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Green Bay, Lake Michigan: A proving ground for Great Lakes restoration

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ABSTRACT

Green Bay has sometimes been referred to as the largest freshwater "estuary" in the world. Its watershed, much of it in intensive agriculture, comprises one-third of the Lake Michigan basin and delivers one-third of the lake's total phosphorus load. At one time, the major tributary, the Fox River, was considered the most heavily industrialized river in North America, primarily from paper manufacturing. Deterioration in water quality and the loss of beneficial and ecological uses have been extensive and began well back into the last century. More recently, the bay has also become a test case for our resolve to remediate and restore ecosystems throughout the Great Lakes and elsewhere. Green Bay has stimulated a significant amount of widely relevant research on the fate and behavior of toxics, biogeochemistry, habitat, biodiversity, and ecological processes. The bay represents a true "proving ground" for adaptive restoration. Key findings of the recent summit on the Ecological and Socio-Economic Tradeoffs of Restoration in the Green Bay Ecosystem are summarized here. Foremost among recommendations of the workshop was the creation of a "Green Bay Ecosystem Simulation and Data Consortium" serving as a data clearing house, building upon the significant progress to date, and developing a modeling framework and visualization tools, furthering public outreach efforts, and ensuring a sustained growth in scientific expertise. Funding was estimated to be on the order of ~$15–20M over the next ~5 years – a modest investment relative to the value of the ecosystem and the long-term cost of inaction.

In many ways, Green Bay represents a model mesocosm of all the environmental stressors that have disrupted Great Lakes ecosystems for more than a century, and that still confound their recovery and management today. This is reflected, in part, in the lower bay's designation by the IJC as an Area of Concern with 13 of a possible 14 Beneficial Use Impairments (BUIs) present. But the existence of an impairment does not reflect the magnitude of the problem. Nearly every conceivable stress, from industrial toxins to soil erosion and nutrient runoff, from invasive species to excessive algal and cyanobacterial blooms, from hardened shorelines and filled wetlands, to loss of sub-lacustrine habitat and extensive hypoxia, from dredge spoil disposal to increased storm erosion, from natural lake level fluctuations to climate change, have all impacted the Green Bay ecosystem to a significant degree over the last 100 years (H.J. Harris et al., this issue).

It is within the context of this complexity that Green Bay may represent one of our best "proving grounds" for testing our understanding, ability, and willingness to reverse decades of environmental mismanagement in the early part of the 20th century within the natural variability and the uncertainties of the future. Great progress has been made since the enactment of environmental legislation in the 1970s, and efforts for remediation continue: PCB clean up, the Cat Island barrier restoration, riparian wetland restoration, and nutrient abatement efforts. Today the bay and the lower Fox River show encouraging signs of recovery, yet complex challenges remain. For example, hypoxia is a persistent reoccurring feature during the summer stratified period (Klump et al., this issue) and the benthos has clearly suffered in terms of diversity and abundance (Kaster et al., this issue).

Because of the dominance of the Fox-Wolf watershed driving external inputs, coupled with its morphology and estuarine-like hydrodynamics, the waters of Green Bay exhibit a strong south-to-north progression in trophic conditions from hypereutrophic in the southern bay to meso- to oligotrophic conditions where it connects with the waters of Lake Michigan some 160 km to the north (e.g. Sager and Richman, 1991; Yurista et al., 2015). This has attracted research for decades, but particularly since the 1970s, when it became clear that, if we were going to fulfill the promise of the Clean Water Act, Green Bay would be ground zero for testing our resolve. Much of what we know today with respect to the fate of contaminants, for example, results from ground breaking work in Green Bay in the 1980s and 90s. H.J. Harris et al. (this issue) chronicle some of that history with the goal of understanding Green Bay in the context of what new insights,

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technologies, and models can be brought to bear as we go forward. Removal of long standing impairments and stresses will be neither quick nor easy nor without significant investment whose payoffs may accrue largely in the future. But we are at a point in the “Green Bay saga” where agreement over the need for remedial actions is becoming more widespread within user communities and the complementary need for linking economic tradeoffs of the value of ecological services against the costs of implementing management practices and regulatory controls, are both more widely recognized.

Pressure to show improvement and delist impairments is mounting throughout the Great Lakes, in no small measure, as a consequence of the investment of the Great Lakes Restoration Initiative. Delisting can be a relatively subjective assessment, neither black nor white. Howe et al. (this issue) outline an objective, transparent, adaptive methodology that provides a rational approach to delisting for 2 BUIs in the Green Bay system: “loss of fish and wildlife habitat” and “degradation of fish and wildlife populations” and is an example of the proving ground concept that has application region wide.

Green Bay is a data rich environment, in no small part due to the long-standing monitoring program launched in 1986 by the Green Bay Metropolitan Sewerage District (now NEW Water) (Kennedy, this issue; Qualls et al., 2013), including a 15-minute interval time series of temperature, conductivity and dissolved oxygen that has given clues as to the long-term existence and evolution of hypoxia in the bay (Klump et al., this issue). Since 2012 this data set has been augmented by the Great Lakes Observing System (glos.us) with a monitoring buoy (NOAA buoy 45014) deployed during the recreational season (May–October) that provides continuous water quality data and meteorological conditions in near real time for the southern bay. Such high-resolution temporal data expands our understanding of hourly to daily dynamics (see e.g. LaBuhn and Klump, 2016), and the ability to extend such high-resolution information into parameters like dissolved phosphate has resulted from the development of in situ sensors capable of unattended subhourly measurements (Zorn et al., this issue).

Gaps certainly exist, but the list of “unknown, unknowns” is generally considered to be contracting. The same cannot be said, perhaps, for unanticipated ripple effects of, for example, a new invasive. Merkle and DeStasio (this issue) and DeStasio et al. (this issue) chronicle the impact of the invasive spiny water flea *Bythotrephes longimanus*, as well as the influence of dreissenid mussels in altering energy transfer in the lower bay's food web, phytoplankton and cyanobacterial abundances. Smith et al. (this issue) have tracked survival of the nonindigenous Asian clam *Corbicula fluminea* and the suggested role of winter conditions on overwintering. Monitoring invasives is challenging but, in the case of fish communities, B.S. Harris et al. (this issue) have employed an adaptive management approach of refining sampling gear and methods and report that no non-indigenous fishes previously unknown to the Great Lakes have been detected. Therefore, it is probably fair to say that the baseline data for building the essential models that allow projecting future conditions are generally available or obtainable with a relative modest investment in monitoring or study. One important exception is trophic transfer exchange dynamics, a complex dynamic for which our understanding appears to be lagging.

In July of 2017, the Cooperative Institute for Great Lakes Research (CIGLR), convened a 3-day workshop at the University of Wisconsin-Green Bay “The Summit on the Ecological and Socio-Economic Tradeoffs of Restoration in the Green Bay, Lake Michigan Ecosystem” (https://ciglr.seas.umich.edu/opportunities/summits-working-groups/green-bay-summit/) during which approximately 60 participants were tasked with an ambitious charge of considering the elements of a decadal scale research plan or framework that would identify and define:

1) Our current understanding and the gaps in this understanding, the filling of which will be needed for a lasting, cost effective and scientifically robust restoration strategy and plan.
2) The models that include the requisite complexities within the system sufficient to inform over simulation time frames greater than a year.
3) The means to assess whether currently recommended and future proposed management practices will be sufficient under a changing climate and the massive ongoing alterations in agriculture, urbanization, and development within the watershed.
4) The means to translate scientific information into a form that is useable by managers, policy-makers, and others and that will help gauge if we are “moving the needle” in improving water quality as well as ecosystem resiliency and sustainability, while simultaneously addressing economic benefits and costs across the entire system.

Ultimately, the goal is to forecast future conditions in the bay and determine which management practices and landscape-scale changes will provide the maximum benefits and over what time frame. This necessitates the conduct of the science necessary to reduce the uncertainties, to the extent possible, in the development of a linked model framework that integrates watershed management with the ecological and biogeochemical response of the bay.

The initial focus looked at key disciplinary areas as to the state of knowledge, gaps and monitoring needs. Although not all inclusive, a summary included the following:

1) Watershed modeling. Considerable progress has been made. Basin-wide SWAT model frameworks exist, but higher resolution of conditions and practices is needed, e.g. soil test P, manure and fertilizer application rates, better accounting of BMPs, inclusion of ephemeral gully erosion and drainage tile sub-models, and the addition of small watershed scale and farm scale agriculture models like the Agricultural Conservation Planning Framework (Tomer et al., 2013) and the Integrated Farm System Model (Rotz et al., 2016).
2) Biogeochemistry and hydrodynamics. Working, well verified hydrodynamic models and physical forcing mechanisms (Bravo et al., 2017; Grunert et al., this issue) and the quantification of basic biogeochemical cycles are reasonably well developed for the bay (Klump et al., 2009; LaBuhn, 2016). Gaps include incorporation of wind-wave models and an understanding of resuspension and its role in carbon and phosphorus cycling, the delineation of diagenetic vs. rapid carbon remineralization and its influence on sediment and water column respiration, the role of denitrification and N-fixation in the overall N budget for the bay and its link to nutrient stoichiometry and phytoplankton and cyanobacterial production. Extending models to multiple year simulations, linking to refined watershed models and engaging a complete range of downscaled regional climate scenarios to assess the magnitude of projected variability for the 21st century are necessary to provide more robust projections and guide expectations for adaptive management efforts.
3) Ecosystem modeling and trophic dynamics. Gaps include the role of the nearshore environment (the “bathtub ring”) and inclusion of upper trophic levels, benthos and fish, and their response to hypoxia's variable extent and duration, HABs model forecasting and algal toxin production, energy transfer between wetlands and nearshore environments, and more specific process details on submerged aquatic vegetation management and restoration efforts.
4) Habitat and biodiversity. Questions raised included which sites could be restored successfully and what constitutes “restoration”. The need for comprehensive and long-term data sets for pre- and post-restoration were defined as essential for adaptive management in what are highly dynamic environments, e.g. submerged and emergent aquatic vegetation, the land-margin interface, and occupation by both resident and migratory species. Designing resilient and ecologically functional habitat restoration projects in the dynamic Green Bay system under changing climate forcings (e.g. variability in lake levels and extreme weather events) will benefit from

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