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Commentary

Great Lakes: Science can keep them great

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ABSTRACT

The Laurentian Great Lakes are an invaluable natural and economic resource for two North American countries, but really the entire world. They are threatened by anthropogenic, climate and biotic stresses; and it is increasingly difficult to manage them due to the complexity of interactions among these different stressors. At the same time, funding for Great Lakes scientific research is decreasing and there are threats from the current US administration to decrease funding significantly in the near future. Now is not the time to move our understanding of these incredible ecosystems back in time. We call for implementing a science plan that addresses critical Great Lakes issues, including upgrading infrastructure (e.g. field stations and observing networks) and resolving current and emerging issues (e.g. harmful algal blooms, recurring bottom water hypoxia, invasive species, changing water levels and nutrient cycles) by strengthening NSF, NOAA and EPA support of basic and applied science in the Great Lakes.

> "*A lake is the landscape's most beautiful and expressive feature. It is the earth's eye*"
>
> [- Henry David Thoreau (1854).]

Pressing science and management issues in the Great Lakes

The five contiguous Laurentian Great Lakes of North America cover ~250,000 km^2 and contain about one fifth of all the liquid freshwater water on the surface of our planet constituting a vitally important natural resource (Beeton, 1984; Fig. 1). This largest body of freshwater on Earth supports 179 different species of fish with commercial harvests valued at over 300 million US dollars. Furthermore, the Great Lakes basin is home to over 40 million residents – providing drinking water, and attracting millions of tourists each year. The economies of the Great Lakes states surrounding the lakes represent the world's fourth largest global economy. Clearly, this is a resource of incalculable ecological and economic value to humanity at large. However, today, the Great Lake's vast freshwater resources are facing a myriad of anthropogenic and climate-driven stresses (Allan et al., 2013) which is made even more troubling as support for their study, protection, and restoration is dwindling. It is critical at this time that the Great Lakes community of scientists, managers and policy makers implement a science plan that addresses critical issues by setting up programs specific to understanding, addressing and resolving Great Lakes science and management issues, and allocation of resources to reflect the size, value and vulnerability of the Great Lakes system.

There are three main categories of stressors in the Great Lakes, 1) climate and changing climate, 2) direct anthropogenic stressors, and 3) biotic stressors (Fig. 2). The climate-driven category is particularly problematic because it often accentuates many of the other stressors, potentially pushing the ecosystem non-linearly towards tipping points (Scheffer et al., 2012). Important climate stressors on the lakes are increased temperatures, decreased ice duration, changing water levels, altered precipitation patterns and runoff timing and quantities, and increased duration of summer stratification with implications for hypoxia and nutrient regeneration from the sediments. Today, ecologists are being challenged to predict dynamic tipping points of ecosystems and shifting thresholds under a confluence of conditions where interactive effects play a key role (Scheffer et al., 2012; Costanza, 2017). How to study the interactive effects of multiple stressors that are contemporaneously acting on an ecosystem is no small challenge – but one that must be addressed.

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Fig. 1. Image of North America's Laurentian Great Lakes from space showing visible coastal phytoplankton blooms in lakes Michigan, Huron, Erie and Ontario (Credit: NASA). The World's largest freshwater resource is under intense anthropogenic stress from forces such as climate change, invasive species, pollution, and eutrophication as well as oligotrophication – and there is urgent need for bold commitments to its understanding, protection and conservation.

Many of the anthropogenic stressors are well-known and well-studied in lakes around the world, such as excessive runoff of nutrients from land into aquatic ecosystems leading to eutrophication, emergence of harmful algal blooms and hypoxia (HABs; Paerl and Huisman 2008; Michalak et al., 2013; Zhou et al., 2015), but the manifestations in large lakes can be very different from what has been observed in smaller lakes (Downing, 2010; Finlay et al., 2013). Some of these differences are related to their long residence times, but also the increased role of atmospheric deposition across large surface areas implies management of a very different kind of input that is not a direct terrestrial point-source. It is also worth noting that differences in atmospheric deposition of nutrients can lead to large stoichiometric imbalances, which many have noted in Lake Superior but are also problematic in other large lakes (Finlay et al., 2013; Sterner, 2011). A related 'chemical' stressor that has passed under the radar for the most part is increased salinization of lakes in the northern USA and Canada, largely due to road salt use (Dugan et al., 2017). Although concentrations in the Great Lakes are not yet problematic, the trends are of uniformly increasing concentrations of chloride (Chapra et al., 2012). Other important stressors in this category include: toxic contaminants, plastic pollution, watershed diversions, habitat loss (particularly wetlands), and shoreline development that degrade the ecosystem services provided by the Great Lakes system (Niemi et al., 2007; Eriksen et al., 2013; Cornwell et al., 2015).

Biotic stressors include changing food webs, invasive species, bottom water hypoxia, and HABs. In Lake Erie, HABs have been particularly disruptive and costly recently, most visibly during the 2014 shutdown of the Toledo water supply (Michalak et al., 2013). The increased HABs are also coincident with record-setting bottom water hypoxia (Zhou et al., 2015). An important aspect of all of these stressors is that many of them interact with each other and, particularly in large lakes, these interactions develop over longer time scales that make it difficult to decipher the causes, effects and most importantly, the outcomes of such interactions. For instance, zebra mussels and quagga mussels have had an extremely disruptive effect on ecological and biogeochemical

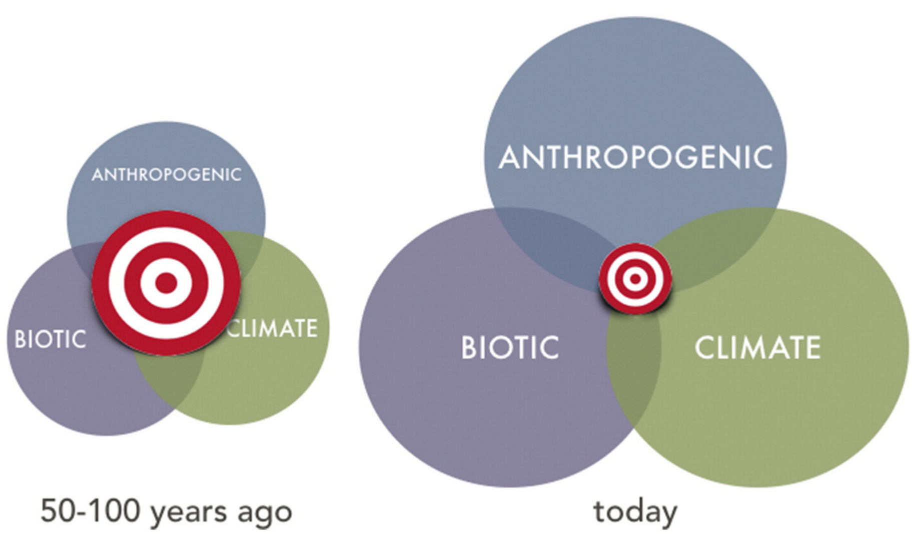

Fig. 2. Schematic diagram of the interactive role of climate and anthropogenic stressors on biotic integrity of the Great Lakes system that make their management ever more challenging (depicted here by the decreasing target size of the management "sweet spot" over time) as both the scale and intensity of stressor interactions are escalating due to the combination of rapidly changing climate and increasing human activity.

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