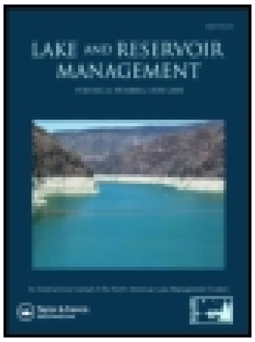

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Scientific advances and adaptation strategies for Wisconsin lakes facing climate change

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ABSTRACT
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Climate change threatens inland lakes, which are highly valued for their ecological and economic benefits. Here, we synthesize adaptation strategies that could offset climate impacts on Midwestern lakes. Our synthesis is based on results from the Wisconsin Initiative on Climate Change Impacts lake adaptation workshop, in which 48 researchers and managers with expertise on Wisconsin's inland lakes gathered to provide input on climate adaptation strategies. We identified recent scientific advances, knowledge gaps, and examples of successful climate adaptation strategies with respect to four key themes: lake levels, water quality, aquatic invasive species, and fisheries. While adaptation strategies for each theme differed, there was consensus around the need for a multifaceted approach that incorporates communication and outreach, policy and regulation changes, traditional resource conservation approaches, and novel engineering designs. Managers should focus on protecting high-quality lakes, building lake resilience, and retaining beneficial ecosystem services. Most importantly, thoughtful and strategic interactions with stakeholders, policymakers, and researchers across multiple disciplines will be key to implementing climate adaptation strategies.

KEYWORDS
AIS; climate adaptation; climate change; fisheries; inland lakes; lake levels; water quality

Inland lakes provide ecological and economic benefits to surrounding communities and are a highly valued component of the cultural identity of lake-rich regions (Garn et al. 2003). Lakes provide recreation opportunities (Lansford and Jones 1995), economic benefit (Sander and Polasky 2009; Reynaud and Lanzanova 2017), recreationally and tribally harvested fisheries (Paukert et al. 2016), drinking water (Reynaud and Lanzanova 2017), and mental health benefits (Wheeler et al. 2012). Ecosystem services provided by inland lakes make them extremely valuable globally (Sander and Polasky 2009; Reynaud and Lanzanova 2017).

Climate change is one of the greatest threats to inland lakes (U.S. Global Change Program 2009) because of coupled impacts on hydrology, chemistry, and biology (Adrian et al. 2009). Lakes respond directly to climate change and incorporate climate-driven changes occurring within the watershed (Adrian et al. 2009). In Midwestern lakes, climate change has been associated with loss of winter ice cover (Magnuson et al. 2000), warming water temperatures (Magee and Wu 2017), low dissolved oxygen levels (Missaghi et al. 2017; Snortheim et al. 2017; Magee et al. 2018), water level changes (Gaeta et al. 2014), changes in fish

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populations and assemblages (Hansen et al. 2017; 2018), arrival and spread of aquatic invasive species (Rahel and Olden 2008), and increased frequency of harmful algal blooms (Paerl et al. 2016).

Predicting the response of lakes to climate change is challenging for several reasons. Climate forecasts themselves are uncertain, and these uncertainties can be magnified through in-lake processes (Kernan et al. 2010). Lake temperature responses to climate change vary due to differences in lake morphometry, surrounding land cover, and water clarity (Rose et al. 2016). Changing lake temperatures influence biota directly through changing metabolism, growth, and survival (Beitinger and Magnuson 1979; Magnuson et al. 1979), but also via indirect pathways including species interactions, phenology, and habitat overlap (Kitchell et al. 1977; Hanson et al. 1997), making biotic responses to climate change highly variable and context dependent (Hein et al. 2013; Hansen et al. 2018). Finally, lakes are subject to multiple interacting stressors and management regimes, which can either magnify or suppress the influence of climate change (Lynch et al. 2016). In sum, these complicated interactions lead to heterogeneous responses to climate change, increasing the challenge of developing effective adaptation strategies (Carpenter et al. 2017).

On a state and regional level, climate adaptation strategies are needed. However, lake responses to climate change, effectiveness of adaptation strategies, and management goals are each uncertain and vary across the landscape of lakes. Thus, the Wisconsin Initiative on Climate Change Impacts (WICCI) hosted a workshop with the goal of exchanging ideas on how to adapt inland lakes to changes in climate. The workshop's objectives were to (1) synthesize recent scientific advances related to climate change on inland lakes in Wisconsin; (2) identify knowledge gaps; and (3) develop climate adaptation strategies. This article summarizes the output of this workshop and may stimulate similar collaborative efforts in other regions.

Methods

The workshop was organized and hosted by the Water Resources Working Group of WICCI. Focal questions and guests were selected by a steering committee with representatives from 10 agencies. Forty-eight attendees (see online resource S1) representing 16 organizations and multiple disciplines were invited to develop a holistic view of inland lake management related to anticipated climate changes in Wisconsin. We selected the diverse group to emphasize partnerships and exchange lessons among researchers, managers, and stakeholder groups.

The one-day workshop consisted of plenary sessions, breakout sessions, and informal discussion. Plenary topics included climate change in Wisconsin, lake levels, water quality, aquatic invasive species (AIS), fisheries, manoomin (wild rice), lake modeling, genetics, social science, communicating climate change adaptation, and an example of successful adaptation in Minnesota. Plenary talks provided an overview of current research and challenges that set the stage for the breakout sessions.

Breakout sessions centered on four thematic areas (Figure 1): lake levels, water quality, AIS, and fisheries. These sessions examined three questions: (1) What are recent advances in our scientific understanding of the theme since the first WICCI report on climate change (WICCI 2011)? (2) What knowledge gaps need to be filled to better understand how climate change will impact inland lakes? (3) What adaptation strategies could reduce inland lake vulnerability to climate change? After the workshop, authors compiled responses to these questions and distilled them into critical points and cross-cutting themes.

Results and discussion

Here, we report on inland lake responses to climate change and adaptation strategies. For each of four themes, we provide a brief background of what is known, describe recent advances in research and management, identify key knowledge gaps that impede adaptation efforts, and recommend adaptation strategies (Table 1). We conclude with cross-cutting themes and recommendations that emerged from the workshop.

Lake levels

Background

Lakes experience a range of water levels from average conditions to infrequent lows and highs,

Table 1. Adaptation actions generated for each of the four workshop themes. Adaptation actions fall into four broad categories of communication and outreach actions, policy and regulation actions, traditional conservation actions, and engineering actions.

Lake levels	
Communication	• Monitor and define the range of lake levels expected • Identify seepage lakes in the state with large lake level fluctuations • Shift cultural norms regarding idyllic lake shorelines to include natural vegetation and minimize human structures
Policy	• Set zoning regulations that protect the riparian zone from development • Set insurance policies based on future climate projections to minimize building below the high-water mark • Promote voluntary practices that protect undeveloped shorelines and wetlands • Limit groundwater extraction to maintain minimum lake levels during drought • Incentivize agricultural and urban development practices that minimize water use and encourage water infiltration
Conservation	• Protect and restore wetlands and lake habitat in riparian and littoral zones • Add woody and other habitat to deep water so it is available when lake levels are low • Protect woody and other habitat stranded above water so it is available when lake levels rise • Tailor agricultural practices to local climate and geology to conserve water and minimize drawdown in lakes

Engineering	• Build adaptable/temporary structures, such as rolling or floating piers
	• Enhance water infiltration in the watershed and in the riparian to minimize flooding after extreme precipitation events
	• Manage lake levels with dams to anticipate future highs and lows
	  • Lakes maintained artificially high for summer recreation are more at risk of flooding
	  • Lakes drawn down especially low to protect structures from ice are more at risk of staying low in drought years
	• Pump water out of seepage lakes when water is too high
	• Design infrastructure to accommodate extreme events

Water quality	
Communication	• Address disconnect for stakeholders who value high water quality but dislike management and regulations • Develop community connectedness with stakeholders • Draw input from lake associations to drive large preventative measures at the local level • Increase communication with stakeholders about drivers of water quality and how climate change may affect drivers • Communicate economic advantages of improved water quality to businesses and other stakeholders
Policy	• Incentivize companies and farmers to reduce nutrients runoff in the watershed • Continue implementation of total maximum daily load (TMDL) programs • Reevaluation of water quality standards and permitting standards to reduce phosphorus, chloride, and fecal contaminants • Remove combined storm overflows in urban areas • Improve stormwater regulations and enforce management practices that reduce runoff and nutrients in urban areas

Conservation	• Best management practices for nutrient reductions
	  • Limit fertilizer application
	  • Grazing and pasture management
	  • Riparian and buffer zones
	• Wetland protection and restoration
	• Reduce application of road salt during winter months
	• Saturated buffers to reduce phosphorus and nitrate loads entering streams from tile-drained agricultural fields

Engineering	• Maintain beach usage through enclosed swimming and treatment systems • Artificial aeration to prevent anoxic conditions to sustain well-oxygenated waters for cold-water fisheries • Increase green infrastructure • Dredging of legacy phosphorus in impacted stream reaches • Constructed water treatment wetlands and detention ponds
Aquatic invasive species	
Communication	• Continue outreach efforts to maintain 100% compliance with AIS prevention efforts • Expand youth education and community-based social marketing to achieve higher compliance rates • Develop simple and consistent messaging • Better articulation of socioeconomic impacts of invasion • Advertise the successes of outreach efforts in preventing invasions
Policy	• Develop proactive long-term monitoring and studies • Develop regulations that close existing and potential future transport vectors • Proactively incorporate AIS management into regulation regarding water quantity management • Incentivize invasive species harvest at the edge of invasion • Adjust ballast water regulations to decrease risk of invasion • Alter standards for boat manufacturers that require design for AIS prevention and decontamination
Conservation	• Promote strategies to increase general health (i.e., resilience) of lakes and reduce AIS impacts • Develop local-scale prediction and prevention strategies • Use long-term monitoring to identify changes in AIS distributions, pathways, and impacts as climate changes • Improved detection methods to identify and manage AIS before they become established • Develop biological control programs for common AIS species • Provide funding and resources for communities and lake associations to control AIS at the local level

(*continued*)

Engineering	• Recreational boat and shipping vessel decontamination
	• Ballast water treatment
	• Changing watercraft design to make AIS prevention easier
	• Fish passage barriers
	  • Electric barriers
	  • Physical barriers (dams)
	  • Acoustic deterrents
	  • Carbon dioxide deterrent
	• Chlorinated locks to prevent AIS from passage

Fisheries	
Communication	• Coupled natural–human systems studies enhancing understanding of human role on fisheries systems under climate change • Outreach on the safe operating space concept • Encourage and/or enhance manager and stakeholder partnerships • Increased transparency in scientific and management basis for regulations • Set realistic expectations and goals for fish communities based on lake conditions
Policy	• Harvest regulations (length and bag limits, closed seasons) to reduce exploitation rates • Stock appropriate genetic strains to maintain local adaptation • Cost–benefit analysis of stocking policies for maintaining the fishery • Alter inland fishery management to what the lake can currently support • Increase protection of forested watersheds
Conservation	• Continue long-term monitoring programs of sentinel lakes • Purchase land in watersheds of resilient lakes with high-value fisheries • Add structural habitat that is resilient to water-level fluctuations • Reduce nutrient loading in watersheds to reduce anoxic conditions and maintain available cold- and cool-water fish habitat • Stock genetically resilient strains
Engineering	• Artificial aeration of lakes with low dissolved oxygen to provide refugia for cold-water fish species

Figure 1. (a) Lake levels: increased precipitation may cause flooding and property damage on some lakes (photo credit: Katie Hein); (b) water quality: increased runoff and warmer air temperatures will increase the frequency of harmful algal blooms on Wisconsin's inland lakes (photo credit: Sarah Collins); (c) aquatic invasive species: climate change will make management of AIS, such as spiny water flea, more difficult in Wisconsin lakes (photo credit: Jake Walsh); (d) fisheries: changing temperatures are predicted to result in shifts in distribution of important freshwater fish, such as walleye (photo credit: Gretchen Hansen).

and some lakes fluctuate more dramatically than others. These lake-level fluctuations translate to changes in lake volume and surface area and have far-reaching consequences for lake ecosystems and economies. Fluctuating lake levels influence water clarity, water temperature, nutrient cycling and algal blooms, water chemistry, structural habitat, macroinvertebrates, fish, and invasive species (Balogh et al. 2008; Brauns et al. 2008; Leira and Cantonati 2008; Wantzen et al. 2008; White et al. 2010; Gaeta et al. 2014; Mosley 2015). Changing lake levels can also have recreational and economic impacts, limiting boat launch and dock usage when lake levels are low, and imposing slow speed, no-wake restrictions, and property damage when lakes flood (Figure 1). Climate change will likely alter the range and frequency of water-level fluctuations in lakes through its effects on precipitation and evaporation rates, ultimately altering a lake's natural lake level regime.

Recent advances

In the past 5–10 yr, technological and scientific advances have improved measurement of lake levels on landscape scales, thus informing understanding of the influence of lake level on ecological and economic processes. Long-term water quantity data sets have increased understanding of climate cycles and shifts to new climate regimes. For example, using records dating back to the 1940s, Watras et al. (2014) found a coherent 13-yr cycle in lake and groundwater levels in the Great Lakes region, suggesting a drier hydroclimatic regime since 1988. Additional data sets include the National Oceanic and Atmospheric Administration (NOAA) National Water Model, the National Water Information System from the U.S. Geological Survey (USGS), fine-resolution elevation data (e.g., LIDAR and 10-m digital elevation models), new remote-sensing opportunities (e.g., moderate resolution imaging spectroradiometer [MODIS] to estimate evapotranspiration, and surface water and ocean topography [SWOT] to quantify changes in water storage), sensor networks like the National Ecological Observatory Network (NEON) and Global Lakes Ecological Observatory Network (GLEON), and volunteer lake-level monitoring.

Because of these datasets, we now know that lake levels affect water clarity, nutrient loading, and mercury cycling in Wisconsin lakes. Using satellite imagery of 5002 Wisconsin lakes, Rose et al. (2017) found that water clarity in many lakes was lower in a wet year (2010) compared to a dry year (2005). Similarly, Lisi and Hein (2019) analyzed a 30-yr dataset from northwest Wisconsin and found that oligotrophic lakes were clearer when water levels were low, but eutrophic lakes were clearer during wet years. Comprehensive, long-term data sets help explain these contrasting results (Robertson and Rose 2011; Robertson et al. 2018). Together these studies show that lake responses to different precipitation regimes depend on their nutrient status and morphology. Lake levels can also influence acidification, dissolved organic carbon (DOC), and mercury bioaccumulation, with more methylmercury in walleye when lake levels are higher (Watras et al. 2018).

Knowledge gaps

Despite technological advances in water quantity monitoring, limited observations and lake level models remain a major knowledge gap. We need expanded monitoring of lake levels and their drivers, particularly precipitation, evapotranspiration, and groundwater. Water balance models that account for these drivers in addition to surface water flow are needed to develop hindcasts and forecasts. We also need to better understand the interactions between water volume and the thermal budget of lakes. Improved hypolimnetic water temperature monitoring and modeling will inform how lake-level fluctuations affect stratification. This in turn could improve our understanding of lake trophic dynamics and the divergent response in water clarity observed between oligotrophic and eutrophic lakes. Finally, the impacts of lake levels on the biological components of lake ecosystems, from sulfate-reducing bacteria to zooplankton to fish, are open for future research. Collecting and digitizing publicly available bathymetric data for many lakes will be key for identifying impacts of changing lake levels and the consequences for aquatic life. Understanding these impacts will inform lake level policies, particularly during drought years when water is in short supply.

Adaptation strategies

Adjusting user expectation from static to fluctuating water level is critical. Expanding lake-level monitoring and reporting expected ranges will aid this effort (Table 1). Policies that protect land near the lake would minimize property damage during floods, and those that encourage water conservation would mediate impacts during droughts (Table 1). Engineering solutions may be the most popular adaptation strategies. Anticipated extreme rainfall events will necessitate evaluation and development of new infrastructure designs to minimize risk and safety concerns (e.g., Wilhere et al. 2017). Although engineering solutions seem ideal, they can be costly and have unintended consequences. For example, several consistently flooded seepage lakes in Wisconsin are now being pumped and discharged to the nearest stream. In addition to concerns about contaminating downstream waters with AIS, nutrients, and higher biological oxygen demand, these pumps are costly to build and run, and may have limited ability to draw down the lake to desirable levels. Still, for some, the benefits outweigh the costs: properties are protected, erosion is minimized, and legacy phosphorus can be removed from the lake.

Water quality

Background

Water quality refers to the ability of a lake to support use for drinking water, wildlife habitat, and recreation. Poor water quality can limit recreational water use (Wolf et al. 2017), cause fish kills (Jacobson et al. 2008), and increase costs for surrounding businesses and homeowners (Wolf and Klaiber 2017), drinking-water treatment (Ho et al. 2012), and water clarity improvement (Walsh et al. 2016). Nutrient reduction to address eutrophication remains a major focus in Wisconsin (Lathrop et al. 1998; Carpenter and Lathrop 2008), but climate change threatens to exacerbate nutrient pollution. Precipitation increases will lead to higher nutrient inflow (Carpenter et al. 2018) and *Escherichia coli* (Kleinheinz et al. 2009) concentrations in agricultural and urban watersheds, which are concerns for water quality. Sedimentation rates (Yasarer and Sturm 2016) will also increase with more preciptiation, threatening water quality in natural lakes and storage capacity in reservoirs (Yasarer and Sturm 2016). Warming water temperatures are associated with larger, more frequent algal blooms (Fig. 1; Paerl et al. 2016), more frequent hypolimnetic anoxia (Snortheim et al. 2017), and reduced fish habitat (Magee et al. 2018; 2019).

Recent advances

We are moving beyond traditional water quality-climate change research to consider previously ignored drivers of poor water quality. For example, higher precipitation increases lake browning (Bertolet et al. 2018), impacting the way in which lake water temperatures and stratification respond to climate changes (Rose et al. 2016) and altering dominant phytoplankton communities (Rengefors et al. 2012). Zooplankton can play a major role in reducing or enhancing water clarity directly through food web effects or indirectly through changes in species dominance with warming temperatures (Hintz et al. 2017; Walsh et al. 2017). We are increasingly recognizing that the interactions of climate, lake levels, and nutrient loading together influence water quality.

One major research advance is the use of advanced statistics and models to investigate the heterogeneous responses of lakes to climate change. Improved model capacity lets us analyze how climate scenarios and management options at the landscape scale affect lake water quality (e.g., Booth et al. 2016). Models can now predict the effects of altered runoff timing and extreme precipitation events, and they can assess uncertainty in anticipated precipitation and land use/land cover changes (Booth et al. 2016). Through coupled physical and biogeochemical models, we are beginning to incorporate previously unconsidered drivers of water quality (e.g., AIS and DOC) into climate change assessment, broadening our understanding of the uncertainties in response and mechanisms. Finally, the quantity and quality of model input and validation data have substantially improved, including land use/land cover data, remote sensing data, and in situ measurements.

While previous research focused on water clarity and harmful algal blooms (HABs), new studies indicate the importance of other pollutants such as chloride and persistent organic pollutants. Persistent organic pollutants (POPs) are widely distributed globally, and through the Midwest, and their fate is strongly associated with temperature (Ma et al. 2016). Research indicates that climate change may alter stability and cycling of POPs in aquatic environment, but effects of this alteration are still unknown in the Midwest (Ma et al. 2016).

In some areas, salt has replaced sand application to roads due to stream sedimentation concerns. Road salt use has increased in-lake chloride concentrations in the Midwest and the northeastern United States (Dugan et al. 2017), which can affect community structure and ultimately increase phytoplankton abundance (Hintz et al. 2017). Sulfates and other impurities in road salts may also enter the water with unknown impacts. Although road-salt use is declining in some areas, changing climate may further alter use rates across the upper Midwest. Initially, warming air temperatures and increased winter precipitation could cause an increase in salt use. Road salt is more effective at temperatures above 25 C, and usage may increase as more lane-miles of salt are applied to prevent winter accidents at near-freezing temperatures. Alternatively, as temperature continue to warm by the late 21st century, total winter road salt application may decrease, especially in southern Wisconsin as the number of days below freezing drastically decreases.

Knowledge gaps

Forecasting cyanobacterial harmful algal bloom occurrence. People want to know when and where HABs will occur for short-term recreational purposes and long-term real estate purchasing decisions, but the capacity to forecast HAB occurrence at relevant scales remains a key knowledge gap. While advances have been made in modeling lake physics (Winslow et al. 2017; Hamilton et al. 2018), modeling lake chemistry and biology remains challenging (Belisle et al. 2016). As with other water-quality parameters, HAB occurrence can vary with lake classification and short- and long-term weather patterns, and can have high temporal and spatial variability within lakes (Foster et al. 2017). We lack in situ and remotely sensed data to assess spatial and temporal variability in HAB occurrence. Remotely sensed and in situ data for calibration and validation especially will inform our understanding of the spatial and temporal extent of HABs across the state and inform HAB forecasting capabilities. Useful forecasting tools at a seasonal scale allows beach managers and local public health departments to prepare for the recreational season (e.g., Soley 2016) and public water utility managers to plan for cyanobacterial toxin removal (Wynne et al. 2013). Researchers need to connect climate changes to changes in bloom outbreaks and incorporate them into novel forecasting methodologies (Wilkinson 2018).

Modeling resilience. Understanding which lakes will maintain desired function despite climate changes (resilience) informs statewide strategies for adaptation. Development of an index based on different parameters and drivers of water quality would classify resilience of Wisconsin lakes to water-quality degradation from climate and land use changes, helping the prioritization of resource allocation and management. Lakes with good water quality and high resilience could be protected to maintain these qualities into the future.

Connecting to lake users. Considering the social science behind behavioral changes will improve development of strategies to reduce lake vulnerability. Uncertainty and variability exist in how people will respond to lake changes and whether they support various actions. The human socioeconomic component of this problem is complicated and requires more research. For example, stakeholders are slow to initiate on-land solutions and strategies despite their known effectiveness. Research that elucidates stakeholder motivation is needed to affect change, especially given the diverging demographics between rural, lake-rich areas of the state and urban areas (Semuels 2016).

Adaptation strategies

Traditional strategies, such as best management practices and policy changes to reduce nutrients and runoff within the watershed, should continue to be used to protect and improve water quality in a changing climate (Table 1), but we must consider the impact of climate changes during design and implementation. Implementation of these practices alone cannot fully reverse or prevent eutrophication of lakes (Osgood 2017) or completely offset the impacts of a changing climate (Morabito et al. 2018).

In cases where water quality improvement goals cannot be met through traditional strategies, managers and stakeholder groups should use novel approaches to maintain beneficial use of lake resources (Table 1). For example, exclosure systems that create clean, safe swimming beaches (e.g., Reimer et al. 2018) can maintain community beach usage and sustain economic value (Houston 2008). While such engineered adaptations are attractive because they sustain beneficial use, we must not rely solely on superficial fixes in place of addressing causes of poor water quality.

Adaptation strategies that address water quality over the long term often require restrictions on watershed land use that can be controversial and difficult to implement. Success requires engaging diverse stakeholders including the agricultural community, legislature, local governments, and private landowners at the local scale. Engagement and cooperation from the wider community has led to success of some large-scale watershed protection initiatives (e.g., watershed protection of cisco lakes in Minnesota; Jacobson et al. 2013).

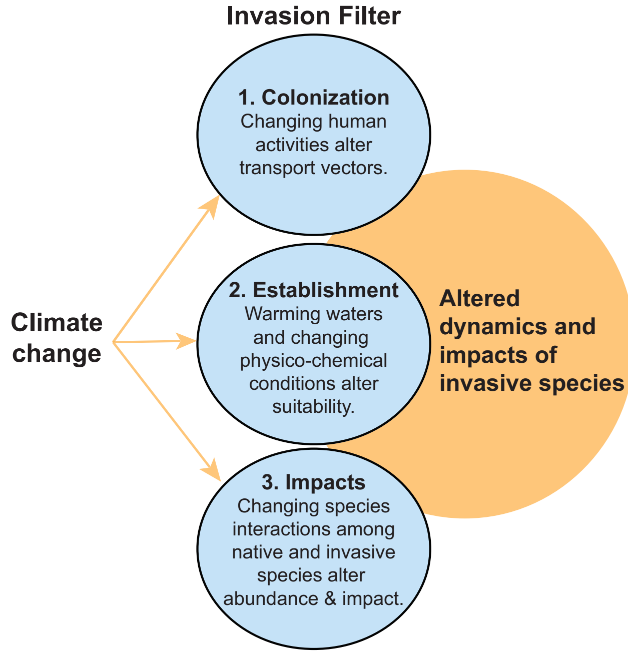

Figure 2. Climate change affects each step or filter of the invasion process. Here, we present an example of three potential invasion filters (colonization, establishment, and impacts) where climate change affects the underlying ecology of each filter. As each filter is altered, we expect to observe change in the dynamics and impacts of AIS. As a result, AIS will be more challenging to manage under climate change, particularly since each of these filters are directly linked and often will be changing simultaneously.

Aquatic invasive species

Background

Wisconsin has a robust AIS management program that includes strong support and funding from the Department of Natural Resources (DNR), engaged leadership from University of Wisconsin (UW)-Extension and Wisconsin Sea Grant, and excellent research capacity through universities. Even with these resources, climate change will make AIS management more difficult in Wisconsin. Species invasions can be conceptualized as a series of steps or filters (Vander Zanden and Olden 2008), and climate change will affect each step (Fig. 2; Rahel and Olden 2008). Climate change will alter the vectors and pathways of species introduction; affect environmental suitability and establishment of invasive species; and change ecological and economic impacts of species introductions (Fig. 2). Consequently, we expect an ever-evolving situation, with all three steps of the invasion process changing simultaneously in response to climate change.

Recent advances

We have improved tools for modeling spread and distribution of AIS and predicting and reducing their impacts. Risk assessment tools linking establishment and impact, climate matching tools, suitability models, and smart prevention tools have allowed us to better triage and manage new invasions (e.g., Hill et al. 2017, Howeth et al. 2016, Koop 2014, Papeş et al. 2011). For example, detailed modeling of lake thermal profiles (Winslow et al. 2017) allows researchers to apply AIS distribution models to a much larger subset of lakes in Wisconsin and predict vulnerability to invasion under current and future climates. Coupling these models with new detection technologies such as environmental DNA (Ficetola et al. 2008) has led to more effective surveillance programs.

Advances in communication science have enhanced adaptive management and AIS prevention. Outreach prevention programs are effective (Ferry 2017; Connelly et al. 2018), and there has been increased focus on novel strategies for AIS communication to the public. Communication professionals are exploring how targeted online outreach and different message frames can be used to increase engagement. An economic approach to compare AIS and climate stressors explicitly links AIS impacts and climate change for policymakers by using the same currency. Studies that monetize impact provide new vocabulary to communicate the harmful effects of AIS (e.g., Walsh et al. 2016) and provide an objective basis for policy decision making.

Knowledge gaps

If we consider the effects of climate change on each of the primary invasion filters (Fig. 2), it becomes clear that key gaps remain in our understanding of how climate change will influence management of AIS. Scale is a key challenge in invasion ecology. We have a continental-scale understanding of invasion pathways, and our ability to predict new species invading via these pathways has improved. However, predicting and, in turn, preventing invasions at the local scale has proven more challenging (Vander Zanden et al. 2017), and these difficulties become more prominent with a changing climate.

We have yet to carefully consider how introduction vectors and pathways will change or how new pathways will be formed as human activity is altered with climate change (e.g., new transatlantic shipping pathways with declining sea ice and assisted migration as a tool for species adaptation; Working Group on Invasive Species and Climate Change 2014). Because humans are the primary vector of AIS introduction and transport (Havel et al. 2015), this is a critical gap in our understanding of the effects of climate change on AIS management. Prevention at the broadest spatial scales will require a more complete understanding of how AIS transport pathways are formed (e.g., trade), how pathways are likely to change with changing climate, and how to regulate existing and potential future pathways.

Similarly, we have a broad understanding of AIS range (e.g., the geographical extent of an invading population) and how ranges will shift with climate change at broad scales, but relatively poor understanding of how AIS are distributed at finer scales (e.g., how lake differences modulate the effect of climate on AIS within a county). Finally, we do not know how climate change will alter species interactions and AIS impacts on native biota already experiencing climate-induced stresses.

Adaptation strategies

The 3 filters of the invasion process (Fig. 2) provide a framework for understanding the effects of climate change on AIS and allow us to consider adaptation in AIS management. A primary goal of invasive species management is to minimize the spread and adverse effects of nonnative species that are deemed ecologically or economically harmful. To reach these goals, managers and regulators need to develop criteria for AIS management that build on successes of current management strategies while also accounting for climate changes. These actions (Table 1) should form a key component of larger efforts to build resilience to multiple ecological stressors.

Strategies that increase the ability of lakes to maintain ecological functions (resilience) can offset the impacts of climate on the establishment and impacts filters of the invasion process. The Healthy Lakes program, administered by the Wisconsin DNR and UW-Extension, helps stakeholders implement resilience strategies through small grants and expert support. Proactive long-term monitoring and research provide information on impact of climate on AIS distributions, pathways, and impacts, informing resilience strategies. For example, long-term monitoring through the National Science Foundation (NSF)-funded North Temperate Lakes Long Term Ecological Research Program (NTL-LTER) was foundational to our understanding of the invasive spiny water flea (*Bythotrephes longimanus*; Fig. 1) and its management (Walsh et al. 2017; 2018; 2019), providing insight broadly to management of other AIS under climate change.

Controlling AIS introduction vectors and pathways is essential for climate adaptation. Transport vectors can be managed through both policy changes and new pathway-specific prevention approaches (Table 1). Focusing on controlling regional pathways through the Aquatic Nuisance Species Task Force regional panel structure and other interstate collaborations would be a cost-effective strategy. With a warming climate, Wisconsin and other Midwestern states will become more suitable for subtropical aquarium (or aquaculture) species in trade. Changing policy to reconsider blanket regulatory and permitting exemptions for some of these species could help protect from future invasions. For example, Wisconsin is already regulating water lettuce (*Pistia stratiotes*) and water hyacinth (*Eichhornia crassipes*) through administrative codes, based on evidence of their overwintering ability and projected suitability in Wisconsin's future climate.

Fisheries

Background

Climate change has influenced lake temperatures over the last 50–100 yr (O'Reilly et al. 2015; Magee and Wu 2017; Winslow et al. 2017), and these changes have affected fish via individual-, population-, community-, and ecosystem-level processes (Ficke et al. 2007; Heino et al. 2009; Pörtner and Peck 2010). Water temperatures determine habitat suitability (Jacobson et al. 2008; Lyons et al. 2018), feeding, metabolism, growth, and spawning of fish (Kitchell et al. 1977; Magnuson et al. 1979; Hanson et al. 1997), and inland fisheries are unique in that dispersal potential is limited and movement to suitable habitat is often not possible (Lynch et al. 2016; Sass et al. 2017).

Documented effects of climate change on fisheries are rare but increasing (Lynch et al. 2016). In the Midwest, epilimnion temperatures have increased and are projected to increase further with warming air temperatures in both the mid (2020–2040) and late (2080–2100) 21st century (Winslow et al. 2017). Across broad spatial scales, changing water temperatures are predicted to result in distributional shifts of walleye (*Sander vitreus*), smallmouth bass (*Micropterus dolomieu*), and cisco (*Coregonus artedi*), with cool- and warm-water taxa moving northward and cold-water fish experiencing range decreases (Alofs et al. 2014; Herb et al. 2014; Van Zuiden et al. 2016). Warming water temperatures are expected to negatively affect cold-water species most severely and consistently, while effects on cool- and warm-water taxa are more variable (Comte et al. 2013). Variable responses may be due in part to temperature influencing species interactions that are difficult to predict (Jeppesen et al. 2010; Hansson et al. 2013) and individual population responses creating novel communities (Comte et al. 2013). Changes in available thermal habitat under climate change can be used to predict changes in suitable fish habitat in lakes (Magnuson et al. 1990; Cline et al. 2013; Magee et al. 2018), but it is difficult to quantify influences of climate change on fishes across heterogeneous lakes experiencing other stressors in water level changes, water quality, and AIS (Hansen, Sass, et al. 2015; Lynch et al. 2016).

Recent advances

The greatest advancement in our understanding of climate change and inland fisheries stems from the number of funding programs, partnerships, and researchers focused on this topic (e.g., (Lynch et al. 2016; Paukert et al. 2016; Whitney et al. 2016). However, as for other broad-scale aquatic ecological issues (e.g., AIS, eutrophication), recognition of the issue did not lead to swift advances in research (Sala et al. 2000). Recent research has expanded use of models to predict future water temperatures across broad spatial scales, rather than relying on air temperature as a proxy (e.g., Hansen et al. 2017, Winslow et al. 2017). Such models account for variability among lakes in their response, which is critical for understanding and predicting fish responses to climate change, including species-specific suitable habitat (Jacobson et al. 2008; Gaeta et al. 2014; Lyons et al. 2018; Magee et al. 2018), spawning phenology (Lyons et al. 2015), survivability/extirpation (Honsey et al. 2016), and range expansions/contractions (Alofs et al. 2014; Van Zuiden et al. 2016). Variability may dampen or exacerbate potential effects on inland fishes based on adaptability, life history, and physiological responses of individual species and populations (Paukert et al. 2016; Whitney et al. 2016).

Identification of direct and indirect pathways by which temperature affects fishes, populations, and communities has resulted in nuanced and complex views of effects of climate change beyond thermal tolerances. Fish populations may persist in warmer climates beyond what their thermal tolerances predict, or, conversely, may decline when warming temperatures remain within expected limits. For example, invasive, coldwater rainbow smelt (*Osmerus mordax*) persisted in Crystal Lake, WI, after water temperatures were experimentally raised above their expected lethal thermal limit (Lawson et al. 2015), suggesting that behavioral, physiological, and/or genetic resilience to warming water temperatures may temper responses to climate change (Lawson et al. 2015). Conversely, walleye (Fig. 1) are declining in many lakes throughout Wisconsin (Hansen, Carpenter, et al. 2015; Hansen et al. 2018). Failed natural recruitment has been implicated, which has been linked to water temperature (Hansen et al. 2018), despite lake temperature staying below laboratory-derived thermal tolerances for walleye.

Knowledge gaps

The variability and context dependence of fish responses to climate change raise several unanswered questions. Research has been devoted to predicting changes in fish populations under changing temperatures, but accuracy of these predictions has rarely been tested. Uncertainty exists in mechanistic, physiological responses of fishes to changing temperature (Lefevre et al. 2017), and in whether that translates to population or community responses to climate change. The reason why fishes sometimes persist at temperatures above their lethal limits or decline at temperatures within their preferred range remains unknown. Although there has been a great deal of research on understanding the biology and ecology of fishes (Becker 1983), understanding how climate change may alter fish behavior, physiology, and interactions with other species is ripe for research.

Managers need a better understanding of climatic effects on available habitat and influences on population and community parameters. Defining changes to suitable oxythermal (Jacobson et al. 2008; Missaghi et al. 2017; Lyons et al. 2018; Magee et al. 2018) and refuge habitat is the first step in evaluating effects on spawning success, foraging behavior, predation risk, and competitive interactions. Understanding of responses at small spatial and temporal scales can then be used to inform hypothesis-driven ecosystem-scale studies (Lawson et al. 2015).

Another poorly understood aspect of maintaining resilient fisheries is evaluating climate adaptation in a coupled natural–human systems framework. How much will it cost to maintain a fishery? How will tourism be affected if the fishery is lost? Do alternative fisheries exist? What are cultural implications of losing a fishery? Should we prioritize management of climate-resilient fisheries over climate-susceptible ones? Socioeconomic and cultural valuation of fisheries is a critical component of maintaining sustainable fisheries, and human-dimensions research is needed to inform climate adaptation frameworks and strategies (Lynch et al. 2016). Because baseline ecological conditions and valuation of fishes may differ or change over time (Gilbert and Sass 2016), understanding these aspects and behaviors is critical for keeping inland fisheries in a safe operating space (Carpenter et al. 2017).

Adaptation strategies

Management actions can maintain fisheries in desirable states under a safe operating space framework (Carpenter et al. 2017). Under this framework, managers can manipulate local or regional policies such as harvest regulations or watershed land use to influence how fisheries are affected by climate change (Carpenter et al. 2017). Managers and stakeholders should work together to better understand management tradeoffs and alternative fishery outcomes if a lake can no longer accommodate cold- and cool-water species. Adaptation may require changing angler expectations when certain lakes become unsuitable for a species. Instead, the fishery should be managed for what the lake will support under current and future conditions.

Although this outcome may be culturally unpalatable in the short term, it may be the only feasible option in the long term. Regulations to manage exploitation, stocking, and habitat conservation and enhancement may be options for maintaining populations in the long term. Although harvest regulations (e.g., length and bag limits, closed seasons) may need to be quite restrictive to reduce exploitation rates (Mosel et al. 2015), such regulations could be used to preserve vulnerable species. Stocking genetic strains resilient to climate change can maintain local adaptation in the population and can be a cost-effective way to maintain the fishery (Lorenzen 2014). Management that dampens negative effects of climate change will require participation from diverse stakeholders to maintain inland fisheries in a safe operating space (Carpenter et al. 2017) and offset socioeconomic and cultural consequences for humans (Lynch et al. 2016; Paukert et al. 2016).

Actions to improve habitat even as lakes warm may be the most important factor for maintaining resilient inland fisheries. Many adaptation strategies for water-level fluctuations, water quality, and AIS prevention (Table 1) will enhance climate adaptation for fisheries (e.g., watershed preservation, structural habitat additions, aeration, best management practices to reduce nutrient loading). Identification of multiple adaptation strategies will enhance climate adaptation for fisheries and may provide the most resilience in the long term (Sass et al. 2017). For example, Minnesota is currently protecting the forested watersheds of cisco lakes projected to maintain climate refugia under future conditions to ensure their suitability by reducing nutrient loading (Jacobson et al. 2013). Similar approaches have been used by Trout Unlimited to increase riparian tree cover of coldwater streams to increase shading, slow warming, and conserve resilient trout populations.

Management actions and recommendations

During the workshop, attendees determined that developing a multifaceted approach to adaptation that incorporates the human dimension is important for managing inland lakes under climate change.

Multifaceted approach

Responses to climate change, adaptation options, and societal support are all heterogeneous across the landscape of Wisconsin lakes, so "one-size-fits-all" adaptation strategies will likely be ineffective. Wisconsin's climate adaptation strategy must take a multifaceted approach (Fig. 3) that encompasses traditional conservation practices and new innovations. Breakout groups focused on three general approaches to adaptation: resistance, resilience, and response (Millar et al. 2007). A resistance approach (e.g., green infrastructure and TMDL implementation) defends and protects high-value lakes against changes caused by climate. Resilience (e.g., wetland restorations) improves the capacity of lakes to return to prior conditions by reducing stress and minimizing vulnerabilities. Response develops actions (e.g., beach exclosure systems; Reimer et al. 2018) that intentionally accommodate change and minimize undesired outcomes.

Breakout groups also identified four classifications of adaptation strategies: communication, policy, conservation, and engineering (Table 1; Fig. 3). Communication actions were identified as most critical regardless of theme. Stakeholders must learn what to expect from lakes under a changing climate and what options may be effective in mitigating undesired outcomes. Policy actions, such as zoning regulations and incentivization programs, can be used to resist, develop resilience, and respond to climate changes in lakes, but must be accomplished at the governmental level and require community support. Traditional conservation and best-management practices combined with innovative engineering actions round out adaptation strategies. AIS adaptation actions relied heavily on communication and outreach with stakeholders, but promise exists in engineering actions that remove transport vectors through technological means (e.g., ballast water exchange and treatment; Briski et al. 2015). Fisheries adaptation actions were heavily skewed toward traditional conservation methods. Although engineering solutions can minimize negative impacts on water quality and control lake levels, they can also be risky and have unintended and catastrophic consequences (e.g., dam breaching). Thus, conservation-focused

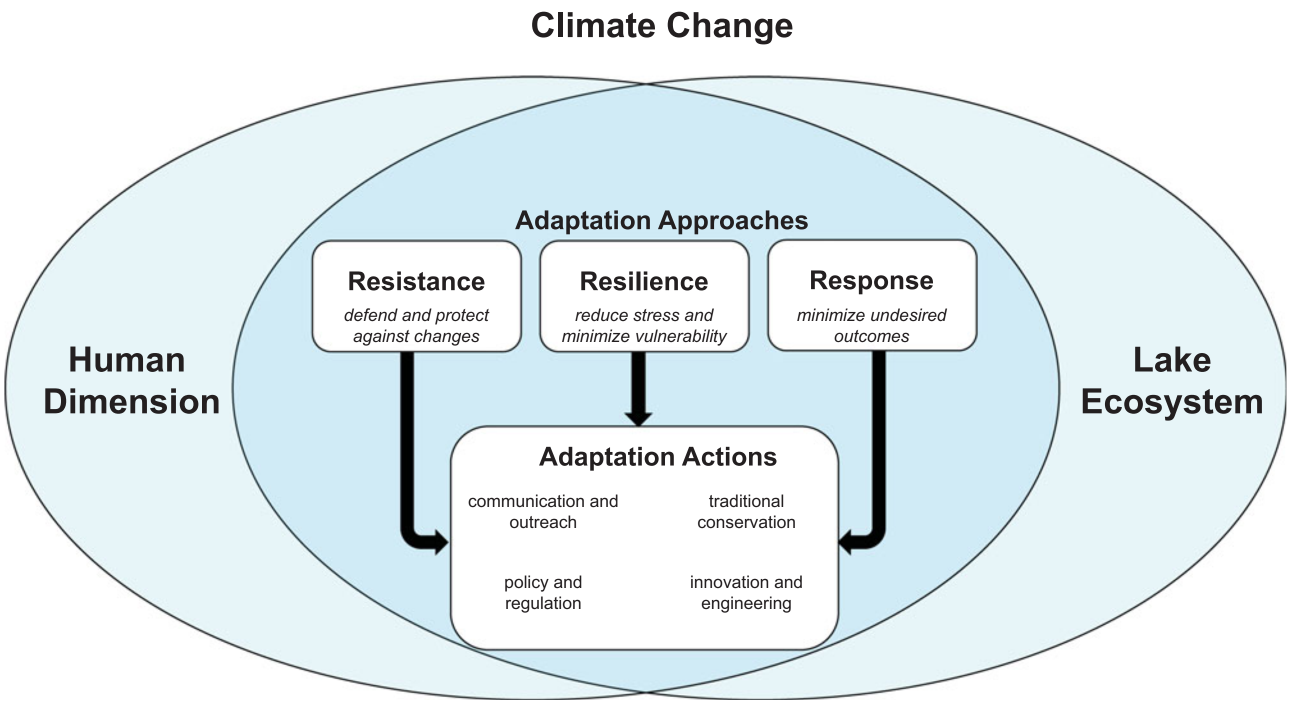

Figure 3. Conceptual diagram of a multi-faceted climate adaptation strategy for Wisconsin's inland lakes. Resistance, resilience, and response are effective adaptation approaches when tailored to the local communities' values and lake ecosystem. Each of these adaptation approaches can be achieve through adaptation actions that address communication and outreach, policy and regulation, traditional conservation actions, and innovation and engineering.

adaptation strategies remain important for water quality and lake levels as well.

Incorporating the human dimension

Communities that depend on healthy lakes and watersheds face daunting challenges when preparing for future change (Swanston et al. 2018). Communicating climate change impacts and emphasizing adaptation options are critical. Yet traditional science communication is fraught with misconceptions and beliefs that scientific outreach should fill a knowledge gap, or a deficit in understanding to change beliefs and behaviors (Varner 2014). This one-way mode of communicating risk is outdated and ineffective (Davies 2008). Instead, managers and researchers must work with stakeholders to become agents of change by building community capacity (Anson and Paulson 2016). Human behavior and beliefs are value based, and it is these values that shape lake-user perspectives and perceptions of climate-related risks to water resources. Supporting climate-informed decision making requires listening to people and their needs, considering place, perspectives, and values to create relevant outreach materials, and supporting creative and flexible approaches to meet management goals (Swanston et al. 2016). By following this value-driven approach, communicators are more likely to have a substantive discussion of near-term and long-term risks and opportunities.

Conclusions and recommendations

Ecosystems worldwide have already been affected by climate change, and the magnitude of these changes will only increase in the coming decades. While climate change will undoubtedly have a range of effects on lake ecosystems, some of the key areas of expected change include lake levels, water quality, AIS, and fisheries. Here, we identify recent scientific advances, knowledge gaps, and adaptation strategies to climate change. A holistic approach to climate adaptation for inland lakes includes protecting intact resources (resistance), improving the capacity of lakes to return to their prior condition (resilience), and accommodating changes while minimizing impacts (response). Communication and outreach, state and municipal level policies, traditional resource conservation, and engineered solutions can all be effective approaches for adapting to climate change. Perhaps most important is the human dimension of climate adaptation. Key to affecting change is ensuring that local communities' values inform adaptation approaches and that communities themselves are the agents of change.

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References

Adrian R, O'Reilly CM, Zagarese H, Baines SB, Hessen DO, Keller W, Livingstone DM, Sommaruga R, Straile D, Van Donk E. 2009. Lakes as sentinels of climate change. Limnol Oceanograph. 54(6):2283–2297.

Alofs KM, Jackson DA, Lester NP. 2014. Ontario freshwater fishes demonstrate differing range-boundary shifts in a warming climate. Divers Distrib. 20(2):123–136. doi:10.1111/ddi.12130.

Anson A, Paulson N. 2016. Relationship building and people work: an exploratory study of social networks and environmental activism. Human Soc. 40(4):424–441.

Balogh C, Muskó IB, G.-Tóth L, Nagy L. 2008. Quantitative trends of zebra mussels in Lake Balaton (Hungary) in 2003–2005 at different water levels. Hydrobiologia. 613(1):57–69. doi:10.1007/s10750-008-9472-3.

Becker G. 1983. Fishes of Wisconsin. Madison (WI): University of Wisconsin Press.

Beitinger TL, Magnuson JJ. 1979. Growth rates and temperature selection of bluegill, Lepomis macrochirus. Trans Am Fisheries Soc. 108(4):378–382. doi:10.1577/1548-8659(1979)108 < 378:GRATSO.> 2.0.CO;2.

Belisle BS, Steffen MM, Pound HL, Watson SB, DeBruyn JM, Bourbonniere RA, Boyer GL, Wilhelm SW. 2016. Urea in Lake Erie: organic nutrient sources as potentially important drivers of phytoplankton biomass. J Great Lakes Res. 42(3):599–607. doi:10.1016/j.jglr.2016.03.002.

Bertolet BL, Corman JR, Casson NJ, Sebestyen SD, Kolka RK, Stanley EH. 2018. Influence of soil temperature and moisture on the dissolved carbon, nitrogen, and phosphorus in organic matter entering lake ecosystems. Biogeochemistry. 139(3):293–305. doi:10.1007/s10533-018-0469-3.

Booth EG, Qiu J, Carpenter SR, Schatz J, Chen X, Kucharik CJ, Loheide CJ, II, Motew MM, Seifert JM, Turner MG, et al. 2016. From qualitative to quantitative environmental scenarios: translating storylines into biophysical modeling inputs at the watershed scale. Environ Model Software. 85:80–97. doi:10.1016/j.envsoft.2016.08.008.

Brauns M, Garcia X-F, Pusch MT. 2008. Potential effects of water-level fluctuations on littoral invertebrates in lowland lakes. Hydrobiologia. 613(1):5–12. doi:10.1007/s10750-008-9467-0.

Briski E, Gollasch S, David M, Linley RD, Casas-Monroy O, Rajakaruna H, Bailey SA. 2015. Combining ballast water exchange and treatment to maximize prevention of species introductions to freshwater ecosystems. Environ Sci Technol. 49(16):9566–9573. doi:10.1021/acs.est.5b01795.

Carpenter SR, Booth EG, Kucharik CJ. 2018. Extreme precipitation and phosphorus loads from two agricultural watersheds. Limnol Oceanogr. 63:1221–1233. doi:10.1002/lno.10767.

Carpenter SR, Brock WA, Hansen GJA, Hansen JF, Hennessy JM, Isermann DA, Pedersen EJ, Perales KM, Rypel AL, Sass GG, et al. 2017. Defining a safe operating space for inland recreational fisheries. Fish Fish. 18(6):1150–1160. doi:10.1111/faf.12230.

Carpenter SR, Lathrop RC. 2008. Probabilistic estimate of a threshold for eutrophication. Ecosystems. 11(4):601–613. doi:10.1007/s10021-008-9145-0.

Cline TJ, Bennington V, Kitchell JF. 2013. Climate change expands the spatial extent and duration of preferred thermal habitat for Lake Superior fishes. PLoS One. 8(4):e62279. doi:10.1371/journal.pone.0062279.

Comte L, Buisson L, Daufresne M, Grenouillet G. 2013. Climate-induced changes in the distribution of freshwater fish: observed and predicted trends. Freshwater Biol. 58(4):625–639. doi:10.1111/fwb.12081.

Connelly NA, Lauber TB, Stedman RC, Knuth BA. 2018. Bait dealers' roles in preventing the spread of aquatic invasive species and fish pathogens in the Great Lakes region. J Great Lakes Res. 44(3):514–520. doi:10.1016/j.jglr.2018.04.005.

Davies SR. 2008. Constructing communication: talking to scientists about talking to the public. Sci Commun. 29(4):413–434. doi:10.1177/1075547008316222.

Dugan HA, Bartlett SL, Burke SM, Doubek JP, Krivak-Tetley FE, Skaff NK, Summers JC, Farrell KJ, McCullough IM, Morales-Williams AM, et al. 2017. Salting our freshwater lakes. PNAS. 114(17):4453–4458. doi:10.1073/pnas.1620211114.

Ferry M. 2017. Stemming the tide. WI Natural Resources Mag. 41(3):20–21.

Ficetola GF, Miaud C, Pompanon F, Taberlet P. 2008. Species detection using environmental DNA from water samples. Biol Lett. 4(4):423–425. doi:10.1098/rsbl.2008.0118.

Ficke AD, Myrick CA, Hansen LJ. 2007. Potential impacts of global climate change on freshwater fisheries. Rev Fish Biol Fisheries. 17(4):581–613. doi:10.1007/s11160-007-9059-5.

Foster GM, Graham JL, Stiles TC, Boyer MG, King LR, Loftin KA. 2017. Spatial variability of algal blooms in Milford Lake, Kansas, July and August 2015. Scientific Investigations Report 2016-5168, Prepared in cooperation with the Kansas Department of Health and Environment and the U.S. Army Corps of Engineers, Kansas City District, 56 p.

Gaeta JW, Sass GG, Carpenter SR. 2014. Drought-driven lake level decline: effects on coarse woody habitat and fishes. Can J Fish Aquat Sci. 71(2):315–325. doi:10.1139/cjfas-2013-0451.

Garn HS, Elder JF, Robertson DM. 2003. Why study lakes? An overview of USGS lake studies in Wisconsin. US Geological Survey. [accessed 2018 Sept 24]. https://pubs.usgs.gov/fs/fs06303/pdf/fs-063-03.pdf.

Gilbert SJ, Sass GG. 2016. Trends in a northern Wisconsin muskellunge fishery: results from a countywide angling contest, 1964–2010. Fish Manag Ecol. 23(2):172–176. doi:10.1111/fme.12170.

Hamilton DP, Magee MR, Wu CH, Kratz TK. 2018. Ice cover and thermal regime in a dimictic seepage lake under climate change. Inland Waters. 8:381–398. doi:10.1080/20442041.2018.1505372.

Hansen GJA, Carpenter SR, Gaeta JW, Hennessy JM, Vander Zanden MJ. 2015. Predicting walleye recruitment as a tool for prioritizing management actions. Can J Fish Aquat Sci. 72(5):661–672. doi:10.1139/cjfas-2014-0513.

Hansen GJA, Midway SR, Wagner T. 2018. Walleye recruitment success is less resilient to warming water temperatures in lakes with abundant largemouth bass populations. Can J Fish Aquat Sci. 75(1):106–115. doi:10.1139/cjfas-2016-0249.

Hansen GJA, Read JS, Hansen JF, Winslow LA. 2017. Projected shifts in fish species dominance in Wisconsin lakes under climate change. Glob Change Biol. 23(4):1463–1476. doi:10.1111/gcb.13462.

Hansen JF, Sass GG, Gaeta JW, Hansen GA, Isermann DA, Lyons J, Zanden JV. 2015. Largemouth bass management in Wisconsin: intraspecific and interspecific implications of abundance increases. Am Fisheries Soc Symp. 82:193–206.

Hanson PC, Johnson TB, Schindler DE, Kitchell JF. 1997. Fish bioenergetics 3.0. Madison (WI): University of Wisconsin Sea Grant Institute.

Hansson L-A, Nicolle A, Granéli W, Hallgren P, Kritzberg E, Persson A, Björk J, Nilsson PA, Brönmark C. 2013. Food-chain length alters community responses to global change in aquatic systems. Nature Clim Change. 3(3):228.

Havel JE, Kovalenko KE, Thomaz SM, Amalfitano S, Kats LB. 2015. Aquatic invasive species: challenges for the future. Hydrobiologia. 750(1):147–170. doi:10.1007/s10750-014-2166-0.

Hein CL, Ohlund G, Englund G. 2013. Fish introductions reveal the temperature dependence of species interactions. Proc R Soc B. 281(1775): 2641. doi:10.1098/rspb.2013.2641.

Heino J, Virkkala R, Toivonen H. 2009. Climate change and freshwater biodiversity: detected patterns, future trends and adaptations in northern regions. Biological Reviews. 84(1):39–54. doi:10.1111/j.1469-185X.2008.00060.x.

Herb WR, Johnson LB, Jacobson PC, Stefan HG. 2014. Projecting cold-water fish habitat in lakes of the glacial lakes region under changing land use and climate regimes. Can J Fish Aquat Sci. 71(9):1334–1348. doi:10.1139/cjfas-2013-0535.

Hill JE, Tuckett QM, Hardin S, Lawson LL, Lawson KM, Ritch JL, Partridge L. 2017. Risk screen of freshwater tropical ornamental fishes for the conterminous United

States. Trans Am Fisheries Soc. 146(5):927–938. doi:10.1080/00028487.2017.1312523.

Hintz WD, Mattes BM, Schuler MS, Jones DK, Stoler AB, Lind L, Relyea RA. 2017. Salinization triggers a trophic cascade in experimental freshwater communities with varying food-chain length. Ecol Appl. 27(3):833–844. doi:10.1002/eap.1487.

Ho L, Sawade E, Newcombe G. 2012. Biological treatment options for cyanobacteria metabolite removal: a review. Water Res. 46(5):1536–1548. doi:10.1016/j.watres.2011.11.018.

Honsey AE, Donabauer SB, Höök TO. 2016. An analysis of lake morphometric and land-use characteristics that promote persistence of cisco in Indiana. Trans Am Fisheries Soc. 145(2):363–373. doi:10.1080/00028487.2015.1125949.

Houston JR. 2008. The economic value of beaches - a 2008 update. Shore Beach. 76(3):22–26.

Howeth JG, Gantz CA, Angermeier PL, Frimpong EA, Hoff MH, Keller RP, Mandrak NE, Marchetti MP, Olden JD, Romagosa CM, et al. 2016. Predicting invasiveness of species in trade: climate match, trophic guild and fecundity influence establishment and impact of non-native freshwater fishes. Diversity Distrib. 22(2):148–160. doi:10.1111/ddi.12391.

Jacobson PC, Fang X, Stefan HG, Pereira DL. 2013. Protecting cisco (*Coregonus artedi* Leseur) oxythermal habitat from climate change: building resilience in deep lakes using a landscape approach. Adv Limnol. 64:323–332. doi:10.1127/1612-166X/2013/0064-0005.

Jacobson PC, Jones TS, Rivers P, Pereira DL. 2008. Field estimation of a lethal oxythermal niche boundary for adult ciscoes in Minnesota lakes. Trans Am Fisheries Soc. 137(5):1464–1474. doi:10.1577/T07-148.1.

Jeppesen E, Moss B, Bennion H, Carvalho L, DeMeester L, Feuchtmayr H, Friberg N, Gessner MO, Hefting M, Lauridsen TL, et al. 2010. Interaction of climate change and eutrophication. In: Kernan M, Battarbee RW, Moss B, editors. Climate change impacts on freshwater ecosystems. Hoboken (NJ): Wiley-Blackwell. p. 119–151.

Kernan MR, Battarbee RW, Moss B, (eds). 2010. Climate change impacts on freshwater ecosystems. Hoboken (NJ): Wiley-Blackwell.

Kitchell JF, Stewart DJ, Weininger D. 1977. Applications of a bioenergetics model to yellow perch (*Perca flavescens*) and walleye (*Stizostedion vitreum vitreum*). J Fish Res Bd Can. 34(10):1922–1935. doi:10.1139/f77-258.

Kleinheinz GT, McDermott CM, Hughes S, Brown A. 2009. Effects of rainfall on *E. coli* concentrations at Door County, Wisconsin beaches. Int J Microbiol. 2009:876050. doi:10.1155/2009/876050.

Koop T. 2014. The PPQ weed risk assessment: introduction and overview. Milwaukee (WI): UW Sea Grant. p. 22

Lansford NH, Jones LL. 1995. Recreational and aesthetic value of water using hedonic price analysis. J Agri Resource Econ. 20(2):341–355.

Lathrop RC, Carpenter SR, Stow CA, Soranno PA, Panuska JC. 1998. Phosphorus loading reductions needed to control blue-green algal blooms in Lake Mendota. Can J Fish Aquat Sci. 55(5):1169–1178. doi:10.1139/f97-317.

Lawson ZJ, Vander Zanden MJ, Smith CA, Heald E, Hrabik TR, Carpenter SR. 2015. Experimental mixing of a north-temperate lake: testing the thermal limits of a cold-water invasive fish. Can J Fish Aquat Sci. 72(6):926–937. doi:10.1139/cjfas-2014-0346.

Lefevre S, McKenzie DJ, Nilsson GE. 2017. Models projecting the fate of fish populations under climate change need to be based on valid physiological mechanisms. Glob Change Biol. 23(9):3449–3459. doi:10.1111/gcb.13652.

Leira M, Cantonati M. 2008. Effects of water-level fluctuations on lakes: an annotated bibliography. Hydrobiologia. 613(1):171–184. doi:10.1007/s10750-008-9465-2.

Lisi PJ, Hein CL. 2019. Eutrophication drives divergent water clarity responses to decadal variation in lake level. Limnol Oceanogr. 64:S49–S59. doi:10.1002/lno.11095.

Lorenzen K. 2014. Understanding and managing enhancements: why fisheries scientists should care. J Fish Biol. 85(6):1807–1829. doi:10.1111/jfb.12573.

Lynch AJ, Myers BJE, Chu C, Eby LA, Falke JA, Kovach RP, Krabbenhoft TJ, Kwak TJ, Lyons J, Paukert CP, et al. 2016. Climate change effects on North American inland fish populations and assemblages. Fisheries. 41(7):346–361. doi:10.1080/03632415.2016.1186016.

Lyons J, Parks TP, Minahan KL, Ruesch AS. 2018. Evaluation of oxythermal metrics and benchmarks for the protection of cisco (*Coregonus artedi*) habitat quality and quantity in Wisconsin lakes. Can J Fish Aquat Sci. 75(4):600–608. doi:10.1139/cjfas-2017-0043.

Lyons J, Rypel AL, Rasmussen PW, Burzynski TE, Eggold BT, Myers JT, Paoli TJ, McIntyre PB. 2015. Trends in the reproductive phenology of two Great Lakes fishes. Trans Am Fisheries Soc. 144(6):1263–1274. doi:10.1080/00028487.2015.1082502.

Ma J, Hung H, Macdonald RW. 2016. The influence of global climate change on the environmental fate of persistent organic pollutants: a review with emphasis on the Northern Hemisphere and the Arctic as a receptor. Global Planet Change. 146:89–108. doi:10.1016/j.gloplacha.2016.09.011.

Magee MR, McIntyre PB, Hanson PC, Wu CH. 2019. Drivers and management implications of long-term cisco oxythermal habitat decline in Lake Mendota, WI. Environ Manage. 63(3):396–407. doi:10.1007/s00267-018-01134-7.

Magee MR, McIntyre PB, Wu CH. 2018. Modeling oxythermal stress for cool-water fishes in lakes using a cumulative dosage approach. Can J Fish Aquat Sci. 75(8):1303–1312. doi:10.1139/cjfas-2017-0260.

Magee MR, Wu CH. 2017. Response of water temperatures and stratification to changing climate in three lakes with different morphometry. Hydrol Earth Syst Sci. 21(12):6253–6274. doi:10.5194/hess-21-6253-2017.

Magnuson JJ, Crowder LB, Medvick PA. 1979. Temperature as an ecological resource. Am Zool. 19(1):331–343.

Magnuson JJ, Meisner JD, Hill DK. 1990. Potential changes in the thermal habitat of Great Lakes fish after global climate warming. Trans Am Fisheries Soc. 119(2):254–264. doi:10.1577/1548-8659(1990)119 < 0254:PCITTH.> 2.3.CO;2.

Magnuson JJ, Robertson DM, Benson BJ, et al. 2000. Historical trends in lake and river ice cover in the Northern Hemisphere. Science. 289(5485):1743–1746. doi:10.1126/science.289.5485.1743.

Millar CI, Stephenson NL, Stephens SL. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecol Appl. 17(8):2145–2151. doi:10.1890/06-1715.1.

Missaghi S, Hondzo M, Herb W. 2017. Prediction of lake water temperature, dissolved oxygen, and fish habitat under changing climate. Climatic Change. 141(4): 747–757. doi:10.1007/s10584-017-1916-1.

Morabito G, Rogora M, Austoni M, Ciampittiello M. 2018. Could the extreme meteorological events in Lake Maggiore watershed determine a climate-driven eutrophication process? Hydrobiologia. 824(1):163–175. doi:10.1007/s10750-018-3549-4.

Mosel KJ, Isermann DA, Hansen JF. 2015. Evaluation of daily creel and minimum length limits for black crappie and yellow perch in Wisconsin. North Am J Fisheries Manage. 35(1):1–13. doi:10.1080/02755947.2014.963752.

Mosley LM. 2015. Drought impacts on the water quality of freshwater systems; review and integration. Earth-Sci Rev. 140: 203–214. doi:10.1016/j.earscirev.2014.11.010.

O'Reilly CM, Sharma S, Gray DK, Hampton SE, Read JS, Rowley RJ, Schneider P, Lenters JD, McIntyre PB, Kraemer BM, et al. 2015. Rapid and highly variable warming of lake surface waters around the globe. Geophys Res Lett. 42(24):10773–10781. doi:10.1002/2015GL066235.

Osgood R. 2017. Inadequacy of best management practices for restoring eutrophic lakes in the United States: guidance for policy and practice. Inland Waters. 7(4): 401–407.

Paerl HW, Gardner WS, Havens KE, et al. 2016. Mitigating cyanobacterial harmful algal blooms in aquatic ecosystems impacted by climate change and anthropogenic nutrients. Harmful Algae. 54: 213–222. doi:10.1016/j.hal.2015.09.009.

Papeş M, Sällström M, Asplund TR, Vander Zanden MJ. 2011. Invasive species research to meet the needs of resource management and planning: management of invasive species. Conserv Biol. 25(5):867–872. doi:10.1111/j.1523-1739.2011.01714.x.

Paukert CP, Glazer BA, Hansen GJA, Irwin BJ, Jacobson PC, Kershner JL, Shuter BJ, Whitney JE, Lynch AJ. 2016. Adapting inland fisheries management to a changing climate. Fisheries. 41(7):374–384. doi:10.1080/03632415.2016.1185009.

Pörtner HO, Peck MA. 2010. Climate change effects on fishes and fisheries: towards a cause-and-effect understanding. J Fish Biol. 77(8):1745–1779. doi:10.1111/j.1095-8649.2010.02783.x.

Rahel FJ, Olden JD. 2008. Assessing the effects of climate change on aquatic invasive species. Conserv Biol. 22(3): 521–533. doi:10.1111/j.1523-1739.2008.00950.x.

Reimer JR, Wu CH, Sorsa KK. 2018. Water exclosure treatment system (WETS): an innovative device for minimizing beach closures. Sci Total Environ. 62:5809–5818. doi:10.1016/j.scitotenv.2017.12.330.

Rengefors K, Weyhenmeyer GA, Bloch I. 2012. Temperature as a driver for the expansion of the microalga Gonyostomum semen in Swedish lakes. Harmful Algae. 18:65–73. doi:10.1016/j.hal.2012.04.005.

Reynaud A, Lanzanova D. 2017. A global meta-analysis of the value of ecosystem services provided by lakes. Ecological Econom. 137:184–194. doi:10.1016/j.ecolecon.2017.03.001.

Robertson DM, Juckem PF, Dantoin ED, Winslow LA. 2018. Effects of water level and climate on the hydrodynamics and water quality of Anvil Lake, Wisconsin, a shallow seepage lake. Lake Reserv Manage. 34(3): 211–231.

Robertson DM, Rose WJ. 2011. Response in the trophic state of stratified lakes to changes in hydrology and water level: potential effects of climate change. J Water Climate Change. 2(1):1–18. doi:10.2166/wcc.2011.026.

Rose KC, Greb SR, Diebel M, Turner MG. 2017. Annual precipitation regulates spatial and temporal drivers of lake water clarity. Ecol Appl. 27(2):632–643. doi:10.1002/eap.1471.

Rose KC, Winslow LA, Read JS, Hansen G. 2016. Climate-induced warming of lakes can be either amplified or suppressed by trends in water clarity. Limnol Oceanogr Lett. 1:44–53. doi:10.1002/lol2.10027.

Sala OE, Chapin FS, III, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, et al. 2000. Global biodiversity scenarios for the year 2100. Science. 287(5459):1770–1774. doi:10.1126/science.287.5459.1770.

Sander HA, Polasky S. 2009. The value of views and open space: estimates from a hedonic pricing model for Ramsey County, Minnesota, USA. Land Use Policy. 26(3):837–845. doi:10.1016/j.landusepol.2008.10.009.

Sass GG, Rypel AL, Stafford JD. 2017. Inland fisheries habitat management: lessons learned from wildlife ecology and a proposal for change. Fisheries. 42(4):197–209. doi:10.1080/03632415.2017.1276344.

Semuels A. 2016. The graying of rural America. The Atlantic. [accessed 2018 Sept 24]. https://www.theatlantic.com/business/archive/2016/06/the-graying-of-rural-america/485159/.

Snortheim CA, Hanson PC, McMahon KD, et al. 2017. Meteorological drivers of hypolimnetic anoxia in a eutrophic, north temperate lake. Ecological Modelling. 34:339–353. doi:10.1016/j.ecolmodel.2016.10.014.

Soley C. 2016. Cyanobacteria abundance modeling: development and assessment of season-ahead forecasts to improve beach management on Lake Mendota [MS thesis]. Madison (WI): University of Wisconsin-Madison.

Swanston C, Brandt LA, Janowiak MK, Handler SD, Butler-Leopold P, Iverson L, Thompson III FR, Ontl TA, Shannon PD. 2018. Vulnerability of forests of the Midwest and Northeast United States to climate change. Climatic Change. 146(1-2):103–116. doi:10.1007/s10584-017-2065-2.

Swanston CW, Janowiak MK, Brandt LA, Butler PR, Handler SD, Shannon PD, Derby Lewis A, Hall K, Fahey RT, Scott L, et al. 2016. Forest adaptation resources: climate change tools and approaches for land managers. Gen. Tech. Rep. NRS-GTR-87-2. Newtown Square (PA): U.S. Department of Agriculture, Forest Service, Northern Research Station. [accessed 2019 Mar 13]. http://dx.doi.org/10.2737/NRS-GTR-87-2.

US Global Change Program. 2009. Global climate change impacts in the United States. Cambridge (UK): Cambridge University Press.

Van Zuiden TM, Chen MM, Stefanoff S, Lopez L, Sharma S. 2016. Projected impacts of climate change on three freshwater fishes and potential novel competitive interactions. Diversity Distrib. 22(5):603–614. doi:10.1111/ddi.12422.

Vander Zanden MJ, Hansen GJA, Latzka AW. 2017. A framework for evaluating heterogeneity and landscape-level impacts of non-native aquatic species. Ecosystems. 20(3):477–491. doi:10.1007/s10021-016-0102-z.

Vander Zanden MJ, Olden JD. 2008. A management framework for preventing the secondary spread of aquatic invasive species. Can J Fish Aquat Sci. 65(7):1512–1522. doi:10.1139/F08-099.

Varner J. 2014. Scientific outreach: toward effective public engagement with biological science. BioScience. 64(4): 333–340. doi:10.1093/biosci/biu021.

Walsh JR, Carpenter SR, Zanden M. 2016. Invasive species triggers a massive loss of ecosystem services through a trophic cascade. Proc Natl Acad Sci USA. 113(15): 4081–4085. doi:10.1073/pnas.1600366113.

Walsh JR, Lathrop RC, Vander Zanden MJ. 2017. Invasive invertebrate predator, Bythotrephes longimanus, reverses trophic cascade in a north-temperate lake. Limnol Oceanogr. 62(6):2498–2509. doi:10.1002/lno.10582.

Walsh JR, Pedersen EJ, Vander Zanden MJ. 2019. Detecting species at low densities: a new theoretical framework and an empirical test on an invasive zooplankton. Ecosphere. 9(11):e02475.

Walsh JR, Spear MJ, Shannon TP, et al. 2018. Using eDNA, sediment subfossils, and zooplankton nets to detect invasive spiny water flea (Bythotrephes longimanus). Biol Invasions. 21(2):377–389. doi:10.1007/s10530-018-1862-5.

Wantzen KM, Rothhaupt K-O, Mörtl M, Cantonati M, G.-Tóth L, Fischer P. 2008. Ecological effects of water-level fluctuations in lakes: an urgent issue. Hydrobiologia. 613(1):1–4. doi:10.1007/s10750-008-9466-1.

Watras CJ, Grande D, Latzka AW, Tate LS. 2018. Mercury trends and cycling in northern Wisconsin related to atmospheric and hydologic processes. Can J Fisheries Aqua Sci. 76(5):831–346. doi:10.1139/cjfas-2018-0157.

Watras CJ, Read JS, Holman KD, Liu Z, Song Y-Y, Watras AJ, Morgan S, Stanley EH. 2014. Decadal oscillation of lakes and aquifers in the upper Great Lakes region of North America: Hydroclimatic implications. Geophys Res Lett. 41(2):2013GL058679. doi:10.1002/2013GL058679.

Wheeler BW, White M, Stahl-Timmins W, Depledge MH. 2012. Does living by the coast improve health and well-being? Health Place. 18(5):1198–1201. doi:10.1016/j.healthplace.2012.06.015.

White MS, Xenopoulos MA, Metcalfe RA, Somers KM. 2010. On the role of natural water level fluctuation in structuring littoral benthic macroinvertebrate community composition in lakes. Limnol Oceanogr. 55(6):2275–2284. doi:10.4319/lo.2010.55.6.2275.

Whitney JE, Al-Chokhachy R, Bunnell DB, Caldwell CA, Cooke SJ, Eliason EJ, Rogers M, Lynch AJ, Paukert CP. 2016. Physiological basis of climate change impacts on North American inland fishes. Fisheries. 41(7):332–345. doi:10.1080/03632415.2016.1186656.

WICCI. 2011. Wisconsin's changing climate: impacts and adaptation. WICCI; 217p.

Wilhere GF, Atha JB, Quinn T, Tohver I, Helbrecht L. 2017. Incorporating climate change into culvert design in Washington State, USA. Ecol Eng. 10:467–479. doi:10.1016/j.ecoleng.2017.04.009.

Wilkinson AA. 2018. Abiotic mechanisms for cyanobacteria physiology and distribution in lakes: a multi-scale approach [Doctoral thesis]. Minneapolis (MN): University of Minnesota.

Winslow LA, Hansen GJA, Read JS, Notaro M. 2017. Large-scale modeled contemporary and future water temperature estimates for 10,774 Midwestern U.S. lakes. Sci Data. 4:170053. doi:10.1038/sdata.2017.53.

Wolf D, Georgic W, Klaiber HA. 2017. Reeling in the damages: harmful algal blooms' impact on Lake Erie's recreational fishing industry. J Environ Manage. 199:148–157. doi:10.1016/j.jenvman.2017.05.031.

Wolf D, Klaiber HA. 2017. Bloom and bust: toxic algae's impact on nearby property values. Ecological Econ. 135: 209–221. doi:10.1016/j.ecolecon.2016.12.007.

Working Group on Invasive Species and Climate Change. 2014. Bioinvasions in a changing world: a resource on invasive species-climate change interations for conservation and natural resource management. [accessed 2018 Sept 24]. https://bugwoodcloud.org/mura/naisn/assets/File/BioinvasionsDec2014.pdf.

Wynne TT, Stumpf RP, Tomlinson MC, et al. 2013. Evolution of a cyanobacterial bloom forecast system in western Lake Erie: development and initial evaluation. J Great Lakes Res. 39:90–99. doi:10.1016/j.jglr.2012.10.003.].

Yasarer LMW, Sturm BSM. 2016. Potential impacts of climate change on reservoir services and management approaches. Lake Reserv Manage. 32(1):13–26. doi:10.1080/10402381.2015.1107665.