Climate Change Impacts in Minnesota: Agriculture

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Climate impacts you heard about include:

- Warmer winters and a longer growing season
- Warmer summers in the future
- Wet conditions and extreme events
- Variability in weather conditions

General references that are helpful for understanding climate change impacts on agriculture in the Midwest include:1) Gowda, P., J.L. Steiner, C. Olson, M. Boggess, T. Farrigan, and M.A. Grusak, 2018: Agriculture and Rural Com- munities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 391–437. doi: 10.7930/NCA4.2018.CH10.

2) Angel, J., C. Swanston, B.M. Boustead, K.C. Conlon, K.R. Hall, J.L. Jorns, K.E. Kunkel, M.C. Lemos, B. Lofgren, T.A. Ontl, J. Posey, K. Stone, G. Takle, and D. Todey, 2018: Midwest. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washing- ton, DC, USA, pp. 872–940. doi: 10.7930/NCA4.2018.CH21 pg 880, figure 10.4

3) Walthall, C.L., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E.A. Ainsworth, C. Ammann, C.J. Anderson, I. Bartomeus, L.H. Baumgard, F. Booker, B. Bradley, D.M. Blumenthal, J. Bunce, K. Burkey, S.M. Dabney, J.A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D.A. Grantz, D. Goodrich, S. Hu, R.C. Izaurralde, R.A.C. Jones, S-H. Kim, A.D.B. Leaky, K. Lewers, T.L. Mader, A. McClung, J. Morgan, D.J. Muth, M. Nearing, D.M. Oosterhuis, D. Ort, C. Parmesan, W.T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W.A. Salas, L.E. Sollenberger, R. Srygley, C. Stöckle, E.S. Takle, D. Timlin, J.W. White, R. Winfree, L. Wright-Morton, L.H. Ziska. 2012. Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin 1935. Washington, DC. 186 pages.

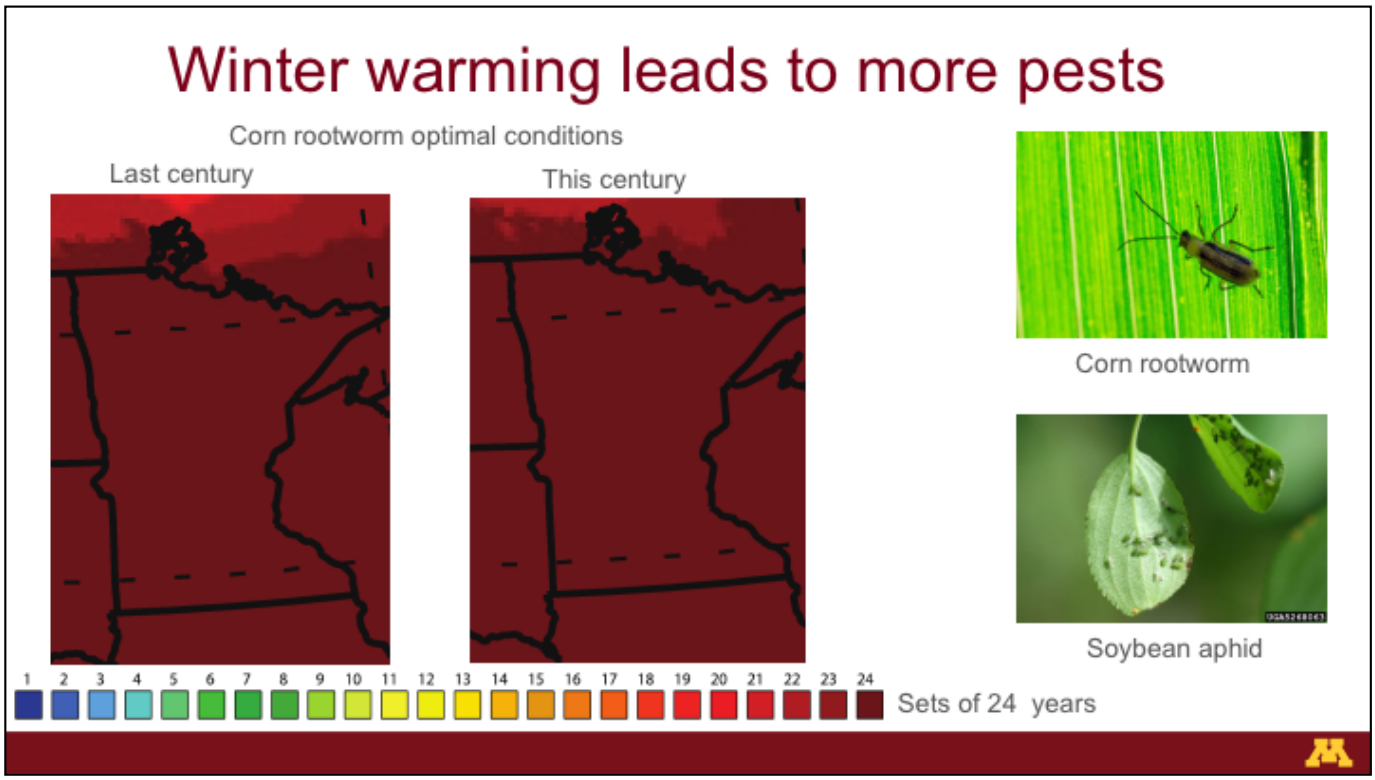
4) https://minnesota.agclassroom.org/educator/images/materials/poster_ag1.jpg

We have diverse crops in Minnesota, demonstrated in this image. We are the top US exporter in turkeys and sugarbeets and while the economic value of some crops is small, such as apples, they are a pride of our state identity. The climate impacts on some crops, such as wheat, soybean, dairy, corn, and livestock, have been researched well, while some, such as sugar beets and apples, have not been explored as much within our state.

Winter warming? Longer growing season? Yes please!

Image courtesy of Bluff county news
https://www.bluffcountrynews.com/content/southeast-minnesota-harvest-finally-progressing

This article is about the management issues related to our wetter climate. Some farmers were out in the snow in southeastern Minnesota having to harvest in the snow because the fields were finally dry enough to be workable.



1) Diffenbaugh, N.S., C.H. Krupke, M.A. White and C.E. Alexander. 2008. Global warming presents new challenges for maize pest management. Environmental Research Letters. **3** 044007 This publication modeled ranges, occurrence, and favorability over time for several corn pests. This map (Figure 2) demonstrates the number of years per 24 year increments that would be favorable to growth of corn rootworm, with more years being favorable under a warming climate. Other corn pests demonstrated similar trends. Similar trends are expected for other pests, including the soybean aphid which is of major concern in our state. The idea behind this is that when temperatures lows in the winter are not as low, eggs of these pests survive, emerge, and the pests then have higher populations during the growing season.

2) Walthall, C.L., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E.A. Ainsworth, C. Ammann, C.J. Anderson, I. Bartomeus, L.H. Baumgard, F. Booker, B. Bradley, D.M. Blumenthal, J. Bunce, K. Burkey, S.M. Dabney, J.A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D.A. Grantz, D. Goodrich, S. Hu, R.C. Izaurralde, R.A.C. Jones, S-H. Kim, A.D.B. Leaky, K. Lewers, T.L. Mader, A. McClung, J. Morgan, D.J. Muth, M. Nearing, D.M. Oosterhuis, D. Ort, C. Parmesan, W.T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W.A. Salas, L.E. Sollenberger, R. Srygley, C. Stöckle, E.S. Takle, D. Timlin, J.W. White, R. Winfree, L. Wright-Morton, L.H. Ziska. 2012. Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin 1935. Washington, DC. 186 pages.

3) UMN extension blog posts from last summer offer a look at combatting high population levels of corn rootworm and soybean aphid. These publications also demonstrate intersecting issues, for example that soybean aphid is beginning to develop resistance to insecticides, and that with increasing populations of these pests, insecticide use may increase- causing potential problems for helpful insects and pollinators, and increasing production costs to farmers.

https://blog-crop-news.extension.umn.edu/2018/07/corn-rootworm-emergence-about-to-rocket.html

https://blog-crop-news.extension.umn.edu/2018/07/soybean-aphid-infestations-are.html

Photos courtesy of UMN Extension

Winter warming could lower apple yields and increase soil erosion

- Without sufficient dormancy periods, orchard trees will have irregular flowering and fruit production

Honeycrisp apples, UMN extension

1) https://www.canr.msu.edu/news/winter_cold_hardiness_in_michigan_fruit_cropsReport by Michigan State University extension describing how trees accumulate “chilling units” over the winter to mark time. Trees need a certain amount of dormancy time for full flowering, fruit set, and bud development. Irregular spring/thaw cycles could lead to early bud break and bud damage for early spring tree growth.

2) https://extension.psu.edu/climate-change-and-orchards-part-2-seasonal-shifts This extension talk from Penn State is also very informative, about largely the same issues as the previous reference. Some of the information is specific to northeast apple growing through.

3) Morton, Lois Wright, Daniel Cooley, Jon Clements and Mark Gleason. 2017. Climate, Weather and Apples. Sociology Technical Report 1046. Department of Sociology, Iowa State University, Ames, Iowa. 16 pp.This study was sponsored by the This research, North Central Fruit, Vegetable and Wine Growers’ Assessment of Soil and Water Vulnerability Under Changing Climate Conditions and Extreme Weather Events funded by USDA-Agricultural Research Service (ARS) Midwest Climate Hub. This is mainly a sociology report, demonstrating how apple growers are more afraid of risks associated with disease, potential reductions in productivity and fruit quality, changing, variable, and uncertain climate conditions, and water availability.

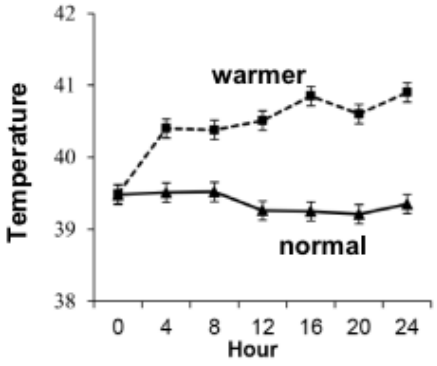
4) That research was echoed by a case study in Michigan, as told by NPR: https://www.mprnews.org/story/2018/08/01/npr-as-climate-changes-fruit-growing-does-too

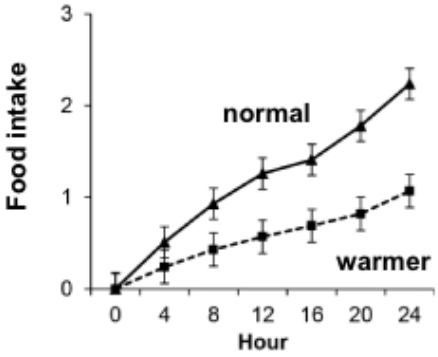
5) Gowda, P., J.L. Steiner, C. Olson, M. Boggess, T. Farrigan, and M.A. Grusak, 2018: Agriculture and Rural Com- munities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 391–437. doi: 10.7930/NCA4.2018.CH10.

6) Angel, J., C. Swanston, B.M. Boustead, K.C. Conlon, K.R. Hall, J.L. Jorns, K.E. Kunkel, M.C. Lemos, B. Lofgren, T.A. Ontl, J. Posey, K. Stone, G. Takle, and D. Todey, 2018: Midwest. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washing- ton, DC, USA, pp. 872–940. doi: 10.7930/NCA4.2018.CH21 pg 880, figure 10.4

These two general references speak to the degradation of soils that’s caused by longer growing seasons and more winter freeze/thaw events.

Warmer summers: hot pigs eat less





References:

1) https://www.scientificamerican.com/article/a-warming-climate-could-make-pigs-produce-less-meat/ (also pig image credit)

2) Pearce, S.C., V. Mani, R.L. Boddiker, J.S. Johnson, T.E. Weber, J.W. Ross, R.P Rhoades, L.H. Baumgard, N.K. Gabler.2013. Heat Stress Reduces Intestinal Barrier Integrity and Favors Intestinal Glucose Transport in Growing Pigs. PLoS ONE 8(8): e70215. https://doi.org/10.1371/journal.pone.0070215 (figure credit)

The scientific American article is a general and informative article summarizing many studies on pork heat stress and related yield losses. They cite that the US pork board has estimated 10% heat stress related losses in pork production per year. They also note some interesting physiological facts. For example, pigs have been raised to be “body builders”, they have less fat and more muscle, this physiology does not cope well with heat. They hardly sweat at all and are not good at regulating their own body temperature. The Pearce et al. article is a more specific study looking at the physiological and growth responses of pigs under stress.

This is a lesson in that each livestock animal breed of interest, may be better or worse adapted to heat stress.

3) St-Pierre, N.R., B. Cobanov, and G. Schnitkey, 2003: Economic losses from heat stress by US livestock industries. *Journal of Dairy Science,* **86**, E52-E77. http://dx.doi.org/10.3168/jds.S0022-0302(03)74040-5

This article was a large analysis of heat stress related losses in multiple livestock species. The finding in brief was that

For example, $897 million, $369 million, $299 million, and $128 million were lost in 2000 for dairy, beef, swine, and poultry industries, respectively in the US. This is as an example of potential economic losses due to heat stress for animals.

4) Rojas-Downing, M, A.P. Nejadhashemi, T. Harrigan, S.A. Woznicki. 2017. Climate change and livestock: Impacts, adaptation, and mitigation. Climate Risk Management 16, 145-163.

This publications discusses in depth how heat causes many physiological changes in animals including reduced feed and increased water intake, metabolic change, higher respiration and heart rate, and reproductive efficiency for many livestock species.

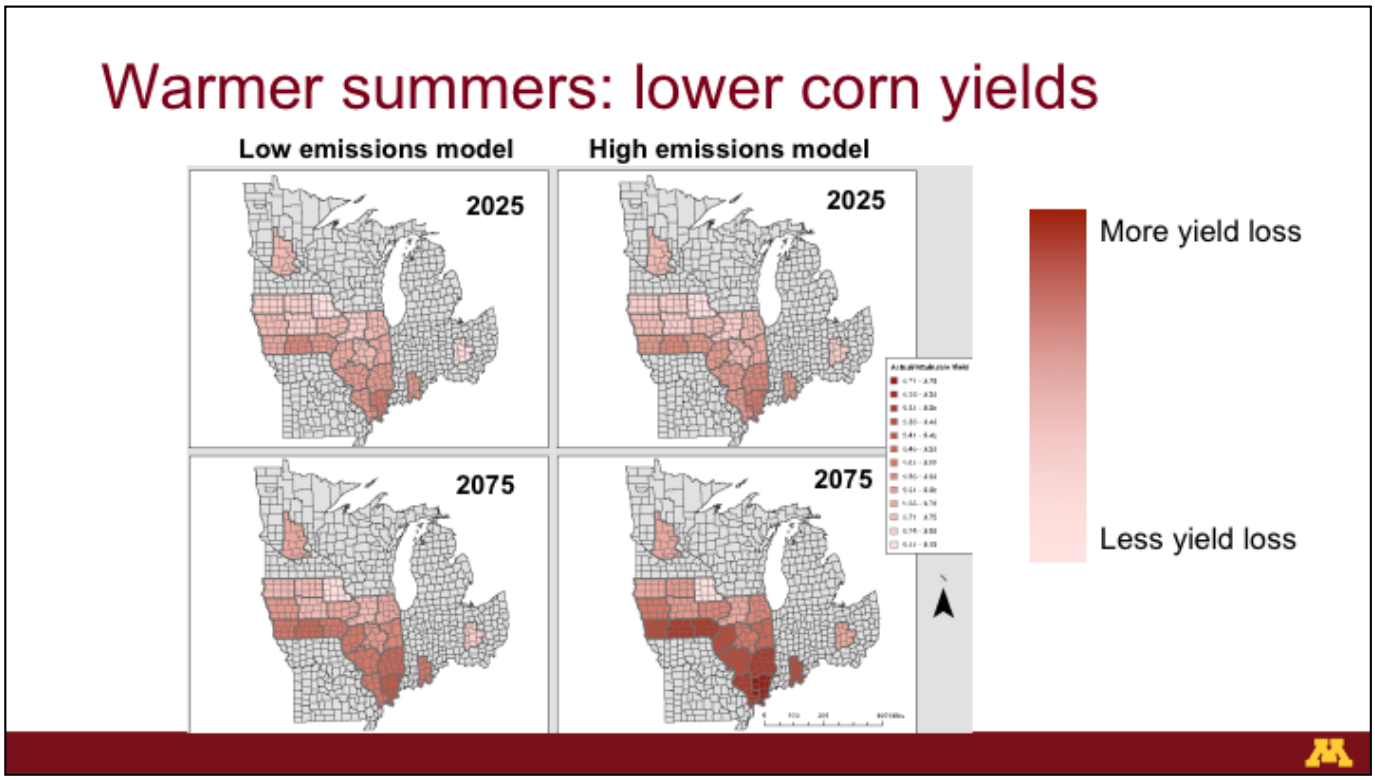
Of note to issues in Minnesota, swine and poultry have similar issues in having relatively narrow optimal temperature ranges, meaning that they can easily get too cold or too hot.

5) Smith, M.R. and S.S. Meyers. 2018. Impact of anthropogenic CO2 emissions on global human nutrition. Nature Climate Change. 8, 834-839. https://doi.org/10.1038/s41558-018-0253-3

Another important factor in livestock production is the evidence that climate change is causing a decline in the nutritional content, specifically protein, iron, and zink, of many agricultural food crops. This means that it will be more challenging to adequately feed livestock, and ourselves, a nutritious diet.

6) Key, N., S. Sneeringer, and D. Marquardt, 2014: Climate Change, Heat Stress, and U.S. Dairy Production. Economic Research Report No. ERR- 175. USDA Economic Research Service, Washington, DC, 45 pp. https://www.ers.usda.gov/publications/ pub-details/?pubid=45282

Milk production is expected to go down up to 1% by 2030 in the Midwest

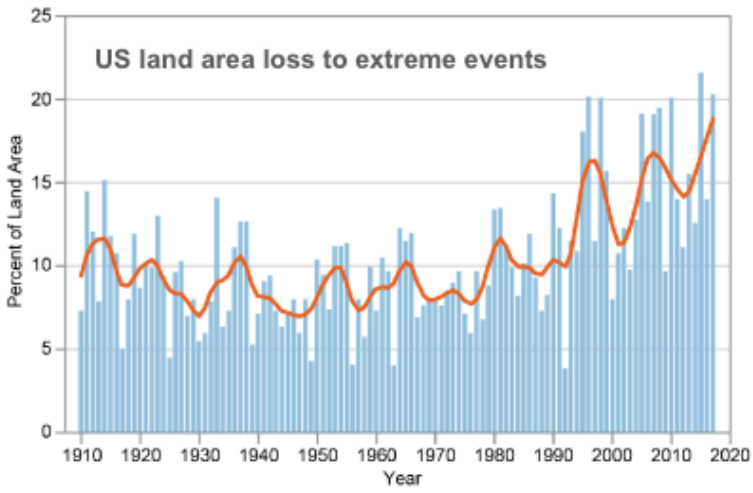


References

1) Hatfield J.L., L. Wright-Morton, and B. Hall. 2018 Vulnerability of grain crops and croplands in the Midwest to climatic variability and adaptation strategies. Climate Change. 146: 263-275. Figure 5.

This paper is an examination of corn (Maize) yield potential, which is the maximum amount and how far from those potential yields we will be under different warming scenarios in the midwest. They found that warming decreases yields more and more over time, depending on how warmer our climate will get. RCP 4.5 is a lower warming estimation in the models, RCP 8.5 is a higher warming estimation.

Extreme events and wet conditions cause more crop damage, soil loss, disease



References

1) Angel, J., C. Swanston, B.M. Boustead, K.C. Conlon, K.R. Hall, J.L. Jorns, K.E. Kunkel, M.C. Lemos, B. Lofgren, T.A. Ontl, J. Posey, K. Stone, G. Takle, and D. Todey, 2018: Midwest. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washing- ton, DC, USA, pp. 872–940. doi: 10.7930/NCA4.2018.CH21 pg 880, figure 10.4

Problems associated with a more wet climate in the midwest pg 880 discusses the increased soil erosion and disease prevalence of a more wet climate.

Extreme events

2) Gowda, P., J.L. Steiner, C. Olson, M. Boggess, T. Farrigan, and M.A. Grusak, 2018: Agriculture and Rural Com- munities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 391–437. doi: 10.7930/NCA4.2018.CH10.

Land loss due to extreme events: Figure 10.4 shows increasing land loss due to single day extreme events such as storms and hurricanes. Soil erosion represents a loss of carbon and nutrients from which crops grow, also limits the ability of land to store carbon. These losses of land also represent crop losses over time due to extreme events.

Multiple state articles and extension publications have documenting the increased problems for management and risk of crop loss due to flooding:

3) Helpful general article from UMN extension:

https://blog-crop-news.extension.umn.edu/2018/07/flooded-fields-and-saturated-conditions.html

https://www.postbulletin.com/agrinews/news/minnesota/flood-damage-marks-the-next-snag-for-minnesota-farmers/article_be2e8fca-853a-11e8-a0cb-dfd81b4597ef.html

4) https://agfax.com/2018/06/22/minnesota-corn-soybeans-excessively-wet-field-conditions-what-can-you-do/

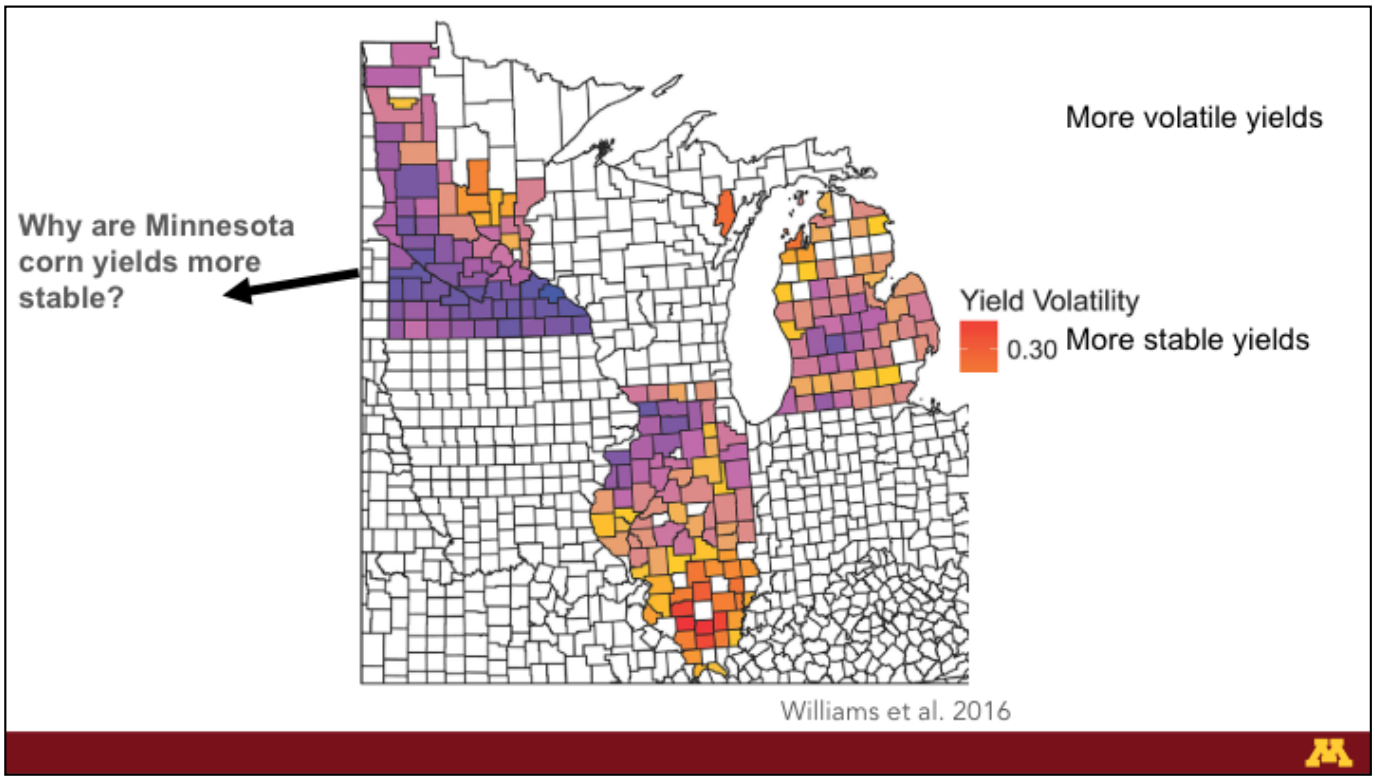
This is a UMN Extension bulletin discussing management challenges and management options under very wet conditions.

5) https://crops.extension.iastate.edu/cropnews/2016/09/wet-weather-creates-challenges-harvest

This is an extension bulletin from 2016 as an example of disease and very wet conditions altering corn rot and storage in the fall. They cite a 35% reduction in shelf life and 50% loss in storage time due to wet fall conditions.

6) Rosenzweig, C., A. Iglesias, X.B. Yang, P. R. Epstein, E. Chivian. 2001. Climate Change and Extreme Weather Events; Implications for Food Production, Plant Diseases, and Pests. Global Change and Human Health. 2, 90-104.

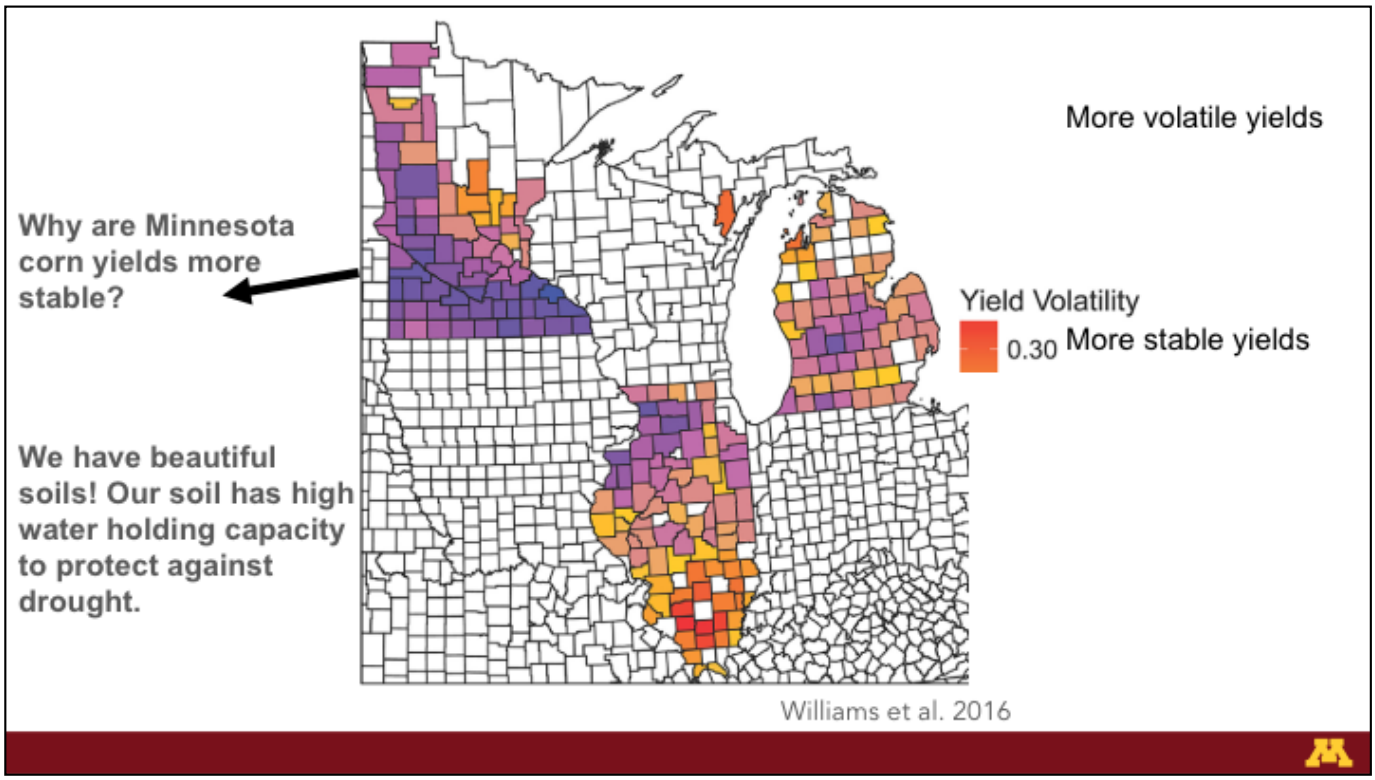
An older but helpful article modeling how extreme weather, and changing weather patterns, alter the occurrence of plant diseases and pests. They document the range shifts in many important plant diseases and pests, such as the entry of Fusarium solani (sudden soybean death syndrome) into the state of Minnesota during the 1990s. Problems like this are expected to get worse, and wet seasons will see an increase in disease presence in our crops, leading to losses or increased costs of fungicides and pesticides.

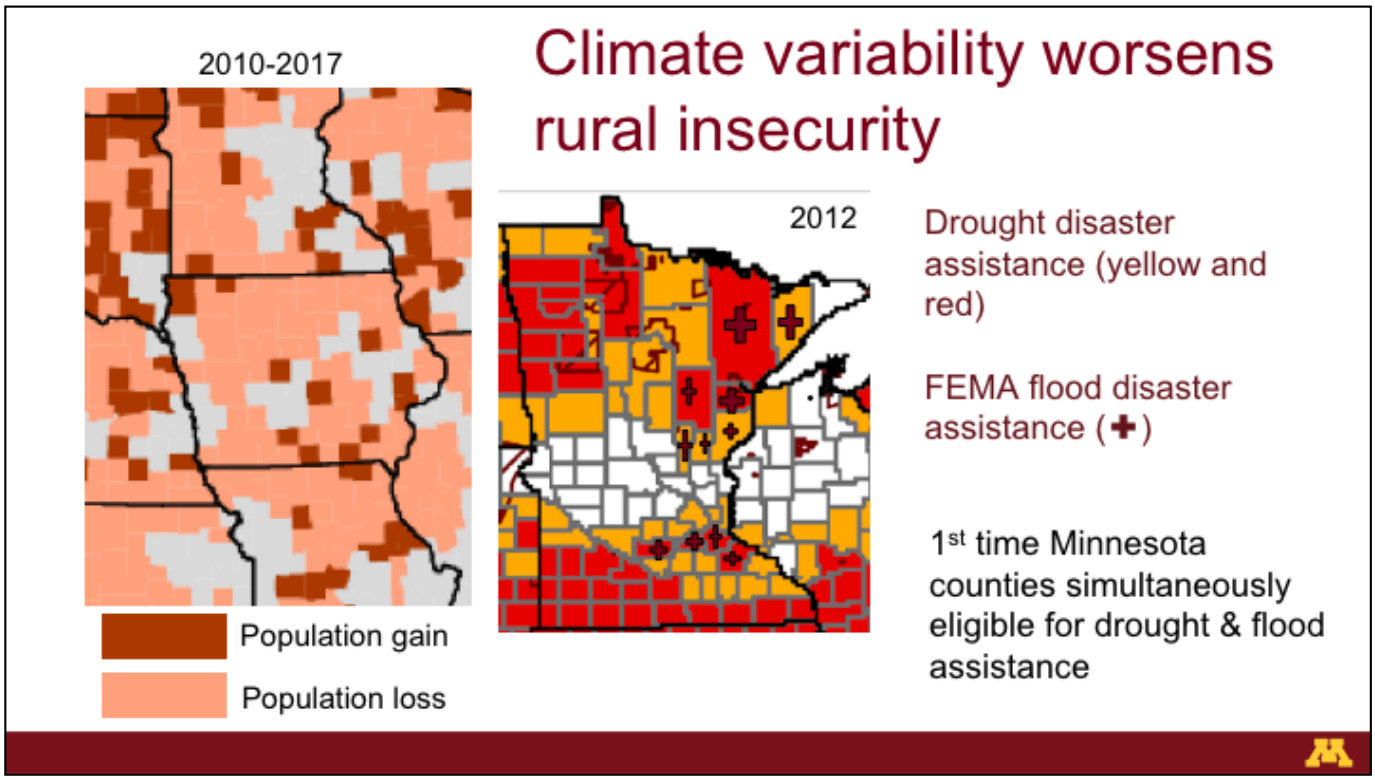


Reference:

1) Williams, A., M. C. Hunter, M. Kammerer, D. A. Kane, N. R. Jordan, D. A. Mortensen, R. G. Smith, S. Snapp, and A. S. Davis. 2016. Soil Water Holding Capacity Mitigates Downside Risk and Volatility in US Rainfed Maize: Time to Invest in Soil Organic Matter? PLOS One **11**:e0160974.

In this paper they examined how temperature is related to increased or decreased corn yields and made a measurement of “volatility”. Volatility is a measure of how much the yield or productivity changes with a given change in temperature. High volatility means that any small change in temperatures results in a big change in yields. Conversely, low volatility can also mean very stable yields that do not change as much as the temperature changes. The second step in this paper was a big analysis of what factors lead to high or low volatility, and water holding capacity, the ability of the soil to hold more water, was the main factor that they found.


More volatile yields
Why are Minnesota corn yields more stable?
Yield Volatility
0.30
More stable yields
We have beautiful soils! Our soil has high water holding capacity to protect against drought.
Williams et al. 2016



References and information

1) Gowda, P., J.L. Steiner, C. Olson, M. Boggess, T. Farrigan, and M.A. Grusak, 2018: Agriculture and Rural Com- munities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 391–437. doi: 10.7930/NCA4.2018.CH10. Figure 10.2

2) Keller Jensen, J., 2009: Climate Change and Rural Communities in the US. Draft Briefing Paper. Rural Policy Research Institute, Iowa City, IA, 13 pp. http:// www.rupri.org/Forms/Climate_Change_Brief.pdf

Summary: Current yield declines and declining profitability of farming are leading to population loss and rise of poverty in many areas of the US. We have lower poverty rates in rural Minnesota to date, but increasing risk and losses could increase poverty and rural population loss in the future, further devitalizing our rural communities. Improved local ability to make adaptive improvements in share community resources will improve resiliency.

3) https://amp.theguardian.com/us-news/2018/dec/12/as-climate-change-bites-in-americas-midwest-farmers-are-desperate-to-ring-the-alarm. Accessed January 12, 2019.

Great article on variable and unpredictable growing conditions, and the stress that it gives to farmers. A summary of this article is that farmers in some areas are feeling the pressure of higher temperatures and humidity, as well as the stress of not knowing what a given growing season will bring in terms of yields or crop losses.

We can adapt!

In summary, there are many impacts across our state and many things that we don't yet know as well as we need to. BUT, we also have opportunities to adapt and lead these efforts.

E-mail me if you have questions: jgut@umn.edu

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Climate Change Impacts in Minnesota: Cities

Dr. Bonnie Keeler, Assistant Professor, Humphrey School of Public Affairs
Center for Science, Technology, and Environmental Policy

17 January 2019

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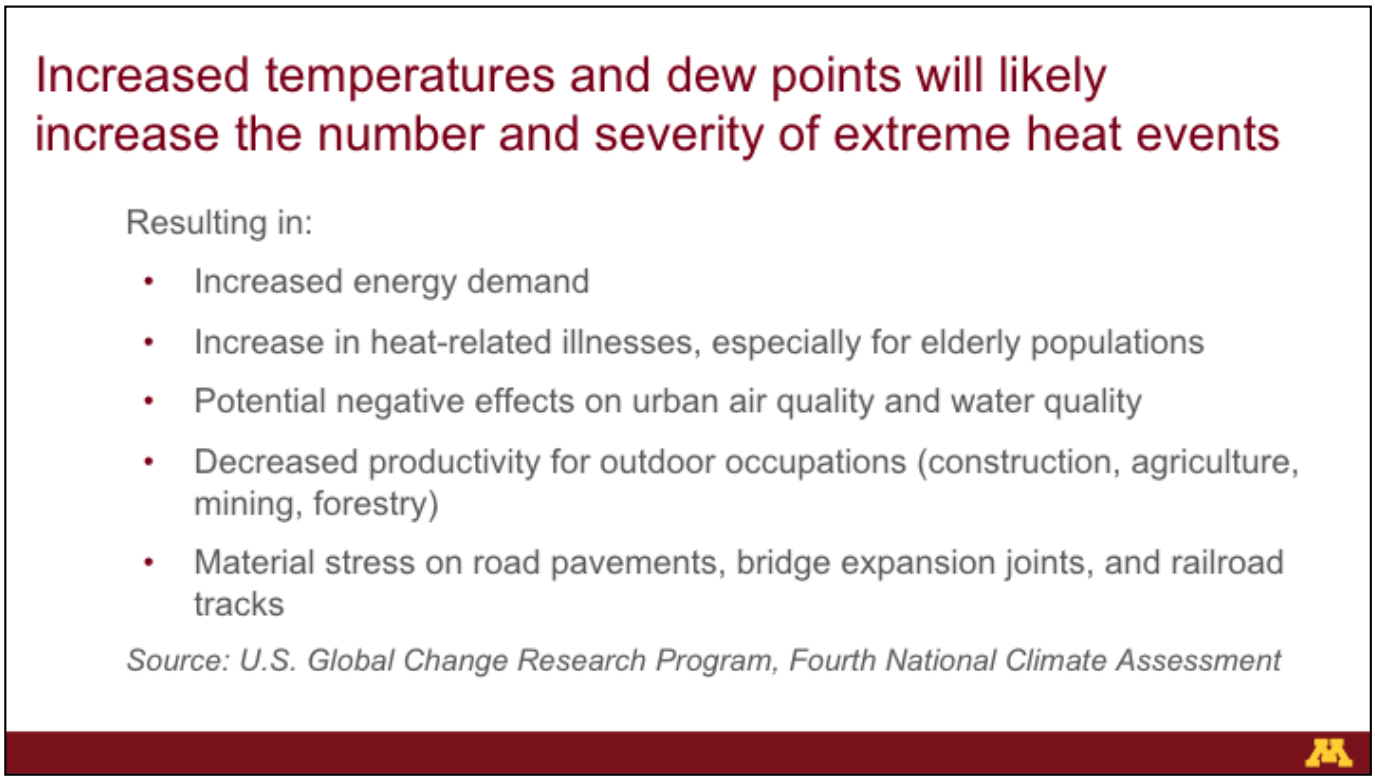


daytime high temperatures are increasing; by mid-century (2041-2070) Minnesota is projected to experience five to 15 more days per summer with a maximum temperature above 95°F (Pryor et al., 2014). Second, daily minimum temperatures or overnight lows are increasing faster than daytime high temperatures, limiting the ability to cool off at night (Zandlo, 2008). Third, dew point temperatures may be increasing, which elevate the apparent temperature (heat index) and prevent sweat from evaporating off the skin, which enables the body to cool itself (Seeley, 2013). Increased maximum and minimum temperatures and dew point temperatures will likely increase the number and severity of extreme heat events in the future. USGCRP

Effects of Climate Change on Air Quality Climate change may have negative effects on air quality. Increases in temperatures and air stagnation events are likely to cause negative impacts on air quality. Warmer summer temperatures may both increase the natural emission of VOCs from plants and vegetation (Bernard et al., 2001), and catalyze the process of ozone formation (Jacob & Winner, 2009; Bernard et al., 2001). Warmer spring and summer temperatures also are driving a lengthening of the allergy season, an increase in allergenic pollen plants, and increases in the potency of allergenic pollen (Rogers et al., 2006; Jacob & Winner, 2009; Bernard et al., 2001). Increased temperatures may increase PM2.5 as a result of more fossil fuel combustion to meet electricity demand for increased air conditioner use. Climate change also may increase the frequency of air stagnation events, which allow pollutants to hover and create poor air quality (Jacob & Winner, 2009; Wu et al., 2008). The worst air pollution days often occur during air stagnation events when there is no wind to blow away pollutants. Stagnant air events occur both in summer and winter, causing air quality alert days for ozone and fine particle pollution, respectively.

2012 was an ideal year for mosquitoes carrying WNV – including a long warm season, higher than normal temperatures, and drought across most of the state's farmland.

Tale of one city….

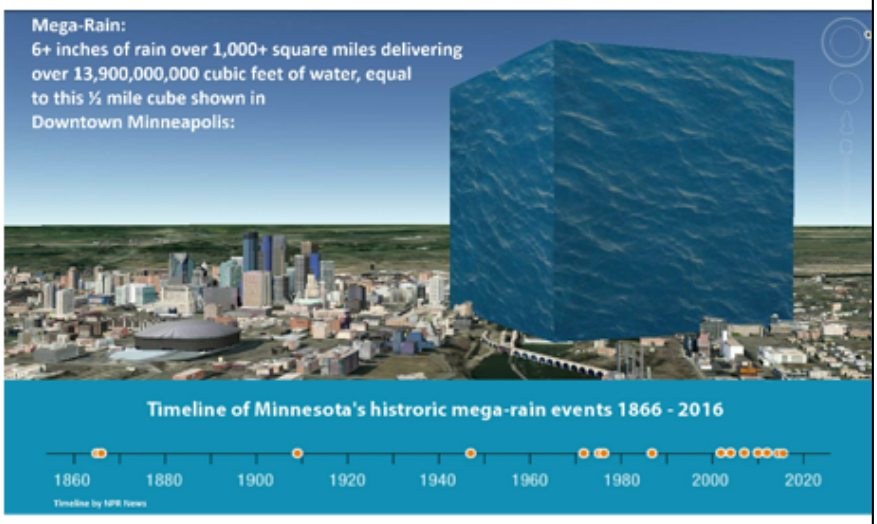
- By 2100, Faribault can expect an increase of 5-10° in annual average temperature, an increase to 54 days above 95 degrees, 43 fewer days below freezing, and an increase in air conditioning demand by 300%.
- By the middle of this century (2040-2070) Summertime conditions for Faribault are projected to be similar to the conditions currently felt over 500 miles or further to the South...the equivalent of moving the City 315 feet south every day.

Source: MPCA Climate Adaptation Framework 2018

Increased frequency and intensity of precipitation events

Resulting in:

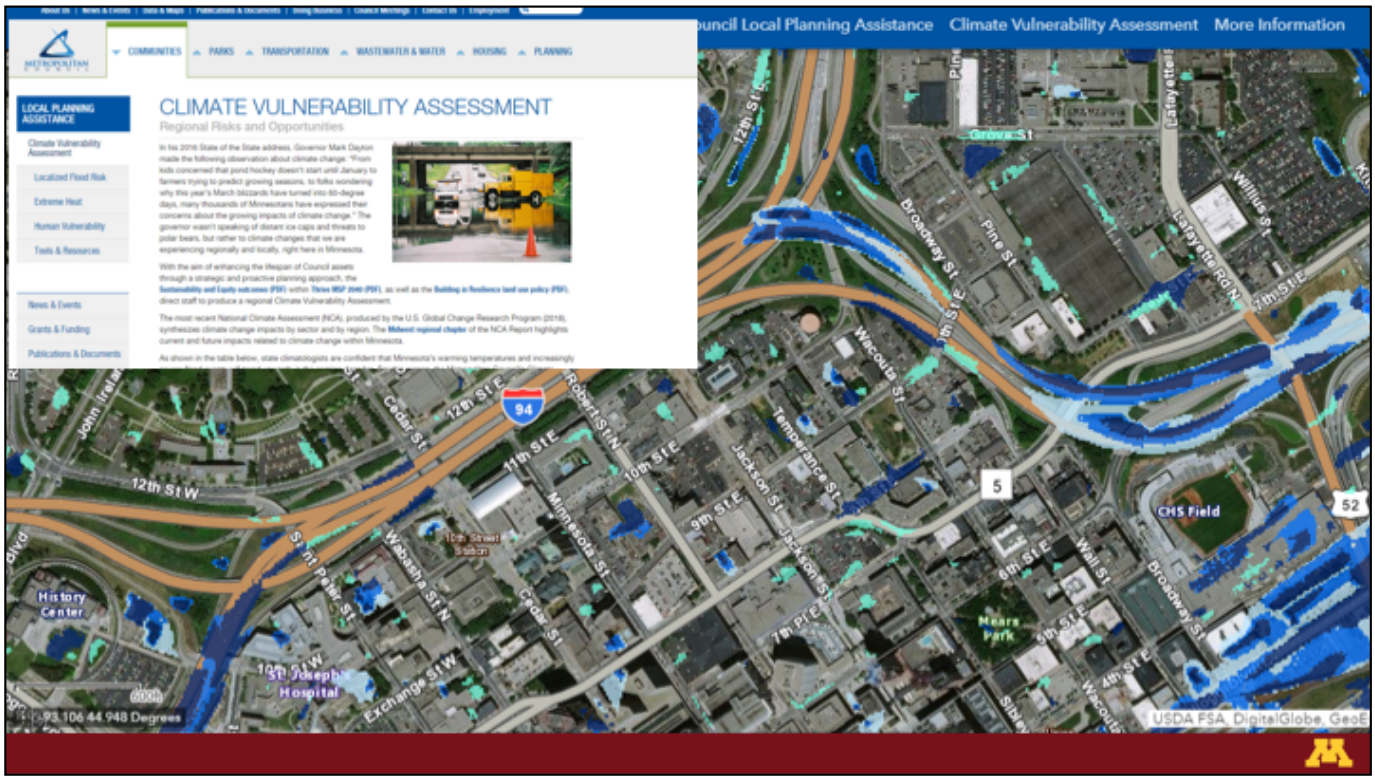
- More frequent flooding and extreme rain events
- Damage to transportation, infrastructure, and property, especially water and sewer systems
- Increased burden on emergency management, and a growing financial toll on businesses, homeowners, and insurers



Source: U.S. Global Change Research Program, Fourth National Climate Assessment

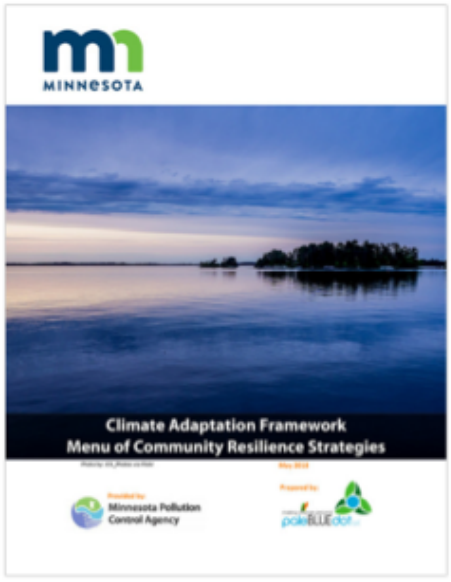
Winter and spring precipitation are important to flood risk in the Midwest and are projected to increase by up to 30% by the end of this century. Heavy precipitation events in the Midwest have increased in frequency and intensity since 1901 and are projected to increase through this century

Already have a funding crisis for infrastructure just to repair what we have, not to mention increased costs to bring infrastructure into compliance with future climate change.



Adaptations: Update building codes to account for future climate rating systems,
Zoning: Protect floodplains, promote infiltration and green infrastructure.

Resources



MINNESOTA CLIMATE CHANGE VULNERABILITY ASSESSMENT **2014**

Minnesota Department of Health

Climate Change Impacts in Minnesota: Public Health

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January 17, 2019

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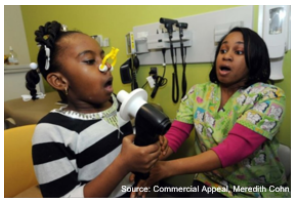
- **The Lancet Countdown:** Tracking Progress on Health and Climate Change is an international research collaboration, dedicated to tracking the world's response to climate change, and the health benefits that emerge from this transition.
- Reporting annually in The Lancet, it will follow a series of indicators, demonstrating that this transition is possible, that it has already begun, but that more work is needed.
- **Resource**: Find the 2018 report, summary for policy makers and infographics at http://www.lancetcountdown.org/the-report/

Faces of Climate Change

Heat-Related Illness

Asthma & Allergies



Drought & Flooding (Mold)

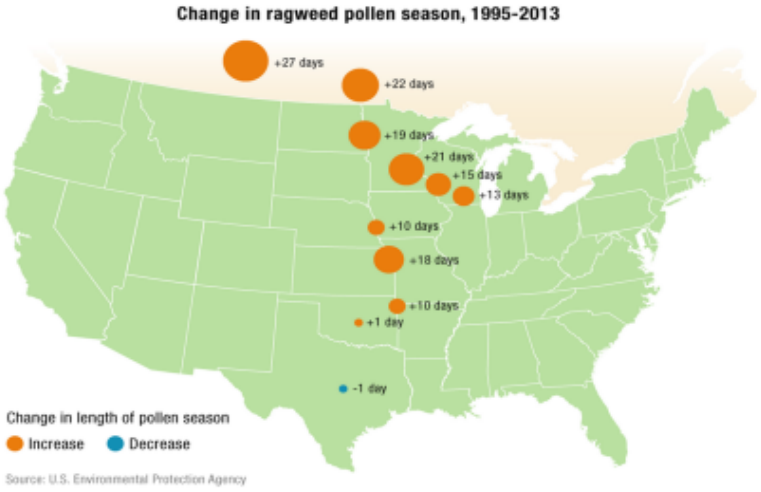
Mental Health

Displacement

Climate Changes Health

- Allergies
- Asthma
- Heat Related Illness
- Mold
- Vector Borne Illnesses
- Mental Health

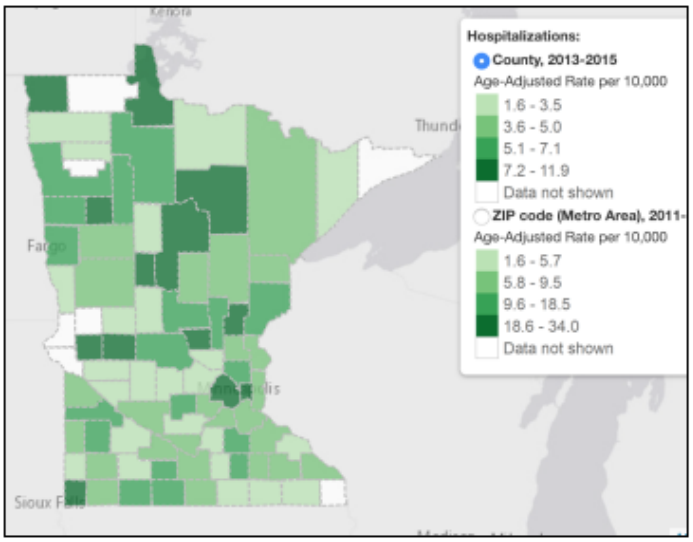
Climate Change & Allergies



Climate Change and Allergies- what do the experts say?

- Allergic illnesses, including hay fever, affect about one-third of the U.S. population, and more than 34 million Americans have been diagnosed with asthma.
- These diseases have increased in the United States over the past 30 years . The prevalence of hay fever has increased from 10% of the population in 1970 to 30% in 2000.
- Asthma rates have increased from approximately 8 to 55 cases per 1,000 persons to approximately 55 to 90 cases per 1,000 persons over that same time period.
- **Resource: Report from Allergy and Asthma Foundation of America** :https://www.aafa.org/media/1634/extreme-allergies-global-warming-report-2010.pdf
- **Position statement on climate change and allergies from AAAI** American Academy of allergy, Asthma and Immunology- https://www.aaaai.org/Aaaai/media/MediaLibrary/PDF%20Documents/Practice%20and%20Parameters/Climate-change-and-our-environment-2013.pdf

Burden of Asthma in Minnesota



What is the current burden of asthma in Minnesota?

- One in 14 children (7.1%) and one in 13 adults (7.5%) currently have asthma, adding up to around 408,000 Minnesotans who have asthma.
- Asthma death rates are 4 times higher among African Americans than among whites.
- In 2014, asthma cost an estimated $669.3 million, including $614.9 million in direct medical expenses and $54.3 million in lost work days.
- **Resource:** More information on asthma in Minnesota can be found at http://www.health.state.mn.us/asthma/
- **Resource: American Thoracic Society position statement on climate change & Health-** https://www.thoracic.org/statements/resources/eold/climate-change-and-human-health.pdf

How does climate change worsen asthma?

1. Pollen- Heat and increased carbon dioxide increase the duration of the pollen season, the allergenicity (a measure of how much particular allergens, such as ragweed, affect people) of pollen triggering asthma attacks and taking away from productivity of Minnesotans- https://health2016.globalchange.gov/air-quality-impacts

- Neil, K., and J. Wu, 2006: Effects of urbanization on plant flowering phenology: A review. *Urban Ecosystems*, **9**, 243-257. George, K., L. H. Ziska, J. A. Bunce, and B. Quebedeaux,

2007: Elevated atmospheric CO2 concentration and temperature across an urban–rural transect. *Atmospheric Environment*, **41**, 7654-7665.

2. Climate Penalty Factor- Heat and Ozone

- The American Lung Association puts out a report every year called the State of the Air. In the report, they discuss the air quality progress in different parts of the country. Minnesotan cities rank amongst the cleanest top 25 cities! But, this is threatened by increasingly warm summers. The damage to our climate causes hotter summers. This causes stagnation of polluted air. These pollutants then bake together in the hot sun to form high levels of ground-level ozone that is a known

trigger for asthma attacks.

Resource: State of the Air 2018 report-
https://www.lung.org/assets/documents/healthy-air/state-of-the-air/sota-2018-full.pdf

3. Wildfires:

- Climate change will worsen the intensity and duration of wildfires. This smoke travels to Minnesota from Canada and the NorthWest US causing poor air quality. The main pollutant in wildfire smoke is called Particulate Matter- PM2.5. This is a microscopic pollutant that causes heart attacks and triggers asthma. The American Heart Association put out a statement in 2010 outlining the “causal” link between PM2.5 and cardiovascular mortality. This is very significant in scientific terms, as now there is as strong a link between smoking and lung cancer as there is between air pollution and deaths. There is NO safe level of PM2.5

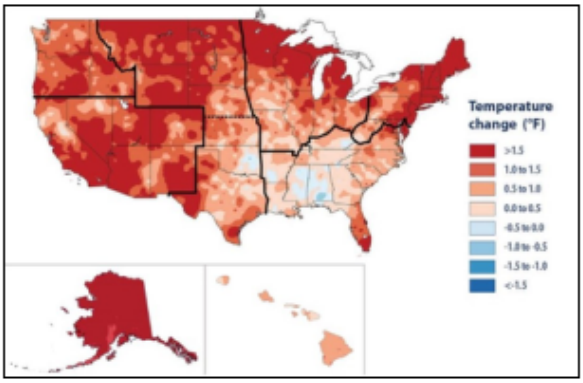
Resource: American Heart Association statement on
https://dnr.wi.gov/topic/AirQuality/documents/AHA_Circulation_2010.pdf

4. **Mold:**

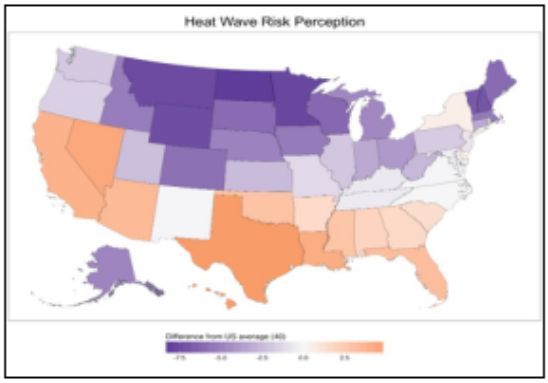
- With increased precipitation in Minnesota, we will see an increase in chronic flooding of homes. Water damaged homes lead to a rise in mold and respiratory related illnesses. This was best demonstrated after hurricane Katrina. Unfortunately, this impacts low-income families and is also an issue of equitable housing. J Environ Public Health 2017;2017:2793820. doi: 10.1155/2017/2793820. Epub 2017 Apr 9. Increased Sensitization to Mold Allergens Measured by Intradermal Skin Testing following Hurricanes. Saporta, Hurst

Climate Change & Extreme Heat

Extreme Heat in Minne-SNOW-ta? You betcha!



Source, EPA & CDC, Extreme Heat, Melillo et al, 2014



Source: Heat wave risk perception, *Howe, Marlon, and Leiserowitz, unpublished data, 2017*

Climate change and a rise in heat related illness

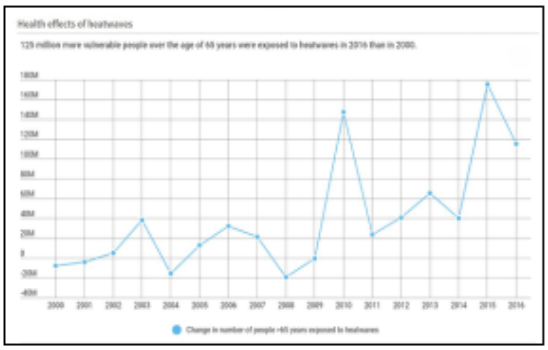
- Minnesota has gotten noticeably warmer, especially over the last few decades. Data for the last half century (1960-2013) show that the recent rate of warming for Minnesota has sped up substantially to 0.5°F per decade (5.3°F per century)
- This, with a rise in dew point and urban heat island effect, elderly who live alone and in homes without air conditioning will be at highest risk for heat stroke

Resources:

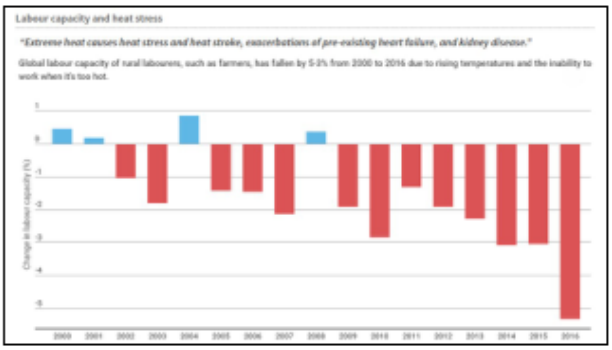
- The 4th national climate assessment- Midwest- https://nca2018.globalchange.gov/chapter/21/
- Climate change and extreme heat, what can you do to prepare- EPA & CDC document- https://www.epa.gov/sites/production/files/2016-10/documents/extreme-heat-guidebook.pdf
- An Assessment of Climate Change Impacts on the Health & Well-Being of Minnesotans http://www.health.state.mn.us/divs/climatechange/docs/mnprofile2015.pdf

Climate Change & Heat Illness Burden

Every degree of warming matters-Our planet has a fever!



Lancet Countdown, 2017



Lancet Countdown, 2017

Lancet Countdown 2018 Extreme Heat and Implications for United States

- Heat exposure in the U.S. is increasing as hot days and extreme heatwaves become more frequent. In 2017, the majority of Americans experienced temperatures that were well above average or the warmest ever recorded, with increasing frequency and intensity of heatwaves.
- The cost of hospitalizations, emergency department encounters, and outpatient visits related to just one heatwave event was estimated at $179 million.
- If America maintains its current electricity mix with 30% from coal, as many as 1,000 additional deaths may occur annually by midcentury from air pollution due to the electricity generation for air conditioning alone. A transition towards less-polluting electricity sources is key

Resource: Lancet Countdown 2018, United States briefing for Policymakers-
http://www.lancetcountdown.org/media/1426/2018-lancet-countdown-policy-brief-usa.pdf

Climate Change, Drought & Flooding

Did you know?
7 of the 15 Minnesota mega-rain events have occurred since 2002.

Heavy Precipitation, Chronic Flooding & Mold

Mold:

Molds are fungi that grow in warm, damp, and humid conditions. Following floods and other extreme weather events, standing water and water intrusion into homes can encourage the growth of molds.

Resource:

1. Climate change, mold & Asthma:

https://insight.livestories.com/s/health-impacts-of-climate-change-mold-and-respiratory-illness/567b2bb962b12600174b9e02/

2. WHO guide for mold, dampness and air quality:

http://www.euro.who.int/__data/assets/pdf_file/0017/43325/E92645.pdf

3. Report on Climate Change, the Indoor Environment, and Health- Institute of Medicine of National Academies

The committee concludes that climate change influences indoor environmental quality, warranting attention and action

http://www.nationalacademies.org/hmd/~/media/Files/Report%20Files/2011/Climate-Change-the-Indoor-Environment-and-Health/Climate%20Change%202011%20Report%20Brief.pdf

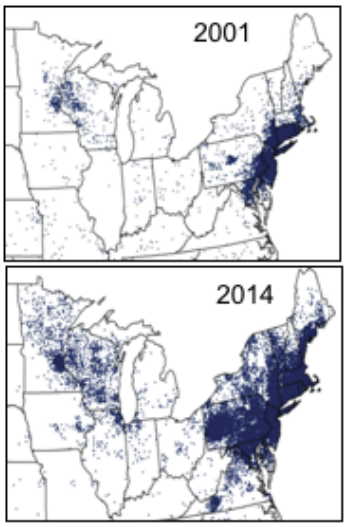
Heavy precipitation also means more runoff, both in rural and urban areas

Resource:

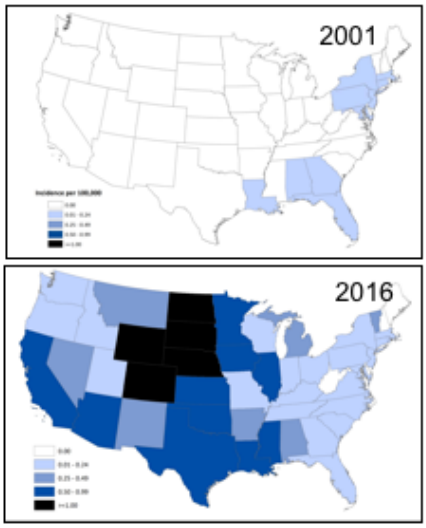
1. Blue Baby Syndrome due to Nitrates from agricultural runoff contaminating water – Environ Health Perspective, 2000 Jul; 108(7): 675–678. Blue babies and nitrate-contaminated well water. L Knobeloch, B Salna, A Hogan, J Postle and H Anderson
2. Health threats of nitrates in drinking water with links to colon and thyroid cancer in adults- https://www.ncbi.nlm.nih.gov/pubmed/30041450

Carcinogenic coal Tar PAH in Great lakes and Storm Water- MPCA report- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4101084/#R36

Climate Change & Vector Borne Illness



Lyme disease

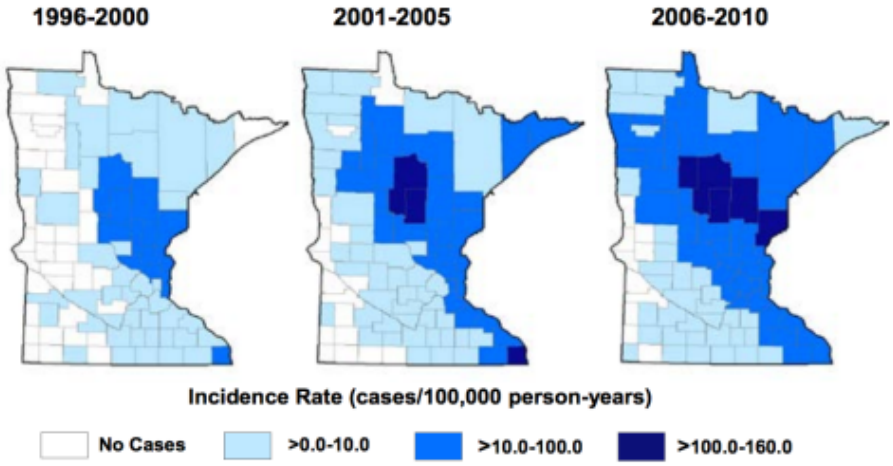


West Nile Virus Disease

West Nile Virus:

- "West Nile virus (WNV) is the leading cause of mosquito-borne disease in the United States. From 1999 to 2013, a total of 39,557 cases of WNV disease were reported in the United States. Climate change will influence human vulnerability to vector-borne disease by influencing the seasonality and the location of exposures to pathogens and vectors." Reference: Ch. 5: Vectorborne Diseases. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Beard, C.B., R.J. Eisen, C.M. Barker, J.F. Garofalo, M. Hahn, M. Hayden, A.J. Monaghan, N.H. Ogden, and P.J.Schramm, 2016: U.S. Global Change Research Program, Washington, DC, 129–156. http://dx.doi.org/10.7930/J0765C7V

Lyme Disease in Minnesota



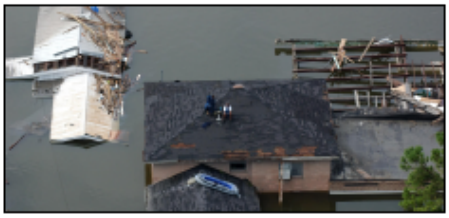
Increasing temperatures and the accompanying changes in seasonal patterns are expected to result in earlier seasonal tick activity and an expansion in tick habitat range, increasing the risk of human exposure to ticks. While Lyme disease spread is multi-factorial including deforestation and changing patterns of human-deer interaction, temperature variability has a well defined role.

References:

- “Ticking Bomb”: The Impact of Climate Change on the Incidence of Lyme Disease, Igor Dumi, Edson Severnini, Can J Infect Dis Med Microbiol. 2018

- Ch. 5: Vectorborne Diseases. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Beard, C.B., R.J. Eisen, C.M. Barker, J.F. Garofalo, M. Hahn, M. Hayden, A.J. Monaghan, N.H. Ogden, and P.J.Schramm, 2016: U.S. Global Change Research Program, Washington, DC, 129–156. http://dx.doi.org/10.7930/J0765C7V

Climate Change & Mental Health



PTSD after natural disasters

Farmer suicides in drought

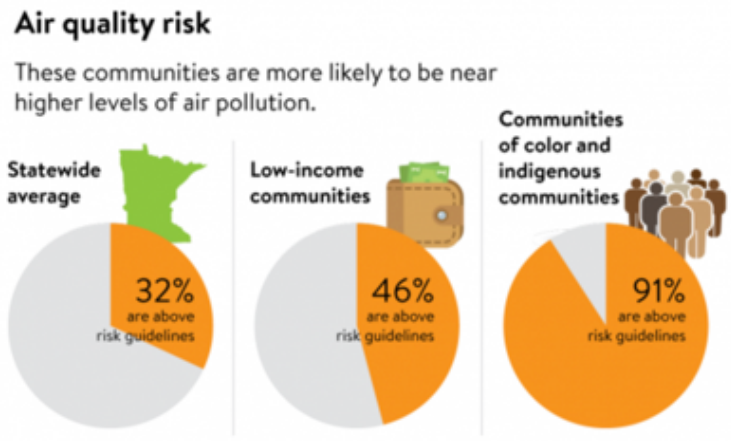
Sense of loss of place

More than 40 million adults in the U.S. suffer from a mental illness.

- Victims of natural disasters are at an increased risk of anxiety, depression, PTSD, and suicide.
- 25-50% of people exposed to an extreme weather disaster are at risk of adverse mental health effects.
- Up to 54% of adults and 45% of children suffer depression after a natural disaster.
- After a record drought in the 1980s, the suicide rate doubled, including more than 900 farmers in the Upper Midwest.
- Communities that rely on the natural environment for sustenance and livelihood, as well as populations living in areas most susceptible to specific climate change events, are at increased risk for adverse mental health outcomes [High Confidence].
- **Resource:** Dodgen, D., D. Donato, N. Kelly, A. La Greca, J. Morganstein, J. Reser, J. Ruzek, S. Schweitzer, M.M. Shimamoto, K. Thigpen Tart, and R. Ursano, 2016: Ch. 8: Mental Health and Well-Being. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 217–246.

Environmental Justice

Should your zip code determine how long you live?



UMN studies show disproportionate exposure to air pollution

- Enter your zip code and find out what your life expectancy is at https://www.rwjf.org/en/library/interactives/whereyouliveaffectshowlongyoulive.html
- In Minnesota, study the environmental injustice impact with MPCA data- https://www.pca.state.mn.us/air/disproportionate-impacts-minnesota
- Even though we do not frack for natural gas in Minnesota, we do use natural gas drilled in other places and we sit atop a maze of pipelines carrying fracked gas. In this way, we are

outsourcing pollution to rural communities elsewhere to our fellow Americans making it an environmental justice issue. Fracking and environmental justice- PSR Fracking compendium,

https://www.psr.org/wp-content/uploads/2018/04/Fracking_Science_Compendium_5.pdf

- Twin Cities Environmental Justice – Center for Earth Energy and Democracy http://ceed.org/twin-cities-environmental-justice-mapping-tool-released/

- UMN study finds Air pollution exposure inequity- Spatial Cluster Detection of Air Pollution Exposure Inequities across the United States, Bin Zou , Fen Peng, Neng Wan, Keita Mamady,

Gaines J. Wilson, March 19, 2014, PILOS One

Every major medical society in the United States- American Medical Association(AMA), American College of Physicians (ACP) and American Academy of Pediatrics (AAP) and worldwide – World Health Organization, has a position statement on how climate change is impacting our health.

Specialty organizations have position statements on how climate change will have specialty-specific impacts- Eg: American College of Obstetricians and Gynecologists (ACOG) discuss impacts on women's health; the American Psychiatric Association discusses mental health impacts and American College of Emergency Physicians (ACEP) warns about impact of extreme weather events **Reference:**

American Lung Association-Declaration on Climate change and Health

https://www.lung.org/our-initiatives/healthy-air/outdoor/climate-change/a-declaration-on-climate-change-and-health.html

Faces of Climate Action

Energy Efficiency

Sustainable Farming

Health Professionals

Renewable Energy

Electric Transportation

Legislators

What's good for you is good for the planet too

- **Climate change, Air Quality and Asthma:**

  - There is virtually no chronic illness that would not benefit from exercise. https://www.health.harvard.edu/staying-healthy/is-exercise-really-medicine

  - Car trips of under a mile add up to about 10 billion miles per year, according to the 2009 U.S. National Household Transportation Survey (NHTS)
  - Data shows that 28% car trips are less than 1 mile and 40% are less than 2 miles. https://www.bikeleague.org/content/national-household-travel-survey-short-trips-analysis

  - Instead of vague advice of "drive less", we can impact change by aiming for active transportation - walking/biking, when our trips are 2 miles or less. Data from EPA shows this results in savings and decreased GHG emissions. https://www.epa.gov/greenvehicles/what-if-we-kept-our-cars-parked-trips-less-one-mile

  - Climate change is already impacting our air quality as we saw in the previous slide. On an individual level, we have to alert our public on how to deal with the impacts. Leave the house to bike/walk ONLY if the outdoor air quality is permissible. If anyone of you has/knows someone with asthma or heart disease, make sure that they have access to an air quality app.

  - We live and work in cities that were designed for cars. Not for people. As such, we need city planning and complete street policies that can create safe streets for people to walk and bike. We understand this very well in Minneapolis, which is consistently one of the most bike able cities in the US. And, the investment into infrastructure is paying off with savings in human health costs as seen in reports from MNDoT

https://www.dot.state.mn.us/bike/research/economic-health-impact.html

- Finally, we cannot bike/walk everywhere. So, we need to electrify our entire transportation system and move away from diesel/LNG/Gasoline powered vehicles. This will give us immediate benefits in improvement in air quality, but also help decrease our green house gas emissions. These results will only be magnified when we combine electric transportation with a clean renewable energy grid free of fossil fuels.

- **Climate Change and Extreme Heat**

  Resource: Extreme Heat, Climate Change and Health - http://climatehealthconnect.org/wp-content/uploads/2016/09/ExtremeHeat.pdf

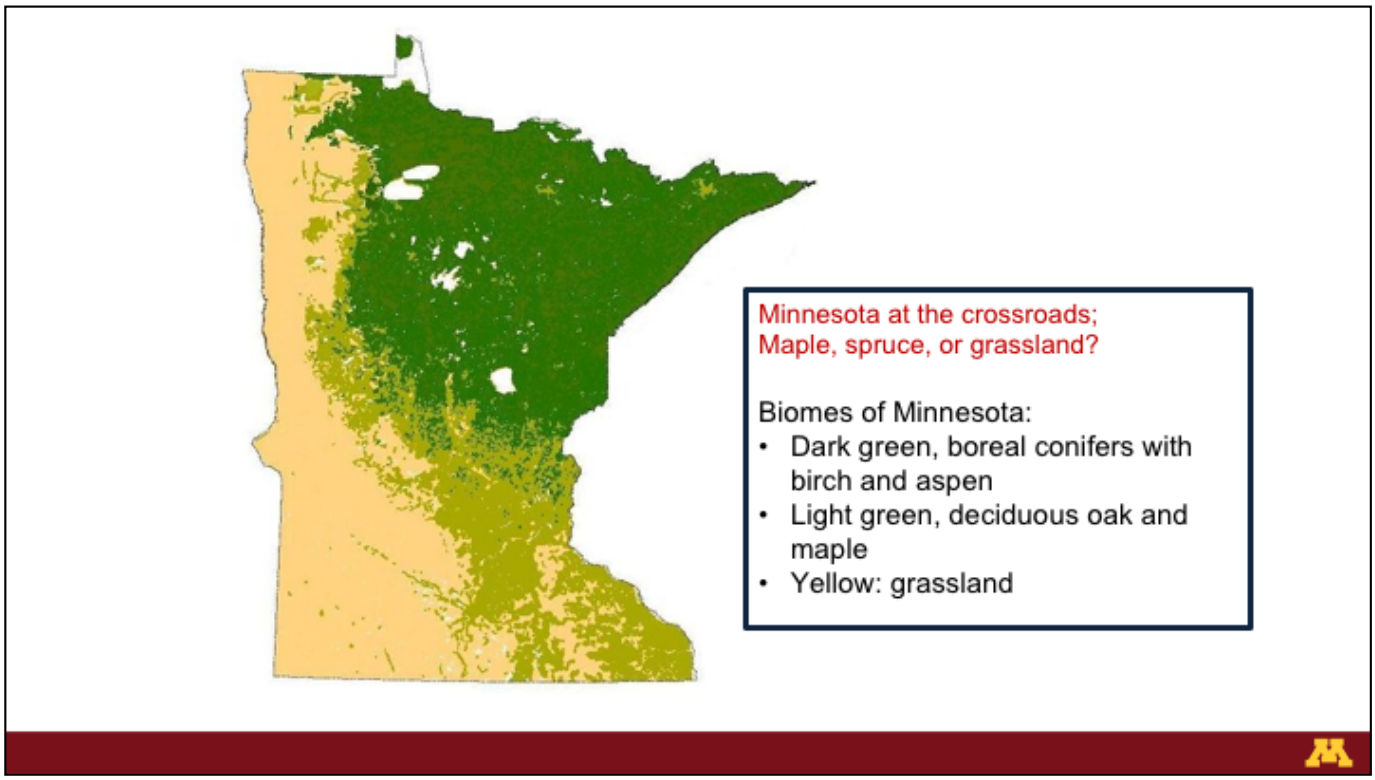
  - Use air conditioning, or get to a cool place like a cooling center or air conditioned shopping center or public building
  - Encourage individuals to check in on neighbors, friends and relatives during extreme heat events. Encourage patients to make sure they have a “heat buddy” who will check in on them
  - Advocate for “urban greening”— planting trees and building green infrastructure — in neighborhoods that are tree and park poor, to increase shade and cooling.
  - Support policies that mandate the use of cool roofs and green roofs and cool pavements, for example Los Angeles Cool Roof ordinance
  - Support policies that increase energy efficiency and the use of clean, renewable energy. This limits global warming, but also reduces local impacts like the creation of urban heat islands, which often result from increased energy use at the local level.

Climate Change Impacts in Minnesota: Biological Resources

Lee E. Frelich, Center for Forest Ecology

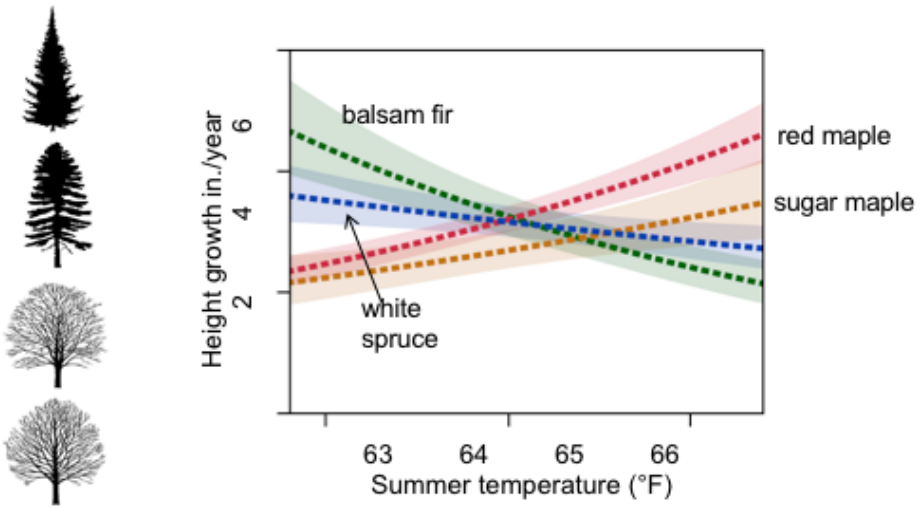
January 17, 2019

UNIVERSITY OF MINNESOTA
Driven to Discover®



Minnesota is in one of the two places on the planet where boreal forest, temperate forest and grasslands come together in an interior continental setting. While this makes Minnesota an extremely interesting place, it also makes it vulnerable to changing climate.

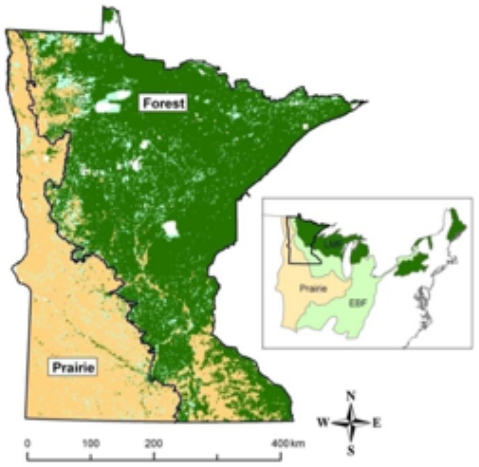
Mean summer temperature determines the balance between temperate and boreal forest

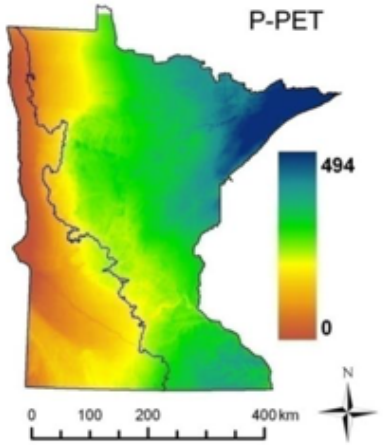


After Fisichelli, Frelich and Reich. (2012) Global Change Biology 18: 3455-3463. There is a tipping point in mean summer temperature between 64 and 65 degrees mean summer temperature. At cooler temperatures boreal trees like spruce and fir outgrow temperate trees like maple and oak, while the reverse occurs at warmer temperatures. A shift to summer temperatures above 66 F could eliminate boreal tree species.

Photo by Lee Frelich. There was no balsam fir in this forest in 1980. Widespread invasion of boreal forests by temperate forest tree species is already occurring with the warming that has already occurred.

Location of the prairie-forest border in Minnesota depends on the balance between precipitation and evaporation



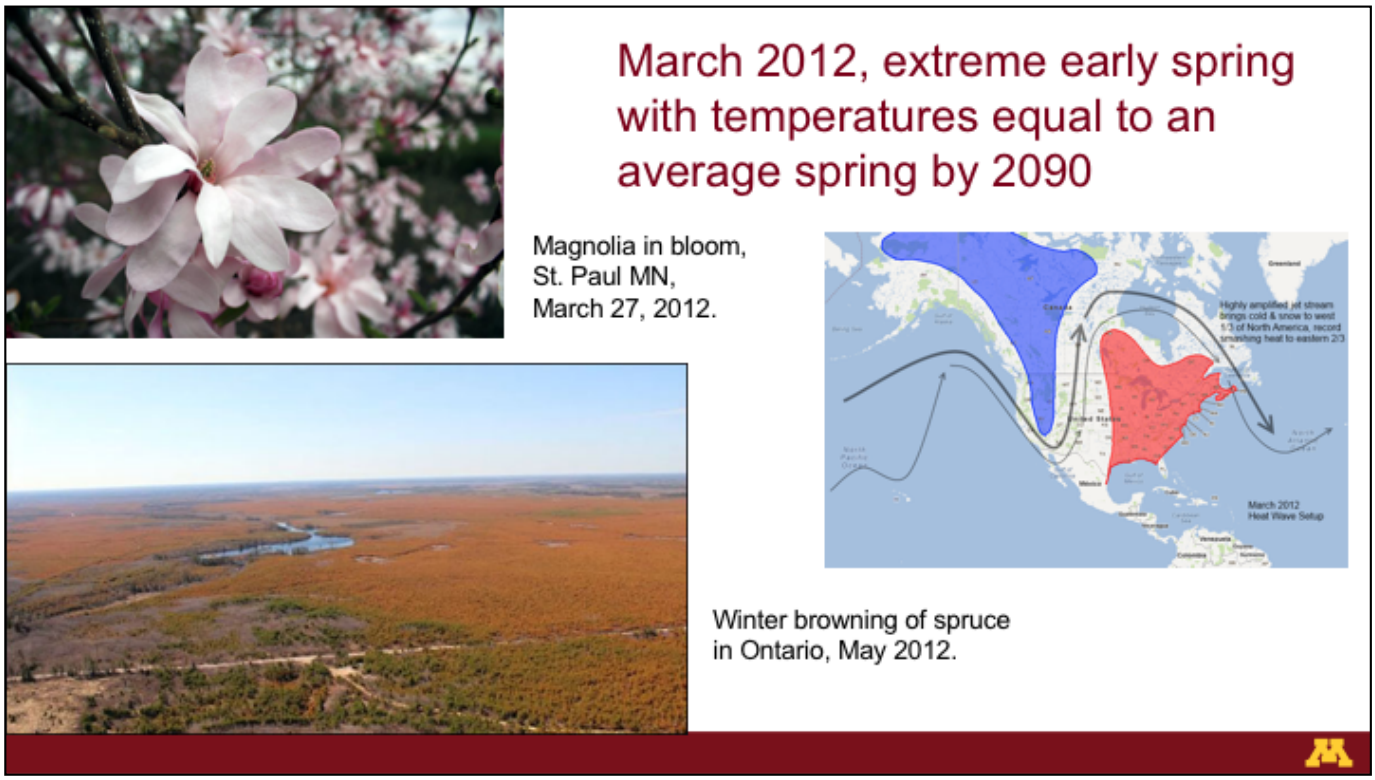


Where there is excess precipitation over evaporation (blue and green areas), forests occur, while grasslands occur in areas with negative water balance (brown).

From: Danz, Reich, Frelich and Niemi, 2011, *Ecography* 34: 402-414;

Danz, Frelich, Reich and Niemi, 2013, *Journal of Vegetation Science*, 24: 1129-1140

A variety of factors affecting forests will also change when the climate changes. More droughts and fires will occur and a number of insect pests currently limited by cold winter temperatures will be able to increase the extent of infested forests, including mountain pine beetle and emerald ash borer. Photos on left: Photos above and below: Dave Hansen, UMN



Early springs in a warmer climate are good for grasslands and temperate forests, but will kill boreal forests. Upper Photo, Jenna Williams. Lower photo, Ontario Ministry of Natural Resources.

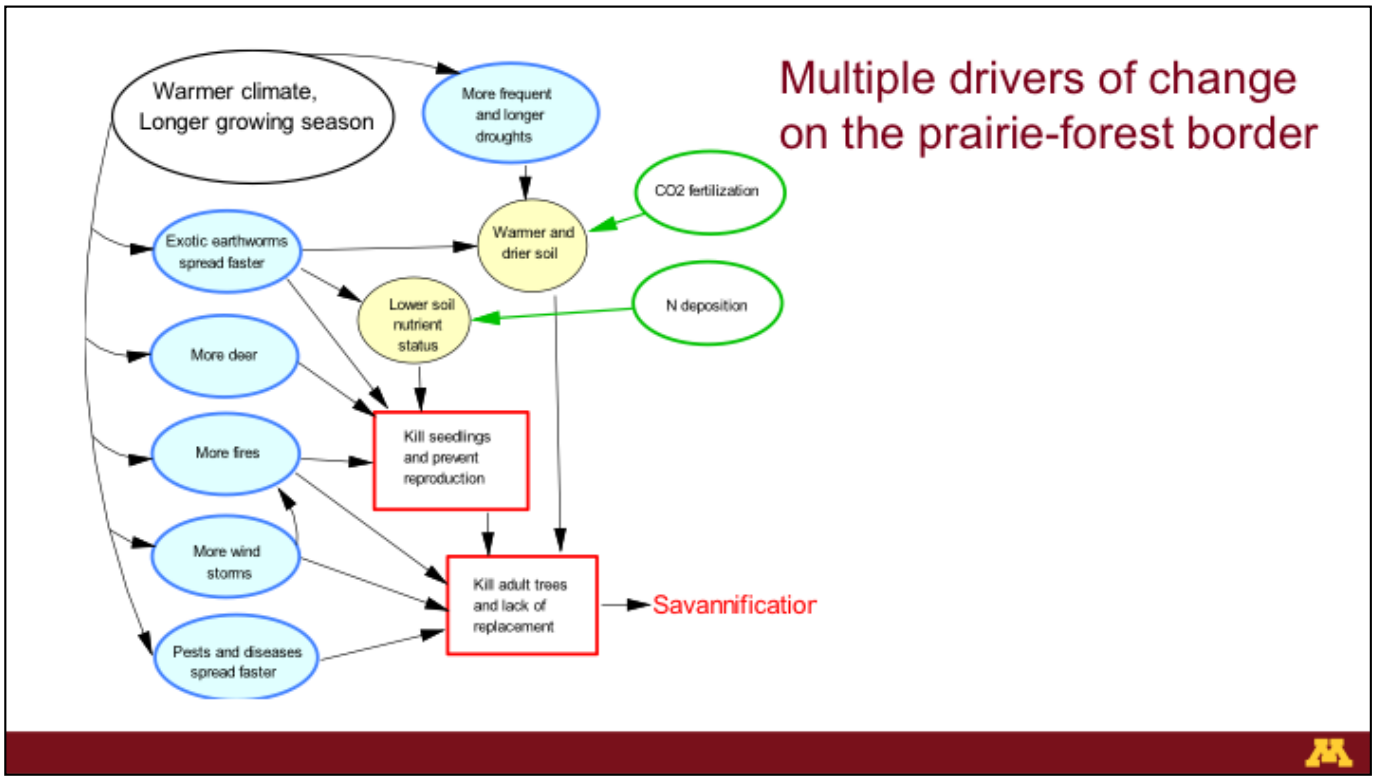


Diagram from Frelich and Reich, *Frontiers in Ecology and the Environment,* 2010. The blue ovals represent 6 factors changed by climate that will affect forests at least as much as direct impacts of rising temperature.

These are the most common species in northern MN today, but also the species most likely to be lost from MN in the future.

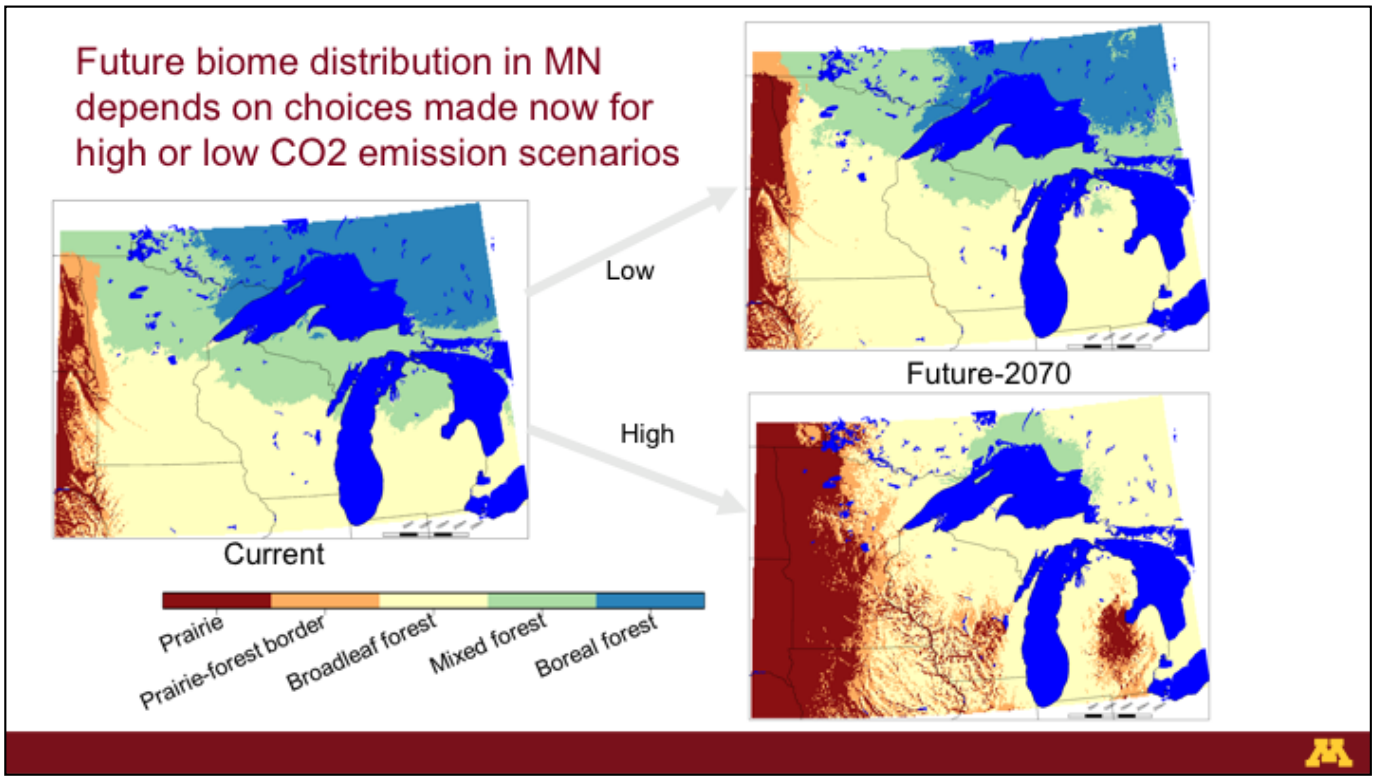
These are tree species most likely to replace boreal tree species in northern MN (in places that will support tree growth). Growth of new forests will lag behind the changing climate and likely take a few centuries to develop.

Climate analog:

Minnesota's Boundary Waters Canoe Area Wilderness today (blue star) and analog climate by end of the 21st Century (orange star)

Photo, Eli Anoszko. Typical boreal black spruce forest in the boundary waters of northern Minnesota

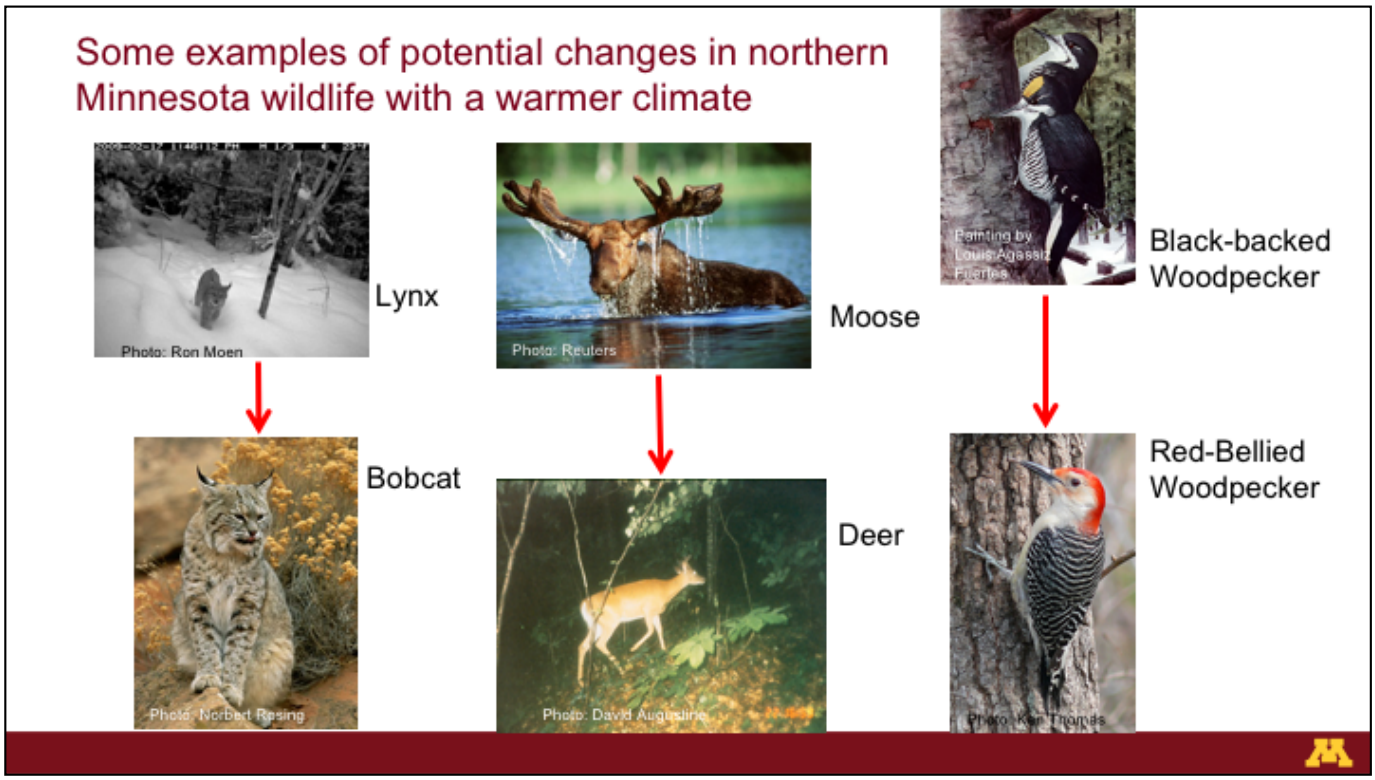
Photo Dave Hansen, UMN. The natural area has savanna vegetation with mixtures of grasses and trees, near Granite Falls MN. This is a good analog for the future of the boundary waters because of the rocky terrain.



This is the result of new research on current and future biomes in the Western Great Lakes Region from the University of Minnesota Center for Forest Ecology

Lee E. Frelich (Director) and Ryan Toot (graduate student), with Peter B. Reich (Regents Professor), and Ethan Butler (post doc)

Funding from the National Park Service and a gift from Geri and Darby Nelson



Wildlife species depend on vegetation type, and when vegetation changes, wildlife species also change. Lynx depend on mixed aspen, birch and conifer forests with deep, long-duration snow cover. Moose cannot tolerate warm summers like those in southern MN today, and likely to occur in northern MN by end of the 21st Century. Many boreal forest bird species will not persist in a warmer climate, this is just one of dozens of possible examples.

Conclusions

Big changes are coming to the Midwest because of global warming

For a business as usual CO_2 emission scenario, Minnesota could be the 'new Kansas'

Boreal forest is likely to disappear from the region, along with 1/3 of all native species

There is still time to change the outcome of future climate. A low emission scenario could allow forest to remain in the Boundary Waters

Thank You!

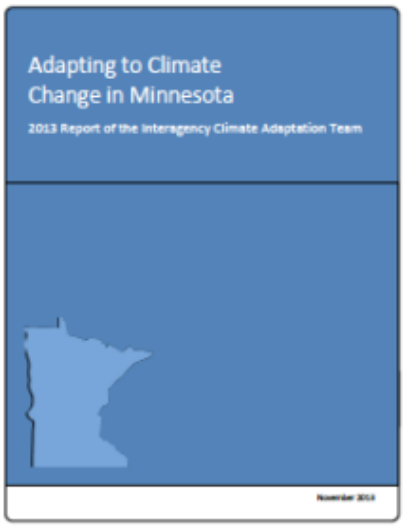
Climate Change Solutions for Minnesota: Adaptation

Dr. Jessica Hellmann

Main points: a) Will need to make adjustments across Minnesota to keep or protect the things we value as the climate changes (adaptation); b) How we adapt to climate change will affect greenhouse gas emissions; it can reduce emissions climate change or make them worse; c) We can invest now in strategies that increase the resiliency of people and places to climate change; larger amounts of climate change may overwhelm that resiliency; d) We cannot think of climate change in isolation; it is affected by and can drive other changes that affect our state and economy, e.g., demographic change; and e) Scenario planning is a tool to consider alternative futures and identify win-win strategies.

How do we address the impacts that we have discussed the last couple of days? Reduce greenhouse gas emissions across electricity sector, buildings, transportation and agriculture. This is MITIGATION. Much of mitigation is about ECONOMIC TRANSITION. A main motivation is avoiding climate change, but there are other benefits such as economic development, cleaner air and other sustainability practices. But mitigation is only part of the climate change challenge.

Adaptation



2017

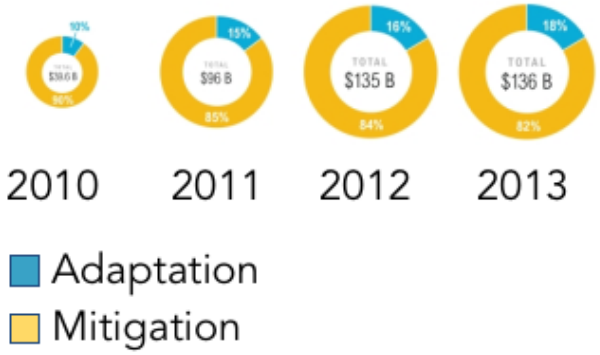
The other part is ADAPTATION. Even if we stop greenhouse gas emissions (GHG) emissions today, the climate has and will warm (some) more.

"Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts… changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change."

https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/what-do-adaptation-to-climate-change-and-climate-resilience-mean

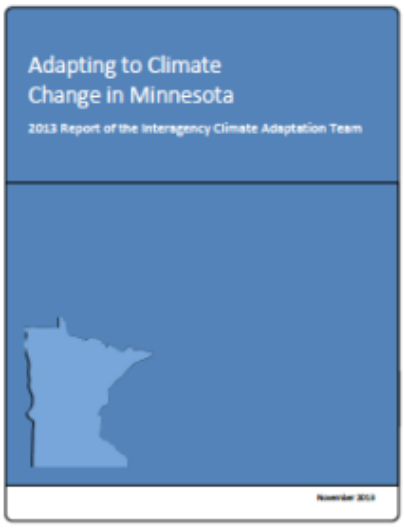
"While it is important to continue to mitigate climate change by reducing emissions to avoid calamitous change, we also need to adapt to changes that are already occurring."
2017 Report, MN Interagency Climate Adaptation Team
https://www.pca.state.mn.us/air/adapting-changing-climate

Adaptation



2010 2011 2012 2013

Adaptation
Mitigation



2017

Investment in adaptation lags investment in mitigation globally; do not have good data about private adaptation investment
World Resources Institute, from Buchner et al. 2014
https://climatepolicyinitiative.org/wp-content/uploads/2014/11/The-Global-Landscape-of-Climate-Finance-2014.pdf

Example

We do know that there smart and less-smart ways to go about adaptation. Example: reducing urban heat. Air conditioning connected to fossil fuels cools but also releases greenhouse gases. Green roofs and urban trees also cool, but do not release GHGs and have other benefits.

Example, for Chicago: green roofs could reduce a summer heat wave by 5-6 deg F. This difference saves lives and reduces energy demand.

Sharma, A., P. Conroy, H. Fernando, A. Hamlet, J. Hellmann, and F. Chen. 2016. Green and cool roofs to mitigate urban heat island effects in Chicago metropolitan area: evaluation with a regional climate model. Environmental Research Letters 11: 064004.

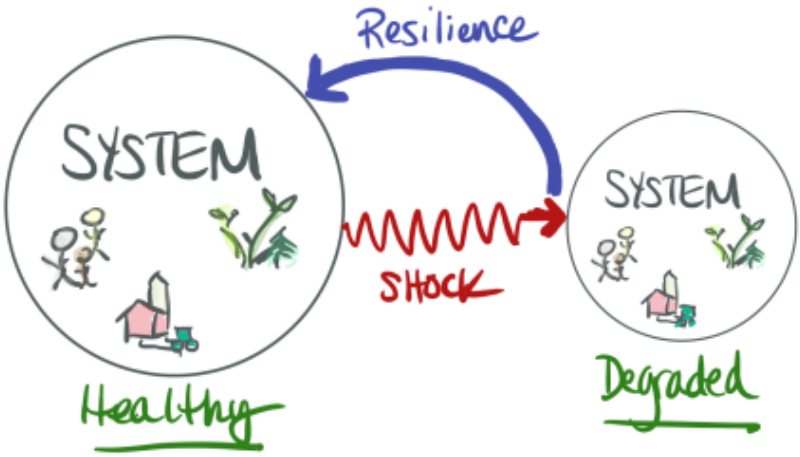
http://iopscience.iop.org/article/10.1088/1748-9326/11/6/064004

Another example: we will likely need irrigation for agriculture during drought. A smart strategy for sustainably increasing water for irrigation is holding it locally on the landscape and recharging ground water through the strategic placement of wetlands.

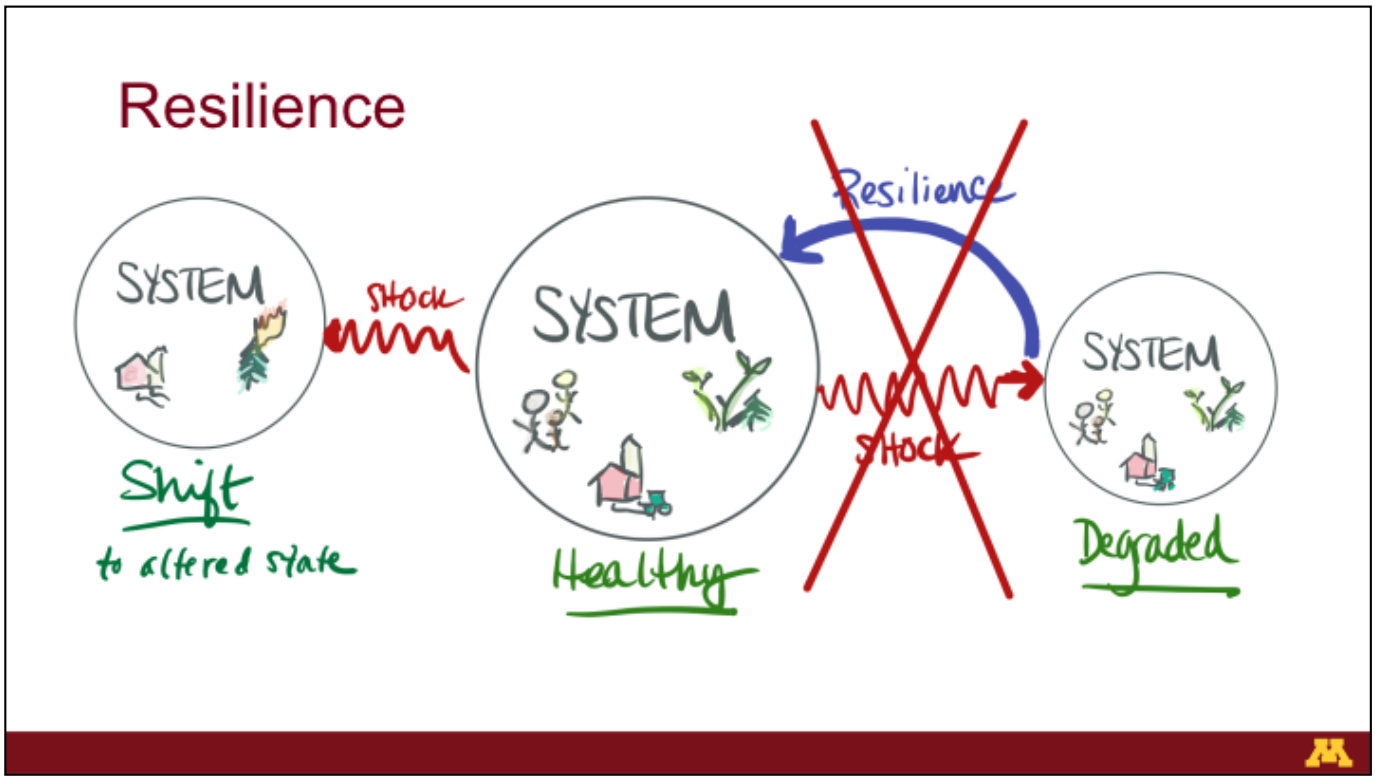
Taylor et al. 2013. Groundwater and climate change. Nature Climate Change 3: 322. https://www.nature.com/articles/nclimate1744

(Note that groundwater sources vary across MN as a function of geology; not all groundwater is recharged or recharged from wetlands; other issues such as contamination affect groundwater usage in some areas.)

Resilience



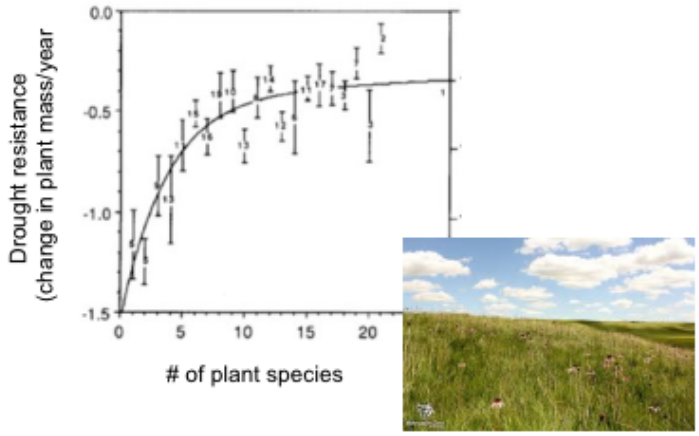
RESILIENCE=the ability of a system—human or natural—to absorb disturbance when it occurs, including natural disasters or other climate shocks. Resilience helps us avoid system degradation.

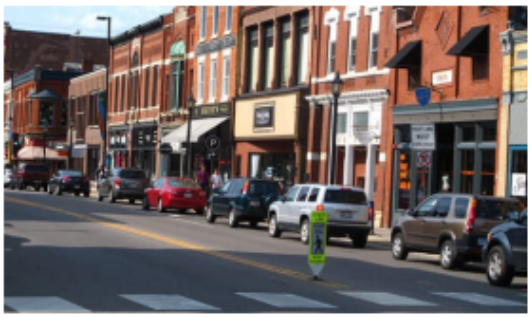


Large climate change can, however, overwhelm resilience and shifting a system to something else, e.g., farming now longer possible or fire risk that converts to another biome. This is one reason why mitigation and adaptation/resilience must go hand-in-hand.

Resilience

- diverse ecosystems





- diverse economies

- connected communities

We know that DIVERSE ECOSYSTEMS and DIVERSE ECONOMIES often have increased resilience.

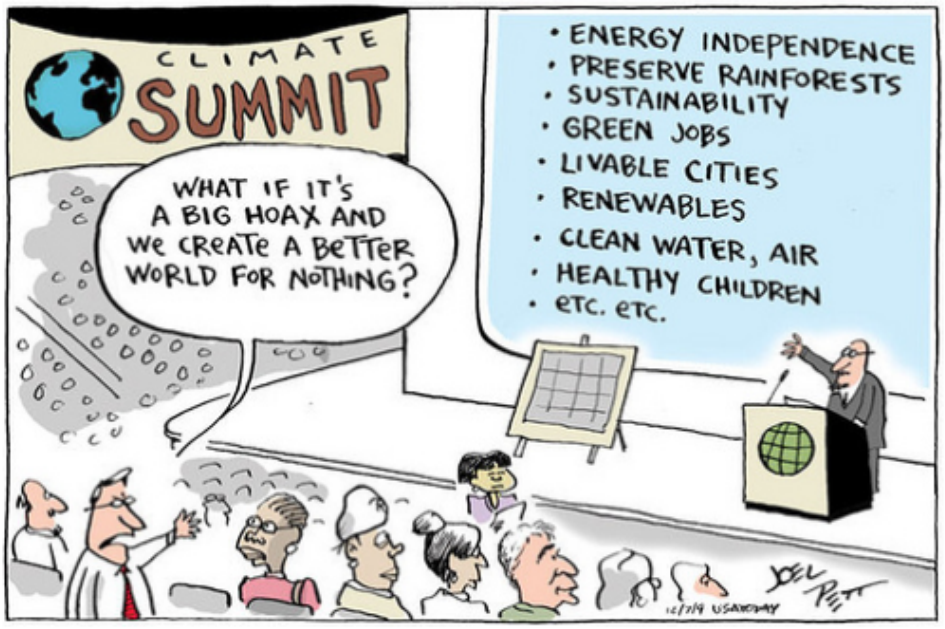
Example: greater # of species in grasslands leads to greater drought resistance

Tilman, D., and J. A. Downing. 1994. Biodiversity and stability in grasslands. Nature 367: 363-365. https://www.nature.com/articles/367363a0

Strong social networks and public infrastructure enhance SOCIAL RESILIENCE.

Smith, J. W., D. H. Anderson, and R. L. Moor. 2012. Social capital, place meanings and perceived resilience to climate change. Rural Sociology 77. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1549-0831.2012.00082.x

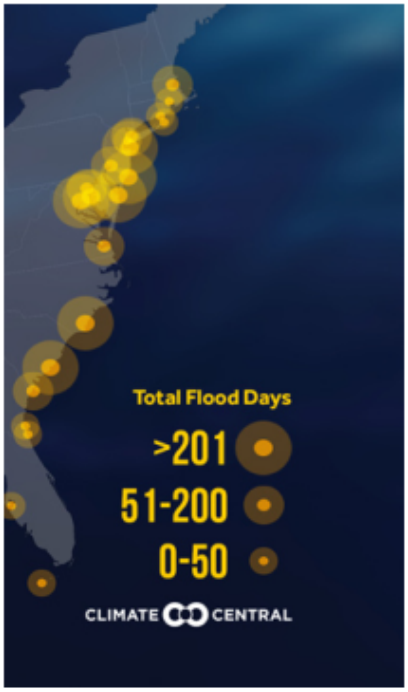
Co-benefits



There are real challenges and costs to mitigation, adaptation and building resilience, but there also are opportunities or CO-BENEFITS.

Example reference: West, J. J. et al. 2013. Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. Nature Climate Change 3: 885. https://www.nature.com/articles/nclimate2009

Indirect effects

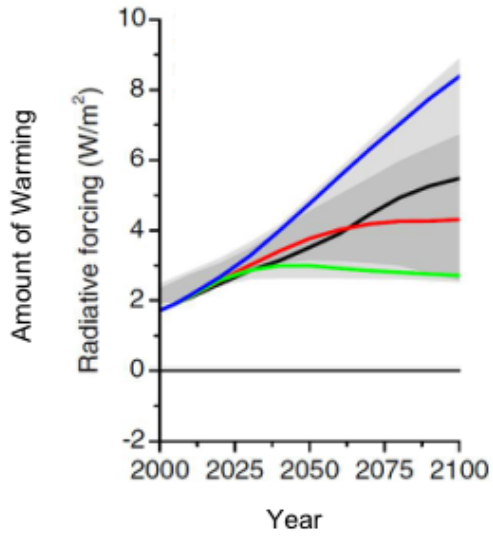


To hold both mitigation and adaptation in our minds at the same time requires SYSTEMS THINKING, recognizing that all parts of human and natural systems are interconnected. It's tempting to focus on the DIRECT EFFECTS of climate change—such as the amount of rain that will fall or how hot it will get—but climate change will have INDIRECT consequences. One possibility for MN is demographic change: as other regions experience more dire consequences of climate change (e.g., coastal flooding or wildfire), ours could be a climate refuge. This itself is both an opportunity and a challenge.

Reference: Coastal flood days, 2005-2014; https://www.climatecentral.org/gallery/maps/atlantic-coastal-flood-days

Photo: Associated Press, July, 26, 2018, Carr Fire, Redding, CA

Scenario planning

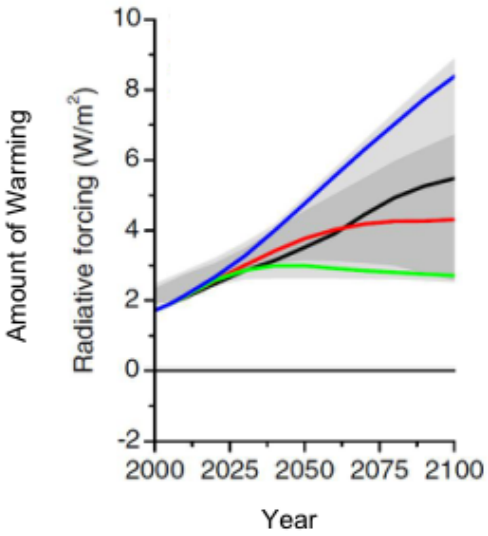


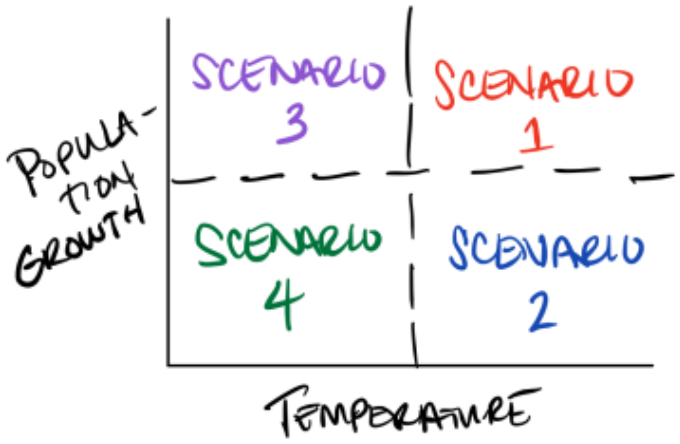
We are certain that GHGs warm the climate, but there is uncertainty about the effects of climate change, especially at the local level. One way to grapple with uncertainty is to consider multiple scenarios, or future possibilities.

Climate modellers do this by examining different emission scenarios (called “representative concentration pathways”) and by comparing across models built by different teams around the world. We do the same when making demographic or economic projections.

Reference: IPCC AR5; http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

Scenario planning





Policies can be evaluated against any climate scenarios to answer questions: Is this policy specific to only one future scenario? How likely is that scenario? Would this policy have benefits across multiple scenarios? What are the co-benefits in those scenarios?

Example reference: Star, J. et al. 2016. Supporting adaptation decisions through scenario planning: enabling the effective use of multiple methods. Climate Risk Management 13: 88.
https://www.sciencedirect.com/science/article/pii/S2212096316300262

Climate Change Solutions for Minnesota: Adaptation & Agriculture

Jason Hill, Bioproducts and Biosystems Engineering, @jdhill

January 17, 2019

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Farmers continually adapt

BUSINESS

With corn and soybean prices down, wheat's on the rise in Minnesota

Acres planted rose by 40 percent in 2018, and some predict another uptick in 2019

By Adam Belz Star Tribune | JANUARY 9, 2019 — 9:56PM

STAR TRIBUNE FILE

Minnesota farmer Jack Weber harvesting wheat in 2017. More Minnesota farmers are planting wheat as an alternative to corn and soybeans, which have produced low profits and even lost money for some farmers in recent years.

Agriculture will need to respond to changes and to increased uncertainty

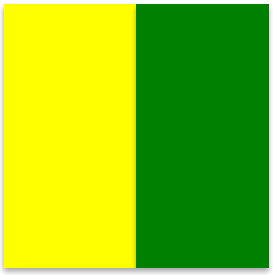
Adaptation should be attentive to the concerns of both farmers and the public

Agriculture can adapt while also playing a role in climate change mitigation

Marsden Farm experiment

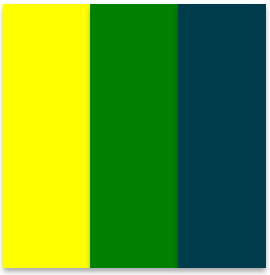
Marsden Farm experiment

2-year rotation



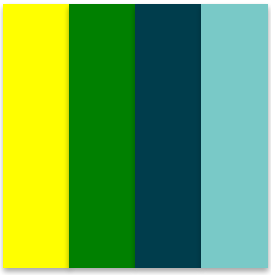
600 acres
300 acres corn
300 acres soybean

3-year rotation



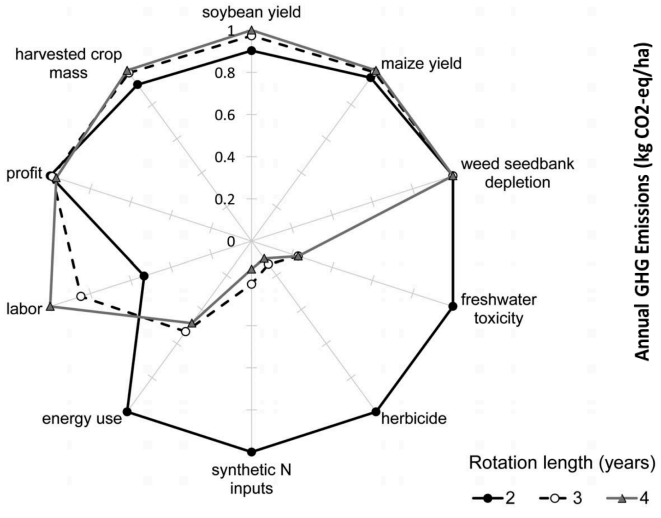
600 acres
200 acres corn
200 acres soybean
200 acres oat

4-year rotation

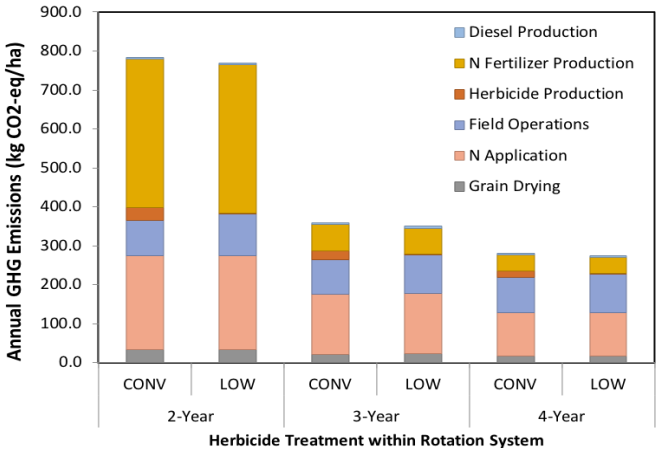


600 acres
150 acres corn
150 acres soybean
150 acres oat
150 acres alfalfa

Marsden Farm experiment



Davis *et al.* (2012)



Hunt *et al.* (In preparation)

Conclusion

Dr. Jessica Hellmann, Institute on the Environment

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THANK YOU! For more information or to access additional experts or scholary resources, contact Jessica Hellmann, Director, Institute on the Environment; http://environment.umn.edu; @UMNIonE; http://www.jessicahellman.org; @jessicahellmann; hellmann@umn.edu