in algal biodiversity threatens to reduce the natural filtration services provided by these algaes. *Microcystis*, an algal species that produces toxic microcystin and is often associated with harmful algal blooms in Lake St. Clair, Lake Ontario, and Lake Erie, is found to decrease the diversity of algal families up to 58% (Magrann et al., 2012). As discussed in the ***Great Lakes*** subheading, harmful algae blooms are predicted to increase as temperatures rise (Chapra et al., 2017). Microcystin contamination is already affecting the water treatment plants of Monroe South County, the City of Monroe, and Frenchtown Township, which together serve 99,000 residents (Michigan Department of Environmental Quality, 2014).

As harmful algae blooms increase, microcystin contamination will likely increase, and biodiversity losses will reduce natural water filtration from other algae species. In order to adapt to increases in microcystin poisoning, some municipalities might consider a HAB-specialized "automated call processing menu system (pg. 209)" to streamline calls to Poison Control, as was piloted by Fleming et al. (2007).

Disparate impact on Native Americans

In Michigan today, eleven Native tribes are federally recognized. Eight reservations are located on or near the coastlines of the Great Lakes (Native Languages of the Americas, 2015). Often, watershed management does not actively include Native American voices, but meaningful political inclusion, the building of positive relationships between Native and white communities, development of values such as trust and cooperation, and efforts to provide relevant resources to Native tribes correlate to Native participation and involvement in watershed management (Cronin & Ostergren, 2007).

The participation of Native peoples is vital, as biodiversity losses affect their ability to eat traditional foods (Lynn et al., 2013). Genetic predispositions may make Native persons' bodies less able regulate fat production when consuming a diet high in processed foods, causing high rates of obesity and diabetes (Gittelsohn et al., 1998). Community health, in this case, depends on the ability of Native persons to eat traditional diets (Filakowski, Okoror, & Boushey, 2012). For the Ojibwe, manoomin (wild rice) is a traditional food that is subsistence, cultural, and spiritual. The ability of manoomin to grow is being threatened by climate change impacts, limiting the ability of Ojibwe people to engage in traditional eating (Cozzetto *et al.*, 2013). Poor health rates in First Persons and Native peoples is found to be linked to lower educational attainment in a comprehensive study by Sharma and Burns (2018). Climate change begins a chain-reaction wherein biodiversity losses lead to diet changes, which have negative health effects that then limit the opportunities of Native peoples.

Resiliency, Mitigation, and Potential Adaptation Techniques

Research has established that climate change is occurring— and considering all of the above— Michigan will face consequences. Thus, the following section is dedicated to action plans, technology, and frameworks that will enable Michigan to prepare for and adapt to this new world.

Different management techniques, as general frameworks, are suggested in the literature. The consensus is that current management practices will need to be altered, adapted, or abandoned in favor of strategies that are specifically aimed at reducing climatic effects. Lin and Peterson (2013) critique conservation frameworks that conceptualize ecosystems as closed systems that reach balance, and emphasize that climate change will shock these systems. In a continually changing climate, equilibrium modelling seems inadequate. Resiliency-based management has been suggested as a general alternative as well as a route for research (Lin & Peterson 2013). Multi-scalar management and conservation techniques are another alternative, though not mutually exclusive to resiliency-based management (Poiani et al., 2000)

Areas already protected tend to have lower rates of invasive species, even in areas where the climate is suitable for invasives. Newer Natura 2000 areas have higher rates of invasive species, a European study finds (Gallardo et al., 2017). Long-term resiliency, then, might include better and greater conservation efforts, as a means of preserving biodiversity in small areas with the intention of spreading this biodiversity outside of protected areas post-climatic stress.

In regards to resiliency of aquatic ecosystems, two major pathways have been suggested. The first of these is the sharing and application of traditional knowledge from indigenous groups.

The Native American groups of Grand Traverse Band of Ottawa and Chippewa Indians have river restoration practices related to their spiritual and ancestral connections to rivers and watersheds in Michigan (Fox et al., 2017). Better and genuine inclusion of these groups in decision-making processes and management planning will add perspectives that may be otherwise overlooked.

A second general pathway for resiliency in the Great Lakes ecosystems is improved knowledge and research, which can be used to generate models and information for dissemination. Modelling of Lake Erie done by Manning et al. (2019) can be used to estimate and anticipate harmful algal blooms, and at multiple scales including differentiation between near-shore and whole-lake bloom biomass predictions. The development of multi-scalar models for other climatic effects and in other ecosystems can help local officials and residents to prepare and adapt. Moving forward, management practices can integrate this and similar models to better prevent and remediate Lake Erie before or during a harmful algae bloom.

In terrestrial ecosystems, existing management programs will need to be expanded and adapted. Many regulations and protections have been put in place since European settlers began logging in Michigan in the 19th century. These regulations serve to protect and monitor the health and quality of forests, both because Michigan's economy is heavily reliant on timber products, and because it is now known how integral forest ecosystem stability is to other ecosystems throughout Michigan. Since 1999, the USDA has been conducting surveys of Michigan forests to assess species composition and forest health/productivity. This year-by-year assessment will be increasingly important in the future if the threat of climate change continues at its present rate (Pugh et al., 2009). Some of these protections include the Michigan Society of American Foresters (MSAF), the USDA Forest Service Inventory and Analysis program, the Qualified

Forest Program (QFP), and the Michigan Conservation Reserve Enhancement Program (CREP). As the effects of climate change continue to alter forest ecosystem health and stability, these programs and more will be essential in the future as we assess the change and determine a course of action.

Actions have already been implemented that aim to identify the most imminent threats facing Michigan's forests. Invasive species are among the most threatening, and therefore rigorous management efforts have been, and are currently, underway that attempt to slow their spread and aid in prevention efforts (Davidson et al., 2015; Knott et al., 2019). Threatened native species are also of great concern to forest ecosystem health but are often given less attention and resources. Identifying which species are considered "keystone" is often difficult and requires rigorous study and experimentation. Regardless, native species should be monitored to address their rate of decline (or growth) over time, and to assess the potential impact a loss of these natives might have on the forest ecosystem health and stability.

Some have attempted to alleviate the damage caused by invasive species through other means. As stated prior, Ash trees have been decimated by the Emerald Ash Borer and are likely to suffer further from rising temperatures associated with climate change. One mitigation strategy for dealing with this loss of species is planting native non-ash species where ash trees once persisted. The end goal is to restore soil quality and overall ecosystem productivity in places where ash trees have been killed (Iverson et al., 2016).

Assessing the vulnerability of ecosystems requires an assessment of individual habitats and communities against each climate change impact. In order to safeguard them, it is vital to continue research geared toward indicating the sensitivities of various habitat types to specific climate change impacts such as increased precipitation, drought, and extreme weather events.

Adaptation plans must account for a range of potential future conditions in order to develop reliable plans that are resilient to a variety of climate change projections (National Park Service, 2007).

Land trust officials when demarcating protected areas should consider anticipating range shifts of species and invasive pests. Anderson & Ferree (2010) use the term 'conserving the stage' to refer to a proactive approach that emphasizes protecting the geophysical settings in which species presently exist and are expected to shift towards. This approach suggests that protecting vital biological corridors and habitat before they become vulnerable will ensure greater faunal stability (Anderson & Ferree, 2010). In addition, according to Griscom et al. (2017), improving our land stewardship practices is integral in order to achieve the Paris Climate Agreement goal of maintaining warming below 2 °C. Improving land stewardship practices for grasslands, forests, and other ecosystems means that communities and land managers must encourage resilience through the removal of invasive plants, restoration of vital native species, and protection of habitats from further degradation and development when feasible (Griscom, et al., 2010).

Future Opportunities

Historically, the Potawatomi tribe occupied a large area in Michigan prior to forced displacement by European colonizers. In the words of Kyle Whyte, a Potawatomi descendent and member of the Potawatomi Nation, seasonal stewardship and harvest practices are "deeply physical...relationships among [humans and other species] ensured" (pg. 69) continuation of a healthy ecological system. Whyte attributes the disruption of these cultural practices with European settlement and the tangent ecological disruption that occurred (Whyte, In: Barton 2018). European colonization was in large part the displacement of Native peoples by white

Europeans, but the human colonizers did not come alone. Europeans brought multiple species from the Eastern hemisphere, including agricultural flora and fauna, disease, and ornamentals. The environmental colonization that resulted from this forced exchange in no small part contributed to and continues to contribute to the disruption of Native cultures that had developed diverse and varied relationships with the existing ecosystems (Cronon, 2003).

This experience of disruption, displacement, and harm is not unique to the Potawatomi tribe. Indeed, all Native Peoples were and are affected following the settlement of North America by Europeans. Climate change will certainly exacerbate ecological disruption, and for the Native Peoples whose culture and sense of identity are ingrained in specific ecological systems, climate change will exacerbate harms from American colonization.

Thus, climate action presents an opportunity: there is potential to reduce the ongoing impact from historical harms on Native persons and Native culture by adopting management systems that integrate community needs and ecosystem needs (Uprety, Asselin, & Bergeron, 2017). The different perspectives from indigenous communities are valuable for resiliency planning and adaptation for climate change, and just as importantly return power and input to communities that have been historically silenced.

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Chapter 3 Recreation and Tourism

Emily Marcil and Sarah Fisher

Introduction

Climate change will likely affect the recreation and tourism sector in Michigan. More specifically, the following chapter addresses how the impacts of climate change will affect fishing, water, winter, and land recreation, hunting, local communal activities, agricultural tourism, and major attractions in Michigan. Following higher-emission scenario for Michigan, it is projected that a normal summer day will feel like summers in Missouri or Arkansas (Wagner, Keusch, Yan, & Clarke 2018). In addition, the number of extreme heat days, which are days between 95 degrees Fahrenheit and 100 degrees Fahrenheit, are increasing (Hayhoe *et al.* 2009). Within 2010-2039, there will be 3-5 extra days that are considered extreme heat days; by 2100, there will be an additional 10-22 extreme heat days based on lower emission scenario and 44 days based on higher emission scenario (Hayhoe et al., 2009).

The increase of toxic dead zones, or algal blooms, are likely with the increase in temperature, reduced dissolved oxygen content, length of ice-free periods and light, and nutrients; the following chapter will outline the impacts this has on tourism and recreation (Johnson *et al.* 2003; Huff & Thomas 2014). Bud development is expected to occur 7 days earlier by 2040 and 16 days earlier by 2060 and Michigan's hardiness zones are in a transitioning phase which will both impact tourism and recreation specifically surrounding agriculture. The following chapter will also outline the impacts of an extended growing season, increase in precipitation by about 2-4 inches, and increase number of consecutive dry days. Specifically, Michigan's growing season has extended by an average of 28.8 days since 1971 and has seen an increase of 3.8 growing degree day per year since 1980 (Schultze 2015). At the end of each section, we have provided adaptation and mitigation techniques that could be implemented to deal with the changing climate in Michigan.

Fishing

Increasing air and stream temperatures will affect fishing in Michigan, which may decrease cold-water fish species, causing a negative effect on fishers. Annual air temperatures in Michigan are projected to increase by 2.9, 4.3 and 4.7 degrees Celsius, depending on the predicted carbon increase of either 550 ppm, 720 ppm, or 850 ppm by 2099 (Cherkauer & Sinha 2009). Increasing air temperatures has led to increasing water temperature and decreasing ice cover in the Great Lakes. Michigan surface water temperature is projected to increase 2-7 C by 2100 (Collingsworth *et al.* 2017). Thermal changes in air and water, combined with changing precipitation patterns, will decrease flow by an average of 1.8%. Decreasing the flow of streams exacerbates surface water temperature increase and phosphorus loading.

Increasing air temperatures will decrease the number of suitable streams for fish. Nationwide we will see a 33% to 39% decrease in the number of streams suitable for cold-water fishes and an 11% to 22% decrease in the number of streams suitable for cool water fish (Mohseni, Stefan & Eaton 2003). If enough food and oxygen is present for the fish, they can continue to thermoregulate their body temperature even in streams that are too warm (Collingsworth *et al*. 2017). In many cases, the required food and oxygen will not be sufficient to support constant thermoregulation.

Due to the increased air temperature, many lowland stream fish will need to travel long distances to maintain their ideal climate niche. As species continue to lag behind the shifting temperature ranges, the number of endangered aquatic organisms are likely to increase. This has resulted in an average lag time of 46.8 meters per decade moving toward higher elevations and

15 kilometers per decade moving from upstream to downstream gradients (Comte & Grenouillet 2013).

Climate change will also limit fish habitat survival through overlapping anoxic and warm zones. As Michigan winters become shorter, we can expect the Great Lakes to have increased time of thermal stratification that will limit nutrients in the euphotic zone, the layer closest to the surface. Primary production in Lake Michigan will decline as the euphotic zone warms. As the productivity of the lower food chain is diminished, fishery production will decline (Brooks & Zastrow 2002).

There are some positive impacts of climate change on fishing. Warmer winters and earlier spring warming have led to fish exhibiting earlier behaviors like migration and spawning. This shift in fish behavior has started to occur in lake fish. In Lake Michigan, Yellow Perch has begun to spawn earlier in the calendar year (Lynch *et al.* 2016). As fish exhibit earlier spawning habits, we can expect the fishing season to last longer in areas suitable for fish.

Social impacts

The socio-economic status of recreational fishers is influenced by both environmental conditions and environmental policy, as shown in Figure 3-1. Environmental conditions may include cold-water fish population declines and more extreme weather events, including increased precipitation. Michigan will experience 1-2 more days of heavy precipitation events per year by 2041-2070, making it less likely that fishers will take trips on days of inclement weather (GLISA, Hunt *et al.* 2016). Fishing regulations are often made in response to changing environmental conditions and affect fishers' decisions to take trips. Changes in environmental policy is likely to influence the satisfaction and income of recreational fishers (Hunt 2005).

Adaptation and mitigation

Potential adaptation strategies for the Great Lakes tourism sector include public-private partnerships and bioeconomic management frameworks. Public-private partnerships include the collaboration of government bodies, fishing businesses, and climate scientists. This strategy would improve fishing management and planning in the Great Lakes, while also strengthening climate change management (Chin *et al.* 2019). However, decision making in public-private partnerships tends to exclude unrepresented groups from discussion (Fenichel *et al.* 2013). A bioeconomic framework may reduce conflict in PPP's by combining biological and social science to rank different outcomes (Fenichel *et al.* 2013). Policymakers can follow this normative framework to merge socio-ecological preferences of constituents.

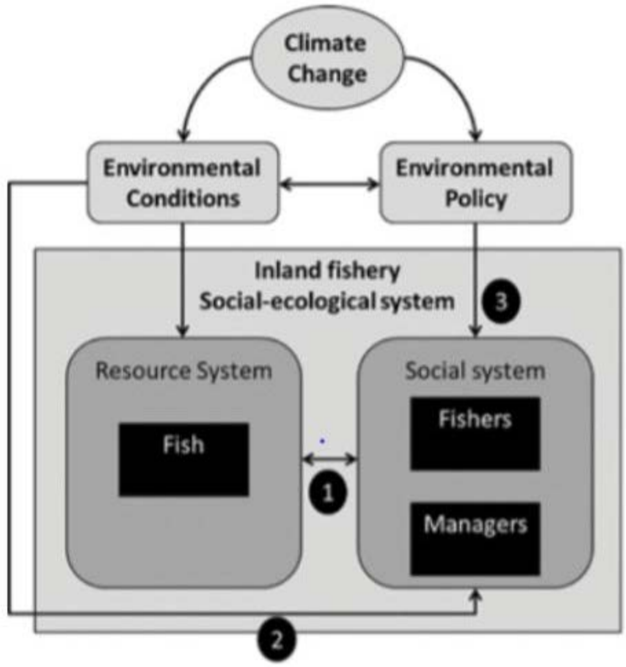

Figure 3-1 Climate change influences the Socio-economic status of recreational fishers. From Hunt (2005)

Adaptation strategies among subsistence fishers will be at the household or community level. These strategies may include diversification of food sources and income, moving to new fishing areas, storage or surplus food, weather forecasting, selection of stress-resistant fish, and pooling of resources (Savo, Morton & Lepofsky 2017). The choices fishers will select may depend on their skills, environment, and available resources.

Hunting

Hunting provides the public with economic incentive while simultaneously managing deer populations. Hunters can purchase a license to hunt white-tailed deer, coyotes, foxes, squirrels, various birds, bears and more, providing the state with immense economic growth. Deer hunters make up a significant portion of Michigan hunting, with nearly 600,000 deer hunters in 2016. Each dollar spent in Michigan on hunting and fishing provides a 36.7% return for hunters (Calantone & Vickery 2016**)**. Similarly, every one million dollars spent creates 20 jobs in the hunting and fishing sectors (Calantone & Vickery 2016). In addition to providing economic incentive, hunting helps mitigate negative impacts caused by high deer populations including deer-vehicle collisions, loss of crop yields, and changing forest structure (Knoche & Lupi 2012). It is expected that some game species in Michigan will decline due to wetter and warmer winters, but others, including white-tailed deer and turkeys, will increase.

Many northern game species will be affected by temperature and moisture change. The Michigan Department of Natural Resources has reported that 17% of Michigan terrestrial game species are vulnerable due to changing climatic conditions. Increasing temperature of 3 to 5 degrees F by 2050 will limit the population range of important game species including moose, American marten, snowshoe hare, and ruffled grouse. These four species are unlikely to return to past levels, and will no longer be available for hunting (Hoving *et al.* 2013).

More common game species in Michigan, including white-tailed deer, may benefit from increased precipitation and shorter winters. Figure 3-2 and Figure 3-3 show that increased June precipitation and temperature have favored white-tailed deer population growth from 2001 to 2015. Warmer and wetter springs improve the ability of white-tailed deer neonates to thermoregulate, which improve survival rates (Michel *et al.* 2018). The referenced figures are for North Dakota, South Dakota and Minnesota. Due to Michigan's location in the Midwest and expected climate change effects of warmer and wetter springs, we can expect Michigan to see similar trends in white-tailed deer populations.

As deer populations increase, the spread disease will too. White-tailed deer in Michigan are currently being affected by chronic wasting disease, which is a density-dependent disease that affects the neurological system of deer. CWD is contagious between deer populations and can travel long distances, tracking migratory patterns (Edmunds *et al.* 2017). Density-dependent diseases spread faster where there are more hosts of disease (Cooney & Robert 2010). Unchecked spread of disease among deer could devastate the deer population, which will decrease hunting satisfaction in Michigan.

Adaptation and mitigation

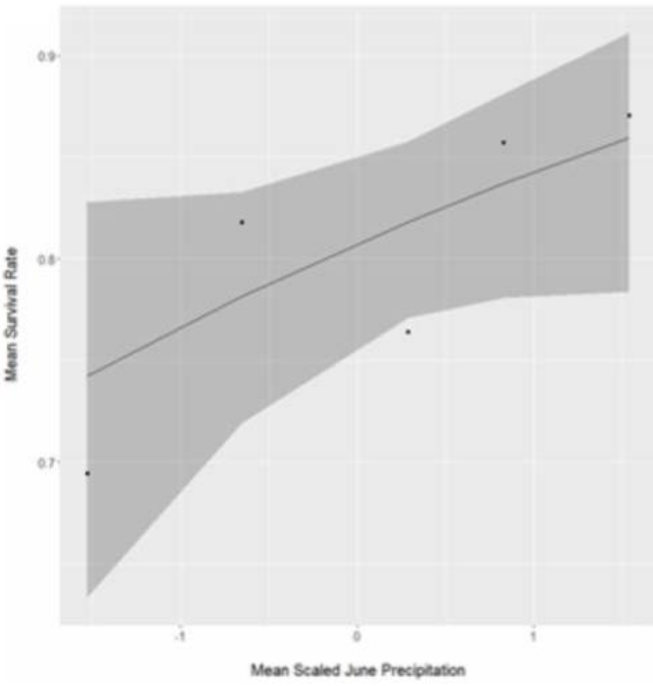

Figure 3-2 As June precipitation increased, white-tailed deer (O. virginianus) survival rate increased from 2001 to 2015. From Michel et al. (2018)

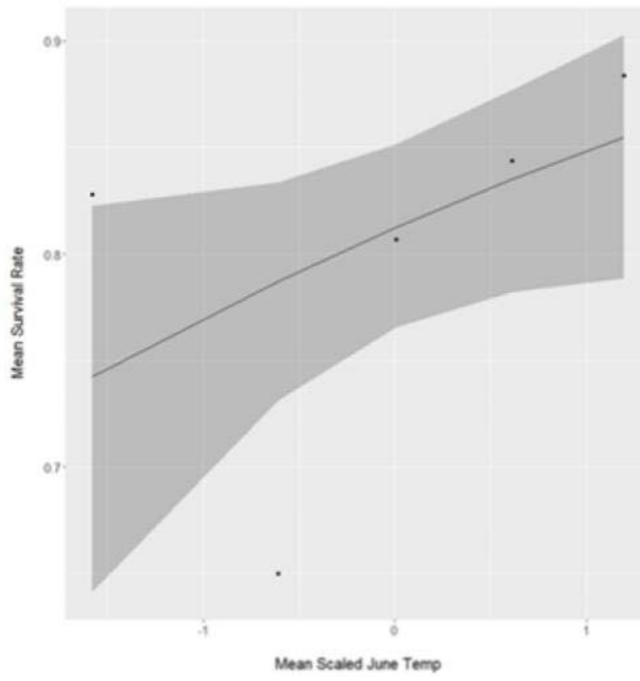

Figure 3-3 As June temperature increased, white-tailed deer (O. virginianus) survival rate increased from 2001-2015. From Michel et al. (2018)

Using lethal management strategies as a means of reducing wildlife disease has gained public support in recent decades (Melissa & Mertig 2004). According to hunters and scientists alike, herd culling provides an adequate response to mitigate the risks of diseases in white-tailed deer (Cooney & Robert 2010, Wasserberg *et al.* 2009). To date, there is no evidence that humans can contract CWD by eating infected deer, and many studies suggest doing so is an adequate solution to managing CWD (Melissa & Mertig 2004, Cooney & Robert 2010, Wasserberg *et al.* 2009). Increasing public education of wildlife diseases and human health may increase hunting support and participation (Melissa & Mertig 2004).

Local Communal Activities

Local farm recreation

Local farm recreation encompasses a wide range of activities that Michigan residents engage in such as corn mazes, apple orchards, pumpkin patches, Christmas tree farms, cherry orchards, vineyards, farmers markets, petting zoos and animal sanctuaries. Local agricultural tourism operations in Michigan provide about 4,000 full time jobs on an annual basis as well as providing work and training to 28,000 part-time employees (Veeck 2016). Vineyards and wineries, orchards and farmers markets make up the largest portion of sales in all agricultural-tourism sectors; they account for approximately 64 percent of sales (Veeck 2016). There are about 53,300 farms in Michigan and 90 percent are family operated, and 62 percent of Michigan farms have annual sales of less than $10,000 (USDA 2003). Climate change, however, has the potential to change this sector of recreation and tourism.

Increase in temperatures. As mentioned previously, the change in average temperature is leading towards an expanded growing season, which can be beneficial. The species that cannot survive in a changing environment could migrate north. This could be a severe impact on farmers and availability of recreation and tourism in regions that once flourished in the economic benefit of farm based recreation such as Christmas tree farms.

Michigan’s wheat yields could expand due to climate change because of the higher concentration of atmospheric carbon and higher temperatures. However, it is unclear whether this would really be an advantage since projections also predict severe droughts and/or floods (U.S Global Change Research Program 2016). In addition, the corn yield is expected to decline because of very hot and dry summers as well as heat waves (U.S Global Change Research Program 2016). This could heavily affect the recreation that is centered on corn especially in the fall with corn mazes.

Another concern in regards to higher temperatures is that it causes heat stress to livestock animals that are in sanctuaries and outdoor petting zoos. According to a study done by Lopez, West, Dong, Goni, Kirtman, Lee, and Atlas (2018), it was discovered that human-caused greenhouse gases that drive climate change would be the main factor in heat waves within the next fifteen years in Michigan and the greater Great Lakes region. This is a concern for the recreation that surrounds animal sanctuaries and petting zoos. Directly affecting the health and welfare of livestock, heat waves disrupt the animal’s metabolism and immune system as well as causing oxidative stress. All of these effects cause the likelihood of death and disease to increase (Lacetera 2019). It is estimated that each year environmental heat stress accounts for a loss of millions of dollars (Hatfield et al. 2016). In order for Michigan farms to adapt to this change, development needs to link climate data with disease surveillance systems (Lacetera 2016). Not only will doing this help prevent diseases, but it also opens up more opportunities to implement mitigation and adaptation strategies.

Change in hardiness. It is estimated that Michigan has already changed by one hardiness zone as shown in Figure 3-4. Plant hardiness is the typical way one assesses the survival of plants and how well they are able to adapt to changes in temperatures, fluctuations in cloud cover, precipitation and humidity (Teqja, Kopali, Libohova, Owens, 2017). It is estimated that the increase in precipitation could cause soil erosion and loss of nutrients (Teqja et al., 2017). On the other hand, plant hardiness zones could help introduce new crops in Michigan as growing conditions change which those crops could be tied around recreation and tourism (i.e. tart cherries and wine grapes as previously mentioned).

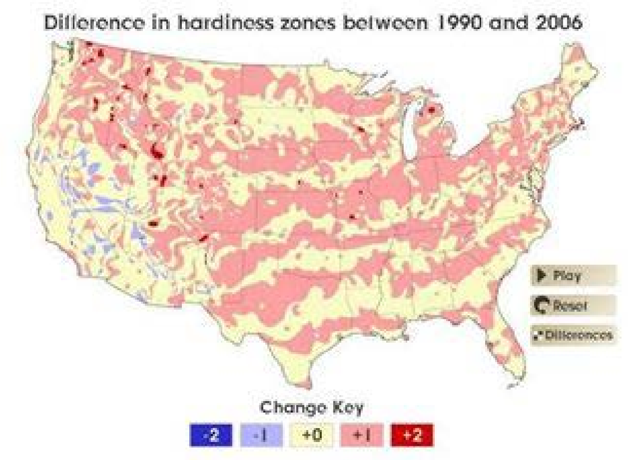

Figure 3-4 Difference in hardiness zones between 1990 and 2006. From Arbor Day Foundation (2012)

Extended growing season. Michigan's growing season has many implications. It is likely to both positively affect certain crops (e.g. grapes) and negatively affect others (e.g. pumpkins). When the growing season is prolonged, pests and diseases are able to survive and thrive in warmer conditions. A study that was conducted by crop scientists at the University of Illinois focused in on the pest, *Phytophthora capsici,* and pumpkin production. The findings indicated that pumpkins and peppers were the most susceptible hosts to the pest. The pests were more virulent on the jack-o-lantern pumpkin in particular (Tian & Babadoost, 2004). This directly affects pumpkin patches and other farms that rely on seasonal activities such as small-scale farmers and markets that sell locally made pumpkin pie, cider, and donuts. Many other diseases are better able to survive in warmer climates. The diseases that affect squash production (e.g. pumpkin production) also include powdery mildew which occurs when there is warm weather coupled with high humidity, rainfall or dew, all of which we expect to see with the changing climate in Michigan. Other diseases that affect the yield of specialty crops are *Pseudomonas syringae pv. Lachrymans* (spotting on leaves), *Didymella bryoniae* (fungus that causes black rot or gummy stem blight), and *Pseudoperonspora cubensis* (plant shrivels and then dies) (Bachmann 2003). Michigan is one of the top producers of pumpkins, which are mostly used for processing and fresh, but also for u-picks (e.g. pumpkin patches). If warmer winters contribute to pests and diseases then the Michigan pumpkin production could be impacted.

Another consequence of an extended growing season is the decline of pollinators. Warmer average temperatures can directly affect bee behavior as well as physiology (Bianco, Cooper, & Fournier 2014). It could be harder for the bees to reproduce and navigate. In addition, it is predicted that change in their environment can increase competition amongst other species and races of bees thus straining the resources (LeConte and Navajas). Pollinators are valued at almost $57 billion dollars annually (Losey & Vaughan 2006). Michigan's crops heavily depend upon honeybees and wild bees to pollinate crops such as apples, blueberries, cherries, cucumbers, dry beans, peaches, pears, plums, soybeans, pumpkins and squash. With the decline of pollinators, farmers have to face the increasing costs of commercial pollination services thus driving the cost customers have to pay.

The economic impact of pumpkin production is significant. It is estimated that in 2018 alone, the value of pumpkin production in Michigan was almost 15 million dollars (United States Department of Agriculture, 2018). If pests and diseases increase with the warming winters and extended growing season, then Michigan might expect yield or quality to decrease. The result will hurt small farmers more than large companies such as Libby's, the largest corporate producer of pumpkins who is also affiliated with Nestle (USDA, 2018).

Farmers markets

Farmers markets are unlike corporate, 'A & P' style grocery stores in a sense that they provide fresh, local food as well as providing a place for communal events and leisure time. Farmers markets will be impacted by the increase of temperatures and the changing climate because they rely on the growing season, the temperatures, and frost and thaw dates. It is hard to say whether these changes will be positive or negative, but nonetheless they are changes that Michigan will face in the future. If climate change impacts the local food system in the following ways Michigan would expect to see a shift in the $6.1 billion local food industry (Low et al. 2015). In addition, Michigan State University researchers calculated that Michigan's food system not only generated $63.7 billion in economic activity, but it also supported around 1.05 million jobs (Krieger 2009). The agri-food system is approximately second to the automobile industry being the highest gross state product (Krieger 2009). Climate change has to ability to affect this sector. The vulnerabilities listed below are subject to change and are not definite. It is likely that climate change can negatively affect certain areas of the local agricultural system while also positively affecting certain areas.

Change in frost and thaw cycles. A disruption that comes along with an extended growing season in Michigan is changing frost and thaw dates. More regions in Michigan are projected to have an average temperature that is close to the freezing point during the years 2041-2070. This implies that there will be a frequent cycle of freezing then thawing, freezing then thawing etc. (Mallen 2018). The freezing-thawing cycle will change the means of production as well as negatively affect produce sold at the farmers market since it is likely that the majority of crops will die after a frost. If the current warming trend continues in Michigan, and the first fall frost date occurs much too later or the last frost date occurs much too early, then we would expect to find a very unstable market around Michigan's local food production (Schultze 2015). Already, small Michigan farms are in competition with large scale, industrialized and technologically intensive farms. Climate change is most likely going to favor larger farms as opposed to small, 215-acre farms that make less than $10,000 per year (Che, Veeck & Veeck 2005). An unstable market around food is a common stressor amongst farmers who report depression or suicidal thoughts. Other stressors that one may find more prevalent in farmers as climate change continues include physical environment, bureaucracy, family structure and uncertainties in farming (Torske, Hilt, Glasscock, Lundqvist, & Krokstad 2016). It is not yet proven whether these are simply general occupational stressors. Anxiety and depression is much higher than any other occupation (Torske et al. 2016). Either way, it is something that is a concern within the agricultural field and local food production in Michigan.

Increase in precipitation. The expected increase and variability of precipitation is highest in the spring, which could lead to frequent flooding therefore damaging certain crops such as different varieties of squash and dry bean producers. For example in 2015, Michigan experienced heavy rains in June that affected the growing of about 25% of beans; this is significant since the production of beans bring in $250 million to the local economy (Carmody 2015). The expected increase in shown in Figure 3-5.

Adaptation and Mitigation. The changes and vulnerabilities listed above all affect the local food supply. Food prices will fluctuate with the yield, which is dependent on the weather. This raises the question "who will be affected by higher prices of food and/or the change in Michigan's local food supply?" First off, it directly affects farmers who are trying to make a living solely on their yield. Secondly, it directly affects those who are low-income and SNAP users in which the large demographic consists of elderly, single women, and minorities. So how can Michigan adapt to these changes in order to ensure food insecurity is not affecting more people? According to Cheftel, J.C. (2010), the key to mitigation and adaptation is to use technology and new forms of political government. Technology such as GMOs and agrochemicals can be beneficial for some crops as they face climate change, but Cheftel says there are many risks with intensive biotechnology such as increase use of pesticides, bacteria resistance, soil erosion, water contamination, and environmental pollution, which would only exaggerate the effects of climate change (Cheftel 2010). Since globalization, the food prices in the United States are competitive with countries around the world, which could either increase or decrease the cost of food in

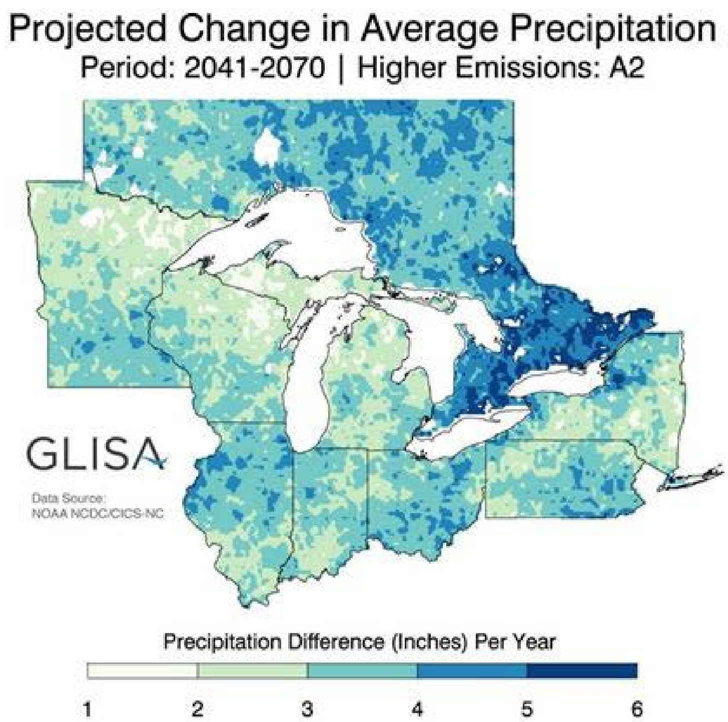

Figure 3-5 Increase temperature in the Midwest. From GLISA/NOAA

Michigan. In order to adapt to this, the increase of international trade agreements should be fair and take into account the effects of climate change (Cheftel 2010). In order to adapt to the changing climate, Michigan farmers should also turn towards drought-tolerant crops such as alfalfa and sorghum.

Outdoor and indoor festivals

Michigan is home to more than thousands of annual festivals, most of which occur during the summer months. Festival and events not only bring out Michigan residents but out of state residents as well for more of the major events. About 4.5 million attendees participated in Michigan county and local fairs and contributed to the local economy (Ginsberg-Schultz 2015). If climate change reduces the number of fairs because of increased temperature and periods of drought, then the local economy could be severely impacted. However, if more people migrate to Michigan because of its ability to better adapt to the changing climate, festivals and events could be positively impacted.

Increase risk in criminal activity. There seems to be a correlation between higher temperatures and criminal activity. Although, only some would argue that there is not a significant correlation between the two. Others, such as Ranson (2014), a data science manager who holds a PhD in public policy from Harvard University, argues that increase in temperature results in a strong positive effect on crime. Figure 3-6 illustrates the severe impact that climate change and crime could potentially have in the United States. The cost of need to increase security will affect everyone.

Warmer temperatures are generally linked to increase of crime because hotter temperatures tend to illicit irritability and anger (Agnew 2001). It might also be the case that more people are outside during hotter days which exposing them to criminals (Agnew 2011). This is important because it will affect the way festivals and events operate in regards to security. In addition, some people might have increasing fear about going to large public events because of either perceived or real threats.

Criminal activity	# of possible cases in the United States
Murder	22,000
Rape	180,000
Assaults (aggravated)	1.2 million
Assaults (simple)	2.3 million
Robberies	260,000
Burglaries	1.3 million
Larceny	2.2 million
Vehicle Theft	580,000

Figure 3-6 Expected number of crimes due to higher temperatures in the United States 2010-2099. From Ranson (2018)

Increase temperatures: heat waves, energy usage, blackouts and public health.

Extreme heat days and heat waves will most certainly affect how and when festivals and events are scheduled. Within the next fifteen years, Michigan is most likely going to witness hotter days, which will increase the need for energy to cool buildings off and keep people safe from the heat (Lopez et al., 2018).

Furthermore, Wagner et al. (2018) conducted a survey that detailed the correlation between people's motivation to engage in outside activities and weather conditions. They found that half of Americans (51.8%) would delay their summer activities because of too hot of temperatures and about 43.9% of Americans would delay their winter activities due to challenging weather conditions (Wagner et al., 2018). Hotter summers could mean some people opting out to go to outdoor festivals and events. The kind of economic effect this would have is not certain. It highly depends on how hot temperatures actually will be and people's perception of extreme heat.

Adaptation and mitigation. Increasing the need for air conditioning indoor festivals and events could lead to an increase risk of blackouts. Since energy is needed to cool down areas during the summer months at outdoor and indoor events, blackouts could be more frequent if Michigan does not adapt to the increasing consumption of energy (Kenward & Raja 2014). Michigan heavily relies on importing most of its energy needs. Approximately 97 percent of Michigan's petroleum is imported; 82 percent of natural gas needs and all of its coal needs are imported (Michigan Public Service Commission 2011). Ways that Michigan can adapt to increase of energy demands include use of renewable energy (e.g. solar and wind), green roofing, cut emissions and decrease need for coal. Renewable energy will decrease our risk of using too much energy from the grid (Michigan Public Service Commission 2011). Being energy independent can provide more jobs as well as providing energy needed for entertainment, industry and residential use. Green roofing is another effort that can be made to mitigate heat waves and reduce energy consumption. Green roofing is the installation of green rooftops on buildings that help reduce temperatures in urban areas by as much as 5.5 degrees Fahrenheit (Andresen, Hilberg, & Kunkel 2012). Some argue that providing technology and implementing the infrastructure to do this will be too costly, but the consequences and effects directly and indirectly from climate change could be more costly in the long term.

Major Attractions

Without tourism, Michigan's economy would not be as strong. Tourists spend about $120 a day on average at their destinations. About 80% of the money spent is captured by local economies (Karetnikov, Ruth, Ross, and Daraius 2008). Of these tourists, most come to see the natural environment that Michigan has to offer which includes beaches, islands, national parks, dunes, waterfalls, and nature reserves. It is estimated that 3.5 million Michiganders, or more than a third of the population, participates in wildlife watching, fishing and hunting (Karetnikov et al 2008).

Sleeping Bear Dunes

Sleeping Bear Dunes is located near Lake Michigan and attracts 1.7 million people per year on average. It is another great source of economic strength in Northern Michigan as visitor spending averages about $183.1 million dollars (National Park Service 2016). Visitors engage in dune climbing, bike riding, kayaking, canoeing, boating, swimming and spending time at the beach. Climate change has the potential to change the tourism surrounding Sleeping Bear Dunes in the following ways.

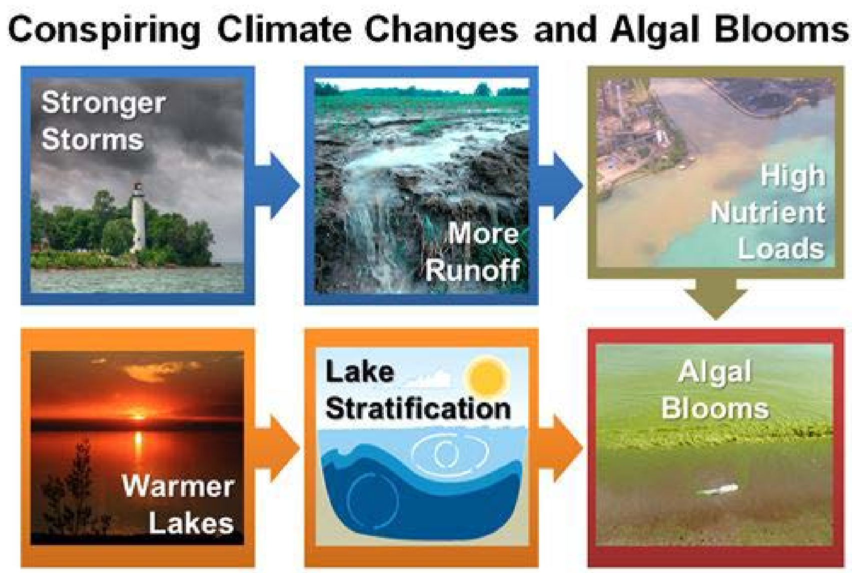

Figure 3-7 How climate changes affect and encourage algal bloom. From GLISA/University of Michigan

Shoreline change. Sleeping Bear Dunes consists of around 100km (64 miles) of mapped shoreline. Within the coming decades, coastal changes linked to climate change are expected. It is estimated that thirty-seven percent of the shoreline is at very high change potential; twenty-three percent is considered high; eighteen percent is considered moderate; and nineteen percent is considered low (Pendleton, Thieler & Williams 2007).

Algal blooms. Primary productivity in Lake Michigan is the foundation of the food web and ecosystem. The future projection in Lake Michigan is longer ice-free periods and higher surface water temperatures meaning that there will be an increase in primary production (Brooks & Zastrow 2002). According to Johnson et al (2003), an increase of 10 degree Celsius would lead to a four-fold increase in primary production. This is concerning since an increase in primary production, if not controlled, will result in degraded water quality and, in worst-case scenario, algal blooms, as shown in Figure 3-7. If Lake Michigan experiences more algal blooms in the future, it might affect tourism and recreation in that area which also includes Sleeping Bear dunes.

Economic impact. Sleeping Bear Dunes brings in about 1,678,126 people per year. Those people spend around $177 million in communities near the park adding about $121.2 million of value to the area (Thomas, Koontz, & Cornachione 2017). If tourism declines due to the change in climate, North Michigan could lose economic value. In addition, the immediate costs of algal blooms include monitoring and testing, conducting risk assessments, and treatment of the water (Steffensen 2008). The long term costs are loss in tourism generated revenue and environmental disruptions (Steffensen 2008). Ways to mitigate and adapt to increase in frequency of algal blooms is to create small storages that reduce the light; this costs around $7.1 million dollars for a couple of storages (Steffensen 2008). Another, yet harder, way to adapt is to divert runoff away from lakes and rivers so that the chances of an algal bloom from occurring are reduced (Steffensen 2008)

Tahquamenon Falls

Warmer temperatures. As mentioned, based on current scenarios, Michigan is expected to see an increase to about five degrees Fahrenheit within the next 50-60 years (Bradley, Karmalkar, and Woods 2018). With this, comes shorter winters. Evidence for this is in the fact that March river flows were increasing and the date of peak runoff is earlier (Waybrant & Zorn 2008). The prediction is that there will be an increase in tourism.

Fishing recreation. Fishing is a large part of the local economy as it is responsible for thousands of visitors annually. Seasonal flow stability in Michigan Rivers is high mostly due to permeable glacial drift deposits that cover most watersheds (Waybrant et al. 2008). That being said, there is much logging activity that affects fish communities (Waybrant et al. 2008). On top of that all, warmer temperatures allow invasive species to thrive and it has been a problem in the Tahquamenon Falls area specifically Eurasian milfoil, dandelion, loosestrife, autumn olive, and zebra mussels (Waybrant et al. 2008).

Pictured Rocks National Seashore

Increased temperatures effect on dissolved oxygen in lakes. As mentioned before, increase in temperatures that allow the surface temperature to warm to a certain extent increases primary production (Johnson et al. 2003). Not only will increased temperatures increase the probability and frequency of algal blooms occurring, but also the increase of precipitation causes increase runoff. Increased runoff accounts for a major driving factor in algal blooms since chemicals, fertilizers and other organic compounds are making its way into the water (Huff et al. 2014). Again, this is a major health concern particularly with a tourist attraction because dead zones take weeks, sometimes months, to clean up and restore back to normal.

Adaptation. Creating a Climate Action Plan could help Michigan adapt to the impacts climate change will bring. Reducing greenhouse gas emissions could counteract temperature increase and should be done through policies in order to ensure success (Huff et al 2014). In order to reduce the runoff of chemicals and fertilizers from nearby farms and industries, regulations and standards can be put in place to reduce the amount of chemicals used and dumped (Huff et al. 2014).

Isle Royale National Park

Forest change. Loss in biodiversity and forest changes kind of go hand-in-hand in a sense since species can die if their habitat (e.g. forests) is being altered. It is expected that by the end of the 21st century, summers in Isle Royale National Park could be as hot as recent summers in Wisconsin (Huff et al 2014). With this shift in climate, some species may not be able to adapt and survive. This may put a strain on tourism meaning that some people may not want to travel to a national park if it is not the same park, the park doesn't have the same species of birds to bird watch, the park loses its natural diversity etc. (Huff et al. 2014). However, the opposite could happen and warmer temperatures may increase the amount of tourists because of new species that arrived (Huff et al. 2014).

Pests and diseases. Ticks may show up earlier than normal as well as later than normal because of warming (Fisichell, Abella, Peters, & Krist 2014). This is important in regards to tourism because it could deter tourists from walking in the park or reduce the amount of people willing to take a risk. Not only will pests and diseases affect humans, but it also has the potential to alter the forest.

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Chapter 4 Water

Selena Chiparus, Austin Jackson, Eric Haas, and Christine Wysocki

Introduction

In addition to the Great Lakes, the state of Michigan is home to approximately 36,000 miles of streams and over 11,000 inland lakes (Giesen & Givens, 2016). These bodies of water hold a significant amount of the world's freshwater resource; the Great Lakes alone are one of the world's largest surface freshwater ecosystems, providing about 21% of the world's supply of surface fresh water (EPA, n.d.). Along with being a viable water resource for human populations, these bodies of water provide habitats for important biotic communities that contribute to many ecosystem functions and services. Many native populations are particularly adapted to historic conditions of Michigan's aquatic systems. With changing climate conditions, environmental pressures constantly force local species to make a choice; either they adapt to the new conditions, migrate, or diminish into extinction. In many instances this results in a requirement rather than a choice, as competition with better-adapted or invasive species for resources and space becomes intolerable for individuals dealing with more persistent stressors, such as increasing temperatures and extreme fluctuations of water levels.

Michigan currently faces challenges that threaten water resources, including flooding, drought, water quality degradation, varying water availability, storm water management, ecosystem impairment, and invasive species (Giesen & Givens, 2016). Unfortunately, climate change effects, inevitably altering important freshwater systems, will likely exacerbate these. Groundwater levels in many aquifers are declining due to decreases in natural recharge; as lake surface temperatures are rising, so are evaporation rates, depleting water from lakes (Safaie, Litchman & Phanikumar, 2017). Rainfall can also temporally intensify with increased temperatures, until the precipitation intensity exceeds the infiltration rate capacity and produces runoff (Froehlich, 1995). The trend towards more intense precipitation in late winter and spring has contributed to an overall increased risk of flooding (Bartolai et al., 2015). Ultimately, combined effects of climate change are expected to have varying impacts on Michigan's water resources.

Surface Water

Flooding

The Great Lakes provide the largest area of freshwater in the world (Michigan Legislature, 2001). Surface water is affected by the increase in average precipitation. The frequency of floods is likely to increase with average annual precipitation in most of the Midwest increasing between 5 to 10 percent. Extreme rainfall and flooding have amplified throughout the past century causing a decline in water quality, and impacts on other topics such as transportation, agriculture, human health, and infrastructure (U.S. Global Change Research Program). Since the 20th century, the Great Lakes region has experienced an increase in yearly precipitation by 11% (GLISA, n.d.). Flooding is hard to predict and can occur anywhere in cities and rural areas. A flash flooding event in Houghton, Michigan in the summer of 2018 caused property damage to roads, homes, and businesses, stranded residents in flooded homes, and caused the death of a 12-year old boy (Associated Press 2018; The Daily News 2018; Proto and Shapiro 2018). Referring to the incident as "what a natural disaster looks like," the Houghton City Manager at that time emphasized the importance of working together as a community (The Daily News 2018). Flash flooding is just one impact from increased precipitation.

Michigan's streams and lakes, along with the Great Lakes represent sources of drinking water, irrigation, waste management, and recreation. However, the abundance of surface water is also a source of vulnerability from climate change in terms of flooding, water contamination, and quality. In addition to one's proximity to bodies of water, households with private wells may be at increased risks for water-borne or respiratory diseases depending on water levels (Luber, 2014).

Contamination

Severe rainstorms allow the possibility of sewers to overflow into lakes and rivers, threatening drinking water supplies (EPA, 2016). "Heavy rains in August 2014 led to nearly 10 billion gallons of sewer overflows in southeastern Michigan, much of which ended up in Lake St. Clair and eventually Lake Erie" (EPA, 2016). The contamination of Michigan water systems raise concern for water quality, ecosystem health, public health and many other aspects of life in Michigan.

Storm water management

Sewer and storm water systems allow contaminants to flow into lakes and streams due to heavy precipitation increases from climate changes (Bartolai et al., 2015). With extremes in precipitation, the Great Lakes and surrounding regions are more at risk for issues surrounding storm water management (GLISA, n.d.). Extreme precipitation events are becoming more frequent and more intense in the Great Lakes region. The region's precipitation has a projected change of 37% (GLISA, n.d.), increasing the risk of storm water management problems. With U.S. infrastructure consisting mostly of impervious surfaces, a larger amount of surface runoff can be expected. With storm water drainage systems, we still experience unpredictable weather and extreme rainfall, which makes providing proper storm water management a vulnerable and difficult task (Yeowon, Eisenberg, Bondank, Chester & Mascaro, 2017). Whether we can improve future infrastructure, not knowing exactly how climate change will affect us will leave us at risk of providing essential structures to stand the extreme changes to Michigan's climate (Yeowon et al., 2017).

Groundwater

Flooding

Craig (2010) found that flooding could cause an overload to storm and wastewater systems, cause damage to water and sewage treatment facilities and increase risks of contamination in groundwater. Surface water flooding can increase groundwater while overfilling pore space and fractures in the ground resulting in the flooding of groundwater. While rainfall is transported through the ground, potential pollutant, nutrients, and carbon can accumulate in the groundwater from the surface water influencing water quality (Reiss et al., 2019).

Contamination

A multitude of contaminates from non-point and source point pollution can intensify in Michigan waters due flooding. PFAS in Lake Erie and Lake Ontario sediment have increased in the last 50 years contributing to climate change vulnerabilities with contamination of Michigan's Great Lakes (Codling et al., 2018). Lake Michigan, Superior and Huron have been exposed to fluorinated materials such as PFAS that indicate non-point source contamination in some areas (Codling et al., 2018). PFAS are found in all water bodies that continues throughout a chain reaction into the drinking water, fish, and then our food. Manufacturing was banned in 1979 although we see increasing rates in our water systems and destroying human and aquatic health (EPA, n.d.). More than fifteen communities across Michigan have confirmed PFAS contamination in the soil, groundwater or surface water (EPA, n.d.). Uncertainty shrouds the sites as residents worry about their health and property, and question whether their government is doing enough to protect them. PFAS is only one of many contaminates that can make its way into our groundwater faster with increased precipitation. Furthermore, increasing temperatures will reduce the amount of snowpack, cause an increase in snowmelt and result in degradation of water quality from concentrating pollutants (Craig, 2010).

Water depletion

If contaminants in groundwater do not biodegrade, the number of contaminants in aquifers may take thousands of years to reach a steady-state, which will have severe negative effects on access to fresh drinking water (Kornelsen & Coulibaly, 2014). Decreasing groundwater levels in Lansing, Michigan from the Great Lakes Basin may result in entirely dewatered aquifers in the area (Lofgren et al., 2002). It is predicted that climate change in the Great Lakes causing an increase in lake temperature will result in decreasing lake water levels due to increased evaporation (U.S. Global Change Research Program). While precipitation in the Lake Superior basin has remained relatively constant, evaporation increased and as a result, water supplies have been declining (Bartolai et al., 2015).

Policy

The Clean Water Act. The Clean Water Act creates the basic structure for regulating pollutant discharge into U.S. waters while regulating standards for surface waters (EPA, 2017). According to the EPA nonpoint source, pollution from agriculture became the primary source of contamination in 2009 although it is unregulated by the Clean Water Act (Craig, 2010). Per- and polyfluoroalkyl substances (PFAS) has been classified as a non-point source in some areas of the Great Lakes according to Codling (2018). This allows these contaminates to fall short of regulation by the Clean Water Act. Heat is a pollutant under the Clean Water Act, yet they fail to incorporate effects of climate change appropriately (Craig, 2010). US Court of Appeals for the Fifth Circuit recently accepted that the Clean Water Act does not block state law “with respect to global warming" (Craig, 2010) although it also does not provide critical regulations in collaboration with climate change impacts.

Social perspective. People in the United States and Michigan specifically are affected by climate change impacts and effects of contamination altogether. The Flint water crisis resulted in death and suffering of many people striving for clean and safe water. While people such as the people of the city of Flint are scavenging for freshwater supplies, corporations like Nestle are contributing to the overall shortage of lake water caused by climate change. Although removing the water from our Great Lakes is not the reason for climate change, taking away from what is already reducing will not contribute to any positive change from our warming climate. The implications dealt with surrounding these issues compare to issues we see caused by climate change. In these cases, increases in temperature were not the cause, however changes in climate will inflict similar burdens, which we should be prepared for to protect society and resume to a quality way of life regarding water usage.

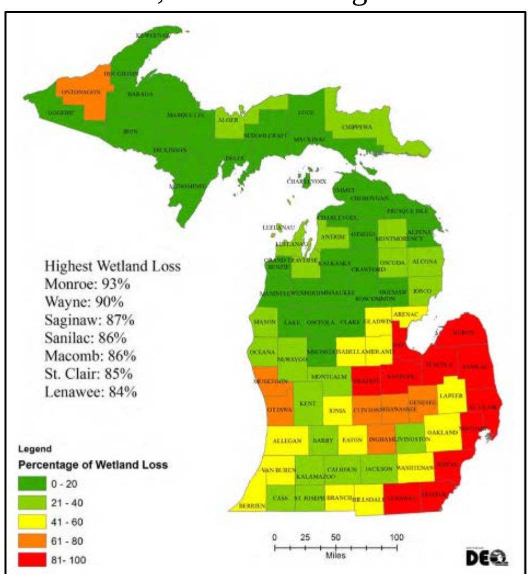

Figure 4-1 Wetland lost by county in the state of Michigan from 1800 to 2005. Green indicates 0-20% loss while red indicates 81-100% loss. From Williams (2015)

Wetlands

Wetlands, often out of the realm of public awareness, are one of the most important protectors from the effects of climate change. Roughly 33% of Michigan is comprised of wetlands; that number used to be around 55% before European land development and wetland draining, which occurred in the 1800's (Figure 4-1) (Williams, 2015). In this section what constitutes a wetland, how wetlands act as a safeguard against the threat of climate change, and climate change's impact on wetlands will be explored. Hopefully, after this section it will become evident that the state of Michigan needs to create more wetlands in order to combat the effects of climate change.

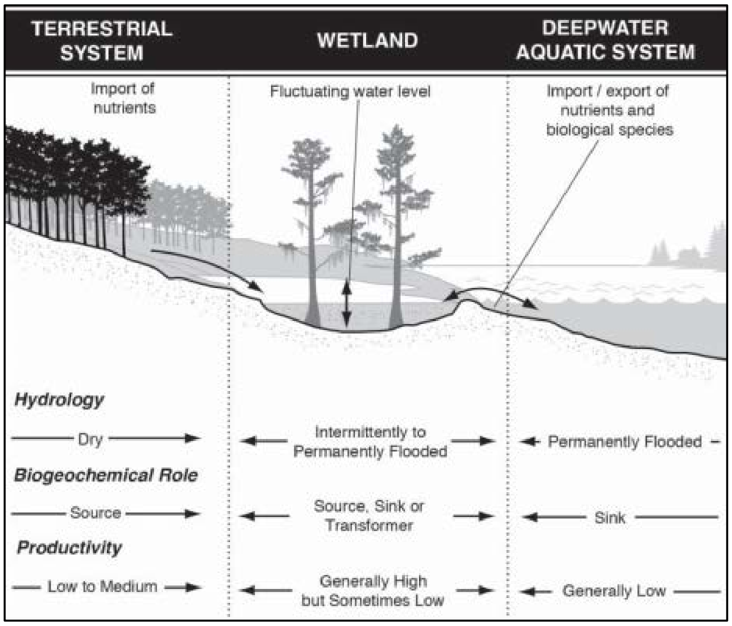

Figure 4-2 Wetlands are often situated in between the dry terrestrial system and the permanently inundated deep-water aquatic systems From Mitsch & Goesselink (2015)

Wetland definitions

It is imperative to be able to realize what comprises a wetland in order to protect one; the following is the definition of a wetland provided by the U.S. Fish & Wildlife Service. "Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification, wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes (plants specifically adapted to live in wetlands); (2) the substrate is predominantly undrained hydric (wetland) soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year" (Cowardin & U.S. Fish and Wildlife Service, 1979). (Wetlands are also found in what is known as a "transitional zone," an area in between the typically dry upland zone and the permanently wet aquatic zone. Figure 4-2 perfectly illustrates the difference in these zones and the differences in hydrology, biochemistry, and productivity. Next, how wetlands provide a range of services that help society, especially in this era of rapid climate change, will be discussed.

Wetland ecosystem services

The benefits that wetlands provide and create to society are called wetland ecosystem services, and they are divided into three categories: (1) *provisioning*, (2) *cultural*, and the most important concerning climate change, (3) *regulating*. Provisioning ecosystem services include the physical goods gathered from the ecosystem, such as food, water, wood, medicinal ingredients, etc. Cultural ecosystem services include the benefits people gain from the ecosystem, such as education, natural aesthetic, spiritual enrichment, recreation, etc. Regulating ecosystem services include flood regulation (Figure 4-3), carbon sequestration/climate regulation, water purification, disease and pest regulation, forest fire suppression, and air quality regulation (Mitsch & Goesselink, 2015). More extreme weather events will bring about an era of increased floods, limited availability of clean drinking water, and many more disastrous effects (GLISA). Hopefully by now it has become evident that nearly all of these negative effects listed can be mitigated through wetlands.

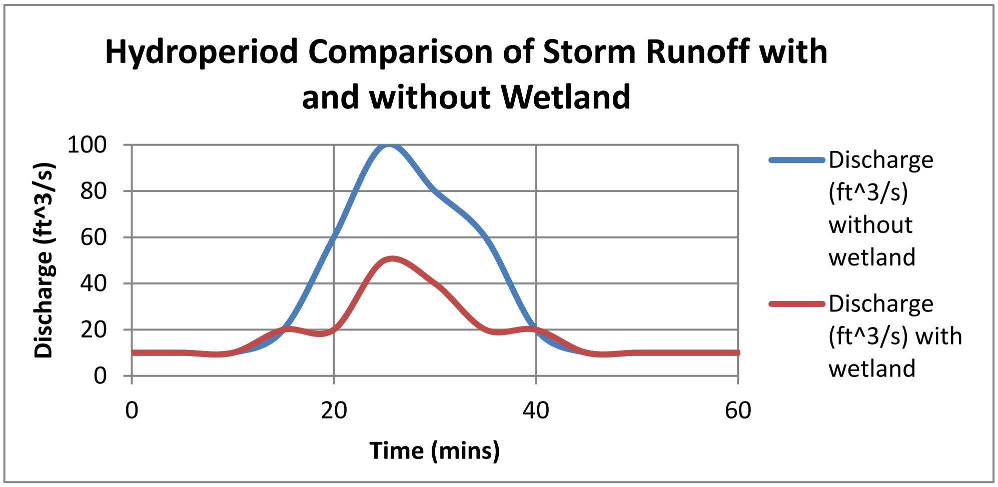

Figure 4-3 Hydroperiod example of how wetlands regulate flooding during a storm. The blue line indicates discharge (ft3/s) without a wetland while the red line indicates discharge with a wetland. Notice that the peak discharge at 25 minutes is minimized when a wetland is present.

Wetlands and climate change

Wetlands are extremely important for curbing the effects of climate change. Wetlands are only about 5-8% of the terrestrial Earth, yet they store about 830 teragrams (10^{12} grams) of carbon per year (Mitsch et al., 2013). This is why it is unfortunate that around the world and in

Michigan natural wetlands are being lost due to climate change and anthropogenic activities. In his term of the presidency, George H.W. Bush implemented what is known as the “no net-loss” policy. The policy’s goal is to mitigate the loss of wetland acreage by forcing any entity that converts or destroys a wetland, to replace it (Wittenberg, 2018). In trying to combat climate change in Michigan, policymakers need to implement a net-gain policy in wetland area. Second, there is no replacing the original wetland its function. The amount of carbon sequestration by a created wetland may never live up to the original or harbor the same biota (Mitsch & Goesselink, 2015).

In some cases, wetlands can be overrun by invasive species once created. Wetlands are excellent sinks, both of carbon and of seeds, which is why the biodiversity of a wetland is so vast. Consequently, increased carbon emissions along with a high influx of nutrients (due to mostly agriculture) in the wetlands can create a perfect environment for spreading invasive species. In turn, these invasive species usually grow tall and thick stands, blocking out sunlight to the native species, and spread toxic allelopathic chemicals in the soil, which disrupts germination and growth of

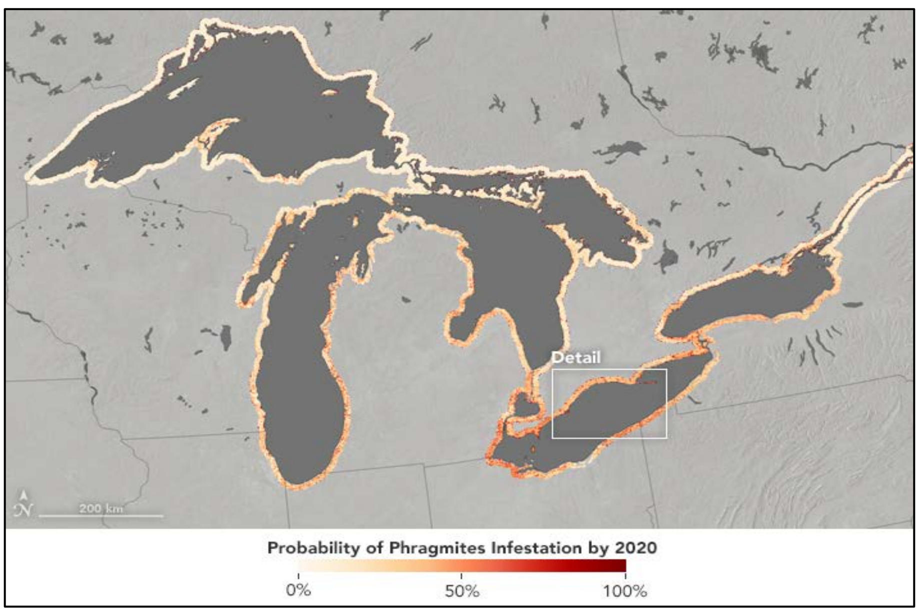

Figure 4-4 Probability of Phragmites australis infestation by the year 2020. From Using Satellites, 2017

other species. They spread quickly, sometimes taking over entire ecosystems. A good example of a species that acts this way is the *Phragmites australis* (common reed) (Figure 4-4).

Temperatures are gradually increasing as carbon emissions are rising. Consequently, higher emissions will cause days above 90°F to become increasingly more common in the mid-to-late century (GLISA; Hayhoe, 2013). If this occurs, Michigan's wetlands will most likely dry up due to increased evaporation. Michigan's peatlands are especially in danger; peatlands are comprised of Sphagnum moss, which is developed in the peatland by sequestering carbon, and need waterlogged soil to survive. If the increases in temperature persist, the peatlands will dry up, decompose, and release carbon dioxide. On a global scale, the amount of carbon that would be released if all of the peatlands decomposed would be around 100 petagrams (10^{15} grams) of carbon by the year 2100 (Mitsch & Goesselink, 2015).

The permanent inundation of soils in wetlands can also create problems with regards to climate change, potentially making the greenhouse even worse. The inundation of the soils creates reduced conditions (meaning anaerobic conditions) over time and with depth of the soil. The reduced conditions deplete all of the oxygen in the soil creating an anaerobic environment, which then sets into motion a series of biogeochemical reactions. Some of these biogeochemical reactions that occur end up producing methane, nitrous oxide, and hydrogen sulfide (Mitsch & Goesselink, 2015). Environmentally speaking this is bad because methane is a gas that is twenty-five times more powerful than carbon dioxide, nitrous oxide is about three-hundred times more powerful, and hydrogen sulfide is poisonous (EPA, 2019). However, there is one wetland management technique that can circumvent this creation of greenhouse gases and it is relatively simple; periodically flushing the wetland with new water will deliver oxygen to the soils and prevent these gases from being formed (Mitsch & Goesselink, 2015). If Michigan chooses to create more wetlands in order to combat climate change, this technique should be utilized.

Michigan's coastal wetlands are also in danger. Before European development, 369,000 acres of coastal wetlands existed in Michigan, now, that number is 275,748 acres. Michigan's coastal wetlands are rest on the levels in the Great Lakes and do not mature at the same rate as inland wetlands. In the next section, reasons as to why the Great Lakes' volume will diminish are outlined there, but lower lake levels will also have an effect on Michigan's wetlands. "Short term, temporary water-level fluctuations and long-term cyclic water level changes cause vegetation dieback, erosion and lateral displacements of vegetative zones which leads to the constant rejuvenation of coastal wetlands" (Christie & Bostwick, 2012). Essentially what this means is that if the Great Lakes dip below a certain level due to more evaporation, the coastal wetlands will have no way of being replenished and will eventually disappear.

The Great Lakes

Temperature

An enhanced greenhouse effect will trap more long-wave infrared radiation in the atmosphere. Some of that radiation gets absorbed by the oceans, which then heats them. However, ocean temperatures have been on the rise since the early 20th century; this leads to drastic effects on the ocean biota, which are not adapted to the warmer conditions, and more heat could potentially change the ocean circulation patterns (Liu et al., 2015). Similarly, the Great Lakes can be thought as miniature replicates of the oceans with regards to climate change, just much smaller and incredibly less saline. In a study published by the Journal of Great Lakes Research, the authors investigated how climate change and overall warming temperatures affected the temperatures and volumes of the Great Lakes. From this, it can be determined what the effects will be; future Great Lakes volume will be discussed later in the section. The study used climate data from over three-hundred weather stations along the region, future climate scenarios from the Intergovernmental Panel on Climate Change (IPCC) with the Special Report on Emission Scenarios (SRES), and the Atmosphere-Ocean General Circulation Model (AOGCM). With that, the authors were able to extrapolate future surface temperature changes, precipitation changes, the Great Lake's water level and temperature changes, on a scenario-by-scenario basis. In every emissions scenario, but varying in the severity of scenario, the Great Lakes could see an increase of temperature between the range of 2-6 °C (3.5-11 °F) before the end of the century. The higher emissions scenarios will yield higher changes in temperature, while lower emissions scenarios will yield lower changes in temperature (Hayhoe, VanDorn, Croley, Schlegal, & Wuebbles, 2010). They also found that temperature changes would vary greatly, depending on seasonality. "Initially, temperatures are projected to increase more rapidly during the winter season, possibly as a result of feedbacks related to melting snow. During the second half of the century, however, greater temperature changes are projected for summer months, exacerbating concerns regarding water availability. Larger temperature increases are also projected for the more southerly Great Lake states as compared to the northern part of the region" (Hayhoe et al., 2010). These increased lake temperatures, coupled with factors such as low wind and lake morphology, will increase lake stratification in the summer. Lake stratification is problematic for a few reasons. If a lake ceases to mix, the cold hypolimnion will eventually deplete all of the oxygen in the hypolimnion, causing the layer to become hypoxic (Figure 4-5). If this occurs, cold-

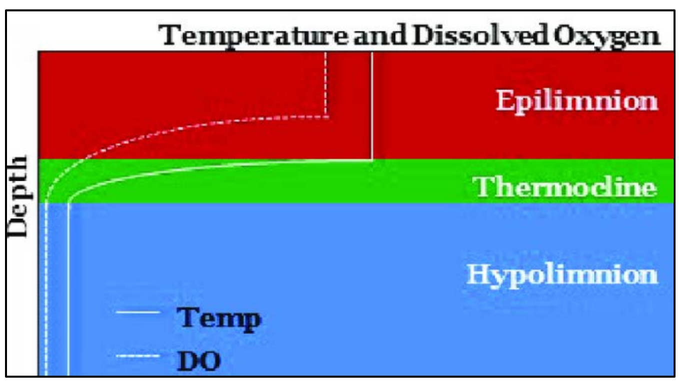

Figure 4-5 Typical layers of lake stratification. Temperature (solid line) and dissolved oxygen (dashed line) decrease with depth. From Medina (2017)

water fish and other organisms at the bottom layer will either have to move into a different layer or asphyxiate (Koretsky, MacLeod, Sibert, & Synder, 2012). Another implication of increased lake temperature is the intensification of the Great Lake-effect. Figure 4-6 displays the 2000 winter snowstorm intensified by the lake-effect, captured by NASA. Figure 4-7 is a diagram illustrating the mechanics of the lake-effect. In the winter, the polar jet stream has a chance of dipping down into the Midwestern United States. Warmer lake temperatures mean more lake evaporation, and when the polar jet stream crosses the lake, it condenses the water vapor and creates snow; this is known as the lake-effect. One study from the American Meteorological Society suggests that due to the rising lake temperatures, the lake-effect along the Great Lakes is intensifying. The authors' dataset used information from 1,230 weather stations to examine cold season snowfall, total precipitation, mean air temperature around the Great Lakes, and past and present data in order to find the general trend of how increasing temperatures are intensifying the lake-effect. They found that over the past eighty years during the post-industrial age, rising temperatures are yielding more snowfall. One caveat they noted however, was that by the end of the century, the lake-effect snow events would start to decrease significantly, as there will be fewer days below freezing (Burnett, Kirby, Mullins, & Patterson, 2003). They also make a few economic and social

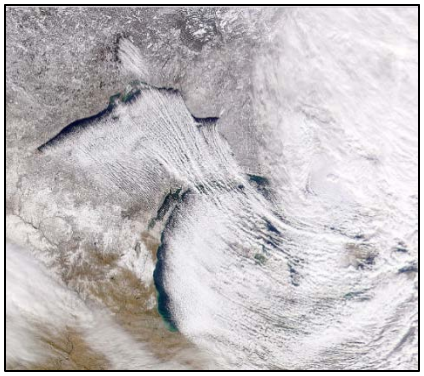

Figure 4-6 Satellite image of the Great Lake-effect on December 5, 2000. From SeaWiFS (2000)

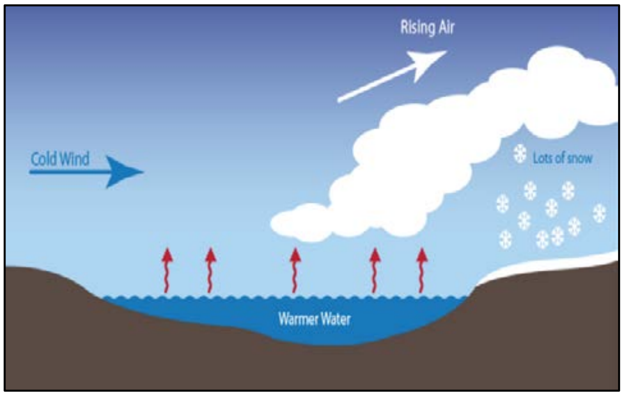

Figure 4-7 Diagram of the mechanics of the lake-effect. From Gaige (2020)

predictions in the discussion, warning that an intensified lake-effect in the region could cost hundreds of millions, if not billions of dollars in damage. Road maintenance, snow removal, spring flooding from increased river levels, reduced air and surface traffic, and agricultural damage would be the result of an increasingly intensified lake-effect (Burnett et al., 2003).

Volume

It is hard to tell exactly how people in the United States will react in the coming century to limited freshwater availability. There have already been several proposals to construct a pipeline that would drain the Great Lakes to accommodate the drier regions in the U.S. going through drought (Matheny, 2015). This has not happened yet, but when the West's water resource completely dries out, a suggestion such as draining the Great Lakes is certainly possible. If a proposal such as the one just mentioned were to be passed, it would have a serious effect on the Great Lakes' volume. This situation is merely hypothetical, however based on current climate modeling, researchers can make a more accurate estimation on the volume of the Great Lakes in the near future. There is some mixed news; the study by Hayhoe et al., (2010), also looked at estimating the future volumes of the Great Lakes. What they found was that while lake and surface temperatures were rising, causing increases in lake evaporation, the evaporation was balanced out by increasing precipitation events; the lakes will experience a no net-gain or net-loss in volume. However, the authors did find that near the late end of the century (2070-2099), under the high-emissions, no-change scenario, all of the Great Lakes could experience a two-feet drop since the evaporation rate would out-weigh the rate of precipitation (Hayhoe et al., 2010). Overall, lower lake volumes imply a higher concentration for pollution via sewage, prescription medicines, oil spills, and run-off of road salts and nutrients, making it more difficult to clean up.

Great Lakes acidification

Some of the high influx of carbon dioxide into the atmosphere is being sequestered into the oceans. This means that here on the surface, life does not experience the full effects of the greenhouse effect. Mixing carbon dioxide and water creates carbonic acid, or H_2CO_3. The carbonic acid can quickly dissociate, losing one hydrogen ion to create bicarbonate, $HCO_{3,}$ or two hydrogen ions to create carbonate, CO_3. The more hydrogen ions that are lost in dissolution, the more acidic the water becomes. This also means that the more carbon dioxide put into the oceans, the more hydrogen ions will be lost, and therefore will reduce the water's pH. Many oceanic and lake organisms are made up of calcium carbonate ($CaCO_3$) or aragonite ($CaCO_3$), and their shells or structures will dissolve if they're in a solution comprised of bicarbonate (HCO_3). Ocean acidification combined with global warming spells disaster for underwater life. Ocean acidification is causing coral reefs to undergo coral bleaching, fish immune systems and metabolism are being affected, and as mentioned earlier, the shells made up of $CaCO_3$ are dissolving (Andersen, 2016). With all that in mind, there is reason to believe the Great Lakes are also undergoing similar acidification. A study published by the Oceanography Society looked into this phenomenon. The authors used the US EPA's biannual survey of the Great Lakes, which surveys 8 – 20 sites per lake, and measured pH, alkalinity, and temperature at four depths per site, in order to extrapolate the pH levels to the year 2100. The authors also utilized various climate scenarios from the IPCC, like the IS92a (the business as usual scenario) and the A1FI (the fossil fuel intensive scenario) in order to estimate how much atmospheric carbon would be sequestered into the lakes. While all the lakes had varying degrees of pH changes due to size, composition, and geography, the researchers concluded that the Great Lakes are projected to see decline in 0.29 – 0.49 units by the year 2100. One example they cite references decreased pH levels describes how they could potentially kill off tons of phytoplankton, which would then improve water quality but would also harbor better conditions for nuisance algae, such as cyanobacteria (Phillips et al., 2015).

Great Lakes eutrophication

"Eutrophication, or hypertrophication, is when a body of water becomes overly enriched with minerals and nutrients which induce excessive growth of plants and algae. This process may result in oxygen depletion of the water body" (Chislock, Doster, Zitomer, & Wilson, 2013). There is evidence that the combination of rising temperatures and changes in water volume will lead to the rise of cyanobacteria, or blue-green algae; cyanobacteria are the algae responsible for creating harmful algal blooms and hypoxic dead-zones (Figure 4-8). A report published by Harmful Algae researched factors such as temperature, stratification, pH, CO_2 concentrations, rainfall, storms, and nutrients to determine what promotes cyanobacterium growth. They found that increased temperatures, increased stratification, increased precipitation, and higher nutrient concentrations promote the growth of blue-green algae. Decreased pH and CO_2 concentrations had conflicting evidence from various other studies as to whether or not they promoted cyanobacteria growth (O'Neil, Davis, Burford, & Gobler, 2012). It is likely that if these effects persist, eutrophication of the Great Lakes will only get worse.

Figure 4-8 Satellite Lake Erie eutrophication and toxic algal bloom. From Borre (2013)

Inland Bodies of Water

Inland lakes

Over the past half-century, the average annual air temperatures have increased by 1.3 C in the Great Lakes region, while water surface temperatures have been increasing at a slightly higher rate (GLISA 2019). These increases contribute to changes in other physical properties of water, such as ice coverage. Small inland lakes currently experience roughly 90-100 days of ice cover, although past records suggest a declining trend that will likely continue into the future (Kling et al. 2003). The freeze period of these lakes has shifted to begin later in the fall, while the ice-out period is occurring earlier in spring, increasing the overall frost-free period by 16 days (GLISA 2019).

Inland lake water levels will likely be influenced by increasing extreme weather events; heavier precipitation and intense drought periods are likely to become more common in the future, as annual average precipitation and consecutive dry days continue to increase. Since the 1950s, total annual precipitation has increased by 13.6%, although land surfaces are expected to become drier due to the effect of warming on evaporation rates (GLISA 2019). There is potential for prolonged periods of environmental stress for organisms that are not adapted to extremely dry or wet conditions, as well as resulting property damages from severe storms, consequences that are discussed in later sections. Increasing summer evaporation rates from lake surfaces can decrease water levels; hence small, shallow lakes plunge into the risk of disappearing if dry periods persist long enough (Manguson et al. 1997).

Streams

Certain streams in Michigan follow an opposite pattern for changes in water and air temperatures compared to inland lakes (Woznicki et al. 2016, GLISA 2019). Increases in summer stream temperatures are expected to be smaller than changes in air temperature, although the difference is significant enough that it translates into shifts in the thermal classes of streams. Streams are typically categorized based on temperature and size. Thermal classifications are determined by mean water temperatures from July; cold streams are typically equal to or less than 17.5°C, cold-transitional streams are between 17.5°C and 19.5°C, cool or warm-transitional streams are between 19.5°C and 21.0°C, and warm streams are greater than 21.0°C (Zorn et al., 2008). Temperatures are projected to increase 0.81-0.82 °C for cold, transitional, and warm streams (Woznicki et al., 2016). Although the temperature changes will be relatively uniform for most stream types, thermal class will have a significant influence on an individual stream's response- transitional streams have relatively narrow temperature ranges; therefore, a large temperature change is not required to shift the stream's thermal class. Additionally, streams can be influenced by their sizes. There are certain size classifications used; streams are a segment catchment area less than or equal to 207 km^2, small rivers are a segment catchment area between 207 km^2 and 777 km^2, and large rivers are a segment catchment area larger than 777 km^2 (Zorn et al., 2008). Zorn et al. (2008) revealed that smaller catchments of water are more vulnerable to water level fluctuations, especially in relation to fish assemblages.

Streams will be faced with changes in ice coverage, precipitation, water levels and dry periods similar to inland lakes (Kling et al., 2003). The persistence of increased temperature, increased evaporation, and lower summer water levels can alter the local hydrologic cycle, reducing groundwater recharge and stream discharge of certain streams, while certain areas will experience more precipitation, specifically during spring, increasing the potential for seasonal floods and excess surface runoff (Kling et al. 2003). Furthermore, Kling et al. (2003) discusses that as extreme weather events are expected to intensify, more frequent floods at larger magnitudes and the excessive amounts of runoff can in turn increase erosion and pollutant inputs from uplands into important freshwater supplies, while simultaneously diminishing nutrient retention within streams by increasing flow velocity and peak flow during these periods. Future predictions indicate that precipitation will increase on average, but not necessarily during all seasons or locations depending on the model used (GLISA 2019). Certain areas and seasons in Michigan may experience heavier precipitation events, while others will have prolonged drought periods, therefore spatial and temporal considerations are necessary when assessing the impacts of increased temperature and precipitation.

The projected temperature increases for North and South Michigan are quite different, although they do follow past changes. Temperature increases were greater during the winter and spring in the southern Michigan and during the winter and fall in northern Michigan (GLISA 2019). These patterns are expected to continue into the next few decades, although changes will become more evident. GLISA (2019) also displayed a persistent pattern in precipitation that follows past increases, with the most pronounced change in southern Michigan, as well as fall and spring seasons. It is also expected that the Lower Peninsula will experience more consecutive dry days. This evidence indicates that the changes in temperature and precipitation will have impacts on Michigan's inland bodies of water that dependent on spatiotemporal aspects, so local mitigation efforts to curtail these changing conditions may be preferred over nation-wide regulations.

Inland water communities

The most likely outcome for streams in Michigan is community shifts as temperatures increase. As mentioned previously, thermal profiles of streams are likely to shift in Michigan streams as temperatures increase (Woznicki et al. 2016). River systems will transition from cold-water fish communities to cool- and/or warm-water fish communities. Water temperatures are expected to increase by 0.19-5.94 C in 30 cold-water streams within Michigan over the next 40 years (Carlson et al. 2017). In particular, the Muskegon river system is expected to shift from cold-water fish communities to warm-water fish communities during the next century, with declines in Coho salmon and brook, brown, and rainbow trout (Steen et al. 2010). Since rainbow trout have a wider temperature range compared to brook and brown trout, the species may adapt better to future warming (Carlson et al. 2017).

Different populations of a species can also vary in tolerance to climate change depending on stream type and location. The water levels of certain streams are expected to decrease with projected climate change effects (Kling et al., 2003). Brook trout assemblages in cold-transitional streams tend to be more vulnerable to stream flow reduction compared to cold-water brook trout (Zorn, Seelbach, and Rutherford, 2012). Additionally, the exposed streambanks resulted in significant declines in mayflies, caddisflies. This is significant as the community structure of benthic invertebrates can determine a stream's health (Mehler et al., 2015).

Public Health

One of climate change's effects on water that humans feel every day is the impact it has on public health. A variety of public health risks have already risen and the potential for more is growing. Public Health is defined as the protection of safety and improving the health of communities through the lens of a multitude of disciplines (University of Pittsburgh, 2019). The health impacts of climate change on Michigan's water system are vast and harsh, its effect's Michigan's public health through extreme precipitation, flooding, and waterborne disease.

Extreme precipitation

The first way climate change is affecting human health through water is with extreme precipitation. Extreme precipitation is a statistical concept that can be defined differently depending on the location and season of the rainfall. It is a term used to describe precipitation that has exceeded what is normal in this paper (Pendergrass, 2018). GLISA states, "Most directly, changing extreme precipitation events will affect storm water management, water quality, and public health." Precipitation in Detroit Michigan has increased at a rate of 0.86 inches per decade from 1960-2019, Grand Rapids has increased at a rate of 0.77 inches per decade since 1960, and Sault St. Marie has increased at a rate of .04 inches per decade since 1960 (National Oceanic and Atmospheric Administration, 2019). These three cities are positioned at distant locations from one another, representing the eastern, western, and northern, areas of Michigan. All three show an increase in precipitation, Detroit and Grand Rapids showing notable changes. Sault St. Marie shows minimal change, meaning extreme precipitation may not be affecting the northern part of the state's public health as drastically as it is the lower, more populated areas. Climate Change causes precipitation extremes through rising global surface temperatures, which increases evaporation, and add water vapor to the atmosphere, with more heat and more moisture, the key ingredients to storm development are more abundant (GLISA, n.d.). GLISA also states that the increase in extreme precipitation is one of the clearest climate changes observed in the Great Lakes region, the most intense precipitation events have become stronger and more frequent. In the first percentile of most extreme precipitation events, the precipitation falling has increased by 37% (GLISA, n.d.). One main issue to public health associated with extreme precipitation in Michigan is mold growth. Mold growth occurs when there is moisture from water damage, excessive humidity, water leaks, condensation, water infiltration, or flooding. (GLISA, 2015). Exposure to mold has been linked to respiratory issues, coughing, and wheezing in healthy people, and more intense symptoms for asthmatics (GLISA, 2015). The ways that public health is affected by these precipitation extremes are shown in the next two sections, flooding, and waterborne disease. More than half of all waterborne disease outbreaks in the United States occur in the aftermath of heavy rain (Earthwise, n.d.).

Flooding

The changing climate is causing an increase in the frequency of flooding in Michigan rainfall during the four wettest days of the year has increased about 35 percent of the past 50 years. Spring rainfall specifically is likely to increase most, meaning the risk of flooding will be most relevant during that time (EPA, 2016b). The highest increases in extreme precipitation are happening in Detroit and Grand Rapids areas, these are the two most highly populated areas of

Michigan, so it puts a considerable number of people and communities at a high public health risk. The effects of flooding will be most heavily felt in areas where the infrastructure is aging, Detroit is one of these areas (University of Maryland Center for Integrative Environmental Research, 2008). Recent flooding events have been especially harsh in Michigan's most populated areas. In 2013 there was historic flooding from the Grand Rapids River, affecting many homes and businesses in the Grand Rapids area. The city of Detroit had to deal with much greater amounts of damage than usual in 2014 (State of Michigan, n.d.). The Grand River Flood was one of the most concerning flood disasters in recent years. Although there were no fatalities, over 1200 homes were flooded and over 300 roads were forced closed, the damage was estimated to be in excess of 43 million dollars (US Department of Commerce & National Oceanic and Atmospheric Administration, 2018). The primary health-based environmental indicators associated with flooding, are infections caused by waterborne pathogens and water-based disease vectors; contact with polluted water that contains the outflow of overwhelmed sewage systems, petroleum products, toxins from built environments, uncollected garbage, and dead animals; and respiratory and neurological diseases caused by mold that forms in damp structures (Singer, 2009). Flooded buildings can experience mold growth that can trigger asthma attacks and allergies during cleanup efforts (Chew et al., 2006). Mental stress following flooding events can cause substantial health impacts, including sleeplessness, anxiety, depression, and post-traumatic stress disorder (Adeola, 2009). Cleanup from excessive rain and flooding can lead to carbon monoxide poisoning from power washers and heaters (GLISA, 2015).

Waterborne disease.

Waterborne disease is a great risk anywhere, but it is even direr in Michigan where the Great Lakes serve as a drinking water source for more than 40 million people (Patz et al. 2008). Waterborne disease comes from a combination of factors including contamination of the source water, transport of the contaminant to the water intake or well of the drinking water system, insufficient treatment to reduce the level of contamination, and exposure to the contaminant. Waterborne disease comes about through large rain events, which can overwhelm drinking water systems, causing untreated sewage mixed with storm water to be released directly into receiving waters. The U.S. Environmental Protection Agency (EPA) has estimated that 770 communities release more than 3.2 trillion liters (850 billion gallons) of combined sewage to the nation's waterways annually (Patz et al., 2008). Aside from drinking water, heavy runoff after severe rainfall can also contaminate recreational waters and increase the risk of human illness through higher bacterial counts (Patz et al., 2008). More than 100 different types of pathogenic bacteria, viruses, and protozoa can be found in contaminated water. Many of these have been implicated in a variety of illnesses transmitted by food or water (Patz et al., 2008). Deteriorating urban water infrastructure, intensified livestock operations, and extreme climate change-related weather events are creating a very harmful risk to humans through waterborne disease (University of Wisconsin, 2008). In 2016-2017, there were three separate waterborne disease outbreaks in Detroit alone. (Gaines, 2017). Contaminated water from infrastructural damage can carry a range of toxins and pathogens harmful to humans. Extreme precipitation and flooding can increase the geographic range of disease-carrying insects and dangerous molds within houses (GLISA, 2015).

Economy

Climate change has an effect on Michigan's economy in a vast amount of ways. This section will focus on how climate change's effect on Michigan's water impacts their economy. The costs it has ranges from an individual level to community-wide to statewide. With impacts to the Great Lakes, climate change creates economic effects on the entire Great Lakes Region. This section will describe climate change's impact on water infrastructure (shipping and wastewater), water resources, and Agricultural production.

Shipping infrastructure

Four of the five Great Lakes surrounds Michigan, which is home to 40 commercial shipping ports (University of Maryland Center for Integrative Environmental Research, 2008) and access to the St. Lawrence Seaway, which allows shipping to the Atlantic. The State of Michigan issued a report in 2017 stating, "For the past decade many of Michigan's in-water navigation channels have not been maintained, limiting the efficiency of ports across the state." (21st Century Infrastructure Commission, 2016). One of the biggest ports is the Soo Locks, which passes 80 million tons of commercial commodities annually (American Society of Civil Engineers, 2018). In order to repair the infrastructure, A 2015 Department of Homeland Security study stated that a 30-day unscheduled closure of the Soo Locks would cost the industry $160 million and a breakdown lasting six months would cripple the United States economy with 11 million jobs lost (American Society of Civil Engineers, 2018). Even without future effects of climate change that costs related to Michigan’s shipping infrastructure are massive. Extreme weather will increase in Michigan due to climate change, The EPA states that extreme weather will affect the reliability and capacity of shipping systems (EPA, 2016a). Aside from this shipping emits a large number of fossil fuels and further advances the impact of climate change. Many conceptual designs and ideas are being developed which could be used to reduce or eliminate the need to use fossil fuels as a primary power source for ships, however, the cost of creating these ships will be steep (Wright, 2013). With fluctuating water levels, a lot more dredging has been necessary, and at the rate we are on right now, dredging Michigan's shipping routes would cost between 92 and 154 million dollars annually by 2030 (University of Maryland Center for Integrative Environmental Research, 2008). If water levels continue to fluctuate as projected system connectivity along the Great Lakes-St. Lawrence route will decline by around 25 percent (Great Lakes Regional Assessment Group 2000). This could cause an annual economic loss of almost $1.5 billion in foreign trade for the ports of in Detroit, Muskegon, and Port Huron (University of Maryland Center for Integrative Environmental Research, 2008).

Wastewater infrastructure

Climate change is one of the main challenges to the urban wastewater infrastructure; this is because of increased rainfall intensities combined with more dry days (Langeveld et al., 2013). Wastewater is water that comes from our sinks, sewage, showers, industrial, agricultural, and commercial sources of used water. It also includes storm water, which carries road salts, oil, grease, chemicals, and debris into our water sources (Denchak, 2018). The NDRC states that more than 80 percent of the world's wastewater flows back into the environment without being treated and the EPA estimates that the United States releases more than 850 billion gallons of untreated water into our water systems each year. In a 2017 state infrastructure report, Michigan received a grade of C on wastewater infrastructure and D- on storm water infrastructure. The grading scale is as follows: A - Exceptional, B - Good, C - Mediocre, D - Poor, F - Failing (American Society of Civil Engineers, 2018). With the amount of water Michigan's water sources supply, plus the condition of Michigan's wastewater infrastructure, climate change is causing the impacts of this to be worse. Every year combined sewer overflows dump 5.7 billion gallons of raw, untreated sewage directly into Michigan's lakes rivers and streams, the costs of treating this will be very high (University of Maryland Center for Integrative Environmental Research, 2008). Public Sector Consultants have estimated that the cost of repairing Michigan's wastewater infrastructure (this includes both wastewater and storm water) will be 2.14 billion dollars (Public Sector Consultants Inc., 2016). This estimate includes only community wastewater treatments; it does not include on-site wastewater treatments. Onsite wastewater treatments are not part of the municipal system and include around 30 percent of homes and businesses. As of early 2019, Michigan is the only state in the country without a statewide septic code. (Michigan House of Representatives, 2018), this leads to septic system failure rates between 25 and 30 percent statewide

Water resources

Climate Change is increasing water scarcity; water scarcity has led to privatization of water. Public water sources originating at the Great Lakes may see their supplies compromised, as water levels decline. Additional stress on the system may come from more frequent rainfall events predicted by climate change models, which may cause flooding and subsequent accumulations of pollutants, necessitating more expensive treatment of the resource (University of Maryland Center for Integrative Environmental Research, 2008). Concerns over increased use and potential diversion of the abundant freshwater resources of the Great Lakes Basin have generated alarms regarding water depletion (Zorn et al., 2012). Water scarcity has forced Michigan cities to look into new technologies for urban water reuse. However, incorporation of water reuse schemes into water/wastewater infrastructure systems is a complex decision-making process, involving various economic, technological, and environmental criteria (Nasiri et al., 2012). To minimize water scarcity, a series of measures have been pursued to reduce water demand and/or increase water supply capacities. Desalination and water conservation and reuse are the most common approaches. Desalination is not the best possible solution as it is a process that is energy-intensive and expensive (Nasiri et al., 2012).

Agricultural production

Agriculture is one of Michigan's larger economic sectors; this section will explain how climate change's effects on water impact this sector of our economy. Michigan's agriculture sector accounts for 17.2% of Michigan's jobs. In 2018, it accounted for a total of 104.7 billion dollars in economic activity (Kundson, 2018). The way climate change affects our agriculture sector through water is from flooding and heavy precipitation causing great damage to crop production (Rozensweig et al., 2002). The cost of crop losses is expected to rise dramatically due to this (Rozensweig et al., 2002). While the longer growing season that climate change will bring to Michigan may increase agricultural output in some crops, extreme weather events and other stresses associated with climate change are expected to decrease agricultural productivity overall. Greater precipitation levels have been found to increase erosion and runoff. A recent study, focused on the Midwest, incorporated current agricultural uses for soil into its model and found similar results. Runoff is expected to increase by nearly 50 percent in the Michigan Thumb area and by 310 percent in the Southeastern Michigan (University of Maryland Center for Integrative Environmental Research, 2008). Runoff is crucial in analyzing the effects on agricultural production that increased precipitation and flooding has because it reduces the amount of land available for farming, thus leading to a lower output. The National Climate Assessment of 2018 stated that due to precipitation changes and extreme temperatures, Midwest agricultural production levels will fall to productivity rates similar to those in 1980 (US Global Change Research Program, 2018).

Effect on the Public Health and Economy of Michigan's Poor Communities

Everyone in Michigan will feel the costs of climate change; however, the poor communities will be disproportionately impacted. The poorest among Michiganders not only live and work in areas most prone to flooding, heat waves, and other climate change effects but are also least resourced to prepare adequately for and withstand those impacts, the ability to prepare and withstand these impacts will be referred to as resilience. Unequal societies have more polluted and degraded environments, perhaps helping explain why more unequal societies are often less healthy (Cushing et al., 2015). The strongest indicator for this is seen in the health implications of air and water quality in poorer communities (Cushing et al., 2015). Climate change is expected to increase the prices of energy, food, and water; these costs will be manageable to communities with resilience, but not Michigan's poor communities (USC Climate Gap). This is because necessities such as water take a greater portion of their income than it would for a person of higher economic status; this is explained along the same line as a regressive tax. Aside from the individuals living in poor communities dealing with the costs of climate change, this cost will be felt by cities too poor to maintain their infrastructure. Extreme precipitation is expected to overwhelm Detroit's aging storm water systems, flooding basements and streets and leading to sewage overflows into the Detroit River and Lake Erie (Molnar, 2015). It is important when mitigating climate change in cities such as Detroit that efforts are focused on the most vulnerable areas because people populate these areas with the least resilience to climate change.

Adaptation and Mitigation

Increased water demand, especially in the Great Lakes region, is in need of a policy to accurately charge a worthy price of Michigan's water supply to outside sources (i.e.: corporations, other states, etc.). Without rightfully charging the respectful amount, incorporating worth and protection of our water, supplies will continue to decrease drastically beyond the effects of climate change. Conserving water will decrease energy use and is beneficial for an increase in demand and in the case of a drought situation. A mitigating device that has powerful effects on improving water quality is the implementation of green infrastructure. The EPA describes green infrastructure as "a cost-effective, resilient approach to managing wet weather impacts that provide many community benefits. While single-purpose gray storm water infrastructure—conventional piped drainage and water treatment systems—is designed to move urban storm water away from the built environment, green infrastructure reduces and treats storm water at its source while delivering environmental, social, and economic benefits." (EPA n.d.). There are many forms of green infrastructure, all of them providing at least some positive resolution to the harms being caused by climate change, these forms are, downspout disconnection, rainwater harvesting, rain gardens, planter boxes, bio swales, permeable pavements, green roofs, urban tree canopy, and land conservation (EPA, n.d.). Rain gardens will assist in the increase of absorbed runoff while taking the weight from storm water management systems in the event of increased rainfall. The Intergovernmental Panel on Climate Change (IPCC) describes one way of mitigating climate change that would be especially effective in Michigan. This is through wastewater transport and treatment technologies that reduce or eliminate greenhouse gas generation and emissions. Better wastewater management would also promote water conservation by preventing pollution from untreated discharges to surface water, groundwater, soils and coastal zones, which would follow to a reduction of pollutants and thus, requiring a smaller volume of water to be treated (IPCC 2008).

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Chapter 5 Agriculture

Ashley Green, Cameron Schmitt, Leah VanLandingham, and Jocelyn Marsack

Background

Climate change poses several impacts on Michigan's agriculture. There are several predictions of climate change, including increased rainfall during the spring and decreased rainfall during the summer seasons. Increased carbon dioxide within the atmosphere and higher temperatures are potential effects for agriculture's growth and economy. A longer frost season and dry periods can also create several long-term impacts for agriculture in Michigan (Wuebbles & Hayhoe, 2004). Many of Michigan's staple crops like corn, soybeans, apples, and cherries are all dependent on weather. Climate change projections, such as soil changes and temperature increases can lead to soil erosion, degradation and a decline in crop quality and yields (O'Neal et al., 2005). Additionally, there are several climate change implications causing heat stresses in livestock. The microclimate affects will affect Michigan's tourism, water, fertilizer, and pest management. There are several economic consequences to climate change with concern to changes in yield, employment, and energy production (Adams et al., 1999). Not only crop and livestock farmers, but also policy influencers will be affected by climate change. Adaptation techniques and agricultural management are crucial in addressing issues of climate change for sustainable practices long term. Climate change may create vulnerabilities in Michigan with regard to agriculture.

Physical Impacts

Relationship between climate change and land use.

Climate change and land use have adverse effects on each other. The aggravation of one factor causes a negative feedback loop. Developing land for agriculture, such as deforestation, increases the levels of carbon dioxide in the atmosphere, which exacerbates the rate at which the global average temperature increases. This is achieved through the practice of deforestation to create land for agricultural use. Deforestation adds CO_2 to the atmosphere through the decay of plant material after extraction and effectively removes carbon from the soil. The loss of soil carbon contributes to soil erosion as well (Dale, 1997).

Land management techniques are critical components of soil health. Proper management, including rotation, determines the soil's ability to provide nutrients to plants and to retain water. Soil erosion is already a large issue in agriculture independent of climate change, and climate change exponentially exacerbates the issue (Southworth et al., 2000; Adams et al., 1988).

Weather and soil

Karetnikov et al. (2008) predicts significant soil erosion and runoff events with increased temperatures and more intense rain events. The frequency of rain events is projected to decrease, which may cause flooding and dry spells. The infrequent rain events would be expected to cause the soil to become dryer, which will allow the soil to be eroded by the variant heavy rain events (Karetnikov et al., 2008; Melillo, Richmond, & Yohe 2014). The organic topsoil is where the seeds are germinated and are allowed to grow. The presence of topsoil is vital for plants to be able to persist. Once topsoil is lost due to erosion, it is difficult to regain, leaving little viable land for continued agricultural production (Montgomery, 2007).

Michigan has already began experiencing the negative effects of climate change in relation to soil conditions. Burmeister et al. (2017) reported dry topsoil conditions in Michigan in June 2017. The dry topsoil resulted in a delay of crop germination and increased moisture stress, followed by continued dry conditions for the remainder of June (Burmeister et al., 2017). The period of dry top soil could lead to the erosion of the soil through weathering by wind and water (Karetnikov et al., 2008). The dry period is also an indication of the impending variance in the ability of agricultural production to function as predicted. In a study performed by Wuebbles and Hayhoe (2004) soil moisture was projected to increase by up to 80% during winter and spring but decrease by up to 30% in summer and autumn. Weather fluctuations can have negative effects on crops that rely on natural occurring weather, such as crops that rely on water levels being recharged during winter months (Wuebbles & Hayhoe, 2004). The projected increase of soil moisture reflects the projected Michigan climatic trend of less days below freezing in the winter (Melillo et al., 2014). Less days below freezing in the winter would allow more liquid moisture to be available for crops.

Water use

A study done by Croley and Luukkonen (2003) demonstrated a fluctuation of groundwater recharge rates in Lansing, Michigan due to weather events such as flooding and prolonged dry period. Flooding events would increase groundwater recharge rates by adding liquid water to surface water bodies, which act as sources for groundwater recharge. Conversely, prolonged dry periods would result in a decrease groundwater recharge rates due to the lack of water being put back into the system through precipitation. The projected decrease in groundwater recharge may lead to an increased demand for water pumping for agricultural use (Croley II & Luukkonen, 2003). A study done by Chiotti and Johnson (1995) supports the hypothesis that indicates an increased demand for water due to prolonged dry periods. The results of Chiotti and Johnson's study indicated that availability of water for crops is projected to reduce with increasing average temperatures (Chiotti & Johnson, 1995). A change in climactic conditions and rainfall patterns will prompt a demand for necessary change in irrigation infrastructure and practices. In addition, changing climatic conditions may change the optimal growing location of many crops that are regionally reliant (Dale, 1997).

Adaptation

Proposed mitigation strategies by researchers focus on taking preventative steps to prepare for the impacts of climate change. Southworth et al. (2000) argues that soil moisture management will be a chief mitigative strategy to combat the effects of climate change on soil erosion. Engineering soil to increase its water holding capacity could potentially allow soil to be more adaptive to increased periods of little rainfall and to withstand heavier precipitation events (Southworth et al., 2000). In terms of crops, land managers will play vital roles in resource partitioning and the identification of suitable replacements for crops that cannot withstand changing climatic conditions (Dale, 1997).

Crop Performance

Crop growth

Crops and their ability to produce yields necessary for economic stability and food production may be modified by climate change. As climate changes further, there will be greater

CO_2 concentrations within the atmosphere. Increases in CO_2 concentrations have shown to stimulate photosynthesis and subsequently increase yields in certain crop types (e.g., C_3 crops) (Ehleringer and Björkman, 1977; Fuhrer, 2003). However, the warming temperatures associated with increasing CO_2 concentrations may cause excessive stress on crops, counteracting positive productivity modifications caused by climate change (Fuhrer, 2003). Furthermore, current projections suggest a greater number of dry periods (Wuebbles et al. 2017) throughout Michigan’s growing season. Certain crops that make up a majority of Michigan’s agricultural industry are sensitive to heat stress (e.g., corn) which may cause decreased yields and economic instability in the future. As climate change progresses, Michigan will be faced with challenges in crop production.

Michigan’s crop industry will face several vulnerabilities as climate changes including, modifications of crop yields and subsequent crop export potential. Michigan’s most exported crops are corn, soybeans, wheat, and sugar beets (USDA, 2018). C_3 crops (i.e., wheat, soybeans, sugar beets) are more responsive to elevated CO_2 concentrations and heat stress than C_4 crops (i.e., corn).The main difference between C_3 and C_4 crops is their ability to metabolize carbon, C_3 crops require their stomata to be open during photosynthesis, which can lead to desiccation (Ehleringer and Björkman, 1977). C_4 crops do not have this constraint thus, can tolerate drought better (Nayyar and Gupta, 2006). C_4 crops are better at dealing with drought stress. However, corn, one of Michigan’s most important crops, is a C_4 plant but is especially vulnerable to heat stress (Wang, Fan, and Heckathorn, 2014).

Current projections suggest an initial increase in crop yield of C_4 crops (e.g., rice, barley, corn) and a decrease in C_3 crops (i.e., wheat, soybeans, sugar beets) as increases in average temperatures and periods of drought occur. As time progresses, there may be a decline in yields that are important to Michigan’s agricultural industry. Subsequently, this may cause a decline in crop export and potentially hurt Michigan's economic stability as agriculture makes up 22% of Michigan's workforce and 10% the state's total export, contributing $104.7 billion to the state's economy annually (MDARD, 2019). Michigan's crops and agricultural industry will be negatively impacted by climate change and may face more challenges in the future.

Plant nutrition

Elevated CO_2 concentrations and excessive heat have shown to cause stress on plants and negatively impact the quality of plant tissue (i.e., nutritional value of the plant) (Bahrami et al. 2017; Tausz et al. 2017). Future projections suggest that average temperatures will increase in Michigan with subsequent greater periods of drought (Wuebbles et al. 2017). Due to excessive heat stress, plants tend to modify their resource allocation (i.e., where plants move nutrients to/ from within its chemical network) more to their roots in search of water rather than to their leaves or fruit (Bassow, McConnaughay, and Bazzaz, 1994). This change in resource allocation causes a reduction in the amount of nitrogen and other nutrients within parts of plants that humans eat (Tausz et al. 2017). Nutrients allocated in leaves and fruit are important in maintaining proper nutrition in humans (Welch, 2002). The amount of nutrients available for human consumption will be at risk as climate change effects exacerbate. As climate change proceeds, Michigan will be faced with lower quality food from crops that may have negative societal implications.

Michigan will face societal vulnerabilities associated with decreased plant nutrition. Decreased plant quality may have negative societal impacts such as, lower quality food for all, an increase in amount of food required per individual, and greater number of cases of malnutrition (Smith and Haddad, 2001; Bahrami et al. 2017; Tausz et al. 2017;). Low-income individuals will be disproportionately more susceptible to only having access to poor quality food (Smith and Haddad, 2001). As nutritional value in crops decrease, this will cause greater demand in overall food intake per person (Smith and Haddad, 2001), due to a lack of nutrients within the plants. This will cause further stress on agricultural production due to greater demand of crops. These societal implications of climate change coupled, may also cause an increase in the number of malnutrition cases observed in Michigan. Decreased plant nutrition has multiple indirect effects on society. Michigan's public health and agricultural industry capacity will be vulnerable as climate change proceeds.

Pollinator changes

Michigan's growing season has already and is expected to extend its length, which may have consequences on fruit producing crops. Michigan's growing season has lengthened by 16 days in the Great Lakes region from 1951-2017 and may extend up to 50 days longer by 2100 (Wuebbles *et al*. 2017). Fruit-bearing crops require pollination from insects in order to reach full flower maturation (i.e., fruit produced). Increased temperatures will extend growing seasons further than they already have and will subsequently modify plant-pollinator interactions (i.e., when pollinators will arrive, when flowering will occur, and the overlap between the two) (Petanidou *et al*. 2014). Having mismatched plant-pollinator phenologies may put Michigan's fruit-bearing crop industry at risk and even more so as climate changes further.

Insect pollinators are a key component to Michigan's fruit-producing crop industry, which may be hurt by climate change. Michigan's fruit producing crops include, cherries, apples, and blueberries (MDARD, 2017) from greatest to least produced, respectively. Moreover, the fruit producing crops make up $758 million of Michigan's agricultural economy (MDARD, 2019). This may have implications of mismatches in plant and pollinator phenology (i.e., time of flowering vs. time of pollinator arrival). As plant-pollinator phenology maintains mismatched, fruit producing crops in Michigan will face a decline and have negative economic consequences on Michigan's agricultural industry.

Livestock

Livestock play an important role in Michigan agriculture for exports. According to the Department of Agriculture and Development (2019), Michigan has 52,194 farms with around 10 million acres of land used for farming. Dairy products are one of Michigan's major agriculture exports (MDARD, 2019). As many as 15 million farm animals have the potential to be affected by climate change in Michigan (MDARD, 2012). The Great Lakes Region is expected to see a decrease in freezing temperature days and increase in warmer temperatures. These conditions have an effect on livestock production including, decline in milk production and heat stresses (Wuebbles & Hayhoe, 2004). Adams, Hurd, Lenhart, and Leary studied the effects of climate and changing temperature on agriculture regionally. Climate change effects on livestock results in lower productivity and performance. Adaptation can be met under intently maintained livestock conditions to prevent exposure to extreme conditions (Adams, Hurd, Lenhart, & Leary, 1998). This has an effect on livestock producers that export livestock products from Michigan and meat and dairy providers.

Heat stress on livestock

Climate change will pose several impacts on livestock with regard to quality of life. Some implications of climate change in Michigan include temperature increases in the winter and spring, and temperature increases in the Upper Peninsula during fall and winter. Livestock may be vulnerable to these hot environmental conditions. According to Winkler et al. (2014), dairy cattle throughout the Midwest are often grown in unconfined spaces, exposing them to the environment (Winkler et al., 2014). Heat stress in cattle due to extended warm temperatures can lead to a decrease in reproduction. This is caused because exposure to higher temperatures leads to abnormal mating behavior, negatively affecting female cows' ability to conceive, according to

Polsky and Keyserlingk (2017). Heat stress has several impacts on dairy cows because lactating dairy cows are affected more by heat stress than non-lactating cows. Heat stress can cause a decline in milk production as DMI, or dry matter intake is reduced. DMI reduces the cow's ability to produce enough nutrients for milk production (Polsky & Keyserlingk 2017). Cows may experience a reduction in fertility as a result.

Heat stress can also play a role in broiler chickens. In a study done to measure the effects of acute heat stress on broiler chickens, Lei et al. (2013) found that heat stress can cause decreased food intake. This is caused by broiler chickens regulating their appetite during exposure to heat stress, which results in anorexia in broiler chickens (Lei et al., 2013). This is of concern for Michigan as temperatures continue to increase and broiler chickens can consume and weigh less.

Similarly, heat stress in cattle can affect broiler chickens ability to lay hens (Adams, Hurd, Lenhart, & Leary, 1998). Heat stress can also affect appetite within growing pigs. In research studying the ways in which pigs respond to heat load, Pierce, Fernandez, Hollis, Baumgard and Gabler's experiment showed pigs experienced a sharp increase in weight loss and water loss after exposure to heat higher than their temperature range. As heat loads were more severe, regulation of appetite resulted in a change in metabolic rate (Pearce et al., 2014). Pigs may be subject to hotter days for longer periods. The annual temperature continues to increase across the Midwest, a trend uncommon in historical records (Winkler et al., 2014).

Reduced reproduction

Michigan is expected to see warmer temperatures over longer periods, which will lead to vulnerabilities to livestock in reproduction (Wuebbles & Hayhoe, 2004). Reproduction may be of concern as environmental changes affect biological functioning and animal behavior. This not only has an important impact for Michigan farmers who raise and aid in reproducing livestock, it is also significant for companies who purchase livestock and dairy products. For commercial hens, exposure to heat stress has a negative impact on the quality of eggs. Mashaly et al. (2004) performed a study on the effects of high temperatures on hens. The study tested egg weight, and the weight and thickness of shells in relation to temperature. The results showed that higher temperatures caused the hens to produce a fewer number of eggs and an increase in the mortality of the eggs. Egg weight and the weight and thickness of shells decreased considerably (Mashaly, et al., 2004). Reduction in the production of eggs may pose problems to Michigan farmers who export and sell egg products.

The issue of reproduction does not only affect commercial hens. Heat stress in pigs can lead to a lack in pregnancy. In a study examining similar conditions of heat stress in pigs, Barati et al. (2008) found pigs who experienced increasing lengths of elevated temperature resulted in a decline in reproductive capability. The results indicated a decrease in the rate of maturity (Barati et al., 2008). The environment is an important factor for internal body temperature regulation. There is also concern for reduction in the fertility of dairy cows. Dairy cows that are exposed to heat stress may cause estrous decline and altered mating behavior. Reproduction is increasingly difficult during the summer months and year-round breeding can be potentially problematic for dairy cow producers (Polsky & Von Keyserlingk, 2017).

Indirect implications for livestock

There are many potential indirect effects of climate change for livestock in Michigan. Several of Michigan's livestock farms are Concentrated Feeding Animal Operations, or CAFOs, facilities. CAFOs provide limited stresses though there are still underlying implications of climate change in these facilities. One indirect impact of climate change on livestock is that there could be an increase in energy usage for confined facilities. The facilities will have to increase energy use to regulate their temperature and humidity. In addition, for transportation and processing of livestock to other facilities, energy use will be increased (Winkler et al., 2014). The availability of feedstock and crop production for livestock may also be affected as yield declines. Grain production could also affect the number of livestock that can be sustained. (Winkler et al., 2014). Furthermore, according to Hatfield et al. (2011), corn yields throughout the Midwest will decline due to rising temperature, drier conditions, and lack of rainfall. Grain yields could reduce by 2 to 3% over the next 30 years in the region (Hatfield et al., 2011). Crop yield can indirectly affect livestock production if feedstock availability decreases, making livestock producers unable to maintain larger quantities of livestock.

Adaptation

Efforts can be made to decrease heat stress, energy, and operational costs for Michigan's livestock producers. These efforts can help to prevent mortality and manage exposure of extreme conditions on livestock. Restricted feeding systems is limiting feed for cattle during the summer season to prevent overheating. Mader, Holt, Hahn, Davis, and Spiers (2011), performed a study to analyze the effects of restricting feed in cattle for heat stress management. Feedlot cattle were given restrictive feeding schedules to manipulate their diet and alleviate heat stress (Mader et al., 2011). Results showed that restricting feed intake help feedlot cattle cope with hotter environmental conditions by reducing their body temperature (Mader et al., 2002). Restricted feeding techniques can be beneficial in response to hotter environmental conditions. The techniques can help producers as a cost-efficient method in livestock production.

Sprinkling on feedlot cattle may also be an option to reduce heat stress and promote fertility and normal biological functioning among feedlot cattle. An experiment evaluating the effects of sprinkling for cattle, Mader, Davis, and Gaughan (2007), tested penned feedlot cattle with misters, it was seen to reduce hyperthermia in cattle and brought on a significant reduction in heat stress. Using methods like sprinkling can help cattle farmers avoid symptoms of heat stress, such as hypothermia that can result in death (Mader, Davis, & Gaughan, 2007). Creating a sprinkling environment to sustain cattle in extreme conditions can be a great benefit for livestock facilities.

Flooding due to increased spring rainfall is predicted to occur (Wuebbles & Hayhoe, 2003). Livestock waste from manure lagoons can leach into soils and nearby rivers and streams. According to Burkholder (2007), Runoff of livestock manure can be detrimental in contaminating water quality (Burkholder et al., 2007). Runoff contamination from CAFOs could also be intensified by climate change, causing concern for public health. Specifically, communities using residential septic tanks can be vulnerable to diseases and water contaminants from microbial fecal pollutants (Cameron et al. 2015). One way to avoid this while utilizing livestock waste is through the incorporation of fertilizer. Application of livestock waste at CAFO sites in contained areas are important in preventing the excessive runoff into water resources (Burkholder et al., 2007). Using livestock waste as fertilizer can also prevent the spread of E. coli or Salmonella from CAFO runoff for Michigan's residents (Cameron et al. 2015). Nutrients from the waste can be beneficial for soil and act as fertilizer for crops. Many livestock waste management sites can use manure for fertilizer for crops and livestock to prevent contamination into freshwater resources. Taking appropriate management of livestock waste will also prevent unwarranted health impacts on human health and the environment (Burkholder et al., 2007). This, in turn, causes the prevention of waste contamination spills and is a cost-efficient method.

Production Practices

Pest management

Climate change in Michigan is expected to increase average winter temperatures (Wuebbles et al., 2017), which may have consequences on agricultural pest abundance and how pests are managed by farmers. Current climate change projections suggest a decreased winter mortality rate due to less extreme winter temperatures, implying an increase in pest population year after year. Furthermore, greater number of generations of pests per year can mean greater total damage during the growing season and extensions of species ranges from lower latitudes (Logan, Régnière, and Powell, 2003). Elevated CO_2 concentrations have shown to decrease nutritional value in plants and subsequently cause greater feeding rates from agricultural pests (Bezemer, Jones, and Knight, 1998). Due to the increase in feeding from pest species, this may cause an increase in the use of insecticide on crops grown in Michigan. Insecticide use on plants have shown to negatively affect plant cell division and DNA (Mahapatra et al. 2019) potentially harming overall yield now and in later generations of crop yields. Moreover, changes in species ranges northward will increase the different types of pests that will be present in Michigan, further exacerbating crop damage from pests. Other studies have also suggested a lag in range extensions of natural enemies of pest species (e.g., parasitoids, predators) for some years, creating no biological control on pest population (Thomson *et al.* 2010).

Pests are a common problem in all agroecosystems, however, as climate change proceeds, pest problems will become worse and the amount of insecticides used on crops will increase. The increased abundance of pests, with no natural biological control (i.e., predators of herbivores), and subsequent increased use of pesticides on plants may hurt Michigan’s agriculture industry by decreasing the number of crops that can be sold in grocery stores and decrease overall yields due to pest destruction.

Fertilizer use

Heat stress will become a major factor in limiting crop growth and yields. Typically, farmers attempt to enhance plant growth through the application of nitrogen fertilizer. Farmers rely heavily on nitrogen-based fertilizers although it produces one of the more potent greenhouse gases (N_2O) that furthers the warming effects of elevated CO_2 concentrations in the atmosphere.

Although it is expected that plant growth and productivity will have an initial increase as climate change progresses in Michigan (Fuhrer, 2003), overall there will be a decrease due to the amount of CO_2 stress on plants and periods of drought (Bassow, McConnaughay, and Bazzaz, 1994). Previous works have shown that in periods of drought, farmers tend to make decisions to apply more fertilizers than they should (Stuart, Schewe, and McDermmott, 2014). Multiple factors go into farmer decision making regarding fertilizer application, however studies have shown fertilizer application is expected to increase as climate changes further (Stuart, Schewe, and McDermmott, 2014).

As climate change proceeds, multiple factors in agriculture will be influenced by excessive fertilizer application. Some factors influenced in agriculture will be soil fertility and nutrient loading in other environments that may be sites for future agricultural land use.

Soil preservation

A major drawback of agricultural land use is the affects it has on soil; this affect will be exacerbated by climate change. Soil degradation associated with agricultural land use include, compaction, erosion, salinization, toxification, and net loss of organic matter (Wathall et al. 2013). Of these examples of soil degradation, soil erosion is the most directly affected by climate change and the most pervasive. Intensive agriculture, now and more so in the future, is expected to cause accelerated erosion across many regions (Montgomery, 2007). Excessive erosion rates decrease soil productivity, increase loss of soil organic carbon and other nutrients, and reduce soil fertility (Quine and Zhang 2002; Cruse and Herndl 2009) subsequently decreasing the ability of crops to grow, crops overall yield, and nutritional quality.

Agricultural land use in Michigan will be affected by climate change negatively. Currently, agricultural land use makes up about 28% of total Michigan land area (Farmland Information Center, 2012). As climate changes further, more water will be used to irrigate agricultural fields. Increased irrigation will cause greater soil erosion and put Michigan land at risk in the future (Koluvek, Tanji, and Trout, 1993). Greater soil erosion will deplete nutrients within the soil and ultimately negatively affect Michigan's agricultural industry and cause greater future vulnerability (Koluvek, Tanji, and Trout, 1993).

Farmer education

Farmers make multiple decisions regarding fertilizer use, crop choice, and time of planting. Although a wide-range of adaptation strategies for farming is available (e.g., crop rotation, climate planting calendars) how much these are utilized is considerably low (Haigh *et al.* 2015). Barriers to increased use of these adaptation strategies include perceptions about climate change, and limited access to information and technological tools (Stuart, Schewe, and McDermott, 2014). However other studies have had mixed results and suggest farmers have more than enough information on climate change mitigation approaches (Schewe and Stuart, 2017). Other studies have shown that larger, private sector intervention plays a significant barrier to farmer adoption of mitigation approaches. Cooperation from private sector companies will be necessary in modifying behaviors, attitudes, and the magnitude of mitigation approaches used by farmers. Climate change in Michigan will exacerbate the need to greater utilize adaptation strategies especially in agriculture.

As climate change progresses, the amount of outreach and education available to farmers about adaptation strategies may be vulnerable and affects of climate change may be worse due to this. The effects of climate change will become exacerbated as time goes on and a lack of education to farmers may lead to negative impacts on Michigan's agricultural industry.

Social Impacts

Tourism

Agritourism is a large part of Michigan's economy and agricultural practices with the cherry and apple industries drawing multitudes of people in from many different locations. Traverse City, Michigan for example hosts the National Cherry Festival drawing tourist to the area. Currently Michigan's state government does not offer much support to the connection between tourism and agriculture even though agriculture and tourism are Michigan's second and third largest industries (Veeck, Che, & Veeck. 2006). A major part of agritourism can be seen in the changing food industry. Some people are drawn to local restaurants because of their farm-to-table style meals (Veeck et al., 2006). Farm-to-table meals are meals that the diners and restaurants buy food from local farmers in order to create their dishes. Farm-to-table restaurants are often seen as being fresher as the food has to travel shorter distances and can be purchased daily. By coming from closer smaller farms the consumers are thought to have more care and understanding of where the food is coming from. Having these local specialty meals can draw more people in, increasing local economies and farmer's operations.

Most agritourism businesses are only open seasonally (Veeck et al., 2006), so the increased growing days (Schoof, 2009) can also be correlated to increased days some agribusinesses are open for tourism. Corn mazes can only be run when the corn is grown tall enough, apple orchards can only be visited when the apples are growing; the winter tends to be an off-season. The longer growing season can add days to agribusiness open season, but the days over ninety increasing may lead some visitors to not want to come out, as well as days with heavy precipitation may drive many customers off. Agritourism could become increasingly more appealing to farmers as a supplement to their income. Also, opens a good chance for teaching and learning activities for visitors of these locations.

Policy

As climate change begins to rear its face to the public, policy may begin to change. When people actually experience impacts of the changing climate, their attitudes towards changing policy shift (Lee, Loveridge, & Winkler, 2017). The public tends to shy away from large sweeping policy changes but are more considerate of policy changes when the changes target a specific sector (Lee et al., 2017). Agricultural climate change adaptation policy changes in particular were supported by seventy nine percent of the respondents during the first half of an extended heat wave in 2012 (Lee et al., 2017). The second half of the warm spell even led some to oppose policy changes (Lee et al., 2017); the longer and more drawn out the warm spells are can affect attitudes differently. Extreme weather events currently play a small role in attitudes for climate change adaptation policy; at the beginning and quickly after severe weather events attitudes change and policy changes are supported (Lee et al., 2017; Ray, Hughes, Monisky, & Kaylor, 2017). Longer lasting weather events due to climate change do less work on changing attitudes, than quicker more frequent ones (Ray et al., 2017). Although this heat wave was just one noticeable climate change event, the attitudes people had while experiencing this specific weather event can be attributed to future events as the events will become more severe and frequent. Citizens' attitudes will be important in rolling out future agricultural policy concerning climate change. Understanding how attitudes are impacted by weather as well as climate can help in developing policy using studies/polls that are more representative of citizens' attitudes towards policy.

In some cases, urban farming initiatives have not only helped food sustainability directly for urban citizens, but also lead to food policy changes and initiatives (Hashim, 2015). Desertification and obesity have led policymakers to question if the government can do anything to help their citizens' public health. These urban farming associations are the people on the ground not only implementing healthier food choices but also do some advising to policymakers (Hashim, 2015). As climate change impacts food availability, especially in urban centers, public health policy and agricultural policies should evolve and be implemented.

Farming community

The farming community has the ability and will to change as climate change impacts become more apparent. After 2012 cherry farmers say they will begin looking and paying attention to longer-range weather and climate forecasts (Rothwell, Woods, & Korson, 2013). The farmers will share information between each other as well as attend many more organized meetings (Rothwell et al., 2013). The farmers also came together to say that their group would be interested in receiving more research information, and research done for their community of farmers, to help their future growing opportunities and overall farm operations (Rothwell et al., 2013).

Urban farming

There has been a large majority of people moving out of rural areas towards suburban and urban areas; this idea is known as urbanization. As climate change begins to become a larger problem, urbanization will be exasperated (McAdam, 2010). While certain things will also lead to the flow of some people out of urban areas to more rural areas, there will still be a large flow to urban centers. Agricultural communities have generally been large open areas filled with farm fields in rural areas, but that does not have to be the case.

The idea behind who a farmer is has already begun to change as more technology has been developed and put into practice. Some farmers today are very tech savvy and could be considered IT specialists when in relation to agricultural technology. With the term “farmer” covering a wider spread of types of individuals, the assumption of who a farmer is, is transforming; anybody can be a farmer if the individual truly wants to be. The idea of urban farming is becoming a larger project. Practicing urban agriculture can increase urban food security in certain areas such as Detroit (Colasanti, Hamm, & Litjens, 2012); areas such as Detroit have been economically challenged and racially segregated. Given the chance to grow food can increase the social welfare of certain groups in the urban areas; the citizens of these locations are often confined to their current geography for a multitude of reasons, increasing potential opportunities through urban farming initiatives can greatly help the communities.

Urban farming has demonstrated how it can help communities in other states, such as Kentucky's Community Farming Association (CFA). The CFA and members worked together to start and implement the first few urban farming projects (Hashim, 2015). Projects like farmers' markets that are supplied with products by urban farms. The projects can be very beneficial in closing food desserts especially in low income and black communities as the projects shown in Kentucky have done (Hashim, 2015). Urban farms and farmers' markets close the distance people must travel to get healthy nutritious food.

Movement of farmers

The mass movement of people throughout the country and into Michigan will also be forcing farmers to other areas to continue their farming as urban populations increase and urban areas spread. Some farmers will be forced out; others will want to follow the plant hardiness zones in order to continue growing the crops in the environment of which the plants thrive.

A few farmers may decide to stay where they are located, if possible, and just change what the farm grows in order to fit the hardiness zone as it changes due to climate change. Michigan is projected to continually change hardiness zones, just as the change has been seen changing in the past (Krakauer, 2012).

The water availability will drive many people to Michigan, which will further decrease the amount of farmable land (Mcadam, 2010). The increased flux of people could in turn also increase locally grown food and increasing prices benefiting the agricultural sectors income.

Economy

Value of agriculture

Economics of agriculture in Michigan is comprised of multiple sectors, including enterprise, employment, and industry (Ferris, 2000). Enterprise refers to the value and category of product produced through agriculture, including livestock, field crops, and “other” crops. Employment refers to the amount and type of individual(s) exerting labor within different enterprises and industries. Industry refers to the value and type of revenue-creating entities, including basic industries such as farms, forestry, food processing, and secondary industries that affect agriculture such as transportation (Ferris, 2000).

Agricultural economic activity in Michigan totaled $104,652,000,000 in 2016 (Knudson, 2018). The total value of agricultural products and farm related income in Michigan was estimated to be $8,135,600,000 in 2016. The total value of crop production was estimated to be $4,231,400,000 and the total value of livestock, poultry, and their products was estimated to be $2,973,900,000. In 2015, Michigan exported $2,043,900,000 of agricultural products. The most important agricultural products that contribute to Michigan’s economy in order of revenue impact include corn for grain, soybeans, dairy, hay, and wheat, respectively (Burmeister et al., 2017; Knudson, 2018).

Agricultural jobs

The estimated total of jobs within the agricultural workforce in Michigan was 805,053 in 2016, which accounted for 17.2% of Michigan employment. Most of the jobs were within food wholesale and retail, totaling 565,915 workers. There were 221,797 jobs within agricultural production and processing. A study done by Knudson (2018) identifies a decrease of employment in food and agriculture in Michigan since 2012. The decline is within the food retail and food service industries and may be due to the increase of other industries (Knudson, 2018).

Agricultural yields

A significant effect of climate change on Michigan agriculture will be in terms of changes in optimal crop production and changes in yield (Wuebbles & Hayhoe, 2006) in which crop yields will be affected and dairy production will experience negative impacts. Production and crop yields are important for market analysis and tracking cash flow and predicting economic trends.

In 2012, corn for grain, soybeans, forage-land used for all hay and haylage, and wheat for grain, respectively, were classified as the top crop items by acre. The classification of "top crop" indicates amount of land currently utilized for the production of the described crop (USDA, 2018).

Corn for grain, soybeans, and wheat experienced record highs of production between 2014 and 2016 (Burmeister et al., 2017). Production trends reported from 2016-2018 from the United States Department of Agriculture demonstrated a 1% decrease in corn for grain production, a 3% increase in soybean production, and a 4% decrease in wheat production (USDA, 2019). The reported trends are consistent with the results found by researchers projecting yields of important Michigan crops because of climate change. Previous research indicate that corn and wheat yields are likely to decrease with increase CO_2 concentration in the atmosphere. Soybeans, conversely, are likely to increase yields with increase atmospheric CO_2 concentration. The ability of a plant to thrive with changing atmospheric CO_2 concentrations is determinant on the biology of the crop and how well it is able to process CO_2. In sum, soybeans can process CO_2 better than corn and wheat and, therefore, is more likely to thrive in an environment with relatively high CO_2 levels (Karetnikov et al., 2008; Southworth et al., 2000; Deschenes & Greenstone, 2007; Adams et al., 1988).

Dairy production from 2012-2016 in Michigan was reported to total 10,876,000,000 pounds, translating to a total value of $1,642,276,000. The annual milk per cow per pound per year has increased since 1990 (Burmeister et al., 2017).

Benefits

Potential benefits to Michigan agriculture include increased CO_2 levels and longer growing seasons (Karetnikov et al., 2008; Southworth et al., 2000). Multiple studies show support for increase crop yields due to increased atmospheric CO_2 levels (Southworth et al., 2000; Adams et al., 1988; Deschenes & Greenstone, 2007) with multiple studies citing soybean production specifically to benefit from increased atmospheric CO_2 levels and for corn to experience little to no influence from CO_2 levels (Southworth et al., 2000; Adams et al., 1988). The increased yield of corn may be attributed solely to the longer growing seasons in Michigan (Southworth et al., 2000).

Drawbacks

Despite increased yield, climate change has been projected to have negative overall effects to Michigan agriculture. In a study done by Karetnikov, Ruth, Ross, and Irani (2008), stress imposed on crops due to pests, droughts, floods, and other extreme weather events is expected to negatively affect the productivity of crops (Karetnikov, Ruth, Ross, & Irani, 2008). A study done by Southworth et al. (2000) found that increased temperatures negatively affect maize yields by inhibiting growth during the early stages of crop development (Southworth et al., 2000).

The study by Karetnikov et al. (2008) also identifies consequences within the dairy industry with temperature increase. Increased temperatures decrease production of dairy at temperatures beginning around 77F (Karetnikov, Ruth, Ross, & Irani, 2008). Dairy has the third largest impact on agricultural revenue in Michigan and there are little to no methods of adapting to changing climate conditions for cows that would not have continued adverse climate effects.

A decrease in quality and productivity of Michigan's top crops has a potential to negatively influence Michigan agriculture job market and decrease revenue from agricultural products.

Adaptation

To adapt to changing climatic conditions to have maximum benefit to Michigan's economy, the agricultural industry will need to shift its production practices and rely upon crops that are resilient to changing conditions. Southworth et al. (2000) proposed the use of GMO corn that is more tolerant of increased heat. A heat-tolerant corn strain is hypothesized to take advantage of longer growing seasons and shifting optimal planting days and will not be stunted in early development by intense heat events. Additionally, Southworth et al. (2000) proposed a shift from corn crops to soybeans, which can withstand both increased temperatures and increased atmospheric CO_2 levels (Southworth et al., 2000).

Adaptations/Opportunities/Resiliency of Farmers

Adaptations and resiliency

Farming has already seen an influx of technological advances. Automotive innovations in tractors, autosteer and other automatic functions in tractors, increased soil and plant research for better treatment of the ground for effectiveness. The amount of data being collected through the new technology being developed is massive. There are companies purely situated around data collection and analysis that farmers are able to use (Wolfert, Ge, Verdouw, & Bogaardt, 2017).

As climate change continues to change the world around the farmers, certain farmers may be able to keep up their operations thanks to the advances in technology.

Other farmers, smaller scale and less profitable farms could possibly be phased out unless they are able to find ways to supplement their income using other agricultural resources such as farm-to-table initiatives with local restaurants. Growing and selling food to local diners and restaurants can be a great supplement to income and is a growing attraction to consumers. Some smaller farms may need to tap into Michigan's agritourism to stay afloat compared to larger scaled farms. While there will be opportunity for adaptation to the changing climate in Michigan, it depends on how farmers' attitudes, and their will to change and accept adaptation practices whether on their own or from policy reforms. Many different things such as age and education level determine Farmer's choices (Morris, Henley, & Dowell, 2017). More and more farms are being run like businesses and their decisions are more calculated and chosen on the idea business practicalities (Morris et al., 2017).

In many occasions farmers are not the most financially advantaged people. If climate change drives up certain prices of land in areas farmers were previously using, gentrification can sweep through certain areas and displace the farmers. While most would say that gentrification is an urban concept, it has been seen in rural areas as well. Certain demographic and economic changes, including a previous generously increasing population has shown an increase in gentrified spaces; causing certain rural areas to fall prey to gentrification (Nelson & Hines, 2018). Previously, large amounts of people have been leaving rural areas moving to urban areas allowing areas to become abandoned. Some of the abandoned places, and older farm homes or barns, are highly valued to particular individuals today, and can add to gentrification in areas that have been solely farming communities for many years (Nelson & Hines, 2018).

As climate changes and forces more people to continue moving around, the individuals moving to rural areas may continue to contribute to this problem of gentrification, continuing to displace farmers and others in farming communities. This issue can have a negative impact on the agricultural field; some farmers will see a way out as land prices increase and they can sell their land for decent prices, but then there are less farmable land available increasing prices further for other farmers. The property owners whom may have not wanted to sell are thus suddenly forced to sell. Rural areas and towns already have a larger percentage of their populations living in poverty in comparison to metropolitan areas (Nizalov & Schmid, 2008). This economic fact reduces an average farmer's resilience to climate change. This phenomenon can also lead to impacts to the entire rural community being disrupted displacing farmers and other rural citizens.

Mitigation

Increasing biodiversity of the crops and animals and incorporating a diversity of agricultural land on each farm has the potential to decrease emissions as an effective mitigation strategy (Altieri & Nicholls. 2017). These biodiverse farms are able to scale emissions back because the farms use less energy, pesticides, herbicides, and fertilizers leading to lower N_2O and CO_2 emissions than monoculture farms (Altieri & Nicholls. 2017).

Another mitigation possibility could be increasing the organic carbon stocks in the soil. The loss of soil organic carbon is one of the largest land-based emissions of greenhouse gasses into the atmosphere (Soussana et al., 2019). The goal would be to increase the stores and ability to store carbon in farming ground (Soussana et al., 2019). By setting a goal for farmers to hit, they could track their soil organic carbon levels and help reduce the human emitted CO_2 levels in the atmosphere. This would be done with low depth carbon stocks as stocks at depth are formed over large periods of time (Soussana et al., 2019). It would be nearly impossible to target an increase of carbon sequestration at all depths because of the time period associated with deeper stores, but to expect an increase in shallower level soil is much more plausible (Soussana et al., 2019). Practicing soil conservation on farms can lead to not only increase in total soil organic carbon levels but can also increase plant production yields from increased nutrition, increased soil moisture, and decreased erosion (Soussana et al., 2019); a benefit for farmers as well as the environment.

Other agricultural practices can also increase the soil productivity such as crops with greater root mass, nitrogen-fixing legumes, using cover crops in fallow periods, and crop rotations (Soussana et al., 2019). The practices described can decrease the amount of soil carbon lost, as well as increase the amount returned to the soil (Soussana et al., 2019). Soil organic carbon is a benefit to the farmers as it can be linked to increased yields, meaning farmers could be making more money at the same time as helping reduce the release of carbon into the atmosphere. These agricultural practices could take many years to implement and get the plans working at maximum levels (Soussana et al., 2019), but all of these land management practices could be large carbon sinks in the future (Soussana et al., 2019), especially if coupled together with each other. Large amounts of cooperation would be required between scientific research, as well as social science research, policy makers, and those subject to any of the changes forced on the individuals such as the farmers themselves.

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Chapter 6 Energy

Victoria Vo and Brendan Arthur

Overview of Climate Change

A climate is defined as the statistical average of the weather taken over a long period, most commonly 30 years. Weather refers to the day-to-day state of the Earth's atmosphere, and is considered short term. The Earth's temperature and weather patterns change naturally over time. Climate change includes major changes in temperature, precipitation, and wind patterns over decades or longer. The Geologic Society of London (GSL) uses data from ice cores drilled out from ice sheets in Antarctica provide past polar temperatures and atmospheric compositions dating back to 800,000 years (GSL, 2010). Using the ice cores, scientists are able to calculate past climates within these reasons, and it is useful to gauge how climate has changed throughout time. The Earth's temperature and weather patterns have changed naturally over periods of time that range from decades to hundreds of thousands, to millions of years (GSL, 2010). Modern Earth is facing a trend of global warming that has resulted in average surface temperatures increasing 1.42 degrees Fahrenheit since the late nineteenth century (NOAA, 2016). The

Intergovernmental Panel on Climate Change forecasts an increase of another 2.5 - 10 ^{o}F within the next century. The Michigan Climate Action Network (MCAN) notes that the effects from climate change that are affecting present day Michigan include: increased rainfall and flooding events, increased risks to the Great Lakes, a public health risk, agricultural changes, and changes to forest regions.

Climate Change Effects on Michigan's Energy Production

The Great Lakes Integrated Sciences and Assessments Program (GLISA) has noted some of the effects climate change has already caused within the state of Michigan. From the years 1951 - 2017, the average temperature has increased by 2.3 ^{o}F, affecting the number of frost-free days within the growing season by lengthening the season by 16 days (GLISA, 2017). The National Climate Assessment of 2017 showed that in the period of 1958 - 2016 precipitation increased all throughout the USA, and the Midwest region only had a small increase in overall precipitation. The total annual precipitation in Michigan increased 14%, and the annual precipitation falling in heaviest 1% of all storms increased 35% (GLISA, 2017). More severe storms may have a negative economic impact due to damages to infrastructure, increased costs of preparation, and clean up (GLISA, 2017). Even though precipitation rates have increased, warming temperatures can also affect the availability of water throughout the state. Land surfaces are projected to become drier overall from not only increasing temperatures, but higher evaporation rates as well (GLISA, 2017). Water availability in turn may interfere with industrial operations that utilize water as a resource such as hydropower plants, thermoelectric plants, and nuclear plant cooling. Warmer temperatures and more frequent heat wave anomalies likely will increase the demand for electricity to power air conditioning units, particularly in urban areas during summer months (Larsen et al., 2017). An increase in the demand for electricity in

Michigan translates to greater volumes of fossil fuels being burned to meet the demand. In turn, this could contribute to a larger per capita emission of greenhouse gases within the state.

Warmer temperatures in the state of Michigan also contribute to a reduced number of days with extreme cold (Larsen et al., 2017). With a reduced number of extreme cold days, there is a projected decrease of overall demand for heat production within the home. Households in Michigan, approximately 78% in 2010, currently rely primarily on natural gas for heating of their home (DTE, 2017). Warmer winters will likely result in a decrease in demand for natural gas usage.

Factors That Contribute to Climate Change

A major process that factors into climate change is the Greenhouse Effect (Harvey 2010). Earth's atmosphere acts as a natural greenhouse due to selective absorbers present that absorb more terrestrial radiation than solar radiation. Incoming solar radiation is still being absorbed at the surface, but as the terrestrial radiation from the Earth is travelling through the atmosphere, it becomes absorbed by the selective absorbers too. These selective absorbers are referred to as greenhouse gases. Greenhouse gases are those that absorb and re-emit infrared radiation in the wavelength range emitted by Earth. Examples of greenhouse gases are water vapor, methane, carbon dioxide, nitrous oxide, ozone, chlorofluorocarbons, and hydrofluorocarbons (EPA, 2017). As these greenhouse gases emit radiation back into the atmosphere, the trapped energy results in higher temperatures at Earth's surface. Without the greenhouse gases our atmosphere would be about 60 degrees (Fahrenheit) cooler (GSL, 2010). Carbon dioxide is one of the more problematic greenhouse gases, because human activity has added large quantities into the atmosphere that would not be there naturally. Increased concentrations of carbon dioxide occur in the atmosphere from the combustion of fossil fuels, especially coal (Harvey, 2014). Carbon dioxide concentration levels alone have increased 40% since start of the industrial revolution in 1750 when the combustion of coal was first being introduced (EPA, 2017). Figure 6-1 shows the increasing trend of CO2 levels in the atmosphere from 1970 to present, and was measured from one of the National Oceanic and Atmospheric (NOAA) Earth System Research Laboratories at Mauna Loa, Hawaii.

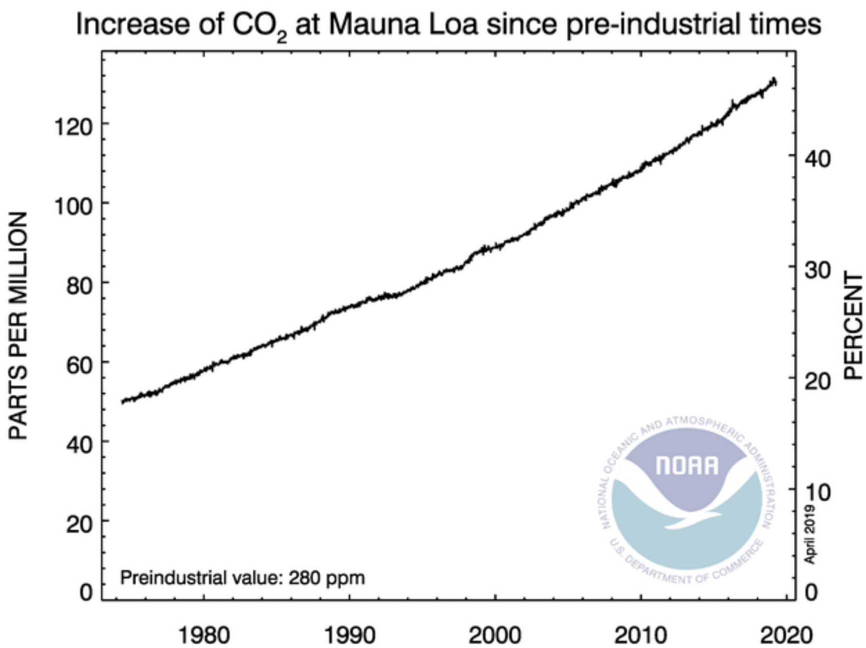

Figure 6-1 Past and present data showing the increasing trend of CO2 concentrations from NOAA's Mauna Loa Earth Science Research facility from 1974 to 2020. From NOAA (2019)

Michigan is heavily dependent on fossil fuels to power the electricity grid within the state. According to the Michigan Climate Action Network (MCAN), Michigan's per capita emissions of greenhouse gases is over 20% higher than the national average. With an average higher that is higher than the national average, Michigan is directly contributing to higher concentrations of greenhouse gases is the atmosphere, and therefore; is contributing to a warming climate. However, Figure 6-2 shows that since 2010 the amount of greenhouse gas emissions in Michigan have been decreasing. Even if the amount per year has gone down on average, Michigan is still contributing largely to greenhouse gas emissions. Out of all 50 states, Michigan is ranked 10th in overall carbon dioxide emissions at 152.6 million metric tons (EIA, 2016).

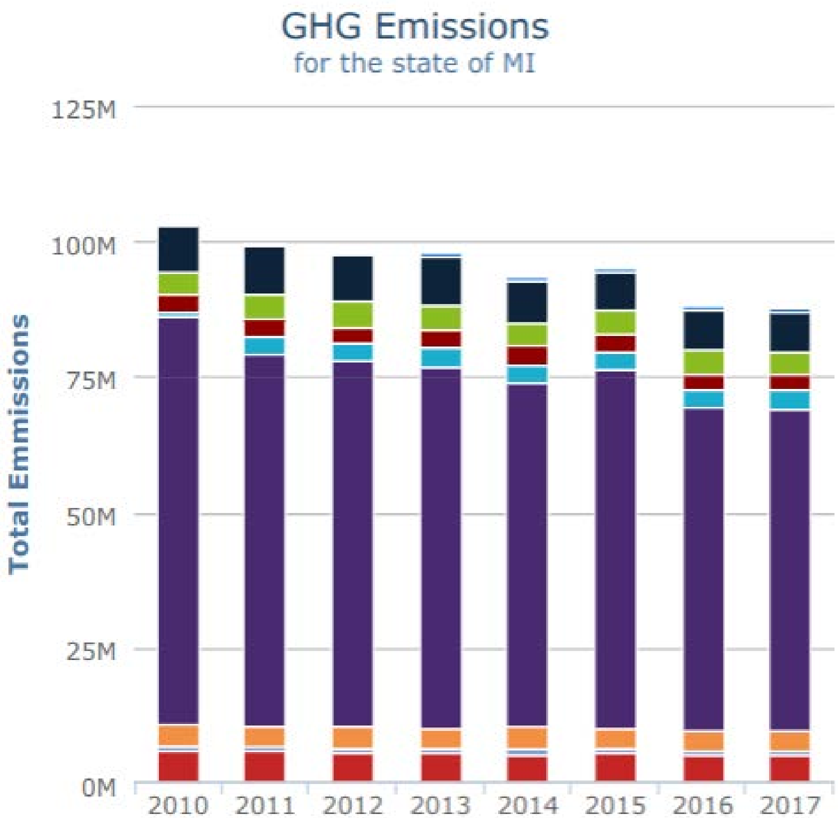

Figure 6-2 The direct emissions of GHG reported by various sectors in metric tons of carbon dioxide equivalents (CO2e). CO2e is a metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). Carbon dioxide equivalents are commonly expressed as million metric tons of carbon dioxide equivalents (MMTCO2Eq). From EPA (2017)

Michigan's Current Use of Energy

Michigan state overview

According to the United States Census Bureau, the population in the state of Michigan as of 2019 is 10,020,043 million people. The number of adequate housing units in 2017 was 4,595,158 million. Employer establishment units totaled 220,412 as of 2016. Michigan's growth rate as of 2019 is 0.29%. In the future, as the population begins to grow, and as more houses are built to house the growing population, it will create a larger demand for electricity.

Current net electricity production.

Currently Michigan's net electricity generation by source is led by coal (EIA 2018). Electricity net generation is the amount of gross electricity generation a generator produces minus the electricity used to operate the power plant. Coal accounts for 3,547 Megawatt-hours (MWh). One megawatt-hour is equal to 1,000 kilowatt-hours, which is equal to 1,000 kilowatts of electricity being used continuously for one hour. According to the U.S. Energy Information Administration, the average electricity source in the United States emits $4.554E^{-4}$ metric tons of CO_2 per 1 kWh. This mean that electricity generation via coal plants alone produced 1615 metric tons just in 2018. The next largest source of electricity generation in Michigan is from a renewable energy source, nuclear energy. Nuclear power generated 1882 MWh as of 2018, but nuclear energy is actually CO2 free energy (EPA, 2019). The third most relied on source for the generation of electricity is natural gas, a fossil fuel. Natural gas produced 2026 MWh of electricity, which produced 923 metric tons of CO2. Other lesser fuel sources include hydroelectric power produced 116 MWh, non-hydroelectric (wind, solar, geothermal) power produced 705 MWh, and petroleum plants produced only 8 MWh (EIA, 2018). With Michigan's heavy reliance on fossil fuels to produce electricity, implementing new strategies could put tension on certain areas of the economy. Michigan has a very active coal business. The state's shipping ports handle roughly 1/3 of all Great Lakes coal shipments (EIA, 2016). Cutting down on coal could remove jobs in many different employment areas. Reliance on fossil fuels means that our state has great potential to reduce emissions that cause climate change. According to the MCAN, shifting primarily to renewable energy within the state could be done in a way that creates 150,000 jobs, saves more than 1,700 lives per year, and saves the average Michigander close to $11,000 each year. Michigan's current ranking for energy production out of the 50 states is 26th (EIA, 2016).

Table 6-1 Michigan's total output emission rates according to the EPA in 2016 (expressed in pounds/MWh).

CO2	1099 lb/MWh
CH4	0.063 lb/MWh
N2O	0.016 lb/MWh
CO2e	1106 lb/MWh
NO(x)	0.8 lb/MWh
SO2	1.5 lb/MWh

Mitigation Efforts. In May of 2017, DTE Energy announced a sustainability initiative to reduce carbon emissions from its operational plants by more than 80% by 2050 (DTE, 2017). While much of this carbon reduction goal is focused on transforming our electric generation from primarily coal to a balanced mix of renewables, natural gas, and nuclear power over the next 25 years. DTE's natural gas business will play a crucial role in meeting the carbon reduction goal as natural gas produces 50-60 times less CO2 emissions than traditional coal (EIA, 2016). DTE is also planning to phase out all coal-powered plants by the end of 2040 as they strive to reduce emissions by more than 80% by 2050.

Energy consumption by sector

Consumption of energy in Michigan is led by transportation services at 27% of overall consumed energy. Transportation requires the combustion of gasoline, and therefore releases carbon dioxide emissions into the atmosphere. Looking at the U.S. as a whole, within the transportation sector, the automobile industry contributes to the largest output of CO2 emissions

(Stefano et al., 2016). Implementing practices such as electric transportation could greatly reduce the amount of energy consumed on average by traditional combustion reliant transportation, as well as greenhouse gas emissions. In turn, this could affect the automotive industry for which Michigan is known. Climate change constitutes a major threat to the core technology that the automotive industry has been using since they began, because it requires a change to the internal combustion engine (Stefano et al., 2016). These changes suggest a major restructuring of the automotive industry's production and organization processes. These changes also pose major effects on economies, and a potential shift in consumer preferences (Stefano et al., 2016). Overall, the problem with the automobile industry is implementing an innovation strategy that ensures that companies are profitable, cars are sufficiently fuel efficient, and are in accordance with the prevailing consumer culture.

Residential areas consume the next largest amount of energy at 25.9%. Residential areas in Michigan use natural gas and electrical energy for the heating/cooling of their homes, appliances within their homes, and recreational activities such as television or video games. Using solar energy to combat the total amount of energy consumed by residents could be worthwhile investment. The use of solar panels has great potential to lower utility bills, and reduce air pollution from utility companies (Walker, 2013). Solar panels also have the potential to pay for themselves over time. Independent power producers (i.e. residents) can invest in solar panels, and sell excess electricity to the utility companies (Green, 2017).

According to the Michigan Public Service Commission (MPSC), industrial energy consumption does not rely on coal as heavily as it used to, and uses more electricity. The industrial sector consumes 25.5% of all energy produced within Michigan (EIA, 2016). Industries as of late are more committed to reducing carbon emissions, and phasing out the use of coal. DTE energy, as mentioned previously, is focusing towards using more natural gas and renewables by 2050. Commercial energy consumption relies heavily on natural gas and electricity as well. Commercial sectors use 21.6% of all energy produced. Michigan's overall consumption of energy ranks 31st of the 50 states.

Michigan Resources

Natural gas

According to the MPSC, Michigan supplies 18% of the state's demand for natural gas. The Antrim Gas Field in the Lower Peninsula is also one of the nation's top 100 natural gas fields. Michigan's underground natural gas storage capacity is 1.1 trillion cubic feet, which is more than any other state too. Almost 80% of Michigan house units use natural gas as the main energy source for home heating (EIA 2017). The total consumption of natural gas in Michigan was 765 billion cubic feet in 2010.

Electricity and coal

Michigan currently has no active coal mines within the state, and receives majority of its coal from Wyoming and Montana (MPSC, 2011). Michigan relies on coal largely for the production of electricity, and 3/10 of the largest power plants are still coal powered (EIA 2017). According to DTE, by 2040 there are plans to have eliminated all coal power plant to meet their quota of reducing carbon emissions by 2050.

Natural resources/renewables

Renewable resources accounted for 8% of the net electricity generation in 2017. Wind farms are spread out along the coasts of some of the Great Lakes. As of 2018, there were 30 utility scale wind farms with 1000 wind turbines in the state. Total generation capacity of electricity in 2018 was 1925 MW (EIA 2018). A large portion of renewable electricity in Michigan comes from biomass fuels such as wood, wood waste, municipal solid waste, and methane produced from landfills (EIA 2016).

Nuclear

Michigan does produce a large amount of energy from nuclear fuel. Nuclear energy accounted for 31.9% of overall electricity generation in 2018 (EIA 2018).

Energy Economics

Energy demands and opportunities

A well-discussed consequence of climate change is the impact it will have on annual temperatures. According to regional climate trends, Michigan has experienced an increase of annual temperatures greater than 2°F, increased frequency of winter and fall warm spells, and a greater average number of extreme heat days since the beginning of the 20th century (Frankson, Kunkel, Champion, and Runkle, 2017.; Constible, Reiser, and Morganelli, 2019). Though mild winters would decrease the necessity of residential heating, air conditioning use during the hotter and more humid summers would more than make up difference. What does this mean for consumers? As temperatures and the demand of energy rise, so will the costs. For many, heating and cooling appliances are highly energy consuming and costly. According to Moon and Han (2011), 49% of energy used by all U.S. residential buildings came from heating and cooling. The total residential energy consumption expense of Michiganders amounted to $8.38 billion in 2016; in 2017, natural gas and coal expenditures accounted for $6.54 billion (U.S. Energy Information Administration, 2019).

As for energy suppliers, rising energy demands may be opportunities to increase employment. Initially, some existing energy suppliers may find it difficult to meet consumer demands, which may slow services. However, with increased exploration in renewable and more efficient energy sources and technologies, energy providers can expand their operations. The market for alternative energy jobs in Michigan is on the rise; a 2017 report conducted by the U.S. Department of Energy revealed that Michigan employed 85,902 individuals in the traditional energy sector; 27,751 of which were employed in electrical power generation and 37,702 in Transmission, Wholesale Distribution, and Storage. Additionally, 87,013 Michiganders were employed in the energy efficiency jobs. Additionally, in 2017 Michigan's green energy private sector housed 109,067 direct and supporting jobs, with 96,767 direct green jobs and 12,300 support green jobs (Jackson, 2017).

A growing green energy industry in Michigan is solar energy. In 2018, the state ranked 18th in the nation for the highest number of solar energy jobs, employing 4,196 individuals (Solar Energy Industries Association, 2019). The workforce composition in this sector is becoming increasingly diverse and inclusive to a variety of socioeconomic, race/ethnic, and gender groups. Green energy employment initiatives, such as the Black-Green Pipeline Initiatives encourages equal employment opportunities for people of color especially in areas of severe unemployment (Jackson, 2017). Energy jobs, whether it be direct production or supporting positions, are expanding, particularly in the alternative energy and energy efficiency sectors. This continued trend towards green energy would reduce the in-state unemployment, as the Michigan's unemployment rate has decreased from 10.9% to 4% in the past ten years (U.S. Bureau of Labor Statistics, 2019).

Changing fuel economics

With greater incentives to investigate alternative and more efficient energy sources, the dependence on fossil fuel sources like coal are likely to decrease. As of 2018, coal and natural gas-fired electricity accounts for 65.7% of Michigan's net energy generation while nuclear and renewable sources make up 31.9% (U.S. Energy Information Administration, 2019). The shift away from a fossil fuel based to a more renewable based energy grid also has implications for industries like transportation. The shift toward hybrid and electric cars and efficient vehicle technologies has increased in the past years creating more opportunities for innovative individual and public transport (Nejad, Mashayekhy, Chinnam, & Grosu, 2017). One solution is increasing the manufacturing of electric vehicles and the availability of wireless and plug-in charging stations. Though initially high in construction cost, an electrical bus system with a life cycle cost of $0.99 per bus kilometer has great long-term payoffs (Bi, Kleine, & Keoleian, 2017). Electric mass transit would be especially beneficial for urban communities where personal vehicles are less common. This transition would be a significant opportunity for new automotive jobs at all levels, from development, construction, and operating vehicles.

Energy Efficiency and Marketing

The market for energy efficiency provides great opportunities for new technologies, investment in renewable resources, and revenue for many businesses. As the interest in energy efficient products rises, the response to rising demands may create opportunities to produce affordable, high efficiency products, which would reduce the average household energy consumption. Michigan has already pledged to increase its Renewable Portfolio Standards (RPS) from 10% in 2015 to 15% by 2021 (Cavallaro, Pearce, & Sidortsov, 2018). With past goals achieved, a projected greater consumer demand for energy, and an expanded workforce meeting and even surpassing the 2021 standard is quite likely (Vermont Energy Investment Corporation, 2015). Businesses can make the most out of the energy efficiency movement by responding to consumer desires. Consumer choice is heavily dependent on the willingness to pay for a commodity. Spending on energy consumption is influenced by factors like the condition of the environment, energy consumption habits, and the inability to control the progression of climate change (Johnson, Halvorsen, & Solomen, 2011). The increased concerns for the environment and out of pocket costs reflects the desire for low environmental impact, highly cost-effective products.

The need for creating, marketing, and distributing energy efficient products to all demographics will be more imperative as Michigan faces a range of climate change effects. Currently, energy efficient product availability and marketing in lower income neighborhoods is inadequate and the cost for these products is often unaffordable. Residents are less likely to switch to more efficient practices and products due to a lack of accessibility, high cost, and/or the awareness of alternative commodities (Reams, Reiner, & Stacey, 2018; Johnson et al. 2011; Fowlie, Greenstone, & Wolfram, 2018). An example of a current affordable alternative energy commodity are solar photovoltaic panels. The price of solar panels has decreased by 80% since 1998; though the initial installation costs may be high, subsequent residential energy costs could be less than $3/Watt (W) (Vermont Energy Investment Corporation, 2015). It is estimated that the installation cost of residential rooftop solar panels in 2020 will be approximately $3,145/kW, and decreasing to $2,690/kW by 2030 (Vermont Energy Investment Corporation, 2015).

Though individual purchases of solar panels preserve the financial autonomy of residents, temporary options are also available. Utility or third party lease programs allow residents to lease solar panels from a solar farm and receive a monthly proportional allotment of produced energy (Konkle, 2014). An option like this is beneficial for consumers since leases can last up to 20 years with payback occurring within the lease period. Lease programs are typically easy to implement, produce tax benefits that can reduce lease rates, and leasing efforts alone tend to payoff initial installation costs (Konkle, 2014). Community based solar panel projects are another option for those looking for a shared investment. In a community solar project, community investors form a limited liability company (LLC), and though the responsibilities of installation and maintenance are shared, so are the benefits (i.e. tax credits, LLC income, and profits from solar renewable energy certificate (REC) sales) (Konkle, 2014). This approach would be especially favorable in areas where traditional energy costs or current RECs are high.

Societal Implications

Energy demographics and inequalities

Current and future residential energy consumption is a shared concern among all Michiganders; however, the energy inequality of the state will cause the consequences of climate change to be felt disproportionately. Residents from densely populated urban areas, low-income households, and racial or ethnic minority backgrounds are the most disadvantaged compared to suburban, middle and upper class, and white residents (Vojnovic & Darden, 2013). These societal differences, in addition to racial and class tensions, have the ability to shape urban development, which creates disjointed energy inefficient communities.

A large part of this community disparity involves energy efficiency, consumption, and affordability. Fuel disparities vary based on spatial location, with areas of similar demographics having similar energy consumption levels (Bendar, Reames, & Keoleian, 2017). Many Detroiters from low-income and minority backgrounds, on average consume less energy, but experience a lower degree of efficiency. This is typically attributed to older model homes having poor efficiency standards. The cost of inefficiency is also a problem that may be enhanced with climate change. Having to consume more energy in the summers to combat extreme heat would significantly contribute to the energy burdens, or the percent of gross income spent on paying for energy, for these residents. Compared to the energy burden of White, middle-class, suburban households at 1.2%., the energy burden of low-income, minority households in Detroit is 10.4%-- a burden over 6% is considered unaffordable (Reams et al., 2018).

Stakeholder perceptions and lifestyle assessments

Understanding the perceptions and concerns residents have about personal energy consumption and the state of climate change are crucial in creating effective, individualized solutions. Residents tend to rate energy conservation measures, or the degree to which they reduce their energy consumption, based on comfort level (i.e. cleanliness, security and convenience), costs, and savings (Langevin, Gurian, & Wen, 2013). The progression of Michigan's climate towards mild and humid conditions may change energy use preferences and habits as residents try to escape the heat. This may become a prominent issue for energy conservation related to residential cooling.

The effects of additional extreme heat days and high humidity will be felt the most in large cities, where "urban heat islands" are common. Urban heat islands are areas of urban or metropolitan development that are significantly warmer than surrounding areas because of human activity. Excessive fuel emissions from transportation and factories, inadequate residential cooling, and energy efficient infrastructure all contribute the urban heat island effect. Exposure to high temperatures, high impact infrastructure, and the personal inability to avoid the heat in these areas often causes personal discomfort and health concerns related to heat exposure (Gronlund, Sullivan, Kefelegn, Cameron, and O'Neill, 2018). The lifestyles and energy security of many urban Michiganders may be altered because of the shift in climate.

Approaches to Accessible Green Energy

Mitigation strategies like energy efficient programs and products are currently available and are often seen as the first step in residential energy efficiency. These "first step" mitigation efforts, like switching to more efficient lighting, are attractive because of their low upfront costs and high practicality (Reams et al., 2018). Michigan has already made efforts in promoting energy saving solutions. Past policies such as the 2007 Energy Independence and Security Act have established efficiency recommendations, and many manufacturing standards have changed (Reams et al., 2018). The shift towards renewable energy sources would also promote the production of commodities and services of corresponding efficiency.

Though these mitigation efforts promote personal and environmental savings, a major barrier to broad adoption is the variable accessibility and effectiveness of efficiency products and programs. The current ability for some energy assistance programs to identify and aid households is not optimal. The Weatherization Assistance Program (WAP) and the Low Income Home Energy Assistance Program (LIHEAP) are the two largest energy assistance programs in the U.S., both have shortcomings when it comes to providing adequate services (Bendar et al., 2018, Fowlie et al., 2018). A qualification system based on income is a reasonable approach in identifying energy inefficient housing. However, due to shortcomings in providing services, either some qualified households do not receive assistance, or the assistance that is provided is of low quality. Additionally, these programs often have high upfront costs compared to the cost-effectiveness of the provided services (Bendar et al., 2018, Fowlie et al., 2018). Inadequate results and unaffordable pricing of these services, which are primarily used by low-income minority households, only furthers the harms of already strenuous conditions.

Other problems arise with these assistance programs since LIHEAP does not allow the use of renewable energies for heating and cooling (Bendar et al., 2018). A renewable source of energy, like rented solar panels, may be beneficial for multiple residents through a community-based program. The inability to control the state of their homes due to faulty appliances, comfort levels of other occupants and housing authority regulations, like those of the Michigan Public Service Commission (MPSC), is a major obstacle for community energy efficiency (Langevin et al., 2013). Standards of these assistance programs needs to improve because the increased frequency of heavy precipitation, in between long periods of drought, will be most detrimental to Michiganders in urbanized, low-income areas.

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