Climate Change, Recent Floods, and an Uncertain Future

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1. The Driftless Area is expected to experience higher temperatures and more intense and frequent rainfall events as climate changes (high certainty).
2. Soil moisture is expected to decline, especially when droughts occur, but effects may be offset by increases in precipitation.
3. Trout distributions are predicted to decline with warming stream temperatures, and the way species interact (e.g., Brook Trout *Salvelinus fontinalis* and Brown Trout *Salmo trutta*) will change in complex ways, such as being externally influenced by changing parasite-host relationships (e.g., gill lice *Salmincola edwardsii*).
4. Changes in precipitation frequency and intensity will change water:sediment balances in streams, altering stream stability and habitat for aquatic biota. These changes, such as flooding frequency, have been shown to influence trout population dynamics at a regional scale.

Climate Change | Precipitation | Flooding | Species Distributions | Species Interactions

Fig. 1. Flooding in Vernon County, Wisconsin in August, 2018. Over 20 inches of rain fell in some areas. Credit: M. Hoffman, Milwaukee Journal Sentinel.

The Earth's climate is changing, with observed changes since the 1950s being unprecedented over decades to millennia (1). The Driftless Area has experienced heavy rainfall events and large-scale flooding in recent years, and such events are perceived to be occurring with greater frequency. For example, torrential rains upon already saturated soils in June 2008 caused severe flooding in southern Wisconsin (2). More than 12-in (30-cm) of rain fell within seven days in June 2008 (up to 2-in, or 5-cm, per hour), which was preceded by over 100-in (250-cm) of snow during winter 2007-08 and heavy rains in late summer 2007. Thus, saturated soils inhibited infiltration, resulting in a high proportion of runoff. Record gage heights were observed at 21 USGS stream gages across southern Wisconsin, and extensive flooding damaged several communities. This included the Kickapoo River and other portions of the Driftless Area. In 2007, 15-in (38-cm) of rain fell in 24 hours in the Whitewater River drainage in southeastern Minnesota, which resulted in catastrophic flooding that re-arranged stream channels, flooded towns, caused millions of dollars of damage to state parks, and killed seven people (Pioneer Press, 19 April 2015). In 2013, over 36-in (91-cm) of rain fell over three days in the Root River drainage (southeast Minnesota), again resulting in large floods. Heavy rainfalls have caused flooding in northeastern Iowa, southeastern Minnesota, and southwestern Wisconsin in 2004, 2007, 2008, 2013, 2014, 2017, and 2018 (See Preface; Fig. 1); some 2018 events are reviewed by the National Weather Service). The perceived uptick in heavy rainfalls and subsequent large-scale flooding is consistent with expected changes in climate and has led to concern that more heavy rainfall events can be expected in the future.

The Climate is Changing

Climate is defined as long-term patterns in daily weather observations (1). Global annual average surface temperatures have increased 1.8°F (1.0°C) from 1885 to 2016 with greater increases in northern latitudes, and we are currently in the warmest period in the history of modern civilization (3). The last three years (2015 to 2017) have been the warmest on record, and warm temperatures have been accompanied by numerous record-breaking weather extremes, such as prolonged drought and heavy rainfall events. The Fourth National Climate Assessment (NCA4) was released in late 2017 by the

Statement of Interest

Attribution is the action of ascribing one thing as being caused by another. Advances in the science of attribution have led to an increased acceptance based on evidence by both the public and scientists that global warming is human caused (termed anthropogenic global warming). In a review of nearly 12,000 studies on climate change, only 0.7% rejected the attribution of warming to human activities (but see (4)), and 97% of scientists involved in those studies were in consensus that climate warming is attributable to humans (5). Previous polls of a separate set of climate scientists have also shown that 97% concluded climate change is caused by humans (6).

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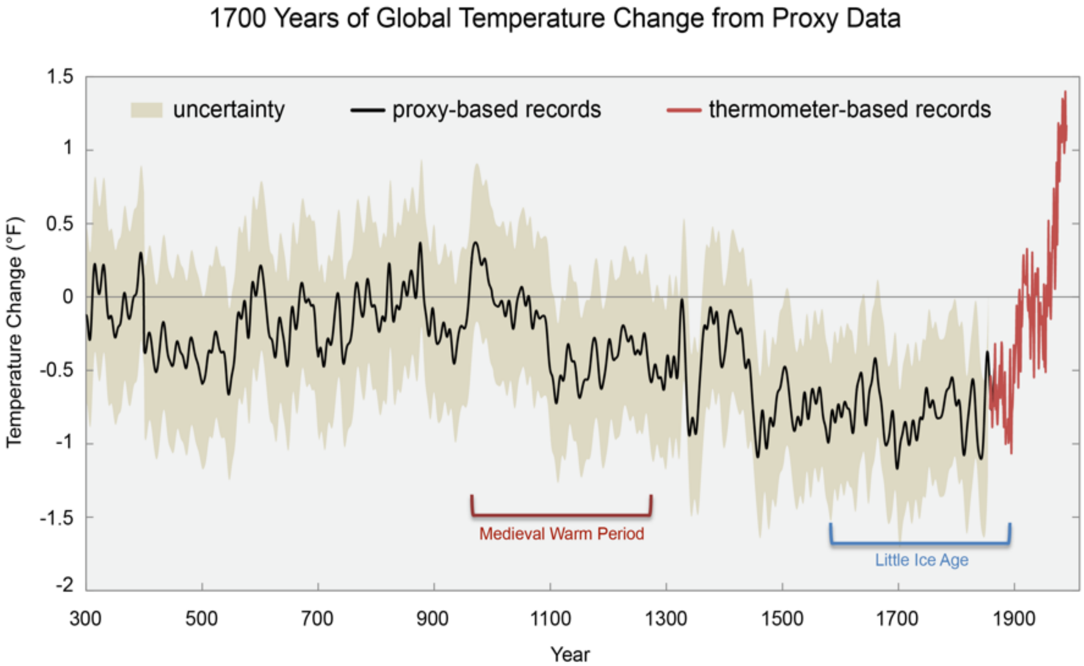

Fig. 2. Global temperature anomalies for past 1700 years from the observational and proxy records. Figure from USGCRP (1).

U.S. Global Change Research Program (1). The report used extensive evidence to conclude that human activities are the dominant cause of climate warming since the 1950s.

The NCA4 is the authoritative source for climate change-related information for the U.S., as is the Intergovernmental Panel on Climate Change (IPCC) (1, 7). Where do those data come from? Recent climatic changes from historical reference periods are typically based on observational records from instrumentation, whereas future changes are projected using climate models that are developed using observational data. For example, four independent estimates of global air surface temperatures are made by the National Aeronautics and Space Administration (NASA; GISTEMP estimate), the National Oceanic and Atmospheric Administration (NOAA; MLOST estimate), the Japanese Meteorological Society (JMS estimate), and the University of East Anglia and United Kingdom (UK) Met Centre (HadCRUT4 estimate). These estimates are obtained from analysis of data collected from 5,000 to 7,000 ground stations, and the estimates are congruent in that they all show global surface temperatures to be increasing (1). Proxy methods are used to reconstruct historical climates, such as in the use of fossil pollen and ocean or lake sediments, and they allow climate reconstruction for over 1700 years (Fig. 2) (8). In addition, the Mauna Loa Observatory run by NOAA has one of the longest running observations of atmospheric CO_2, and it has shown steady increases in CO_2 since the late 1950's that surpassed 400 parts per million (ppm) for the first time in recorded human history in 2015. CO_2 plays a large role in the greenhouse gas effect that absorbs infrared radiation reflected from the Earth's surface leading to surface and atmospheric warming, therefore creating a link between anthropogenic industrial carbon emissions and climate warming (termed anthropogenic forcing). Precipitation, drought, and other climate-related information is similarly monitored and modeled, including in the Driftless Area (9).

Some of the debate associated with climate change is focused on the link between global warming and human activities – a process termed 'attribution.' The ability to attribute changes in climate to human factors has advanced significantly in the last decade, and especially so in the last five years (10, 11). Research has now shown that only increases in anthropogenic-induced greenhouse gases, especially CO_2, can explain the level of observed global warming, particularly since the mid-20th Century (11, 12).

Here we review the main patterns of climate (i.e., temperature, precipitation, drought, floods) as reported from the observational record to present, as well as what climate models are projecting for the future, drawing largely on the NCA4 results for the Midwest (1) as well as Wisconsin-specific analyses (9). We then summarize climate-related research conducted in states representing the Driftless Area, which includes stream temperature modeling using future climate scenarios, how projected changes to stream temperature are predicted to influence stream fish distributions and population dynamics, and how stream temperature warming has and is predicted to change interactions between native and non-native sport fishes and their co-evolved parasites. We end by discussing the uncertainty with some aspects of climate change and how it relates to Driftless Area stream habitat projects and fisheries.

Climate: Past Trends and Projected Futures

Air Temperature. The entire U.S. experienced an increase in average surface temperature from the first half of the last century (1901 to 1960) to the present day (1986 to 2016; Fig. 3). The Midwest experienced a 1.26°F (0.70°C) increase in annual average surface temperature overall, with a higher 1.75°F (0.97°C) increase in annual average minimum temperature (winter minimum) versus a 0.77°F (0.43°C) increase in the annual average maximum in summer (3). That is, winters are warming faster than summers, which is reflected in later

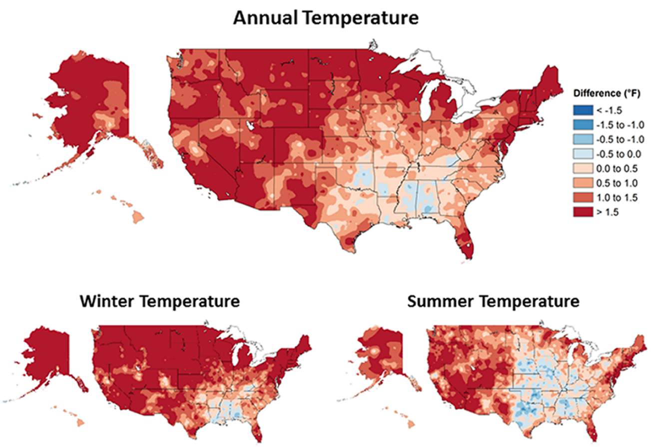

Fig. 3. Observed changes in annual, winter, and summer temperature (°F). Changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawaii). Estimates are derived from the nClimDiv dataset. Figure source: NOAA/NCEI and (1, 14, 15)

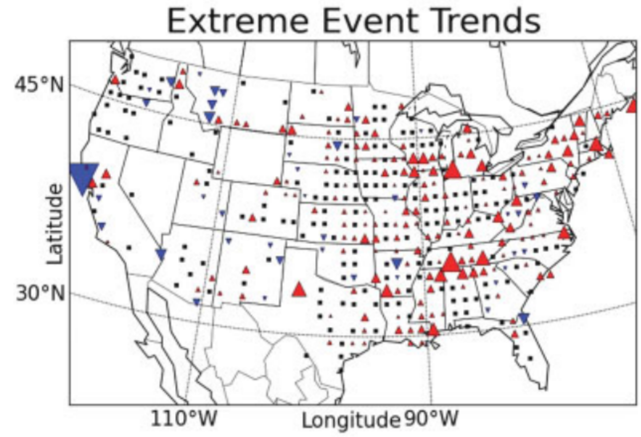

Fig. 4. Significant (95%) trends in an Extreme Precipitation Index (EPI) from 1901 to 2012 for a 2-day precipitation duration and 5-year return interval. Red triangles indicate significant increases, with triangle size indicating trend magnitude. Blue triangles indicate significant decreases, also with triangle size indicating trend magnitude. Figure from Janssen, et al. (17)

formation and earlier breakup of lake ice exemplified by a decrease in days of ice cover of 12.6 days per decade from 1980 to 2002 (13). Analyses of patterns of climate change across the state of Wisconsin also show increases in air temperature metrics from 1950 to 2006, with greater warming during winter and spring (9). However, there were also diurnal differences in warming with nighttime low temperatures warming faster than daytime high temperatures. Annual average nighttime low temperatures increased by 1.1 to 3.9°F (0.6 to 2.2°C) from 1950 to 2006 whereas annual average daytime high temperatures increased by 0.5 to 1.1°F (0.3 to 0.6°C) (9). Wintertime daily average temperatures increased by 1.8 to 6.3°F (1.0 to 3.5°C) across Wisconsin. One notable exception to increases in daytime high temperatures was that daytime highs decreased slightly in portions of the Driftless Area in Wisconsin (-1.1 to -0.5°F, or -0.6 to -0.3°C, decrease).

Precipitation and Streamflows. Climate science is also focused on changes in precipitation (both rain and snow), especially the frequency and magnitude of heavy rainfall events. **Heavy rainfall is commonly defined as 2 or more inches (or >5-cm) of rain in a 24-hour period** (16). The frequency of heavy rainfall events has increased in the continental U.S. over the last half century (Fig. 4)(17). Heavy rainfalls have increased in frequency most in the Northeast but also in the Midwest, and those heavy rainfall events are predicted to become even more frequent according to future climate projections (17, 18). In Wisconsin, average annual precipitation (rain and snow) has increased 2.0 to 3.9-in (50 to 100-mm) from 1950 to 2006, with higher increases in west-central and south-central portions of the state (9). Within that same time period, south and southwestern Wisconsin observed increases in precipitation across all seasons (0.4 to 0.8-in, or 10 to 20-mm), with slightly higher increases in fall (0.4 to 3.1-in, or 10 to 80-mm) and patchy increases in spring and summer (0.8 to 2.4-in, or 20 to 60-mm) with the highest increases in Dane and Sauk counties (to near 3.1-in [80-mm]; Fig. 5) (9).

There is evidence that heavy rainfall events have become more prevalent, but some of the details are dependent on the statistical methods used to assess and detect trends over time. Kucharik, et al. (9), used data from six airport weather stations to explore increases in frequency of heavy rainfall events in the southern and central portions of Wisconsin (Eau Claire, Green Bay, La Crosse, Madison, and Wausau). Using a simple linear regression approach, they detected an increase in frequency of 1, 2, and 3-in (25.4, 50.8, and 76.2-mm) rainfall events from 1950 to 2008 (9). Using a more conservative Mann-Kendall statistical method, they found the frequency of 1-in (25.4-mm) rainfalls to have increased, including near La Crosse, Wisconsin, but no increases in the frequency of 2 or 3-in (50.8 or 76.2-mm) rainfall events were detected.

Regional differences in heavy rainfalls across the United States suggests that there might also be regional differences in the frequency of flooding. However, according to a study by the U.S. Geological Survey there is generally not a cohesive geographic pattern of changes in flood frequency and magnitude; however, the study did detect a decreasing frequency of small floods (0.5 to 1-yr) in some areas such as southern Wisconsin (19). The study also found only weak correlations between changes in flooding and climate indices, suggesting that changes in climate played a small role, if any, in changes to flood characteristics. Several studies have shown that Driftless Area streamflows exhibit decreasing trends in flood frequency when compared to historical records (19). Gyawali, et al. (20) analyzed stream gages in three reference (least disturbed) watersheds and found annual flow volumes to increase from 1951-1980 vs. 1981-2010, minimum flows increased, and maximum peak flows decreased (Fig. 6). Splinter, et al. (21) noted similar findings for Driftless Area streamflows. In addition to long-term trends, there is also a notable step-change (increase) in flows around 1970 and 2005 (21, 22), the earlier of which has been attributed to higher total precipitation but also higher infiltration rates due to less intensive agricultural land practices (improved tillage on fields and grazing cessation on hillslopes) in the Driftless Area (23). Gyawali, et al. (20) approximated that only 60% of the increase in annual flows can be attributed to changes in climate (increased annual precipitation), as changing land use practices were also

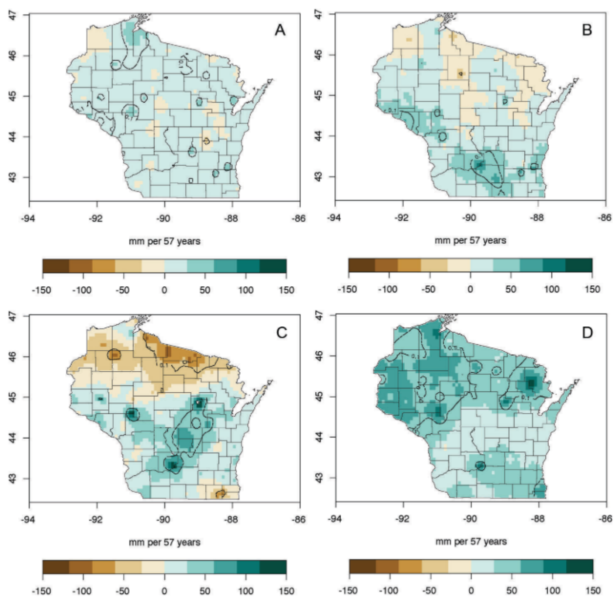

Fig. 5. Trends in total precipitation from 1950 to 2006 for (A) winter (Dec–Jan–Feb), (B) spring (Mar–Apr–May), (C) summer (Jun–Jul–Aug), and (D) fall (Sep–Oct–Nov). Regions that had statistically significant (P > 0.1) trends are enclosed or bounded by dark dashed lines. Figure from Kucharik, et al. (9).

influential.

Drought. Recent droughts and heat waves have increased in intensity in some but not all U.S. regions, but the Dust Bowl era is still the benchmark drought in the historical record (24). In other regions increased precipitation is associated with drought decreases but neither have been attributed to anthropogenic forcing (i.e., attributing observed changes to human activities), which is difficult to detect due to observation uncertainty and decadal-scale climate variability. The 2012 drought was the most extreme recent drought for the Midwest and Great Plains and was driven by an uncharacteristic pattern of natural climate variability whereby typical slow-soaking rains from evening thunderstorms from May to August were absent, but there was little evidence for human influence on that pattern (25). Soil surface moisture is projected to decrease with future warming, but it may be offset by increased precipitation. Although there is some uncertainty, increased future temperatures are likely to exacerbate soil moisture loss when droughts occur (24).

Stream Temperature. Climate and geology interact to provide an abundance of coldwater streams that support trout throughout the Driftless Area. Water temperatures in Driftless Area streams are influenced by many factors, including climate and geology, interacting at different spatial and temporal scales (27). Air temperature is an important climatic factor that affects water temperature, yet stream temperatures may be highly heterogeneous across small spatial scales within streams and among streams within and among watersheds. Groundwater, for example, may cool stream temperatures during summer while surface water, particularly runoff following rain events, may warm streams (Potter, page 15). In winter, the opposite occurs: groundwater helps maintain seasonably warm stream temperatures (e.g., 41°F [5°C]) and surface runoff following snow melt may cool streams to near-freezing temperatures. Precipitation is therefore another important climatic factor that can warm or cool streams depending on the season, and precipitation can interact with land use to recharge groundwater and influence stream baseflows.

Stream temperature models based on monitoring data collected during the June to August summer period show a high concentration of cold and cold transition streams in the Driftless Area of Wisconsin and Minnesota (Fig. 7)(26, 27). Lyons, et al. (28) defined thermal classes for Wisconsin streams based on water temperature during summer and species of fish present. Thermal classes based on the mean water temperature during the month of July are defined as coldwater (<63.5°F [<17.5°C]), cold transition (63.5-67.1°F [17.5-19.5°C]), warm transition (67.1-69.8°F [19.5-21°C]), and warmwater (>69.8°F [>21°C]). Thermal classes based on June-August mean water temperature are coldwater (<62.6°F [<17°C]), cold transition (62.6-65.7°F [17-18.7°C]), warm transition (65.7-68.9°F [18.7-20.5°C]), and warmwater (>68.9°F [>20.5°C]).

Coldwater streams are characterized by the presence of few species, typically salmonids such as Brook Trout *Salvelinus fontinalis* and Brown Trout *Salmo trutta* and cottids such as Mottled Sculpin *Cottus bairdii*, and warmwater streams are characterized by greater species richness including cyprinid (minnows), catostomid (suckers), ictalurid (catfishes), centrarchid (sunfishes), and percid (perches) fishes (28). Warmwater species can survive cold temperatures typical of northern winters but need warmer temperatures to complete their life cycles (29). Transition streams as a thermal class represent thermal regimes intermediate between coldwater and warmwater. Cold transition streams are dominated by coldwater species, but some warmwater species may be present in sparse numbers; warm transition streams are dominated by warmwater species, but some coldwater species maybe present in sparse numbers (28). High quality trout fisheries can be found in both coldwater and cold transition streams in the Driftless Area.

Stewart, et al. (27) used statistically downscaled air temperature and precipitation projections from 10 General Circulation Models (GCMs) to project future stream temperatures for the mid-21st century (2046-2065) for Wisconsin streams. Model projections show what could occur under the assumptions of the GCMs and stream temperature model. Mid-21st century projections of stream temperatures for Wisconsin show the Driftless Area to be more resilient to changes in climate compared to other regions of the state, likely owing to groundwater-dominated flows (Fig. 8)(Potter, page 15). Statewide, the stream temperature model predicts 57% of Wisconsin stream miles as coldwater or cold transition streams thermally suitable to support trout and mid-21st century projections suggest a decrease to 39% (average of 10 GCMs), with a best-case scenario of 47% and worst-case scenario of 26% (27). As streams warm in response to changing climate conditions, water thermally suitable for supporting trout may contract within streams towards headwaters or other groundwater sources of stream water.

Direct Effects on Fishes. Fish are cold-blooded ectotherms and, in some cases, stenotherms, the latter meaning that they can only survive in a narrow range of temperatures. As such, increasing air temperatures leading to increasing stream, river, and lake temperatures are expected to influence the distribution of fishes (30–32). Fishes in the Midwest have been catego-

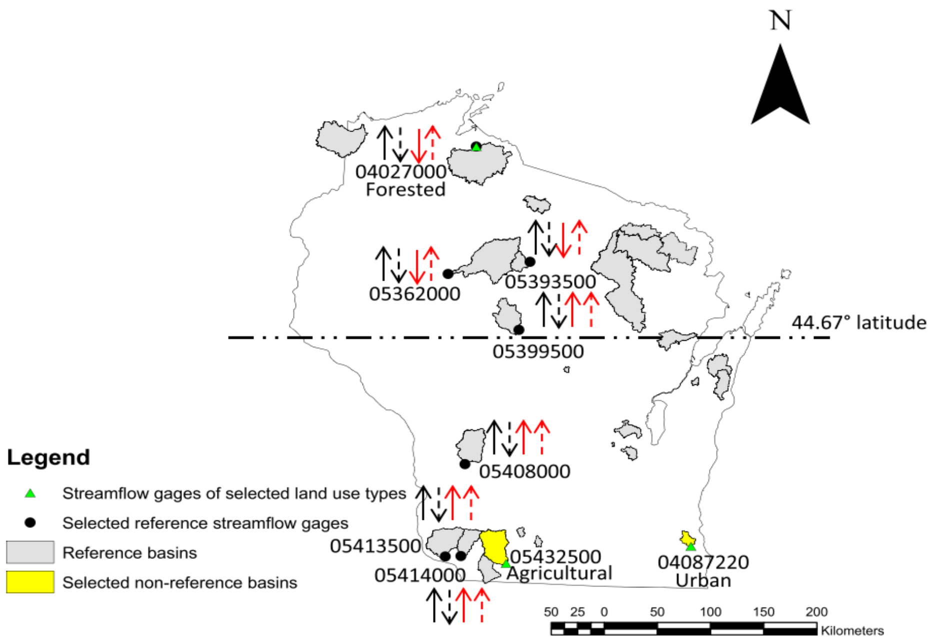

Fig. 6. Seasonal increases and decreases in streamflows at stream gages in Wisconsin between 1951-1980 versus 1981 to 2010. Arrows from left to right indicate winter (solid black), spring (dashed black), summer (solid red), and fall (dashed red) seasons. Figure from Gyawali, et al. (20).

rized generally as cold, cool, and warm-water species (28) and, therefore, can be expected to have differential responses to projected climate warming. Lyons, et al. (33) modeled changes in the distribution of 50 common fish species in nearly 54,050-mi (87,000-km) of Wisconsin streams under current conditions, limited climate warming (1.4°F [0.8°C] increase in water temperature), moderate warming (4.3°F [2.4°C] increase), and major warming (7.1°F [4°C]). Twenty-three species were projected to experience declines in distribution, 4 were projected to be unchanged, and 23 were projected to increase in distribution. Cold-water species were projected to lose the largest amount of habitat, and lose more habitat than warmwater species gain because they exist in small headwater streams that represent a disproportionately high number of all streams. For example, Brook Trout were projected to decline in distribution across Wisconsin by 94% and Brown Trout by 33% under a moderate warming scenario (34). This is similar to other projections made for changes in the distribution of cold-water salmonids given future climate projections (35, 36). Brook Trout and Brown Trout projected distributions for the mid-21st century were updated for the A1B emissions scenario using the stream temperature model described in Stewart, et al. (27) and the fish distribution model in FishVis (26). Models projected a decline of 68% in stream habitat for Brook Trout and a decline of 32% for Brown Trout in Wisconsin (37).

Indirect Effects on Fishes. Although stenothermic fishes like salmonids would appear to be most susceptible to increasing stream temperatures for physiological reasons, in a review of climate-related extinctions Cahill, et al. (38) found that only 7 of 136 extinction cases across various taxa were due to a direct physiological response to increased temperatures. Rather, many extinction cases were a result of changes to prey base or biotic interactions related to climate change. In Ash Creek, Wisconsin, Mitro (39), for example, observed an epizootic of gill lice *Salmincola edwardsii* infecting Brook Trout coincident with anomalously high stream temperatures and low stream flow in 2012. Gill lice are an ectoparasitic copepod indigenous to Wisconsin that co-evolved with Brook Trout, also native to Wisconsin. Multi-year stock-recruitment data indicated that poor Brook Trout recruitment in Ash Creek in 2012-2014 was attributable to gill lice infecting age 0 Brook Trout (39). Gill lice complete their life cycle faster in warmer waters, thus tipping the co-evolved relationship to a point detrimental to Brook Trout and favoring gill lice when more gill lice life cycles are completed during warmer years. With Brown Trout present in Ash Creek and the species not susceptible to infection by *Salmincola edwardsii*, a climate-related decline in Brook Trout recruitment may hasten their extirpation and replacement by Brown Trout. This illustrates that temperature warming may be an indirect rather than proximal cause of species extirpations in a changing climate, and that the effects of climate change may manifest itself in different ways for different organisms. Other researchers have shown that changes in climate-related changes to streamflows and water quality will change benthic macroinvertebrate communities (40), which has important implications for the prey base of stream salmonids.

A Complex and Uncertain Future

The climate has changed over the last 50-60 years compared to conditions in the 1800s and early 1900s, including in the Driftless Area. Climate models are projecting these changes to continue, and climate change studies have predicted undesirable consequences for salmonids that comprise important Driftless Area fisheries (Druschke, page 63). While there is evidence that heavy rainfall events have recently increased in frequency, the streamflow record shows that flood magnitude and flood frequency have decreased or remain unchanged. What drives this discrepancy between the climate and hydrological science?

1. First, changes in land management to incorporate more conservation practices has been attributed to decreased runoff and increased infiltration (20, 23). Changes in land management is likely to dampen the frequency and magnitude of small, 1 to 2-yr floods associated with spring

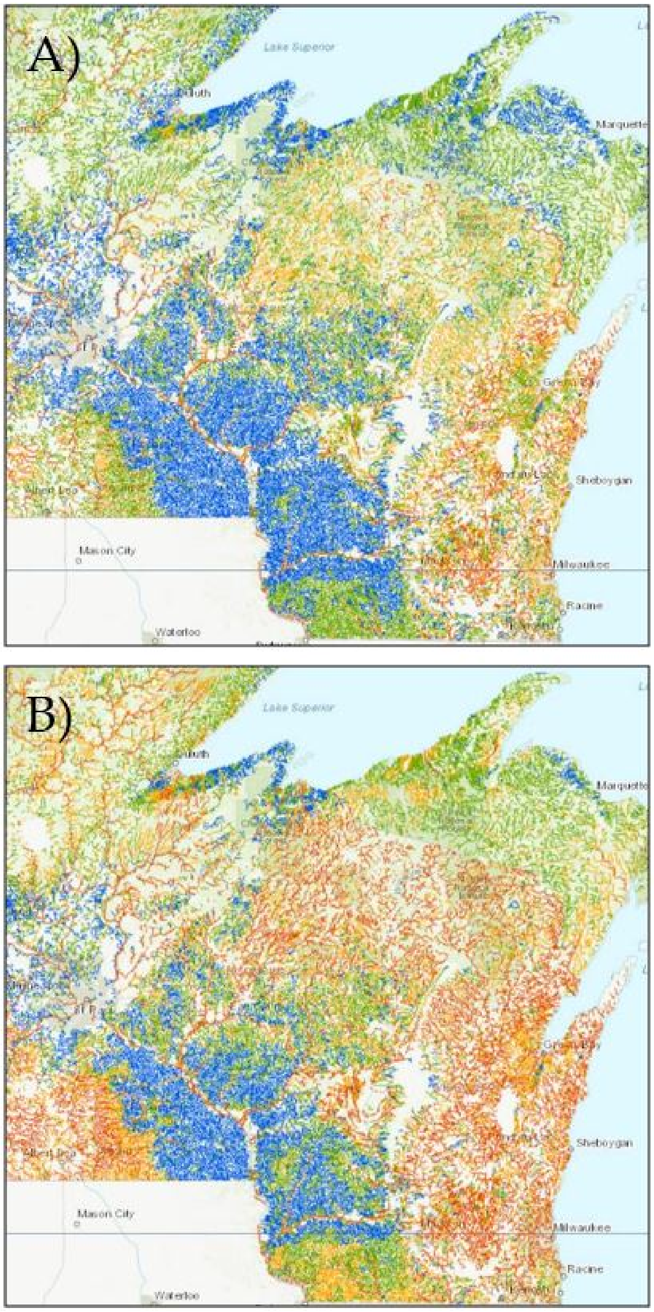

Fig. 7. Current (A: 1990-2006) predicted stream thermal classes and future (B: 2046-2065) projected stream thermal classes. Coldwater streams (July mean water temperature <63.5°F, or <17.5°C) are blue, cold transition streams (63.5-67.1°F, or 17.5-19.5°C) are green, warm transition streams (67.1-69.8°F, or 19.5-21°C) are yellow, and warmwater streams (>69.8°F, or >21°C) are red. Figures created from FishVis Version 1 (26).

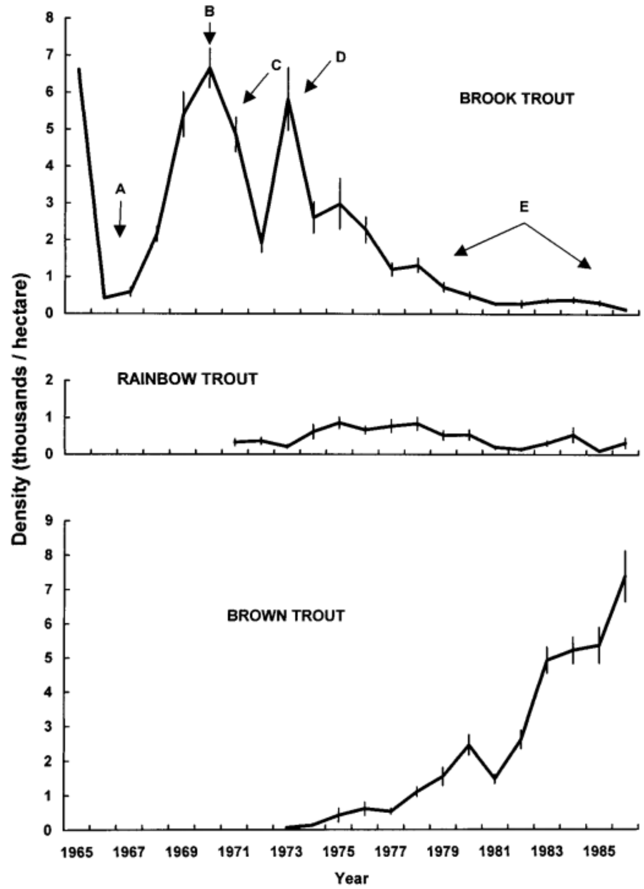

Fig. 8. Density of Brook Trout, Rainbow Trout, and Brown Trout in Valley Creek, Minnesota showing decreases in Brook Trout abundance due to floods (1965-6; A), high sedimentation events (C), and increase in Brown Trout abundance (E). Figure from Waters (41).

runoff or moderate-intensity rainfall events, but it is unlikely to decouple the link between heavy rainfall events and record floods.

2. Second, there could also be a spatial mismatch between weather stations used to evaluate trends in heavy rainfall events and where changes in streamflow have been studied. Rigorous evaluation of both require stations with long-term records (>50 years) with an absence of confounding factors such as urbanization for weather stations or lack of dams for streamflow gages. Different watersheds also integrate precipitation over variable-sized land areas and heavy rainfalls can occur in localized areas, further complicating the issue.

3. Third, most existing studies have relied on statistical methods to detect trends, and these methods often require long time series or very large rates of change to detect patterns in streamflow with a high level of confidence. Studies of extreme events have to be very selective in the weather or streamflow gage stations they use to evaluate changes over time (9), and this further reduces the number of watersheds with both weather and streamflow gaging stations for such analyses (multiple watersheds are needed to make strong generalizations from such data).

4. Last, many of these studies were conducted over a decade ago, and the analyses need to be revisited because there have been numerous heavy rainfall and record flooding events over the last decade, including in late summer of 2018.

Additional well-designed studies, including repeats of old studies with the most recent data, could help to resolve the uncertainties arising from this decoupling to better understand precipitation changes to hydrology in future climates and how they might influence stream habitat and fisheries.

Should heavy rainfall events continue to become more frequent and of higher magnitude as predicted, Driftless Area streams can be expected to adjust to new water:sediment balances. Stream morphology (sinuosity, channel dimensions, etc) reflects sediment and water transport processes that interact with local streambank sediments and vegetation (Melchior, page 20). While no studies of climate change impacts to stream geomorphology have been conducted, historical changes in climate have been linked to changes in hydrology in Driftless Area streams. Knox (42) used relict Holocene stream channels preserved in the sedimentological record to study the influences of past climatic changes on channel-forming flood magnitudes in the Driftless Area of Wisconsin. He found that the magnitude of historical floods as far back as 8,000 years before present ranged from -40 to +30% of present day floods due to fluctuations in climate, and increases in flood magnitudes were accompanied by coarser stream sediments and accelerated lateral channel migration. Any future increases in heavy precipitation events (increase in high-intensity rainfalls), and increases in total precipitation overall (increases in annual precipitation), are likely to cause streams to adjust to new water and sediment transport loads. This includes accounting for the increased flood energy and high shear stress in stream channels that are incised from vertical accretion of floodplain sediments (43). Most stream restoration and habitat enhancement projects are designed for or assume stream stability, which at a minimum suggests stream design standards would need to account for projected changes in flood frequency and magnitude. Design elements focused on dissipating excess stream energy, such as reconnecting floodplains, sloping streambanks, increasing sinuosity, and increasing channel roughness (bed morphology, wood), may also be necessary to promote resiliency of stream channels and restoration projects to floods of large magnitude in the future.

Many studies of climate change impacts on fishes and salmonids in particular have focused on changes in fish distribution in response to projected temperature changes (33, 36). Some studies have also focused on how changes in air and stream temperature and precipitation might influence fish population dynamics and bioenergetics. For example, Driftless Area specific studies have shown floods to influence Brook Trout population dynamics (Fig. 8)(41), Brown Trout growth rates and survival to differ across seasons with different thermal regimes (44, 45), interactions between Brook Trout and Brown Trout influence both species' population dynamics (46, 47), and trout population dynamics to change in response to species interactions and seasonal variation in stream temperature and flow (39). Other midwestern studies have shown Brook Trout and Brown Trout populations to be regionally synchronized due to the negative impacts of high flows during periods when redds may be susceptible to scour and emerging fry may experience high mortality or displacement (48). Research on changes in fish abundance, growth rates, and bioenergetics in response to climate change in the Driftless Area remains an important science need for future trout fisheries management given an uncertain climate future.

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