

# DRAFT Lake Huron Partnership Science and Monitoring Synthesis

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# DRAFT Lake Huron Partnership Cooperative Science and Monitoring Synthesis

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## 1

## Introduction

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The purpose of this report is to synthesize the scientific understanding and monitoring/research data on Lake Huron in preparation for the 2017 CSMI intensive study. It covers the main issues that have been highlighted over the past 10-15 years, so that decisions can be made regarding how to design the 2017 CSMI program to advance or knowledge on these issues.

### 1.1 Background

Several critical issues have been identified in Lake Huron, including contaminants in fish and wildlife, biodiversity and aquatic ecosystem changes in the food web structure, and fish and wildlife habitat conservation. Other issues such as the impacts of sustained low water levels (recently recovered), botulism, beach algal fouling and beach bacterial contamination are also of public concern and pose significant management challenges. The Lake Huron Partnership (LHP) works to prioritize and coordinate environmental activities in the Lake Huron basin and to meet the commitments of the Great Lakes Water Quality Agreement (GLWQA).

Under the 2012 amendment to the GLWQA, the government of Canada and the government of United States of America (the Parties) are committed to a shared vision of a healthy and prosperous Great Lakes region in which the waters of the Great Lakes, through their sound management, use, and enjoyment, provide benefits to present and future generations. To achieve the vision and purpose of the Agreement, the Parties agree to adopt and work to achieve general and specific objectives and commitments under the various Annexes.

The Lakewide Management Annex (Annex 2) contributes to the achievement of the Agreement's objectives by assessing the status of each Great Lake. Among other measures, the Parties, in cooperation and consultation with State and Provincial Governments, Tribal Governments, First Nations, Metis, Municipal Governments, watershed management agencies, other local public agencies, and the public agreed to undertake the following lakewide management actions:

- Assemble, assess and report on existing scientific information concerning the state of the waters including current and future potential threats to water quality;
- Identify research, monitoring and other science priorities for the assessment of current and future potential threats to water quality, and for the identification of priorities to support management actions;
- Conduct surveys, inventories, studies and outreach activities to support the above assessment; and
- Identify the need for further action by governments and the Public to address priority threats to water quality.

The Agreement's Science Annex (Annex 10) also enhances the coordination, integration, synthesis, and assessment of science activities, and the Parties are committed to undertake a review of available scientific



information to inform management actions, identify science priorities, and coordinate scientific efforts in support of the restoration and protection of the waters of the Great Lakes.

The Cooperative Science and Monitoring Initiative (CSMI) was created as the result of a need to coordinate binational science and research activities in support of management of the Great Lakes. The process includes enhanced monitoring and research field activities which are conducted in one lake per year on a five-year rotating cycle, tied to the needs of the Lakewide Action and Management Plan (LAMP) committees. Two years of intensive study on Lake Huron via CSMI have taken place in 2007 and 2012. In addition, annual science and monitoring activities have been conducted through U.S. and Canadian federal and provincial Great Lakes surveillance programs that ensure compliance with water quality objectives, evaluate water quality trends and identify emerging issues. Years of academic research and monitoring have also added to the understanding of the Lake Huron aquatic ecosystem.

To prepare for the 2017 year of intensive study, the Parties are committed to assemble, assess and report on existing scientific information concerning the state of the waters. It is hoped that the findings of this science synthesis will advance the understanding of science and monitoring activities for Lake Huron, call attention to information gaps and opportunities for additional science and monitoring, guide the development of science and monitoring in 2017, and provide current information for a Lakewide Action and Management Plan for Lake Huron and the St. Marys River.

## 1.2 Scope of Report

The scope of this report is to summarize and synthesize the science and monitoring work performed in the Lake Huron basin since that which was summarized in the synthesis report (LimnoTech, 2010) which was done in preparation for the 2012 CSMI program. This report also includes references to work before 2010, because some results prior to 2010 only became available in the 2010 to 2014 period. We have compiled over 200 citations of peer-reviewed papers, reports, presentations, and abstracts related to research and monitoring in the Lake Huron basin. This report focuses on a subset of those references to identify topics that may be relevant from a manager's standpoint. This report summarizes the state of those efforts, identifies key findings relative to Partnership issues, and suggests information gaps relative to the management questions the partnership has posed.

Section 2 of this report summarizes what was done during the 2010 synthesis report and presents major findings relative to management issues. Section 3 of this report synthesizes the research and monitoring conducted in Lake Huron over the past 4-5 years by topic area. Section 4 presents data gaps relative to the work conducted to date on the above management issues that were either identified by a research project or an individual agency. Section 5 will present any new or emerging issues in Lake Huron that have been raised over the past 5 years, including the questions posed by researchers or Partnership members relative to those issues.



## 2 Approach

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The material reviewed in this report was obtained in the following two ways:

1. Scientific findings and monitoring data from the Lake Huron CSMI program for 2012 was sought by contacting the international scientists and resource management agencies responsible for binational Lake Huron (Main Basin, North Channel, Georgian Bay, and St. Mary's River) programs, including federal, state, and provincial environmental water quality surveillance programs;
2. Conduct a literature search and compile citations of peer-reviewed papers, reports, presentations, and abstracts related to research and monitoring in the Lake Huron basin and complete an annotated bibliography.

We then attempted to summarize and synthesize the results of binational Lake Huron aquatic ecosystem research and monitoring studies to present the “state-of-the-lake” and long-term trends to the extent possible. Finally, based on the review of science and data we attempted to identify and suggest information gaps in science and monitoring and recommend actions required to address those gaps necessary to develop informed management approaches for the most pressing threats. It is anticipated that this analysis of knowledge and data will support decisions regarding the 2017 CSMI year on Lake Huron.



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## 3

## Summary of 2010 Synthesis Report

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In preparation for the Cooperative Science and Monitoring Initiative (CSMI) 2012 field year in Lake Huron, the Lake Huron Binational Partnership held a planning meeting in Tobermory, Ontario from October 4-6, 2010. The 2010 synthesis report (LimnoTech, 2010 – Appendix B) served as background for that meeting and a departure point for the participants to identify future management needs and to plan their activities for 2012 and over the next five years of the CSMI cycle.

The 2010 report summarized and attempted to synthesize, from a management perspective, the considerable science and monitoring work that has been conducted on Lake Huron over the 4-5 years, including the 2007 Lake Huron field year, prior to the report. That report included a synthesis of findings on contaminants in fish and wildlife, aquatic ecosystem structure and function, and aquatic habitat conditions.

While considerable information to support lake-wide management actions was acquired over the 10-15 years prior to the 2010 report, information gaps remained to be considered in planning science and monitoring activity for 2012 and beyond. Among them were:

- Information related to fish community dynamics in the nearshore waters of Lake Huron (excluding the major embayments);
- Understanding the relative contributions of invasive species and changes in phosphorus loadings to observations of increased eutrophication symptoms in the nearshore waters and a decrease in phosphorus levels and lower food web productivity in the offshore waters. This includes understanding the interactions between the nearshore and offshore waters of the lake; and resulting changes in ecosystem structure and function;
- More information from long term datasets on nearshore water quality are needed to determine if nearshore ( $\leq 20\text{m}$  depth) regions of the lake have indeed experienced significant water quality changes;
- Information is needed to help quantify and determine the controlling factors for over-winter survival of age-0 fishes;
- Understanding the feed forward and feedback process in the zooplankton community that links the lower and upper food webs in the system. This includes understanding the importance of invaders, such as Bythotrephes, in energy flow;
- Continued assessment of the forage community (benthos, zooplankton, prey fish) structure and function relative to the suite of environmental stressors on this system;
- Understanding the role that winter primary production plays in the fish carrying capacity of the lake and the potential for it to increase in response to climate change;
- With regard to legacy contaminants (PCBs, Hg, dioxin TEC), a major need is to understand how close the fish body burdens are to being at steady-state with the external loads of these chemicals. In other words, how significant is sediment feedback in controlling fish body burdens;
- With regard to emerging chemical, there is a significant gap in data regarding emerging chemicals (such as PBDE's, PFOS, and Pharmaceuticals and Personal Care Products) in Lake Huron water, sediments, and fish; and



- With regard to fish and wildlife habitat, there is insufficient information to assess the response of shoreline ecosystem habitats (especially riparian wetlands) in response to changes in water level regime (timing, magnitude, frequency, and duration of water level conditions on both a seasonal and decadal scale) that might occur as a function of water level regulation actions or as a function of climate induced changes.

Several emerging issues with respect to Lake Huron management and science were raised. One of the most talked about emerging issues was climate change, and research efforts should be directed at both making forecasts of future climate conditions as well as trying to understand the impacts of those changes in concert with other stressors (urbanization, deforestation, invasive species, etc.). Several studies were planned across the Great Lakes looking specifically at the issue of climate change in the context of ecosystem and societal impacts.

Several other research topics received attention in the 5-10 years prior to the 2010 synthesis report. Research related to the sinkholes in Lake Huron attempted to determine the importance of this recently discovered ecosystem as an emerging issue. The Great Lakes research community continued to identify more chemicals of emerging concern in Great Lakes waters. Recent chemicals of concern included polybrominated diphenyl ethers (PBDEs) and pharmaceutical and personal care products (PPCP). Others were bis-phenol-A (BPA), nanoparticles, phthalates, and other chemical additives.

With the recent drop in Great Lakes water levels and continued development on sensitive shoreline areas, the deterioration of shoreline habitat quantity and quality was raised as an emerging issue. The shoreline region is often home to many endangered species, including several bird species. It is also prone to invasion from non-native nuisance species, including such plants as phragmites. Many states, provinces, and communities are faced with issues of increased erosion, loss of wildlife and fish spawning habitats, and poor nearshore water quality. Agricultural practices and other nonpoint sources of pollution can also have a profound impact on the quality of shoreline areas.



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## 4

## Recent Research by Topic Area

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This section presents the major topic areas as identified in the literature.

### 4.1 Physical Processes

Understanding the physical processes of Lake Huron continues to be important to address fluctuating Great Lakes water levels and manage for the adverse effects of climate change. The International Joint Commission (IJC) established a bi-national study to evaluate water levels in the upper Great Lakes and the implications of management actions for regulating levels. Several research projects on physical processes have added to the understanding of the close linkage in water quality between Lake Michigan and Lake Huron (Chapra and Dolan, 2012; Chapra *et al.*, 2012a), hydrodynamics of Saginaw Bay (Nguyen *et al.*, 2014), and of hydrodynamic linkages between main lake, north channel, and Georgian Bay (Zhao *et al.*, 2011).

The International Upper Great Lakes Study (IUGLS) released a report in 2012 on water level uncertainty and possible regulation of water levels. An earlier report completed by IUGLS on the St. Clair River described a 23 cm water level drop from 1963 to 2006 between Lake Michigan-Huron and Lake Erie. The drop was attributed to change in conveyance, glacial isostatic adjustment, and changes in climate patterns (International Upper Great Lakes Study, 2009). A key finding in the second of the two reports was that although lake evaporation is increasing due to lack of ice cover and increasing surface water temperatures and wind speeds, increases in local precipitation in the Lake Michigan-Huron basin may offset the effects of higher evaporation (International Upper Great Lakes Study, 2009). The study also examined restoration of Lake Michigan-Huron water levels through restoration structures in the St. Clair River and concluded that although such a restoration would benefit multiple items (e.g. commercial navigation, recreational boating, Georgian Bay wetlands), it would adversely affect lake sturgeon spawning habitat, hydroelectric generation, Lake St. Clair fisheries, and could increase the number of occurrences of extreme high lake levels (International Upper Great Lakes Study, 2009).

Chapra *et al.* (2012b) examined long-term trends of water chemistry in the Great Lakes and found that Lake Huron had persistent increases in most major ions, such as chloride, sodium, sulfate and calcium. These trends were consistent with observations from Lake Superior and Lake Michigan, and were attributable to the long residence times of the lakes (Chapra *et al.*, 2012b). The concentrations of ions in Lake Huron were generally greater than those of Lake Superior and less than those of Lake Michigan, demonstrating the influence of both lakes, although Lake Huron's trends followed the trends of Lake Michigan more closely (Chapra *et al.*, 2012b).

Zhao *et al.* (2011) used a nested-grid hydrodynamic model to study circulation and dispersion patterns in Lake Huron. Among the findings were a greater hydrodynamic connectivity within the main lake was greater than that of the North Channel or the Georgian Bay. Though the model should just serve as a basis to fully understanding connectivity within Lake Huron, it has the potential to be combined with ecological models to examine connectivity among aquatic lake communities (Zhao *et al.*, 2011).





A three-dimensional, unstructured grid hydrodynamic model was used to examine several physical processes of the Saginaw Bay-Lake Huron system (Nguyen *et al.*, 2014; Nguyen, 2014). The model was able to replicate observed currents, temperatures, and ice cover reasonably well, and can be used to simulate summer and winter circulation patterns, thermal structure, and residence times in Saginaw Bay. It was used to compute 2009-2011 average flushing times of 23 days and 9.9 days for the inner bay and entire bay, respectively, for the summer season, and of 43 days and 15.6 days for the inner bay and entire bay, respectively, for the winter season (Nguyen *et al.*, 2014; Nguyen, 2014).

## 4.2 Zooplankton

The research presented below adds to the understanding of various species in the Lake Huron zooplankton community and recent shifts in community structure. Although some of the researchers point to reasons for the shifts such as introduction of invasive species, increasing oligotrophic conditions in Lake Huron, and loss of coastal wetland habitat, others suggest the mechanisms for certain dramatic shifts in the zooplankton community are still not that well understood.

Pothoven and Hook (2014) studied the roles of *Bythotrephes* and *Leptodora* in Saginaw Bay food webs and found that *Bythotrephes*, and invasive species, has the capacity for a larger impact on zooplankton than the native *Leptodora*. The authors also concluded that *Bythotrephes* should be accounted for when evaluating food webs and energy flow in the Laurentian Great Lakes due to the potentially important role it plays in zooplankton predation (Pothoven and Hook, 2014).

Work completed by Jackson *et al.* (2013) suggests a previously developed length-weight regression model led to substantial underestimations of *Limnocalanus* biomass in other literature. The authors also presented two hypotheses for recent rises in *Limnocalanus* populations in Lake Huron. One suggests that the increase in hypolimnetic primary production in the lake provided opportunity for the zooplankton to adopt a more herbivorous diet. The other hypothesis suggests hypolimnetic diaptomids may have adopted a more herbivorous diet, lowering its trophic position, and *Limnocalanus* is relying on *Diaptomus* as a food source (Jackson *et al.*, 2013).

The increase in oligotrophic conditions in Lake Huron were also hypothesized by Barbiero *et al.* (2012) to have contributed to the convergence of the trophic state and the lower food web.

Bunnell *et al.* (2012) reported on seasonal dynamics of zooplankton communities in Lake Huron between the mid-1980s and 2007, and confirmed the findings of previous studies (August only data) that significant changes to zooplankton community composition have occurred. Bunnell *et al.* (2014) later conducted a more comprehensive synthesis of time series trends across multiple trophic levels. Using correlation techniques, the trends in Lake Huron were more consistent with "bottom-up" regulation than "top-down", although they cautioned that additional mechanistic work would be required to more robustly test this hypothesis. The authors proposed research to better understand the mechanisms so that managers may comprehend whether changes are a short-term response or will stabilize at this new condition.

(Bunnell *et al.*, 2012; Bunnell *et al.*, 2014).

Pothoven *et al.* (2012) investigated life-history characteristics of *Bythotrephes longimanus* in the Great Lakes. Organisms in Lake Huron tended to have intermediate life-history characteristics to lakes Michigan and Erie, and the plasticity was attributed to differences in prey and predator densities. These differences were concluded to make it difficult to model the dynamics of the ecosystems properly, and that additional investigations are necessary to better understand implications of the plasticity (Pothoven *et al.*, 2012).

Cooper *et al.* (2012) commented on the importance of preventing further fragmentation and restoring contiguity of fragmented marshes in order to preserve and enhance the habitat provided to zooplankton, macroinvertebrates, and larval fishes. By studying coastal fringing wetlands in Lake Huron, the authors



concluded that because of edge effects, the impact of lost habitat is greater than the area that is actually lost. Maintaining contiguous marshes will result in a better protected inner core that provides refuge from hydrologic energy and open water predators (Cooper *et al.*, 2012).

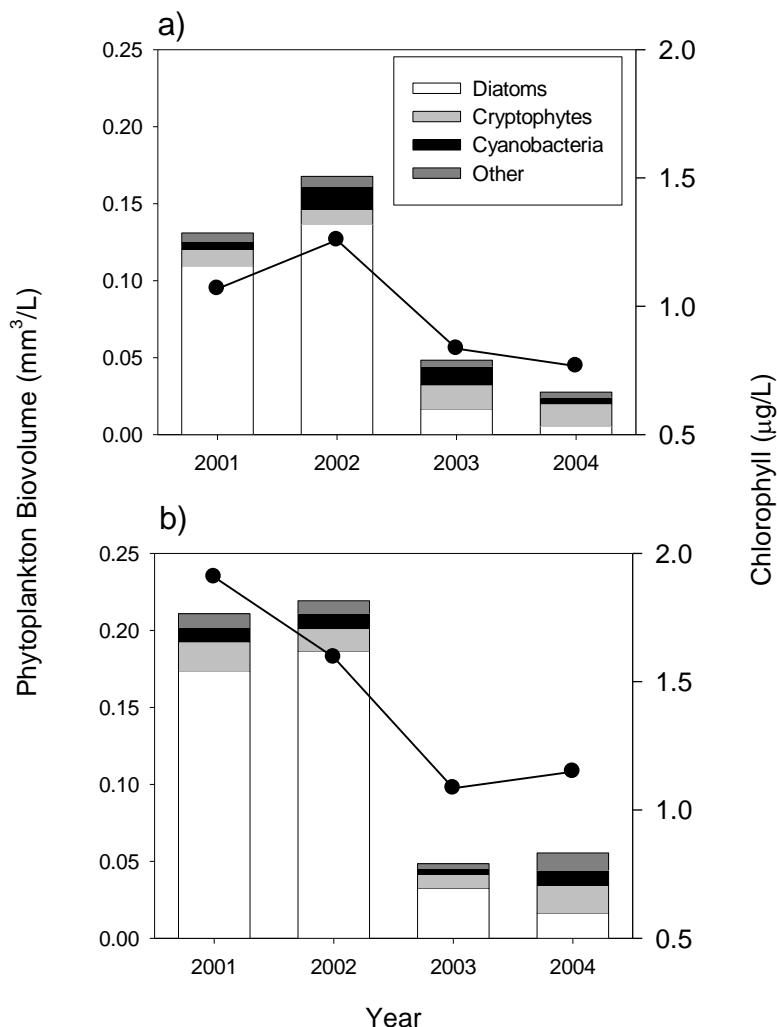
Another zooplankton species studied was *Hemimysis anomala*, a Ponto-Caspian crustacean species that recently invaded the Great Lakes (Questel *et al.*, 2012).

*Mysis diluviana* was studied in lakes Huron and Michigan in spring 2008 by Mida Hinder *et al.* (2012), and the populations in Lake Huron were possible starving, as indicated by lower total lipids and elevated concentrations of fatty acids relative to those sampled in Lake Michigan. The authors suggested further sampling to see if results are similar and to better understand why the species may be facing starvation in Lake Huron.

Barbiero & Warren (2011) synthesized a 24-year dataset (1983 to 2006) to examine relationships between environmental factors in the Great Lakes and changes in rotifer community composition. Among their findings were that decreases in *Keratella* dominance and increases in *Conochilus* dominance in Lake Huron were in agreement with the recent increase in the lake's oligotrophic conditions (Barbiero and Warren, 2011).

Barbiero *et al.* (2011) concluded a reduced food supply was responsible for shifts in the Lake Huron crustacean zooplankton community since 2003 by examining several datasets, including estimates of May chlorophyll from SeaWiFS imagery, estimates of April phytoplankton biovolumes, and *Daphnia* egg ratios. Chlorophyll values estimated for May for 2003-2006 were only 50 to 60% of values estimated for 1998-2002. A plot of the chlorophyll (SeaWiFS) and phytoplankton biomass by major taxa group is shown below in Figure 1. Also showing a pronounced change were *Daphnia* egg ratios in the southern basin of Lake Huron, which dropped from 0.79 to 0.43 eggs per individual from 2002 to 2003, respectively (Barbiero *et al.*, 2011).





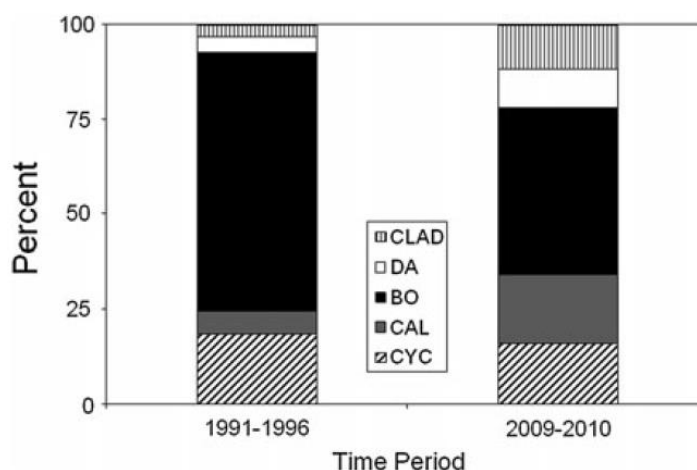
**Figure 1. Spring phytoplankton biovolume and corresponding SeaWiFS estimated chlorophyll for the (a) northern, and (b) southern basins of Lake Huron, 2001-2004, from (Barbiero *et al.*, 2011)**

The crustacean zooplankton community of the St. Marys River was examined under joint funding by the USEPA and Lake Superior State University's Aquatic Research Laboratory (Turschak *et al.*, 2011). Dramatic changes in the zooplankton community included decreases in the relative densities of calanoid copepods and daphnids and increases in cyclopoid copepods and bosminids. *Leptodora kindti*, once a relatively abundant species in nearshore areas and coastal wetlands, was absent from recent samples. The authors suggested that the establishment of *Bythotrephes* and changes in vertebrate planktivory were more likely causes for the zooplankton community shifts, as opposed to bottom-up factors (Turschak *et al.*, 2011).

A study that sought to examine whether excessive predation by fish and invertebrates caused declines in cladoceran and cyclopoid copepod biomass concluded *Bythotrephes* planktivory as the most dominant factor in structuring the zooplankton communities (Bunnell *et al.*, 2011). One of the important findings of this research was that invertebrates (*Bythotrephes* and *Mysis*) consumed far more zooplankton than fish in northern Lake Huron waters in 2007 (Bunnell *et al.*, 2011). Another important finding was that zooplankton consumption in July through October by planktivores exceeded production by zooplankton in each month, which suggests the important role of invertebrates may have played in changing the Lake Huron zooplankton community (Bunnell *et al.*, 2011).



Pothoven et al. (2013) examined the role of the disappearance of the invasive alewife *Alosa pseudoharengus* in zooplankton community change between 1991-1996 and 2009-2010 datasets in Saginaw Bay. Figure 2 illustrates the composition of zooplankton communities between the two time periods. The authors concluded alewife disappearance in Saginaw Bay influenced zooplankton through both direct (release from predation) and indirect pathways, such as an increase in age-0 yellow perch resulting in greater predation of large zooplankton prey or increasing abundance of planktivores that feed on smaller zooplankton prey (Pothoven *et al.*, 2013).



**Figure 2. Percent composition of zooplankton community between two time periods in Saginaw Bay. CYC cyclopoid copepods, CAL calanoid copepods, BO Bosminidae, DA Daphnia spp., CLAD = other Cladocerans (Pothoven et al., 2013)**

In summary, Jackson et al. (2013) suggested that rises in *Limnocalanus* populations in Lake Huron are either because the zooplankton has adopted a more herbivorous diet, or it is using *Diaptomus* as a new food source. Pothoven and Hook (2014) found that the invasive *Bythotrephes* plays an important role in zooplankton predation in Saginaw Bay and should be accounted for when evaluating Great Lakes food webs and energy flows. Pothoven et al. (2013) also found alewife disappearance in Saginaw Bay influenced zooplankton through both direct (release from predation) and indirect pathways. Bunnell et al. (Bunnell *et al.*, 2011) found invertebrates may have played a role in changing the Lake Huron zooplankton community through consumption in excess of zooplankton production in July through October. Finally, Barbiero & Warren (2011) concluded that changes in rotifer community composition between 1983-2006 were consistent with the recent increase in Lake Huron's oligotrophic conditions.

### 4.3 Toxics

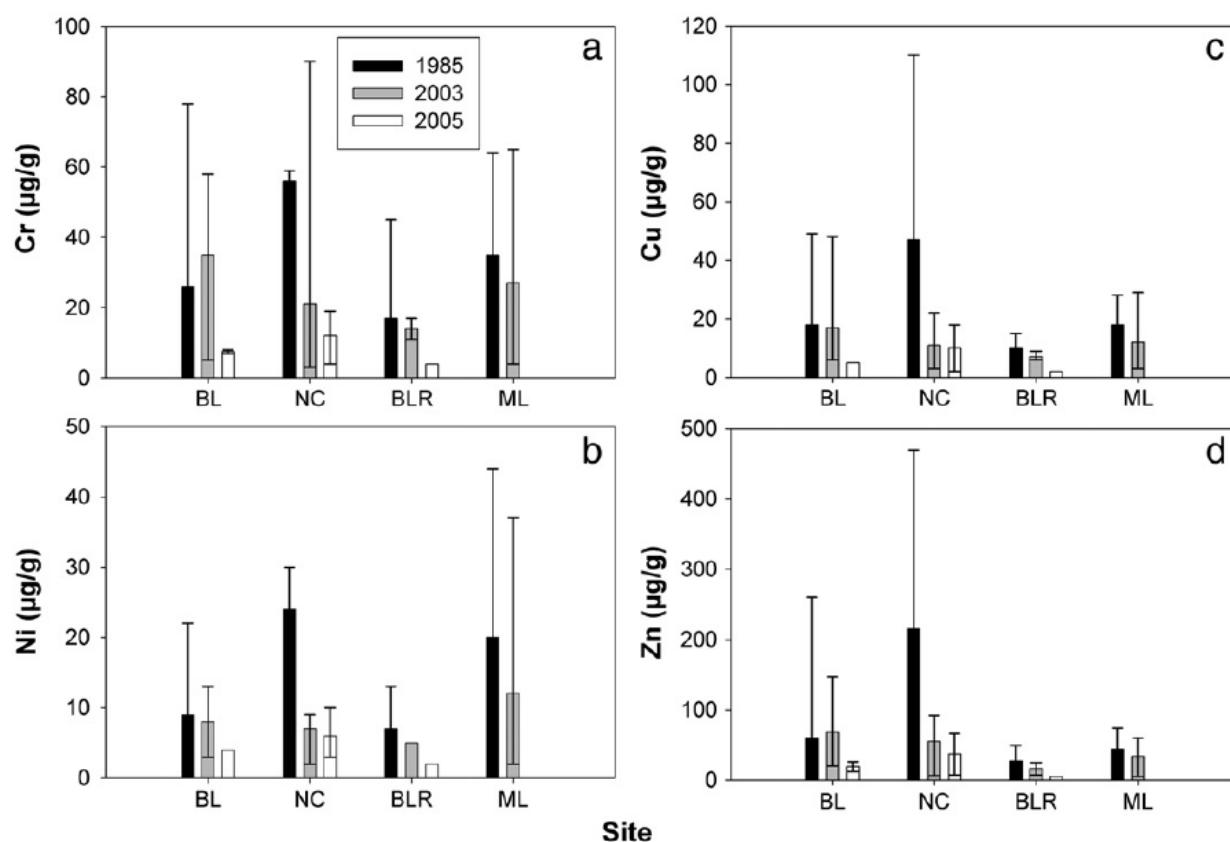
Some mitigation of toxic substances in Lake Huron has been evident, such as the decline in concentrations of several metals in St Marys River sediments reported by Keller et al. (2011) and declining fish tissue PCB concentrations suggested by El-Shaarawi et al. (2011). Bioaccumulation of toxics such as mercury (Abma *et al.*, 2014; Omara *et al.*, 2015) and hexaBB (Lim and Lastoskie, 2011) in fish tissue will continue to be a concern well into the future.

Soonthornnonda et al. (2011) analyzed PCB concentrations in Great Lakes sediments and found that Lake Huron had lower total PCB concentrations than lakes Erie, Ontario, and Michigan. Lake Huron had an average PCB concentration of about 20 ng/g after 1981. The authors used a positive matrix factorization model to quantify anaerobic dechlorination, and concluded that although Lake Huron sediments undergo dechlorination via the same reactions as Lake Ontario sediments, the rate of dechlorination is at a lower level due to the relatively lower PCB concentrations (Soonthornnonda *et al.*, 2011).



In a paper describing the environmental history of the St. Marys River, Ripley *et al.* (2011) commented on the navigational and industrial activities that impacted the area. The authors cited other studies that have found sediments with contamination or elevated levels of oil and grease, PAHs, wood fiber, cyanide, nutrients, and heavy metals. Some remediation of contaminated sediments has occurred in the past decade via dredging and removal, and plans for future removal are ongoing (Ripley *et al.*, 2011).

One of the studies referenced by Ripley *et al.* (2011) was a study of sediment quality in the St. Marys River Area of Concern by Keller *et al.* (2011) that reported on work completed in 2003 and 2005 to update sediment contamination data on the U.S. side of the river. Sampling results revealed that while concentrations of chromium, copper, nickel and zinc were elevated in the recent samples, the overall trend was a decline relative to measurements from 1985 (Figure 3) (Keller *et al.*, 2011).

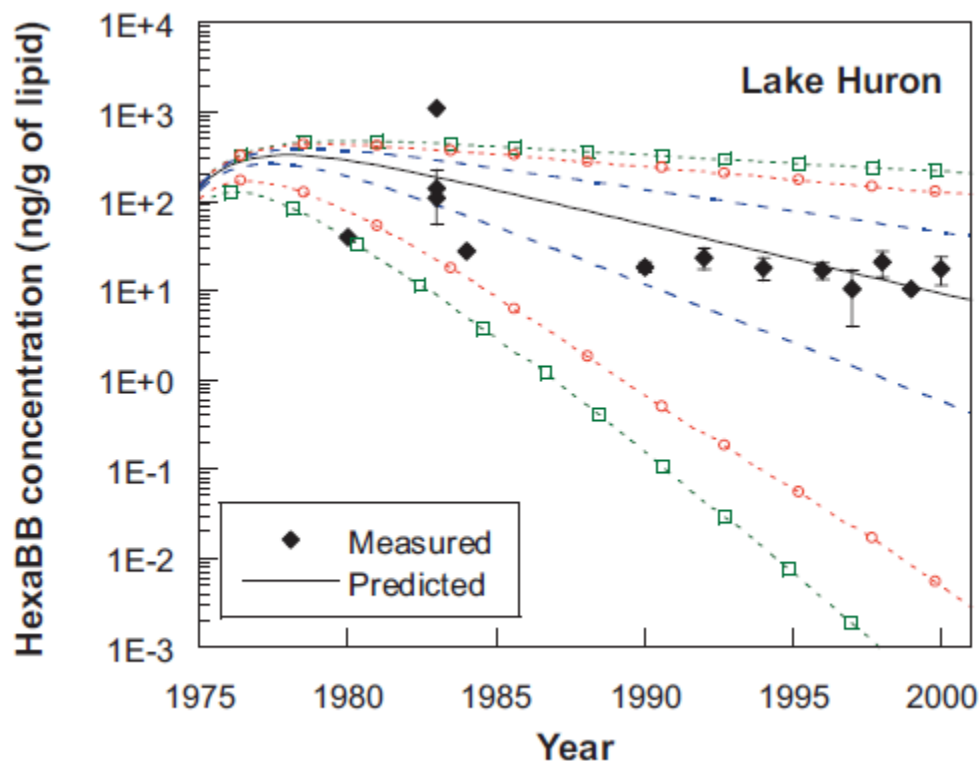


**Figure 3. Comparison of stations grouped by location within the St. Marys River systems sediments from below the locks (BL), the North Channel (NC), below the Little Rapids (BLR), and Munuscong Lake (ML) in 1985, 2003, and 2005. Bars show median concentrations and error bars encompass the full range of values measured at each site. All values are  $\mu\text{g/g}$  dry weight. For each site, in 1985, 2003, and 2005, respectively,  $n = 5, 4, 2$  (BL);  $4, 3, 2$  (NC);  $8, 2, 1$  (BLR);  $8, 20, 0$  (ML) (Keller *et al.*, 2011)**

El-Shaarawi *et al.* (2011) used parametric log-location-scale regression models to examine temporal and spatial changes in PCB levels in Lake Huron fish tissue. The authors found that fish tissue PCB concentrations are on the decline, with acceleration in decline beginning around 1996. Modeling results also suggested lower PCB concentrations in fish in upper Lake Huron and Georgian Bay compared to southern areas of the lake (El-Shaarawi *et al.*, 2011).

A fugacity-based dynamic environmental and bioaccumulation model was used to examine fate of hexabromobiphenyl (hexaBB), a brominated flame retardant, in Saginaw Bay and Lake Huron (Lim and

Lastoskie, 2011). Model results suggested lake sediments accumulate and slowly release hexaBB into food web constituents. A comparison of the bioaccumulation model results and measured hexaBB concentrations in lake trout is shown in Figure 4.



**Figure 4. Comparison of measured and predicted hexabromobiphenyl (hexaBB) concentrations of lake trout in Lake Huron, showing 5th and 95th percentiles of the predicted values with confidence factors of 2 (dashed lines), 5 (dashed lines with open circles), and 10 (dashed lines with open squares). The error bars in the measured data represent standard deviations (Lim and Lastoskie, 2011).**

Abma et al. (2014) compared mercury concentrations in lake trout fish tissue from specimens of varying age class and geographic location within the lake. The highest concentrations were found in fish collected in the main basin of Lake Huron ( $0.19 \pm 0.01$  mg/kg), followed by those from Georgian Bay ( $.15 \pm 0.02$  mg/kg), and then the North Channel ( $0.07 \pm <0.01$  mg/kg) (Abma *et al.*, 2014). Some significant relationships were determined between age-related increases in mercury bioaccumulation, including the greatest age-related mercury increases in fish in Georgian Bay. The authors also suggested that factors associated with food acquisition and foraging efficiency are important in explaining mercury accumulation (Abma *et al.*, 2014). Dove et al. (2012) presented analytical results for mercury for offshore waters collected using clean sampling methods that had not been employed previously. This study showed very low concentrations present in offshore waters of Lake Huron and most other Great Lakes. Recent modeling results and comparison with field data for mercury deposition complement these results (Cohen et al., 2013).

In summary, some mitigation of toxic substances in Lake Huron was evident, such as the decline in concentrations of several metals in St Marys River sediments reported by Keller et al. (2011) and declining fish tissue PCB concentrations suggested by El-Shaarawi et al. (2011). Bioaccumulation of toxics such as

mercury (Abma *et al.*, 2014) and hexaBB (Lim and Lastoskie, 2011) in fish tissue will continue to be a concern well into the future (Omara *et al.*, 2015; McLeod and Mayne, 2015).

#### 4.4 Harmful Algal Blooms

Millie *et al.* (2011) used phytoplankton sampling results from 1990-1996 for the inner and outer bays of Saginaw Bay to characterize and model Microcystic biovolumes. The research included quantifying differences in biomass between the inner and outer bays, examining changes during and after the invasion of Dreissenid mussels, and relationships between Microcystis distribution and environmental variables such as total phosphorus concentrations (Millie *et al.*, 2011).

Cyanobacterial blooms occur in some nearshore areas and embayments of eastern Georgian Bay. Cyanobacteria blooms are particularly severe in the north basin of Sturgeon Bay where phosphorus concentrations are regionally high and areas of deeper water experience low levels of dissolved oxygen. Blooms are attributed to multiple factors including: a lack of circulation and flushing with Georgian Bay waters; land runoff; septic inputs; wetland drainage; tributary phosphorus loading, and resuspension of internal phosphorus from bottom sediment (Charlton and Mayne, 2014). The principal areas for future investigation to better understand the problem in Sturgeon Bay and other sheltered embayments consist of bathymetric mapping, characterizing and quantifying bottom sediment volume, source tracking of phosphorus (tributaries, wetlands, septic discharge), understanding the role of hypolimnetic dissolved oxygen and internal phosphorus loading, the interaction of iron on the structure and biomass of cyanobacteria populations, and integrative modeling (Charlton and Mayne, 2014).

#### 4.5 Benthos

Recent research by Schloesser *et al.* (2014) and Siersma *et al.* (2014) indicates burrowing mayfly nymphs are recovering in Saginaw Bay, though current densities are lower than historic levels before the decline in the 1960s. Tang *et al.* (2014) found that selective rejection by quagga mussels likely promotes Microcystis blooms in Saginaw Bay. Barbiero *et al.* (2012) found that the non-Dreissenid benthos abundance at deep locations in Lake Huron declined between 1997-2007, largely because of the reduction in *Diporeia*.

Craig Stow of NOAA GLERL contributed an editorial to JGRL on the health of the Saginaw Bay ecosystem as an introduction to a special issue on the effects of multiple stressors. The article alluded to several papers referenced within this issue on Dreissenid mussels, the contribution of decaying Cladophora to beach muck, phosphorus loading to the bay, and invasive species (Stow, 2014).

Lavrentyev *et al.* (2014) studied microzooplankton distribution, dynamics, and trophic interactions relative to phytoplankton and quagga mussels in Saginaw Bay which included field sampling in 2008. Microzooplankton were found to be variable both spatially and temporally, with ciliates and rotifers composing the majority of the biomass at 45% and 35%, respectively. Ciliate biomass was most dominant in the spring and early summer, while Rotifers and dinoflagellates increased in late summer and fall (Lavrentyev *et al.*, 2014). Although microzooplankton comprised <4% of available prey for quagga mussels, they contributed 77% to the quagga carbon-based diet during Microcystis blooms, suggesting feeding on microzooplankton by quaggas during noxious cyanobacterial blooms could be an important resource during lean periods (Lavrentyev *et al.*, 2014).

Schloesser *et al.* (2014) used occurrence of mandibular tusks and radionuclides in Saginaw Bay sediments and other historical records to construct a 200-year chronologic record of the abundance of burrowing mayflies (*Hexagenia* spp.). The chronology compiled by the authors suggests an increase in mayflies between 1799 and 1807, relatively high levels between 1807 and 1965, a rapid decline between 1965 and 1973, relatively low levels between 1973 and 2001, and a likely mayfly recovery in the past decade (Schloesser *et al.*, 2014). Excessive eutrophication in the 1950s and 1960s was attributed to the dramatic





decline, and the current mayfly recovery was attributed to several decades of pollution-abatement programs in the Saginaw Bay area (Schloesser *et al.*, 2014).

Siersma *et al.* (2014) also commented on the recent recovery of mayflies in the Saginaw Bay area through research that included sampling in 2009, 2010, and 2012. The overall *Hexagenia* density for these three years was 1.5 nymphs/m<sup>2</sup> with an overall presence at nearly 16% of sites sampled. Although the abundances, densities, and distributions reported were much lower than historical levels, the densities reported suggest *Hexagenia* presence in Saginaw Bay is increasing, as no single sampling effort has found >1.1 nymphs/m<sup>2</sup> across all sites since the 1950s (Table 1). This study also mapped bay sediment composition and suggested high sand percentages reported may pose a hindrance to a more rapid recovery of the species due to lack of suitable habitat (Siersma *et al.*, 2014).

**Table 1: *Hexagenia* distribution and abundance data from published surveys of Saginaw Bay conducted between 1954 and 2001 for which latitude and longitude data were available, and new data collected between 2009 and 2012 as part of the current study (Siersma *et al.*, 2014).**

Reference	Year of survey	Number of locations sampled	Sites with <i>Hexagenia</i> present		Total <i>Hexagenia</i> abundance (nymphs)	Mean <i>Hexagenia</i> density (nymphs/m <sup>2</sup> )	
			#	%		across sites with <i>Hexagenia</i> present	across all sites
Surber, 1954	1954	14*	9*	64*	n/a	n/a	66*
Surber, 1955	1955	19	8	42	n/a	150.7	63.5
Schneider <i>et al.</i> , 1969	1956	52	30	58	n/a	n/a	7.6**
Schuytema and Powers, 1966	1965	24	n/a	n/a	n/a	n/a	1
Shannon <i>et al.</i> , 1967	1965	42	0	0	0	0	0
Batchelder, 1973	1971	28	0	0	0	0	0
Shrivastava, 1974	1971	5	0	0	0	0	0
Schaeffer <i>et al.</i> , 2000	1986	~51	0	0	0	0	0
Nalepa <i>et al.</i> , 2002	1987	30	0	0	0	0	0
Nalepa <i>et al.</i> , 2002	1988	30	0	0	0	0	0
Nalepa <i>et al.</i> , 2002	1990	10	1	10	2	7.1	0.7
Nalepa <i>et al.</i> , 2002	1991	10	0	0	0	0	0
Nalepa <i>et al.</i> , 2002	1992	10	0	0	0	0	0
Nalepa <i>et al.</i> , 2002	1993	10	0	0	0	0	0
Nalepa <i>et al.</i> , 2002	1994	10	1	10	3	10.6	1.1
Nalepa <i>et al.</i> , 2002	1995	10	0	0	0	0	0
Nalepa <i>et al.</i> , 2002	1996	10	0	0	0	0	0
Edsall <i>et al.</i> , 2005	2001	28	1	4	1	3.7	0.1
This study	2009	9	1	11	1	1.2	0.2
This study	2010	9	2	22	11	10.4	2.2
This study	2012	48	7	15	15	13.7	2.0
This study	overall	57	9	16	27	9.0	1.5

\* as reported in Schloesser *et al.*, 2014.

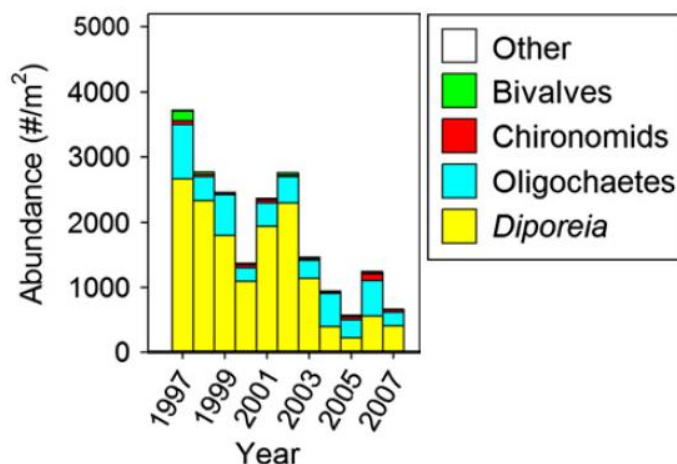
\*\* reported as 12 in Schloesser *et al.*, 2014.

The feeding behavior of quagga mussels (*Dreissena bugensis rostriformis*) was examined in experiments by Tang *et al.* (2014). The study determined quagga mussel clearance rates and selectivities on different phytoplankton taxa. Major findings included a relationship between mussel size and the size of the phytoplankton ingested, food preference for cryptophytes and flagellates, and low clearance rates and rejection in high proportions in pseudofeces for small-sized diatoms, green algae with thick cell walls, and colonial cyanobacteria with gelatinous sheaths Bay (Tang *et al.*, 2014). The findings of this study support the hypothesis that selective rejection by quagga mussels promotes *Microcystis* blooms in Saginaw Bay (Tang *et al.*, 2014).

Barbiero *et al.* (2012) estimated the non-dressenid abundance of benthos communities for deep (>90 m) stations in Lake Huron for 1997-2007 using results from ponar grab sampling efforts. The biggest change was a decline in *Diporeia*, a burrowing amphipod (Figure 5), which dropped from an average of 1,764/m<sup>2</sup> in 1998-2003 to 396/m<sup>2</sup> in 2004-2007 (Barbiero *et al.*, 2012).







**Figure 5. Average areal abundances of benthos, exclusive of Dreissenids, at deep (>90 m) stations in Lake Huron for 1997–2007 (Barbiero et al., 2012).**

#### 4.6 Bacteria

Current *E. coli* assays take an extended period of time, new methods for monitoring beach water quality are needed (Nevers *et al.*, 2014). Attempts have been made to improve monitoring efficiency and efficacy with the use of empirical predictive models and molecular rapid tests. Beach managers have actively incorporated new findings into their monitoring programs. Nevers (2014) review the accumulated research on microbiological water quality of Great Lakes beaches and provide a historic context to the collaborative efforts that have advanced this emerging science. Nevers cited, Kon et al. (2009) who applied rep-PCR DNA fingerprinting of *E. coli* isolates to suggest that agricultural sources were the dominant source of *E. coli* to a Lake Huron beach.

Verhougstraete et al. (2014) tested for multiple fecal indicator organisms in a variety of environments: sediment, algae mat, shallow water, and deep water. The results show algae mats (see also Alm et al., 2006) and sediment had higher levels of bacteria compared to the surrounding water column. Higher concentrations of fecal indicators in shallow waters compared to deep water were attributed in part to sediment and algae bound bacteria and potential regrowth. This suggested the potential for sediment and algal mats to act as non-point sources of pollution in the nearshore zone. Verhougstraete et al. (2014) indicated that future beach protection measures should focus on shallow water monitoring of multiple fecal indicators and beach grooming during calm morning hours (Figure 6).

Recent research has also demonstrated important plant-microbe interactions, particularly in the case of invasive phragmites reeds, which may be useful in developing control technologies (Kowalski et al., 2015).

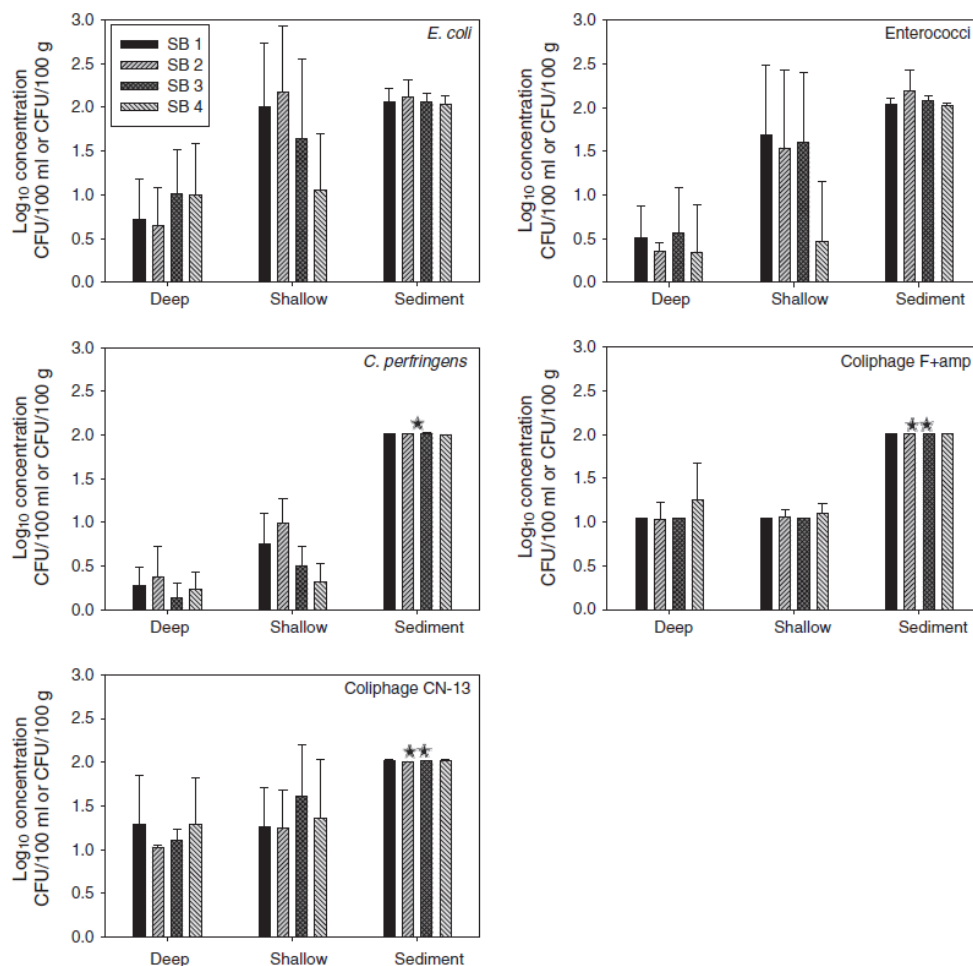


Fig. 2. Geometric mean concentrations of fecal indicator organisms in shallow water (15–20 cm; n = 32), deep water (1 m; n = 32), and sediment (n = 32) at SB1, SB2, SB3, and SB4. ★: Short error bars result of small *C. perfringens* standard deviations; ★★: No standard deviation due to high percentage of non-detects; when organisms were not detected they were assigned a value equal to the lowest method detection limit; water reported as log<sub>10</sub> CFU or PFU/100 mL; sediment reported as log<sub>10</sub> CFU or PFU/100 g wet weight.

#### Figure 6. Geometric mean concentrations of fecal indicator organisms (Verhoughstraete and Rose, 2014)

The objective of Bauer & Alm (2012) was to assess the presence of attachment and virulence genes associated with enteropathogenic and enterohemorrhagic strains of *E. coli* (EPEC and EHEC) in populations of *E. coli* recovered from swash zone sand from seven recreational beaches along Lake Huron and Lake St. Clair in eastern Michigan, USA. The presence in recreational beach sand of attachment and virulence genes associated with *E. coli* pathotypes suggests that horizontal gene transfer events could occur in this secondary environment. This could have public health implications in that beach sand may be serving as a reservoir of genes that could contribute to the emergence of new pathogens.

### 4.7 Cladophora

Francoeur et al. (2014) investigated benthic algae patterns in 2009 and 2010 in Saginaw Bay. They found that most benthic primary producer biomass occurred at depths of 2–4 m, with very little biomass observed beyond 4 m deep. Charophyte and vascular macrophyte abundances displayed consistent patterns related to distance from the mouth of the Saginaw River. Francoeur et al. stated that, “The diverse nature of the benthic producer community could complicate understanding and management of excess benthic biomass and beach fouling in Saginaw Bay.”



Shea et al. (2014) studied the recent distribution of *Baengia atropurpurea* in the Great Lakes. From surveys in 1995 and 2002, this species has clearly spread, with newly identified populations observed in Lakes Huron, Michigan, Georgian Bay and the St. Lawrence River. Correlation analysis, however, revealed significant relationships between the presence or absence of *Bangia* among the studied sites with pH and specific conductance as those locations that had stable populations had a mean pH and conductance of 8.2 and  $353 \mu\text{S}\cdot\text{cm}^{-1}$  respectively (Figure 7)

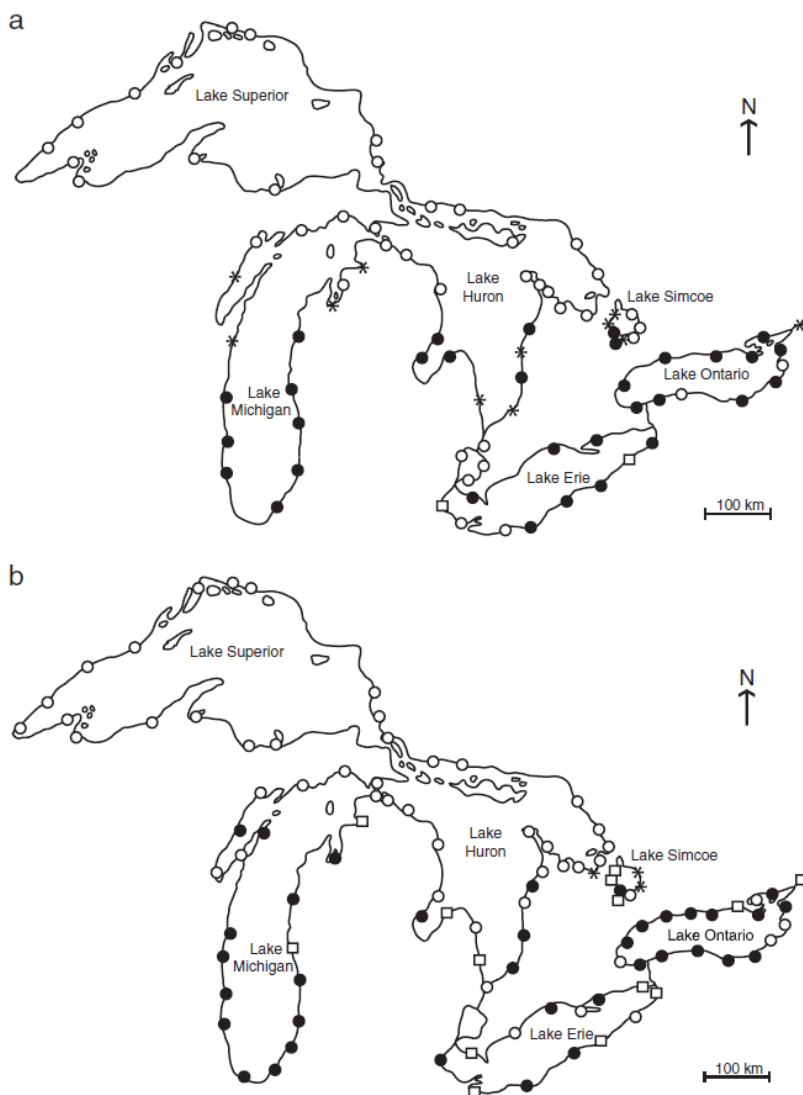


Fig. 1. Distribution of *Bangia atropurpurea* in the Great Lakes for the a) 1995 and b) 2002 surveys. A hollow circle indicates no *Bangia* present, a filled circle indicates a location where *Bangia* was observed, an asterisk indicates a new population of *Bangia* not observed previously (e.g. Sheath, 1987) and a hollow square indicates a the absence of a population of *Bangia* that had been observed previously (e.g. Sheath, 1987).

**Figure 7. Distribution of *Bangia atropurpurea* in the Great Lakes a) 1995 and b) 2002 (Shea et al., 2014).**

Winslow et al. (2014) examined the benthic filamentous green algal (FGA) community of Saginaw Bay. Most of the community experienced both light and P stress, with the exception of 20% of the sampled algae, which experienced saturating levels of midday light. These results suggest that post-Dreissenid invasion increases in water clarity extended the maximum depth limit from  $\sim 3.3$  to  $\sim 5$  m, greatly increasing the area of FGA growth (Figure 8).

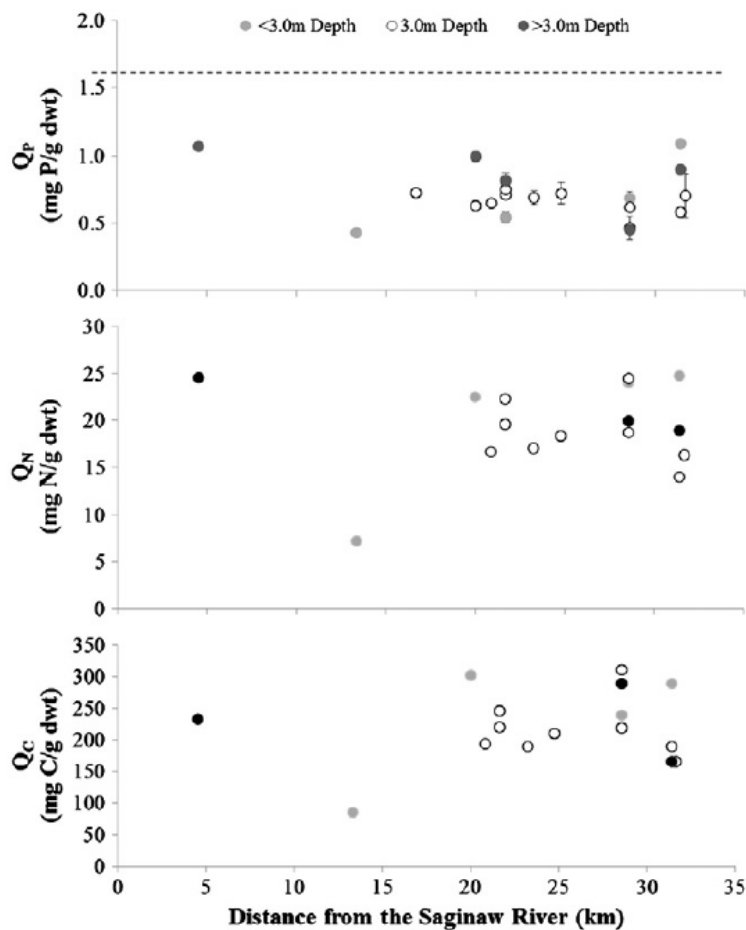


Fig. 2. Tissue phosphorus (top panel;  $n = 21$ ), nitrogen (middle panel;  $n = 16$ ), and carbon (bottom panel;  $n = 16$ ) of benthic filamentous algae in the inner bay of Saginaw Bay, Lake Huron across distance from the Saginaw River. Dashed line in top panel at 1.6 mg P/g dwt is the level below which phosphorus can be limiting (Wong and Clark, 1976). Based on this threshold, 100% are potentially P-limited while 0.6 mg P/g dwt is the critical growth requirement and 26% of the phosphorus samples are below this threshold, indicating severe P deficiency. All data are averaged for each sample site.

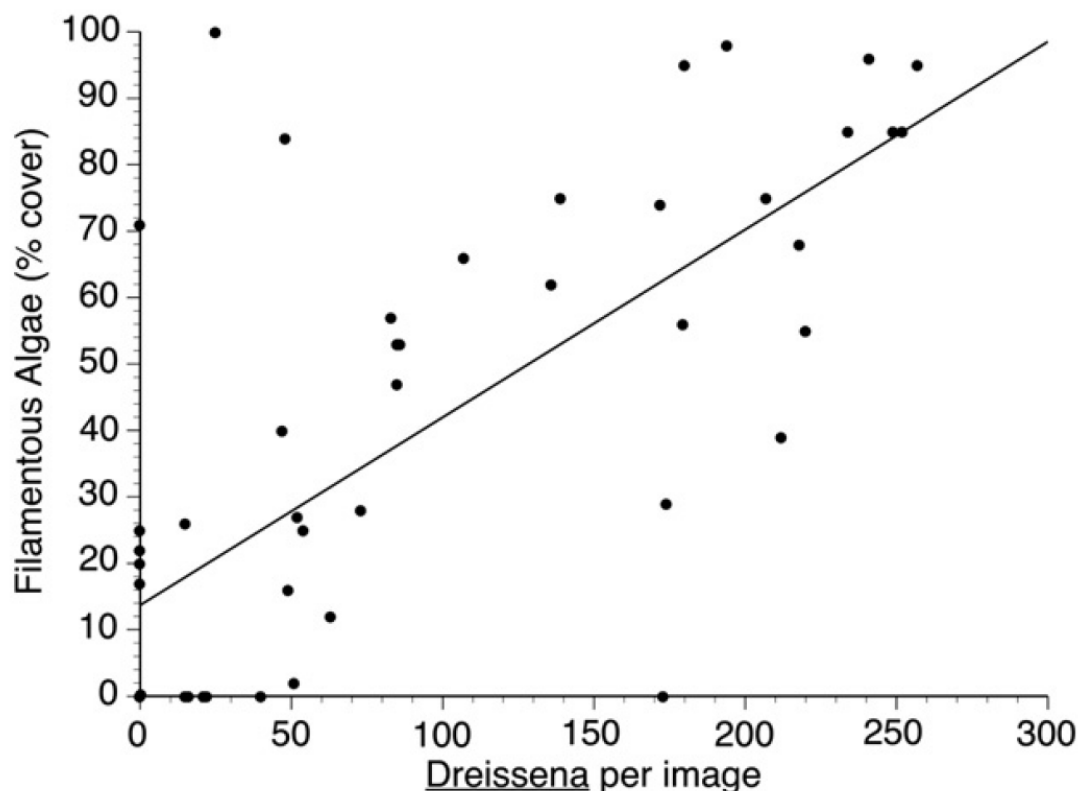
**Figure 8. Tissue phosphorus, nitrogen, and carbon of benthic filamentous algae in Saginaw Bay (Winslow et al., 2014).**

Barton et al. (2013) found that coverage by algal turf increased from 11% of sites in 1977 to nearly 90% in 2007 in the southeast shores of Lake Huron. The proliferation of algae appears to be the result of several recent changes including:

- Phosphorus management and filtering by Dreissenid mussels have reduced phytoplankton abundance, improving the light regime;
- Changes in land use may have increased loadings of phosphorus through shallow groundwater and tributary streams;
- Dreissenids have also redirected nutrients to the lakebed, further enhancing benthic primary production.

Barton et al. (2013) found that in areas with greater *Cladophora* density there are a greater density of Dreissenids as well (Figure 9).





**Fig. 3.** The relationship [ $\%cover = 0.283(\text{number of mussels}) + 13.702, r^2 = 0.518$ ] between *Dreissena* and filamentous algae in video images recorded in July 2007.

**Figure 9. The relationship between *Dreissena* and filamentous algae in video images recorded in 2007 (Barton *et al.*, 2013).**

Depew *et al.* (2011) surveyed selected shorelines and offshore shoals in Lakes Erie, Huron and Ontario. Hierarchical partitioning analysis suggested that while *Dreissenid* mussel abundance appeared to be important in determining the magnitude of *Cladophora* standing crop, the joint contribution of catchment land cover, near shore water quality (nutrient levels and suspended matter) and *Dreissenid* mussel abundance explained nearly 95% of the total variance in nuisance *Cladophora* standing crop observed in this study. Depew *et al.* (2011) concluded that these results provide corroborating evidence from sites across a gradient within and across the lower Great Lakes that is consistent with the operation of the near shore shunt model.

In summary, Winslow *et al.* (2014) found that the *Dreissenid* invasion increased water clarity, and, therefore, the area available for benthic algal growth. In addition, Barton *et al.* (2013) and Depew *et al.* (2011) found that in areas with greater *Cladophora* density there is a greater density of *Dreissenids*. These papers assert that *Dreissenids* are changing the nutrient dynamics and water clarity of the near shore. The nutrient dynamic changes are also reviewed in Section 4.8 Nutrients.

## 4.8 Nutrients

Stow *et al.* (2014a) stated that under the 2012 Great Lakes Water Quality Agreement Canada and the United States are obliged to develop target concentrations for water quality constituents of particular concern. They used data from Saginaw Bay in Lake Huron, to develop a Bayesian hierarchical model that

can be used to evaluate compliance with target concentrations on a temporally and spatially explicit basis. The “confidence of compliance” (COC) with targets can be assessed with the model (Figure 10). This approach allows data to be grouped to represent spatial and temporal domains of particular interest, such as spring mean conditions in a certain area, and facilitates “partial pooling” of information so that regions with sparse data and high uncertainty can “borrow information” from more data-rich areas.

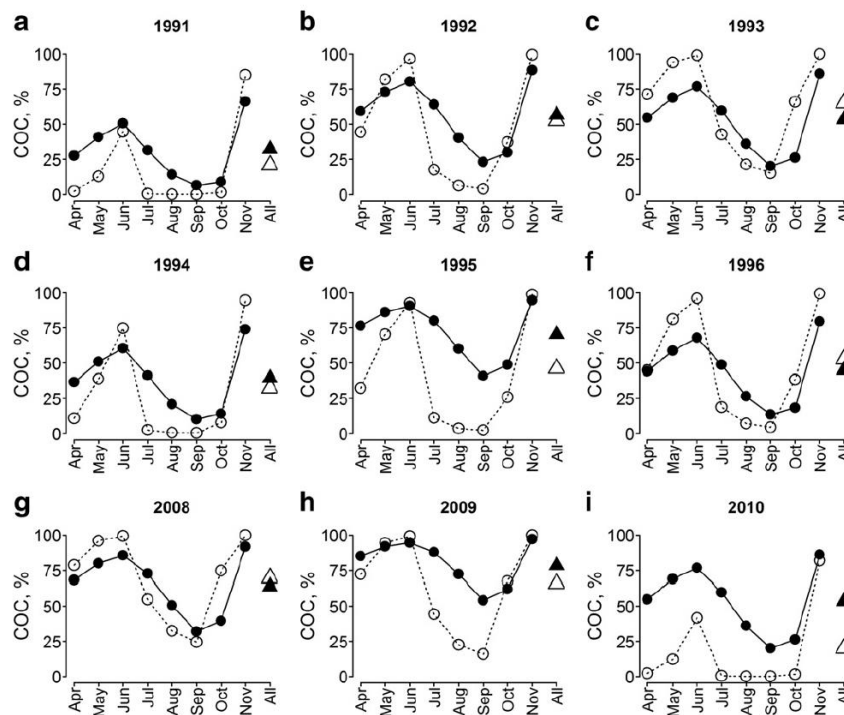


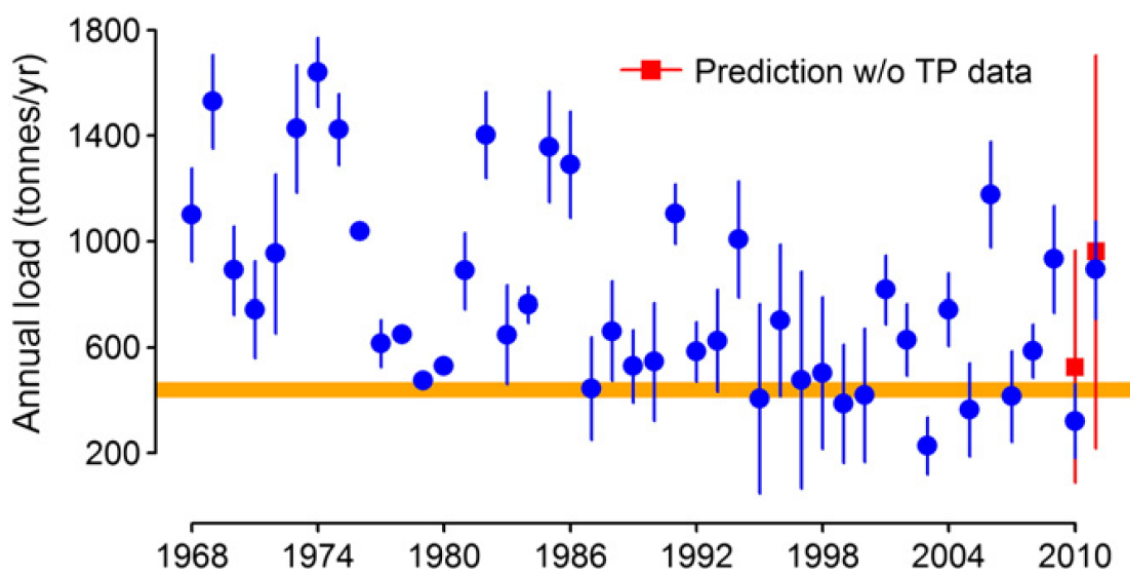
Fig. 6. Month-specific probabilities that the mean has met the 15 µg/L total phosphorus (solid circles) or 3.6 µg/L chlorophyll a (empty circles) reference values from 1991 to 2010. The triangles at the right indicate the overall probabilities across months for each year.

### Figure 10. Month-specific probabilities that the mean has met the 15 µg/L TP, and 3.6 µg/L chlorophyll a reference values from 1991 to 2010 in Saginaw Bay (Stow *et al.*, 2014a)

Howell *et al.* (2014) found that pulse-like inputs of phosphorus from wave-induced erosional events and periods of precipitation-related runoff, both characterized by high levels of particle-bound phosphorus, contributed to highly dynamic and spatially variable levels of total phosphorus (TP), and proportions of TP in dissolved form, in the nearshore. Land runoff enriches nutrient levels along sections of the immediate shoreline, which contrasts sharply with the ultraoligotrophic conditions in the broader nearshore. The nearshore of Lake Huron arguably has always been highly sensitive to phosphorus pollution and it appears likely that the shoreline may be even more so today.

Stow *et al.* (2014b) conducted a 35 year assessment of phosphorus targets and eutrophication objectives in Saginaw Bay. They stated that the 440 tonne P/year target phosphorus load established in the 1978 amendments to the Great Lakes Water Quality Agreement has almost never been met (Figure 11), and total phosphorus concentrations regularly exceed the 15 µg/L concentration objective proposed in documentation supporting the 1978 amendments. They further concluded that the adaptive management framework stipulated in the 2012 Great Lakes Water Quality Protocol should promote better monitoring of Saginaw Bay water quality into the future, with enhanced opportunities to better understand the factors that have maintained ongoing eutrophication symptoms. They assert that the adaptive management concept embodies the recognition that environmental management should be regarded as a series of large-scale experiments with uncertain outcomes, but also an opportunity for better understanding system behavior.





**Fig. 2.** Saginaw River total phosphorus load estimates, updated from Cha et al. (2010). Blue dots represent the mean of the Bayesian predictive distribution, bars represent  $\pm 2$  standard deviations. Red squares and bars depict estimates of TP load for 2010 and 2011 using only Saginaw River flow data, before total phosphorus data became available. Horizontal orange line denotes 440 tonne target established in the GLWQA.

**Figure 11. Saginaw River total phosphorus load estimates (Stow et al., 2014b).**

The results of He et al. (2014) indicate that point sources from municipalities, industrial sectors and business entities contribute approximately 25% of the total phosphorus load to Saginaw Bay, with the remainder being accounted for by nonpoint source contributions.

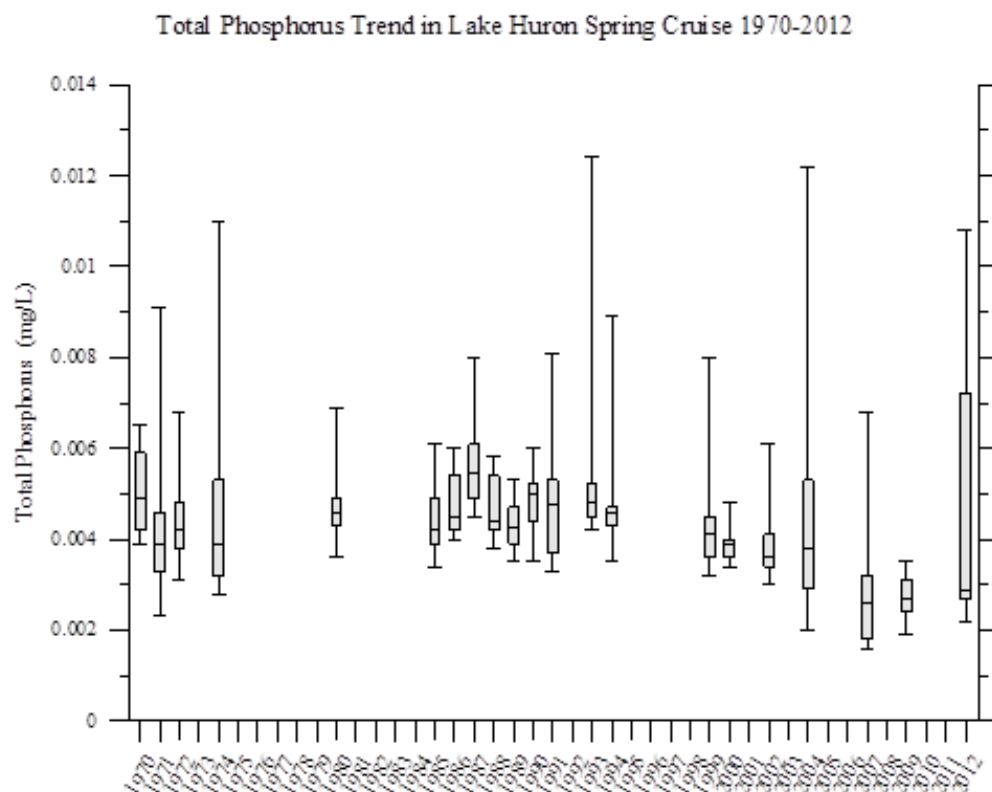
The results of Kao et al. (2014) indicate that phosphorus loads were positively correlated with simulated biomass of most food web groups. They also found that under current conditions of absence of alewives and reduced Dreissenid biomass, the target nutrient loads established in 1978 would not sustain current fishery harvests in Saginaw Bay given food web changes caused by invasive species.

LaBeau et al. (2013) examines the tributary monitoring network currently in place for sampling the amount of phosphorus entering the U.S. Great Lakes. The authors identify three recommendations for policy makers to consider when establishing tributary monitoring networks:

- Provide states with incentives to support the long-term monitoring that is required to estimate phosphorus loads;
- Facilitate the creation of a monitoring protocol that generates enough samples to identify trends and quantify loads at a level of certainty necessary for use in statistical models and load control programs;
- Funding mechanisms capable of supporting long-term monitoring programs need to be established, with programs in Michigan and Minnesota serving as potential models.

The analysis of Dolan & Chapra, (2012) indicates that the GLWQA phosphorus target loads have been consistently met for the main bodies of lakes Superior, Michigan and Huron. However, exceedances still persist for Saginaw Bay. The analysis also indicates that, because of decreasing TP concentrations in the lakes, interlake transport of TP from Lake Huron to Lake Erie has declined significantly since the mid-

1970s. Dove and Chapra (2015) summarize recent offshore data and long-term trends for nutrients in all the Great Lakes, including Lake Huron, and document a general decline in phosphorus and associated oligotrophication, along with increases in nitrogen and silica.



**Figure 12. Total phosphorus trends during Lake Huron spring cruise 1970-2012.**

The phosphorus mass balance model simulation results of Chapra & Dolan, (2012) conform to measured TP concentrations up until about 1990 for all parts of the system. After 1990, the model simulations diverge from observed data for the offshore waters of all the lakes except Lake Superior. In order to simulate these outcomes, the model's apparent settling velocity, which parameterizes the rate that total phosphorus is permanently lost to the lake's deep sediments, must be increased significantly after 1990. This result provides circumstantial support for the hypothesis that Dreissenid mussels have enhanced the Great Lakes phosphorus assimilation capacity.

Barbiero et al. (2012) stated that signs of increasing oligotrophication have been apparent in the open waters of both Lake Huron and Lake Michigan in recent years (Figure 12). Spring TP concentrations in Lake Huron are now slightly lower than those in Lake Superior, while those in Lake Michigan are higher by only about  $1 \mu\text{g P/L}$ . Seasonality of chlorophyll, as estimated by SeaWiFS satellite imagery, has been dramatically reduced in Lake Huron and Lake Michigan.



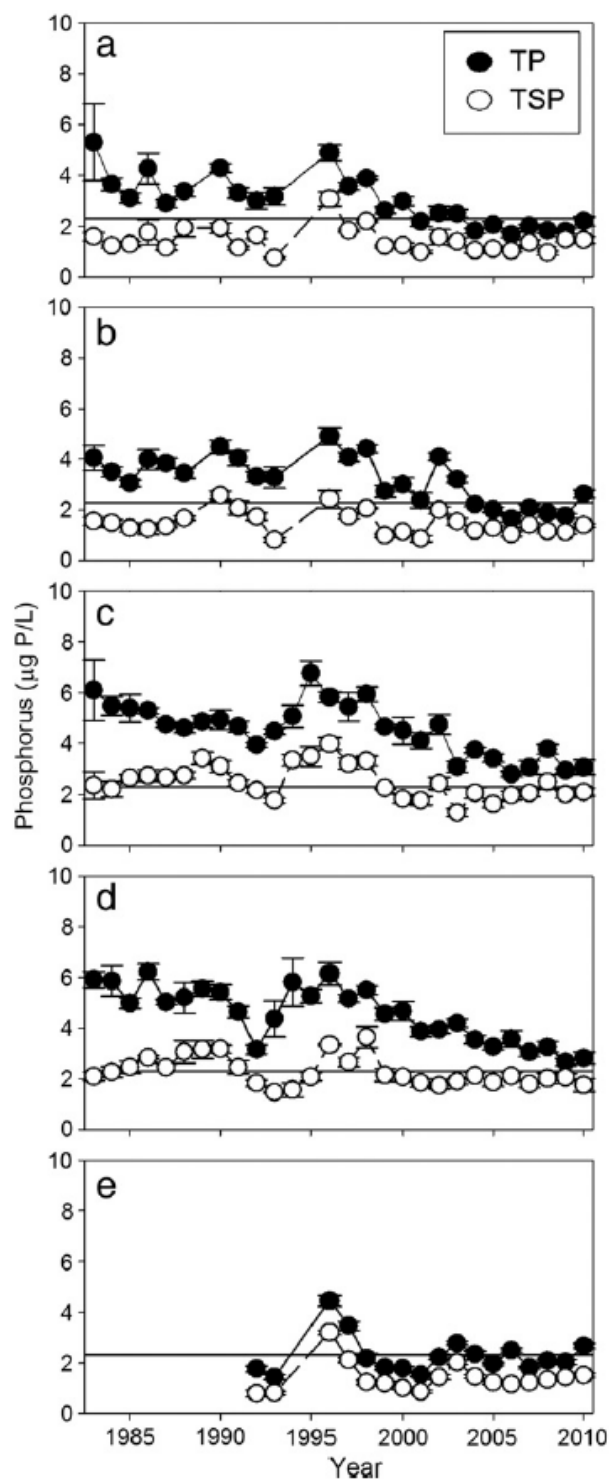


Fig. 2. Spring total (filled symbols) and total soluble (open symbols) phosphorus in: a) northern Lake Huron; b) southern Lake Huron; c) northern Lake Michigan; d) southern Lake Michigan; and e) Lake Superior. Error bars represent one standard error, horizontal reference line indicates long-term (1992–2010) average total phosphorus concentration in Lake Superior.

Figure 12. Spring total and soluble phosphorus in several Great Lakes (Barbiero *et al.*, 2012).



Cha et al. (2011) found that the proportion of tributary phosphorus retained in Saginaw Bay increased from approximately 46-70% when Dreissenids appeared, reducing phosphorus export to the main body of Lake Huron. The combined effects of increased phosphorus retention and decreased phosphorus loading have caused an approximate 60% decrease in phosphorus export from Saginaw Bay to Lake Huron. These results support the hypothesis that the ongoing decline of preyfish and secondary producers including diporeia (*Diporeia* spp.) in Lake Huron is a bottom-up phenomenon associated with decreased phosphorus availability in the offshore to support primary production.

In summary, Dolan & Chapra, (2012) and Stow et al. (2014b) found that the 1978 phosphorus target for Saginaw Bay is still exceeded. In addition to this finding the transport of the P from Lake Huron to Lake Erie has been decreasing steadily. Chapra & Dolan, (2012) and Cha et al. (2011) found that Dreissenid mussels have enhanced the phosphorus concentrations in the nearshore zone of Lake Huron and also directed more of the phosphorus loads to lake sediments (i.e., benthification). This benthification has reduced the amount of phosphorus transported out of Saginaw Bay, and thus contributed to a decline of preyfish and secondary producers (Cha *et al.*, 2011) both Saginaw Bay and the main lake.

## 4.9 Plankton

Reavie et al. (2014) described recent trends in phytoplankton composition and abundance in the Great Lakes using synoptic spring (April) and summer (August) sampling events from 2001 through 2011 a period of rapid shifts in pelagic food webs and water quality. Data analysis identified qualitative and quantitative changes in algal densities, biovolume, and taxonomic composition of assemblages (Figure 13 and Figure 14). Spring phytoplankton declines mainly attributed to diatoms occurred in Lakes Huron and Michigan, a probable result of invasions by non-native Dreissenids. The decline in Lake Huron's spring phytoplankton biovolume was earlier and more severe than that in Lake Michigan.



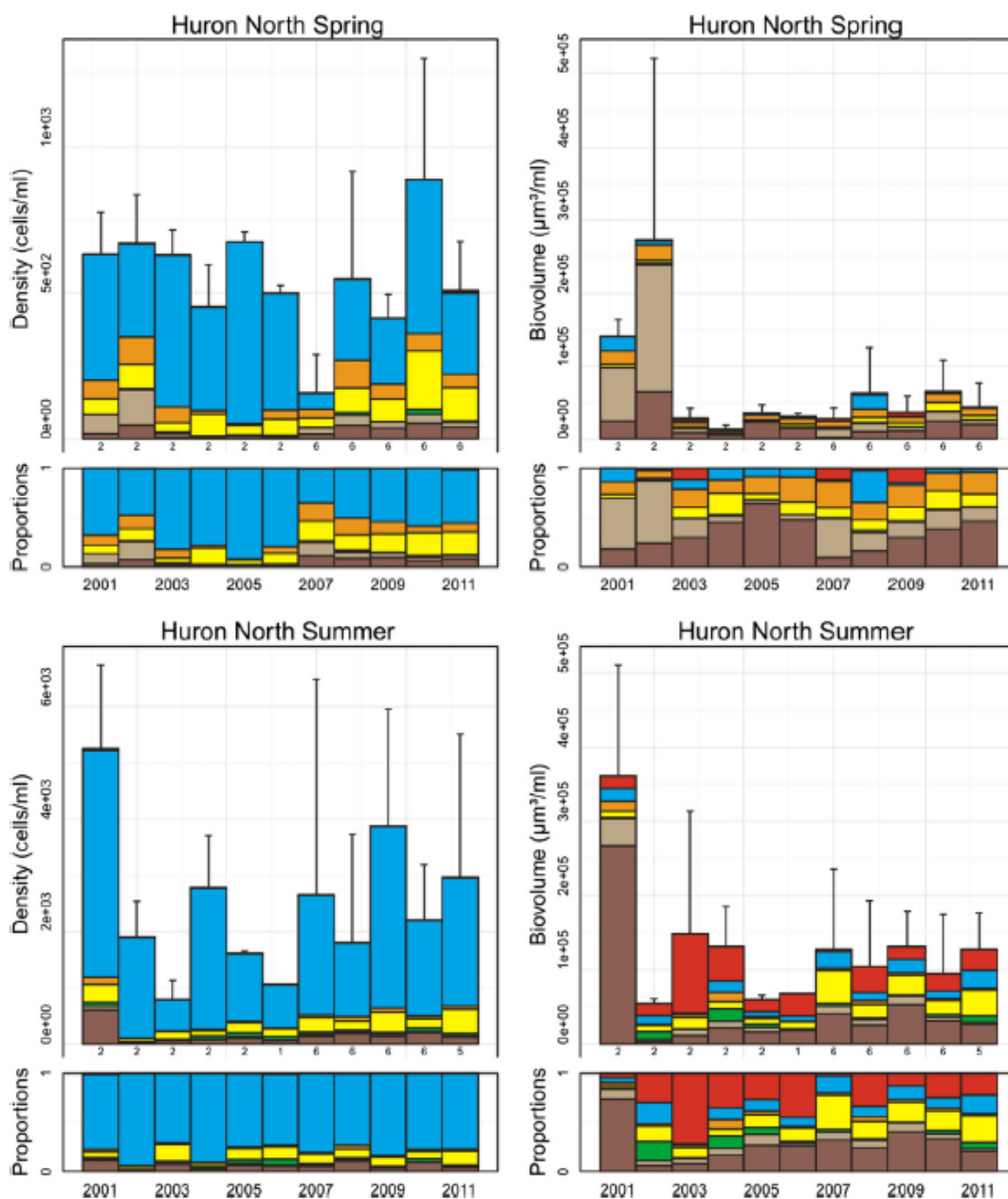


Fig. 7. Basin-wide averages of phytoplankton abundance in Lake Huron northern (upper) and southern (lower) basins. Abundance data are summarized for spring and summer, from 2001 to 2011. Algal cell densities (left) and biovolume (right) are presented. Numbers at the bottom of each absolute abundance bar indicate the number of samples averaged, and below that the relative abundances are shown as proportions. Error bars represent a standard error of the sample totals. A significant positive (+) or negative (-) trend (Kendall's rank correlation test,  $P < 0.05$ ) for the 11-year period is indicated in the respective headings. Taxon group codes match those from Fig. 2.

Figure 13. Basin-wide averages of phytoplankton abundance in Lake Huron northern basin (Reavie *et al.*, 2014).

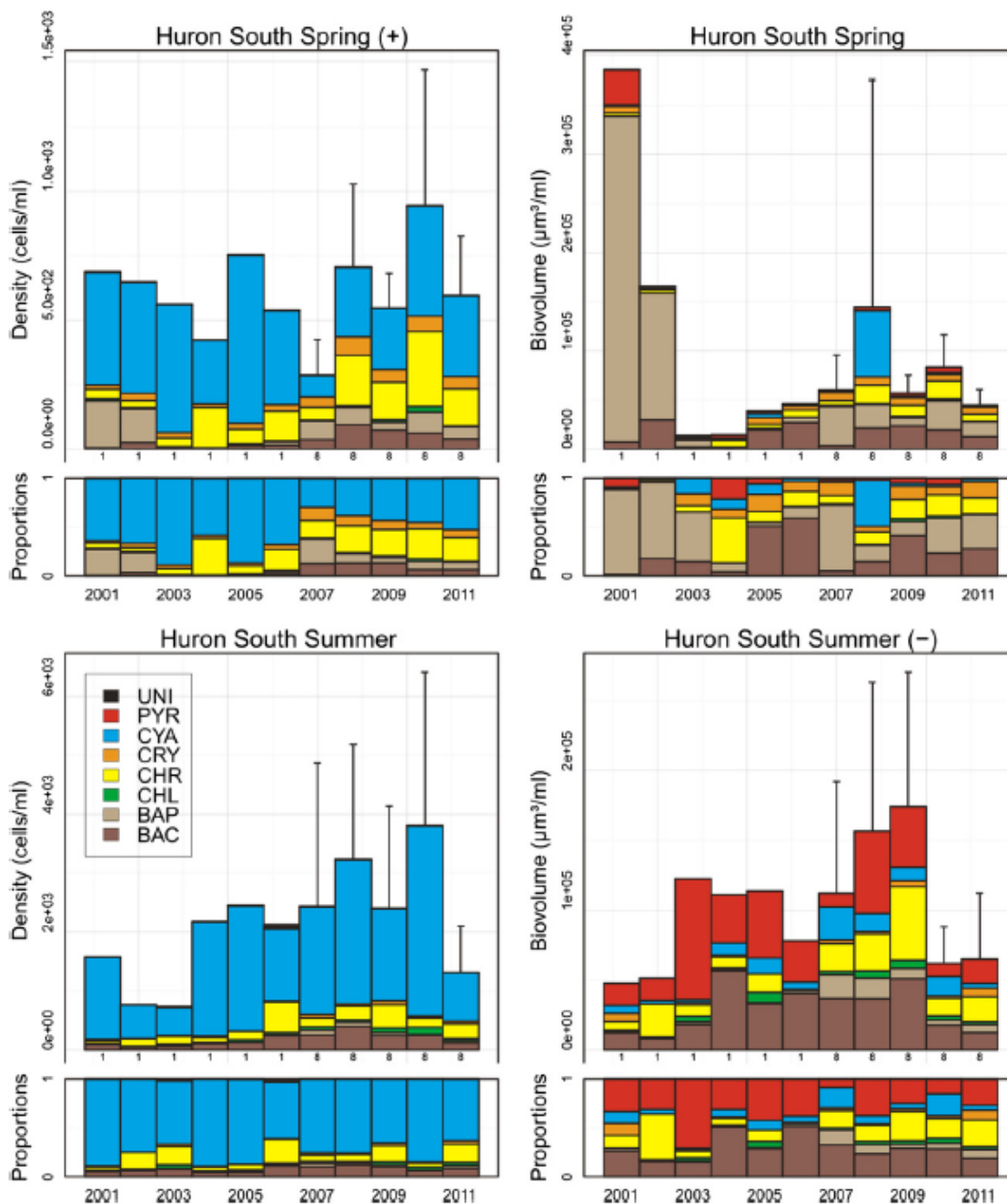


Fig. 7 (continued).

**Figure 14. Basin-wide averages of phytoplankton abundance in Lake Huron southern basin (Reavie *et al.*, 2014).**

Lesht *et al.* (2013) used the GLNPO observations made since 2002 along with coincident measurements made by the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) and the Moderate-resolution Imaging Spectroradiometer (MODIS) to develop a new band-ratio algorithm for estimating chlorophyll concentrations in the Great Lakes [including Lake Huron]. The sensor-specific coefficients for the new algorithm were obtained by fitting the relationship to several hundred matched field and satellite observations. Although there are some seasonal variations in some lakes, the relationship between the

observed chlorophyll values and those modeled using the new coefficients is fairly stable from lake to lake and across years. These results provide, for the first time, a single simple band ratio method for retrieving chlorophyll concentrations in the offshore "open" waters of the Great Lakes from satellite observations.

Shuchman et al. (2013) uses SeaWiFS, MODIS, or MERIS satellite data to estimate concentrations of chlorophyll, dissolved organic carbon, and suspended minerals. New individual lake retrievals were evaluated with respect to EPA in situ field observations, as well as compared to the widely used OC3 MODIS retrieval. The new algorithm retrievals provided slightly more accurate chl values for Lakes Michigan, Superior, Huron. Concentrations are shown in Figure 15.

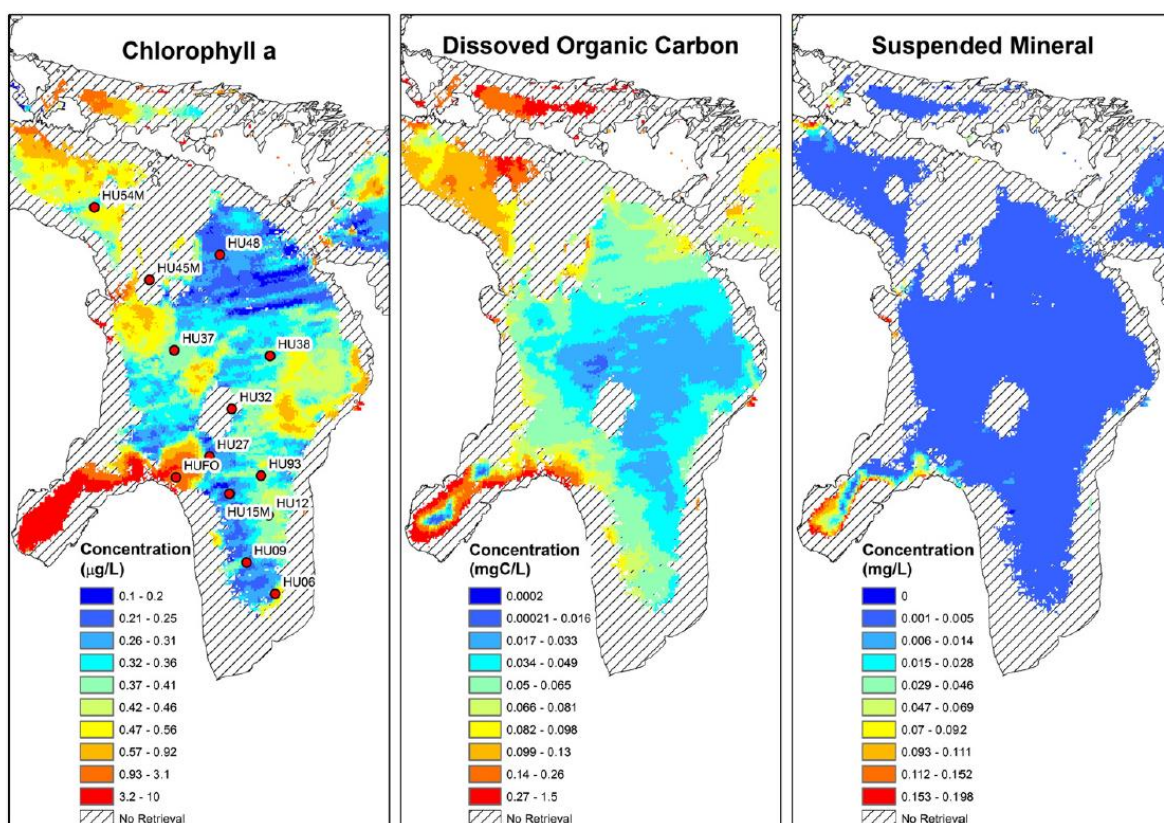


Fig. 6. Lake Huron CPA-A Retrievals for an August 12, 2010 MODIS image. The hatched areas indicate areas of no CPA-A retrieval due to cloud cover or return from the lake bottom. Legends for the concentration values appear next to each map. The EPA sampling locations are shown as red dots in the figure.

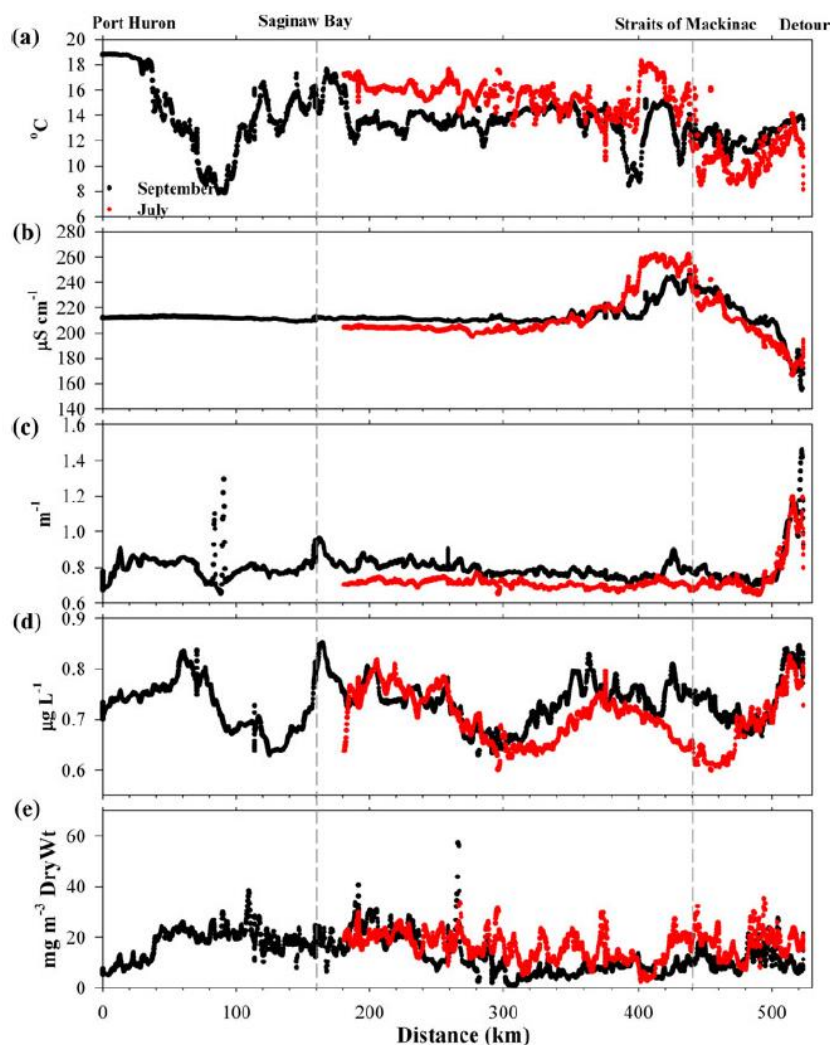
**Figure 15. Lake Huron CPA-A Retrievals for an August 12, 2010 MODIS image (Shuchman *et al.*, 2013).**

Yurista et al. (2012) conducted an intensive survey for the United States nearshore of Lake Huron along a continuous shoreline transect (523 km) from Port Huron, Michigan, to Detour Passage Figure 16. Strong correlations were observed between water quality and spatially associated watershed land use.

The survey results for Lake Huron nearshore are briefly compared with a similar nearshore survey in Lake Superior. The biomass concentrations of lower food web components of Lake Huron were notably approximately 54–59 % of those in Lake Superior. The towed instrumentation survey supported the recent view of a change in Lake Huron to an ultra-oligotrophic state, which has been uncharacteristic in recent history.



Fig. 3 Averaged water column values every 0.25 km along tow track length for a temperature ( $^{\circ}\text{C}$ ), b specific conductance ( $\mu\text{S cm}^{-1}$ ), c beam attenuation ( $\text{m}^{-1}$ ), d chlorophyll *a* ( $\mu\text{g chl } a \text{ L}^{-1}$ ), and e zooplankton biomass concentration ( $\text{mg dry weight m}^{-3}$ ). Values for the July 22–24 tow are in red and for the September 18–21 tow are in black



**Figure 16. Tow track water quality results from Lake Huron (Yurista *et al.*, 2012)**

In summary, Yurista *et al.* (2012) conducted continuous shoreline transect (523 km) and found strong correlations were observed between water quality and watershed land use. Biomass concentrations of lower food web measured by the towed instrumentation survey supported the recent view of a change in Lake Huron to an ultra-oligotrophic state, which has been uncharacteristic in recent history.

Lesht *et al.* (2013) and Shuchman *et al.* (2013) used the GLNPO observations and satellite data to develop an algorithms for estimating chlorophyll concentrations in Lake Huron. Shuchman's algorithm retrievals provided slightly more accurate chlorophyll *a* values for Lakes Michigan, Superior, Huron.

#### 4.10 Wetlands

Cooper *et al.* (2014) stated that the shallow-sloping coastal bathymetry of Saginaw Bay (Lake Huron) supports broad fringing wetlands. Because benthic invertebrates form an important forage base for fish, wading birds, and waterfowl that utilize these habitats, understanding the drivers of invertebrate community structure has significant management implications. Saginaw Bay wetlands had relatively high fetch and watershed agriculture and supported unique invertebrate communities, typified by high abundances of many insect taxa. A 1997–2012 time series from three representative Saginaw Bay



wetlands revealed substantial shifts in community structure throughout the period (Figure 17), especially from 2001 through 2004. These years followed a 1-m decline in Lake Huron water levels that occurred between 1997 and 2000. While factors in addition to water levels were likely also important, this time series analysis reveals the marked temporal dynamics of Saginaw Bay wetland invertebrate communities and suggests that water level decline may have influenced these communities substantially.

Both the spatial and temporal community patterns that Cooper et al. (2014) found should be considered in future bio-assessments utilizing wetland invertebrates.

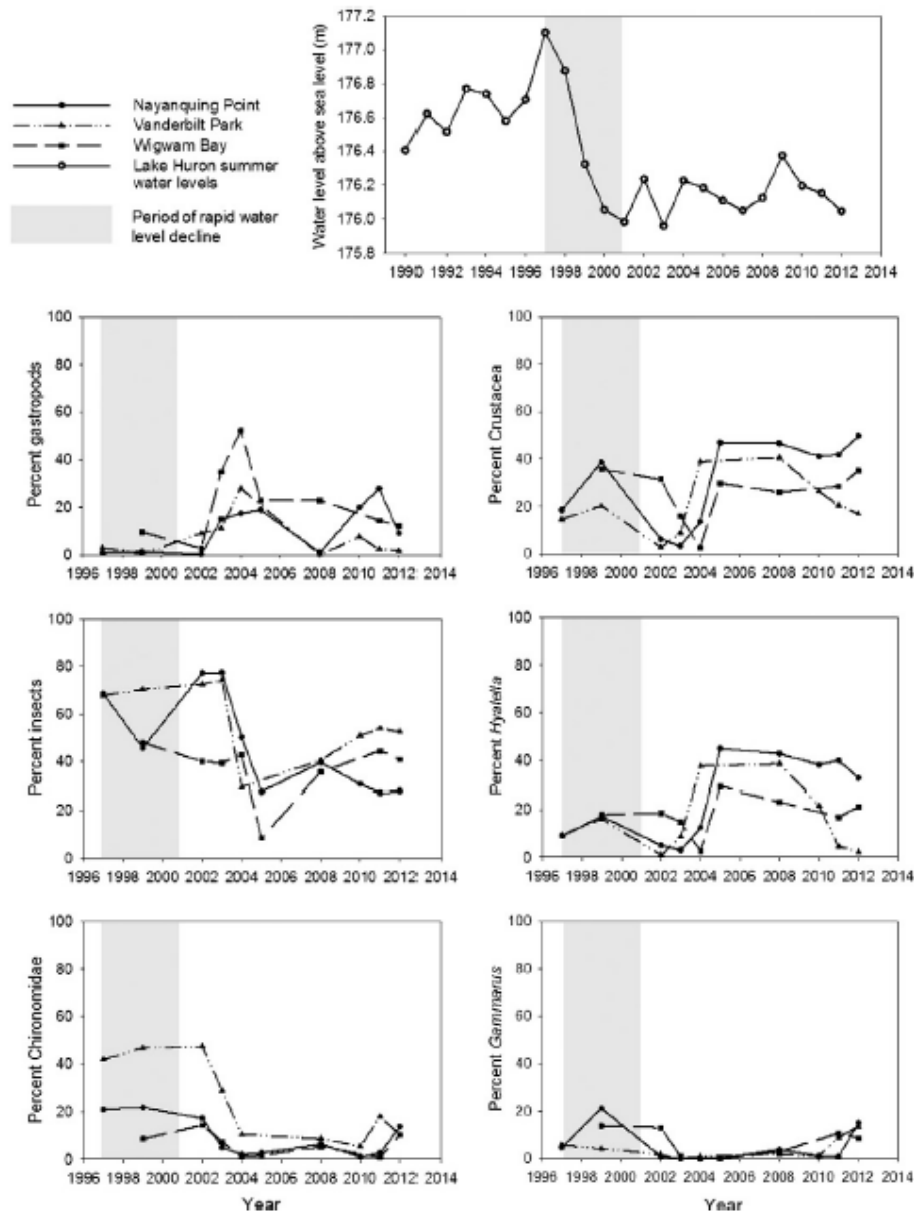


Fig. 5. Temporal trends in Lake Huron spring-summer water levels (mean of daily levels May–August, 1990–2012) and invertebrate community metrics for three Saginaw Bay wetlands.

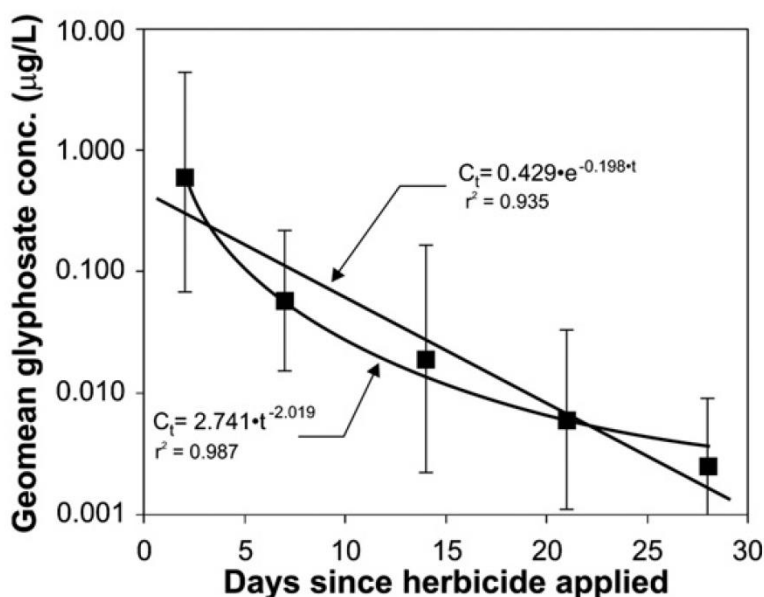
**Figure 17. Temporal trends in Lake Huron spring-summer water levels and invertebrate community metrics for three Saginaw Bay wetlands (Cooper et al., 2014).**

Mifsud, (2014) stated that amphibians and reptiles (herpetofauna) are key bioindicators of environmental health and habitat quality. Mifsud conducted comprehensive herpetological surveys throughout the

Saginaw Bay area and assessed community composition, species richness, and spatial distribution. Herpetofauna were conspicuously unobserved in areas where *Phragmites australis* dominates the vegetation community. Herpetofauna observations were clustered in areas where *Phragmites* and other invasive plant species were rare or absent. Removal of invasive plant species would greatly improve herpetofaunal communities within Saginaw Bay. These results will help resource professionals assess the quality of habitat and set goals for restoration of amphibian and reptile habitats.

Sherman et al. (2013) stated populations of native unionids have been in steady decline over the past century. The invasion of Dreissenid mussels greatly increasing their regional extinction rates. Live unionids were found in coastal wetlands of the Les Cheneaux Islands, the Lake St. Clair delta, and North Maumee Bay with significantly higher unionid fouling in the Les Cheneaux Islands compared to the other two sampling areas. No live unionids were found at Saginaw Bay in this study. Dreissena colonization densities on artificial substrates increased with measures of anthropogenic disturbance and decreased with higher water level fluctuations and aerial exposure. Specific conductance, turbidity, and magnitude of water level fluctuations were important predictors of Dreissena colonization on artificial substrates.

Crowe et al. (2011) studied the application of the herbicide Roundup®, containing the active ingredient glyphosate, to *Phragmites* along a beach on the southern shore of Georgian Bay, Canada, to eradicate the *Phragmites*. Groundwater and lake water were tested to determine if glyphosate enters the groundwater and lake at the beach and how long glyphosate will persist. Concentrations of glyphosate never exceeded the Canadian water quality guideline for the protection of aquatic life (65 µg/L) in either the groundwater or lake water. An approximate half-life for the dissipation of glyphosate by degradation and dilution/flushing as groundwater flows toward the lake, assuming a first order kinetic reaction, yielded a half-life of 3.5 during the 4 weeks after the herbicide was applied (Figure 18). The application of Roundup® resulted in a 90% reduction in the size of the stand of *Phragmites*.



**Fig. 6.** Declining concentrations of glyphosate in the groundwater below the *Phragmites*, over time, showing daily geometric means (squares) and standard deviations. The solid lines show the best fit to concentration vs. time using a first order kinetic equation and a power function.

**Figure 18.** Declining concentrations of glyphosate in the groundwater below *Phragmites* (Crowe et al., 2011).



Johnston et al. (2010) found that latitude was significantly correlated with 13 of 37 environmental variables tested, including growing degree days, agriculture, atmospheric deposition, nonpoint-source pollution, and soil texture, which suggests that latitude is a good proxy for several environmental drivers of vegetation. Using data from 64 wetlands along the U.S. coast of Lakes Huron, Michigan, Erie, and Ontario, they developed linear regressions between latitude and two measures of floristic condition, the Floristic Quality Index. This approach provides a means to identify wetlands worthy of preservation, to establish vegetation targets for wetland restoration, and to forecast changes in floristic quality associated with future climate change.

### Georgian Bay Coastal Wetlands

The coastal wetlands in eastern Georgian Bay are unique among other coastal wetlands in the basin of the Laurentian Great Lakes. They are some of the most pristine and receive minimal impacts from agriculture, industry or urbanization. The largest threat comes from cottage development. Wetland monitoring and assessment has been ongoing in this region for more than a decade using accepted wetland indicators (Indices for wetland water quality, fish, macrophytes). A report on the status of 157 wetlands sampled in 30 quaternary watersheds between 1998 and 2014 completed by Chow-Fraser and Croft (2015) indicates that Wetland quality within Georgian Bay was assessed as Excellent or Very Good for the majority of sampling sites (Table 2), underscoring the fact that within the Great Lakes basin, Georgian Bay has some of the most pristine conditions (Cvetkovic and Chow- Fraser 2011). The only areas that showed some degree of impairment included Severn Sound, Collingwood Harbour, and Spanish Harbour. Lower scores (poorer quality) tend to be found in areas with higher cottage development and road density such as Sturgeon Bay-Hog Bay in Severn Sound, and Matchedash Bay watersheds.

#### References:

Chow-Fraser, P. and Croft, M. 2015. Status of coastal wetlands in Georgian Bay and the North Channel. Report to Environment Canada.

Cvetkovic, M. and Chow-Fraser, P. 2011. Use of ecological indicators to assess the quality of Great Lakes coastal wetlands. *Ecological Indicators*. 11: 1609-1622.

**Table 2. Wetland quality by quaternary watershed with associated wetland scored, n=wetland years.**

Watershed	Area Sq Km	Type	Geology	Water Quality Index		Wetland Macrophyte Index		Wetland Fish Index	
				n	WQI Quality	n	WMI Quality	n	WFI Quality
Sturgeon Bay – Hog Bay	189.8	Mainland	Sedimentary	4	Good	4	Moderately Degraded	4	Very Good
Matchedash Bay	220.8	Mainland	Sedimentary	9	Good	6	Moderately Degraded	8	Very Good
Severn River	702.4	Mainland	Granitic	26	Very Good	28	Very Good	63	Very Good
Moon – Musquash River	717.1	Mainland	Granitic	29	Very Good	35	Excellent	20	Very Good
Spider Bay	89.4	Mainland	Granitic	3	Very Good	3	Very Good	1	Excellent
Parry Island	76.7	Mainland	Granitic	4	Very Good			2	Excellent
East Coast Islands	118.5	Island	Granitic	10	Good	9	Excellent	9	Excellent
Shebeshekong River	193.4	Mainland	Granitic	3	Very Good	4	Excellent	3	Excellent
Shawanaga River	312.6	Mainland	Granitic	3	Excellent	3	Excellent	1	Very Good
Pointe au Baril	117.5	Mainland	Granitic	5	Very Good	5	Excellent	3	Very Good
Naiscoot River	944.5	Mainland	Granitic	5	Very Good	5	Very Good	2	Excellent
Giroux River	102.4	Mainland	Granitic	3	Very Good	3	Excellent	2	Very Good
Key River	195.4	Mainland	Granitic	3	Very Good	3	Excellent	4	Very Good
French River 2	1059.1	Mainland	Granitic	2	Very Good	2	Excellent	3	Very Good
French River 1	1259.2	Mainland	Granitic	2	Very Good	2	Excellent	2	Very Good
Beaverstone River	127.4	Mainland	Granitic	4	Very Good	3	Excellent	3	Very Good
Philip Edward Island	49.1	Mainland	Granitic	4	Very Good	4	Very Good	4	Very Good
Great La Cloche Island	96.4	Mainland	Granitic	5	Very Good	6	Excellent	6	Excellent
Whitefish River	266.4	Mainland	Granitic	11	Very Good	10	Very Good	9	Very Good
Northeast Manitoulin	137.0	Mainland	Sedimentary	1	Very Good	1	Very Good	1	Very Good
Strawberry Island	16.3	Island	Sedimentary	2	Good	2	Very Good	2	Excellent
LaCloche	271.0	Mainland	Granitic	3	Very Good	3	Excellent	1	Very Good
Spanish River	5565.3	Mainland	Granitic	2	Good	3	Good	1	Very Good
North Channel	139.0	Mainland	Granitic	2	Good	2	Very Good		
Echo Bay	403.4	Mainland	Granitic	3	Good	3	Good		
Tobermory	93.5	Mainland	Sedimentary	5	Very Good	2	Very Good	3	Very Good
Fathom Five	13.7	Island	Sedimentary	4	Good	3	Very Good	4	Very Good
South Bruce Peninsula	136.5	Mainland	Sedimentary	1	Good	1	Good	1	Excellent
Saugeen	222.6	Mainland	Sedimentary	1	Very Good	1	Very Degraded		
Blue Mountain	205.6	Mainland	Sedimentary	1	Moderately Degraded	1	Very Degraded		



Midwood et al. (2012) stated that although the eastern shoreline has been designated a World Biosphere Reserve by UNESCO, a complete inventory is lacking. They outline the methodology, analyses, and applications of the McMaster Coastal Wetland Inventory (MCWI) created from a comprehensive collection of satellite imagery from 2002–2008. Wetlands were manually delineated in a GIS as two broad habitat types: coastal marsh and upstream wetland. Within the coastal zone of eastern and northern Georgian Bay there are 12629 distinct wetland units comprised of 5376 ha of LM, 3298 ha of HM and 8676 ha of upstream habitat. The MCWI provides the most current and comprehensive inventory of coastal wetlands in eastern Georgian Bay.

Midwood et al. (2012) stated that coastal wetlands of eastern Georgian Bay provides critical habitat for a diverse fish community. Declining water levels in Lake Huron over the past decade, however, have altered the wetland plant assemblages in favor of terrestrial (emergent and meadow) taxa and have thus reduced or eliminated this important ecosystem service. Their results show that sustained low water levels have led to an increasingly homogeneous habitat and an overall net loss of fish habitat. A comparison of the fish communities sampled between 2003 and 2005 with those sampled in 2009 revealed that there was a significant decline in species richness. The remaining fish communities were also more homogeneous (Figure 19).

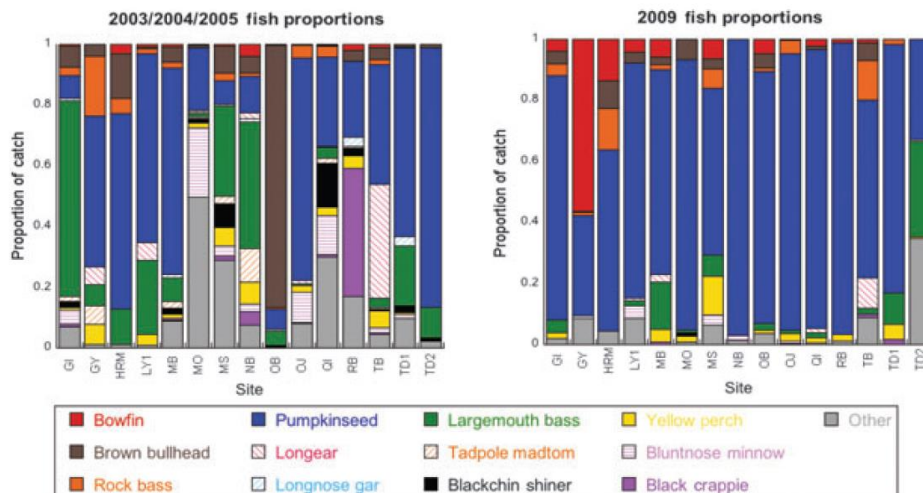


Fig. 4 Proportion of catch represented by each species, in each wetland for the 'Early' (2003–2005) and 'Later' (2009) sampling periods. There was a significant decline in species richness from the Early to Later time periods.

#### Figure 19. Proportion of catch represented by each fish species and wetland (Midwood and Chow-Fraser, 2012)

Cooper et al. (2013) measured gross primary productivity (GPP) and respiration (R) seasonally in benthic, water column, and epiphytic microhabitats of Lake Huron fringing wetlands. Net metabolism (the difference between GPP and R) was close to zero at most wetlands, but when macrophyte productivity was accounted for, most wetlands appeared autotrophic. Both GPP and R were highest in deep wetlands protected from hydrologic energy and declined with increasing wave exposure. With increasing exposure, wetlands were restricted to shallower water and benthic GPP and R increased relative to water column GPP and R. Coastal wetlands are hotspots of productivity in Lake Huron and hydrologic energy is an important driver of total metabolism rates, as well as the distribution of GPP and R among microhabitats.

In summary, Cooper et al. (2014) hypothesized that Lake Huron water levels affected the community structure of benthic invertebrates. They observed substantial shifts in community structure after a 1-m decline in Lake Huron water levels that occurred between 1997 and 2000. Midwood et al. (2012) also found that declining water levels in Lake Huron over the past decade have altered the wetland plant

assemblages in favor of terrestrial (emergent and meadow) taxa and have thus reduced or eliminated this important ecosystem service.

Mifsud, (2014) found that amphibians and reptiles (herpetofauna) are negatively affected when the invasive *Phragmites australis* dominates the vegetation. To control *Phragmites*, Crowe et al. (2011) studied the application of the herbicide Roundup®. The application of Roundup® resulted in a 90% reduction in the size of the stand of *Phragmites*.

Midwood et al. (2012) provides the most current and comprehensive inventory of coastal wetlands in eastern Georgian Bay. This was compiled with a collection of satellite imagery from 2002-2008 in GIS.

#### 4.11 Wildlife

The Wyman et al. (2014) study included waterbird colony sites located between Pigeon Point, Minnesota, and Three Mile Bay, New York, in the U.S. waters of the five Laurentian Great Lakes (Superior, Michigan, Huron, Erie, and Ontario) and their connecting waterways (St. Marys River, Detroit River, Lake St. Clair, and Niagara River) up to 1 km inland. The goal of this study was to understand how site use dynamics are influenced by the physical and avian social environment. Sites with large waterbird colonies and those not susceptible to flooding were most likely to persist as breeding locations into the next survey period, and thus should be prioritized for conservation and management. Wyman et al. (2014) asserted that species-specific responses to presence of other species and to environmental influences were apparent; knowledge of this relationship variability should be incorporated into management strategies to achieve optimal outcomes.

Ridgway and Middel (2011) found two general conclusions that emerged from this survey. First, aquatic productivity from both Great Lakes coast and inland lakes contributes to trends in population and distribution of cormorants in the northern region of Lake Huron and perhaps elsewhere. Second, inland aquatic ecosystems are important throughout a season for foraging cormorants from the Great Lakes and may become more important as Great Lake productivity trends downward.

Ridgway (2010) completed aerial line transect distance sampling surveys of coastal areas in the North Channel and Georgian Bay, Lake Huron, to estimate density of double-crested cormorants (*Phalacrocorax auritus*). In each year, density of cormorants declined towards late summer indicating a large scale outward migration of cormorants from Lake Huron. Density was generally higher in the North Channel relative to Georgian Bay seasonally and during the period 2000-2002 likely reflecting higher per unit area productivity in the North Channel. In the years 2003-2005, density was lower in both regions and similar compared to earlier years of the survey likely reflecting a regime shift that occurred in Lake Huron at that time (Figure 20).

Lake Huron wildlife generally show declining trends in contaminant concentrations in tissue and eggs (McLeod, 2015). There have been significant declines in PCB, DDE, and dioxin concentrations in herring gull eggs from Chantry, Double, and Channel-Shelter Island. Channel-Shelter Island eggs, however, are consistently more elevated compared to Double and Chantry Islands. Mercury, on the other hand, showed declines, but no significant changes in mercury concentrations have been seen from 1994 to 2009 for any colony on the lake. Similarly, no changes in PBDE concentrations have been seen, likely because there has not been enough time since the phase out of penta and octa BDEs.

Data from the St Marys River, Spanish Harbour, and Saginaw Bay suggest that remediation efforts have successfully lowered concentrations in fish and wildlife. Spanish Harbour, an area in recovery, shows remarkable improvements in concentrations in both Double-crested cormorant and herring gull populations. However, it has the highest concentrations of mercury in herring gull eggs of all colonies on the lake, followed by Saginaw Bay (an AOC). Further, it has elevated concentrations of the other organic contaminants compared to the reference colony. In double-crested cormorants, however, there are no



significant differences or lower concentrations for other organic contaminants compared to the reference sites. Both double-crested cormorants and herring gull colonies show remarkable improvements. The St Marys River has higher levels of TEQs in both common tern and herring gull eggs, and higher concentrations of sum alkylated PAHs in herring gull eggs. However, carp and bald eagle populations in the area appear to have recovered with lower concentration of DDT and PCBs. Saginaw Bay, while showing improvements, still has concentrations of PCBs in herring gull eggs close to threshold levels of concern for other colonial water birds including common and Caspian terns. Indeed, their concentrations of PCBs are the highest of all colonies on Lake Huron.

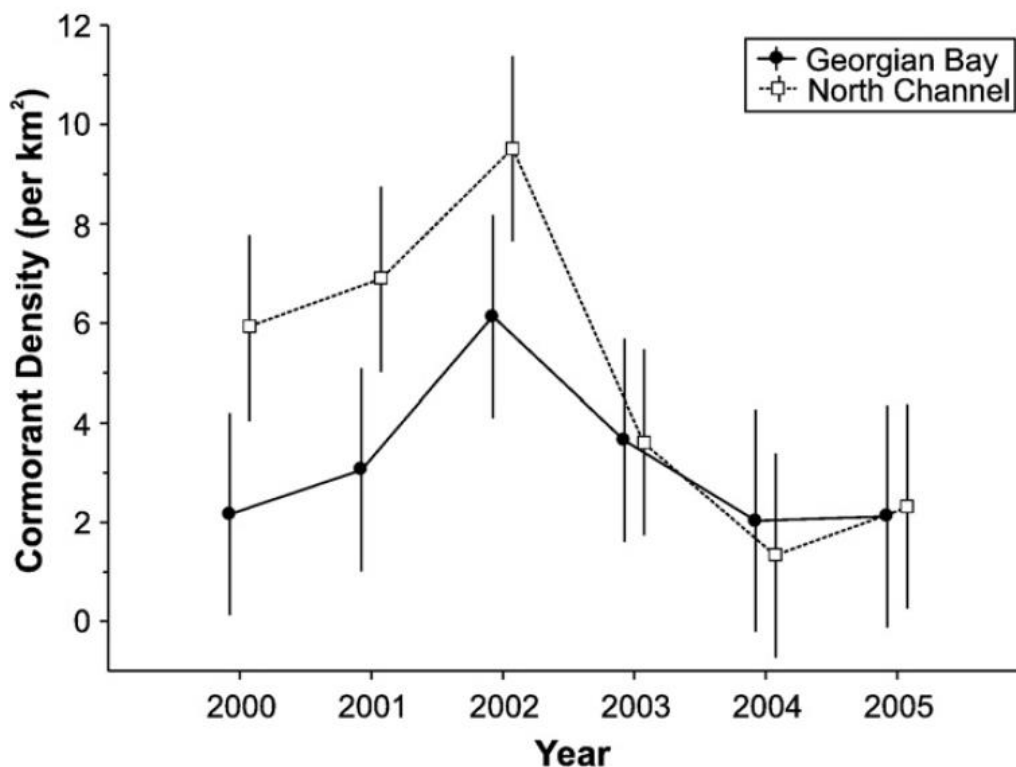
Retrospective stable nitrogen and carbon isotope analysis of archived herring gull eggs identified declines in gull trophic position and shifts in food sources in Lake Huron over the last 25 years; changes in gull diet composition were inferred from egg fatty acid patterns (Hebert *et al.*, 2009). Analysis of herring gull egg volume for Lake Huron sites also showed declining size over four decades (Hebert *et al.*, in press). Lake-wide assessments revealed statistically significant declines in egg volume on Lakes Superior and Huron. During the 1980s, there were no inter-lake differences in mean egg volume. However, in later decades smaller eggs were generally laid on colonies on the upper lakes, i.e. Superior, Huron, compared to the lower lakes, i.e. Erie and Ontario. Declines in egg volume appear to be linked to changes in gull diets, and may contribute to lower reproductive success. These egg volume declines are correlative with declines in energy density for rainbow smelt and lake trout in Lake Huron, consistent with impacts across the food web of open lake oligotrophication (Paterson *et al.*, 2014).

DeCatanzaro *et al.* (2010) examined the relationship between human disturbance (road density and wetland quality) and characteristics of aquatic turtle assemblages. Painted turtles (*Chrysemys picta*) were encountered disproportionately in degraded wetlands and the probability of occurrence decreased with improved site quality. Abundance of painted turtles peaked, however, at intermediate road density in surrounding 1- and 2-km buffers. The common musk turtle (*Sternotherus odoratus*) was absent from degraded wetlands in the lower lakes (Erie and Ontario) that fell within their historical range, but reached high abundances in marshes of Georgian Bay and the North Channel, a region with relatively low human disturbance.

Wyman *et al.* (2014) found that sites with large waterbird colonies and those not susceptible to flooding were most likely to persist as breeding locations, and should be prioritized for conservation and management. DeCatanzaro *et al.* (2010) found that turtle densities are affected in degraded wetlands.

Ridgway and Middel (2011) found that the aquatic productivity of both the Great Lakes coast and inland lakes effects double-crested cormorant population trends, and inland aquatic ecosystems are important as Great Lake productivity downward trends. Ridgway (2010) also found that the density of double-crested cormorants is probably affected by Lake Huron productivity with densities declining in response to lower lake productivity.





**Fig. 5.** Least square means of cormorant density (per km<sup>2</sup>) for years 2000–2005 based on mixed model ANOVA with Season, Season\*Region, Season\*Year and Frame(Year) as random effects.

**Figure 20.** Least square means of cormorant density for years 2000–2005 (Ridgway, 2010).

## 4.12 Fisheries

The fish community of Lake Huron has undergone considerable change in the last few decades and years. Recent research has focused on two of the most ecological important features of Lake Huron, Saginaw Bay and the St. Mary's River. The open waters of the lake were also studied to further understand reasons for the dramatic shift in the upper food web in the early 2000's.

Tucker et al (2014) documented the first record of natural reproduction of Atlantic salmon in the St. Mary's River, Michigan in 2012. Though the extent of natural reproduction is unclear, the authors suggest expanding future spawning surveys to document the spatial and temporal extents. This is especially important given that the Michigan DNR has increased and expanded stocking efforts of Atlantic salmon across the upper Great Lakes.

Leblanc et al (2014) studied muskellunge nursery habitat in southern Georgian Bay and compared conditions now versus 1981. The authors found degradation in habitat likely contributed by sustained low water levels and shoreline development. Subsequently, sites with degraded habitats were absent of young of the year muskellunge. The authors conclude that if the muskellunge population is to remain self-sustaining, then a management strategy that preserves nursery habitat is needed.

Mulvaney et al (2014) surveyed fisheries managers across the Great Lakes to identify information needs related to climate change. Managers perceived climate change to be a threat to a healthy fishery. The



survey identified gaps in knowledge related to climate impacts on fish populations, trophic interactions, and habitat. The researchers identified fish species that may be positively or negatively impacted by climate change. Most agreed that warm water species would be positively impacted and cool water species would be negatively impacted. The authors suggest that research should first focus on species of commercial and recreational interest, because management/restoration plans already exist and it is unclear how climate change could impact those plans.

Robinson et al (2014) studied sea lamprey density in the St. Mary's River to help optimize control methods. The authors found a strong relationship between the acres of river that were treated with lampricide versus sea lamprey density. This research can help to reduce treatment costs to only treat as many acres as necessary to achieve a desirable sea lamprey density. Lamprey populations were reported to be at a 30-year low in Lake Huron in 2015 (GLFC, 2015).

Stow et al (2014) summarizes the research conclusions from a multi-year effort studying the Saginaw Bay ecosystem. The supplemental issue to the Journal of Great Lakes Research provides an update to earlier research work conducted by NOAA in the mid 1990's. Surveys of Dreissenid sampling sites showed that mussel densities were down from the 1990s and are now dominated by quagga rather than zebra mussels. The *a priori* assumption was that beach muck, composed of decaying Cladophora, along the Saginaw Bay shoreline had diminished following phosphorus abatement actions and was a resurgent problem associated with Dreissenid mussel establishment. However, a review of a Park Ranger log book entries from the Bay City Recreation Area revealed that muck was a regular problem throughout that interim period. Additionally, we discovered that although there was a lot of Cladophora in the Bay, and sometimes it constituted a significant proportion of the muck, there were numerous constituents, including other benthic filamentous algae and macrophytes, reflecting the diverse benthic community of the Bay. Though the presence of macrophytes may complicate efforts to control beach fouling, phosphorus limitation was common among the benthic filamentous algae, suggesting that these muck sources may be curtailed with further phosphorus reductions. Although phosphorus concentrations in some areas show declines, the 440 MT/year phosphorus target has not been met and most of this phosphorus is of non-point origin. While additional phosphorus reductions may help reduce continuing eutrophication symptoms, the authors caution that achieving the 1978 target load could compromise the current productivity of the Saginaw Bay fishery. High primary productivity and warm waters currently make the inner Bay excellent nursery habitat for larval fishes, contributing to successful walleye and whitefish recruitment.

Schaeffer et al (2014) summarized the results of the longest running gill net assessment on the connecting channels (St. Mary's River) on the Great Lakes to provide recommendations for future sampling based on intended monitoring goals. Survey results indicated that species composition varied little among years. Effort required to capture 80% of all species observed during surveys ranged from 11 to 21 net sets among years. Reduced effort relative to previous survey years would have little impact on analyses of community composition or species richness. The present gill net survey is likely an insufficient stock assessment tool, but adequate as a fish community assessment tool. If a stock assessment is desired, then gill net effort needs to be increased 2.5 to 5 times.

Sesterhenn et al (2014) studied larval walleye dynamics in Saginaw Bay at multiple hatching sites. The early life survival of walleye in Saginaw Bay was previously limited by alewife predation on larvae, however the collapse of alewife populations eliminated this stressor. Study results indicate that larval walleye survival across the bay is dependent on walleye hatching from multiple sites, each with different opportunities for transport and exposure to a range of environmental and ecological stressors. Although walleye populations have rebounded in recent years, further study is needed to ensure a sustainable population.

Roswell et al (2014) studied yellow perch dynamics in Saginaw Bay and concluded that recruitment dynamics are influenced by an interplay of size-selective mortality and diet-induced reductions in growth.



Kocovsky et al (2013) investigated how the interpretation of hydroacoustic data can influence fish density estimates. The current recommendations by the Great Lakes Standard Operating Procedure (GLSOP) can significantly influence acoustic density estimates, but the degree of importance is lake dependent. The authors recommend additional research to further develop standards to enable multiple research organizations to compare and contrast hydroacoustic data and the derived fish density estimates.

Dunlop and Riley (2013) studied the effects of environmental drivers during the 2003 collapse of the alewife populations in Lake Huron. More specifically the authors looked at cold winter temperatures that could have contributed to the rapid decline. Long-term climate data (1973–2009) showed that the winter of 2002–2003 exhibited the largest drop in degree days relative to the previous year, had the most extensive average March ice coverage, and was among the coldest years on record. Although they found evidence that cold winter temperatures contributed to the abrupt decline of alewife in 2003, they could not explain why the population failed to recover as it had after previous cold winters.

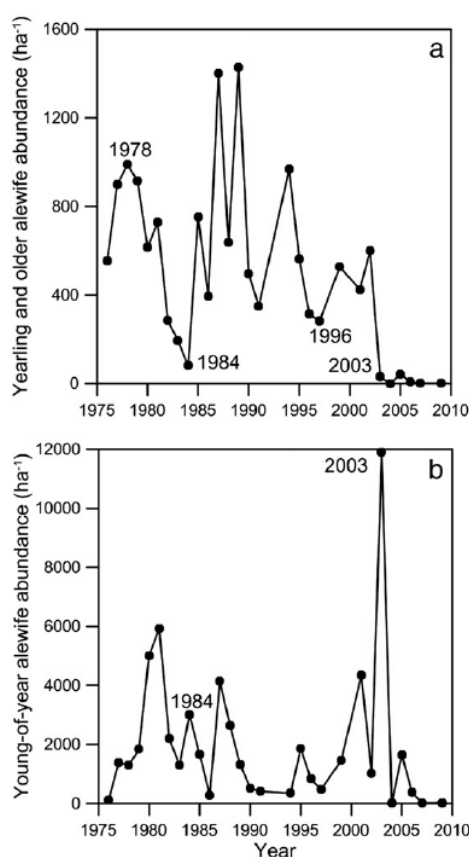


Fig. 1. Temporal trends in alewife abundance in Lake Huron. (a) Yearling and older alewife abundance per ha. (b) Young-of-year alewife abundance per ha. Data are from the United States Geological Survey bottom trawl surveys (Riley et al., 2008, 2012). A few years are labeled for reference.

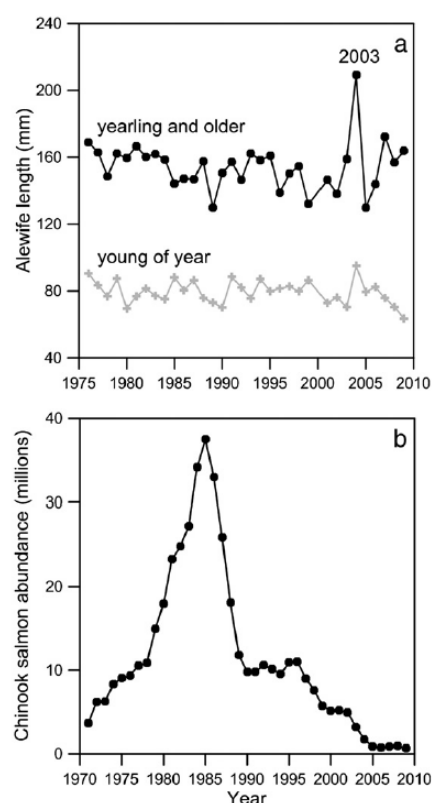


Fig. 3. Trends in Lake Huron alewife length and Chinook salmon abundance. (a) Young-of-year and yearling and older alewife mean length; data are from the United States Geological Survey bottom trawl surveys (Riley et al., 2008, 2012). (b) Chinook salmon abundance for ages 1 to 5 years in the main basin predicted by a statistical-catch-at-age model (Brenden et al., 2012). 2003 is labeled for reference.

**Figure 21 Trends in alewife abundance in yearling and older (top left), young-of-year (bottom left), length (top right), and salmon abundance (bottom right) from Dunlop and Riley (2013).**

Coulter et al (2012) observed differences between wetland and open habitats for round gobies in lakes Michigan and Huron. It has been suggested that some Great Lakes coastal wetlands may be resistant to invasion by several nonindigenous species including round goby. However, there is inconclusive evidence regarding how susceptible exposed fringing coastal wetlands, in particular, are to round goby. The study

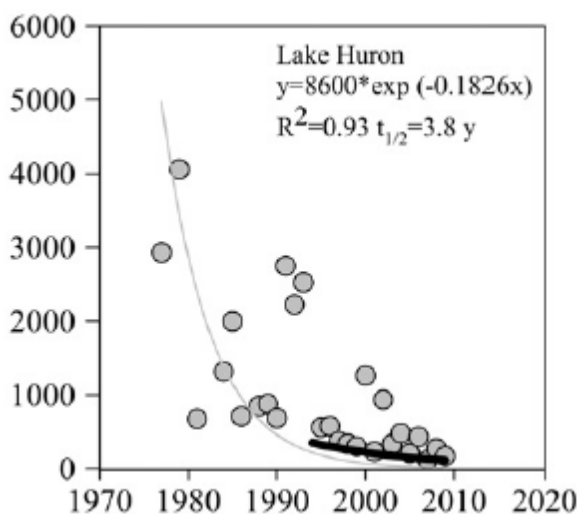
concluded that some exposed fringing wetlands in the Great Lakes, specifically those with high productivity (in the nearshore waters of Saginaw Bay), could have a higher degree of resistance to round goby invasion.

Ridgway et al (2012) studied the impact of double-crested cormorants and anglers on fish production on Manitoulin Island in Lake Huron. Study found that anglers imposed more population stress on their preferred sizes of fish than cormorants imposed on their preferred sizes of fish. Population stress was increased when cormorant consumption of medium size fish was discounted from contributing to large fish production. Angler harvest near (or above) sustainable yield levels will be exacerbated and appear as a fish collapse when cormorants consume fish production destined for fish size segments preferred by anglers.

MacMillan and Roth (2012) observed the rate of by-catch in commercial trap nets in Saginaw Bay. This source of mortality can be significant and is often difficult to quantify. Walleye by-catch averaged 127.3 individuals per trap net lift and 42% of those caught were morbid. The levels of lake trout observed were within the range observed in previous studies, but mortality (percent) was higher than has been previously observed. Lake trout by-catch averaged 39.4 individuals per lift and 39.2% of those were morbid. Surface water temperature and trap net depth most influenced mortality. These results may inform fishers and fisheries managers and highlight the need for comprehensive by-catch monitoring throughout the Great Lakes. A comprehensive by-catch estimate was not made for this study.

Omara et al. (2015) used stable isotopes to show data consistent with a shift in lake trout diets in Lake Huron from alewife to invasive round goby, which was not observed in data for Lake Superior. They also concluded that this shift was contributing to increasing mercury bioaccumulation in lake trout.

Xia et al (2012) reported Toxaphene results of the U.S. Great Lakes Fish Monitoring and Surveillance Program. Combining these results with historical data show an exponential decay regression in all of the lakes. Results for Lake Huron are shown below.



**Figure 22. Toxaphene Concentration (ng/g) in whole fish samples with adjusted historical data.**

Werner et al (2011) examined trends in thiamine level in the eggs of Atlantic salmon from the St. Mary's River. In 2000, the Atlantic salmon raised at LSSU experienced 99% mortality due to EMS related symptoms. Over the period from 2003 to 2007, the egg-thiamine content of eggs from 2005 saw a significant increase, which will significantly help improve egg survival. This one year shift may have larger ecological implications related to changes in the diet of this population of Atlantic salmon.



Bauman et al (2011) discussed the population status and demographics of the lake sturgeon in the St. Mary's River from 2000 to 2007. A total of 192 unique lake sturgeon were captured with a recapture rate of 16%. The population size of lake sturgeon in the St. Marys River was estimated to be near 500 individuals. This study suggests that a recovering lake sturgeon population exists in the St. Marys River, however, it remains unclear as to whether this is a self-sustaining population reproducing in the river. Additional information is needed on metapopulation dynamics, habitat use, and younger age classes to assess recruitment success and population status.

Pratt et al (2011) assessed the health and historical changes of the nearshore fish community in the St. Mary's River. The authors concluded that the nearshore fish community is relatively unaltered over the past 25 years, with many species that were common in the early 1980s remaining important community members today. More invasive fishes now inhabit the river, but unlike many other areas of the Great Lakes, invasives are not common and do not appear to be negatively affecting native species. The overall health of the St. Marys River fish community compared favorably with relatively un-impacted sites from Lake Huron. The Lake Huron Lake Sturgeon Working Group (Boase et al., 2014) reported that a sturgeon tagging operation in southern Lake Huron, which was conducted from 1995 through 2008, would be resumed in 2015. The sturgeon population in southern Lake Huron was estimated at 30,000 individuals based on the previous study, making it one of the largest remaining populations of lake sturgeon in the Great Lakes.

Schaeffer et al (2011) examined long term trends in the open water fish community of the St. Mary's River. Abundance data were available approximately once every six years from 1975 through 2006, and size and age data were available from 1995 through 2006. The St. Marys River fish community was best characterized as a cool water fish community with apparent little variation in species composition, and only slight variation in overall fish abundance since 1975.

Fielder (2010) studied the impacts of double-crested cormorants on yellow perch before and after control measures were implemented. A double-crested cormorant control program was implemented in 2004 with the objective of benefiting the yellow perch population and fishery. As double-crested cormorant abundance declined, yellow perch abundance increased, total mortality rate decreased, the angler catch rate and harvest in the recreational fishery improved, yellow perch growth rate declined and mean age increased. Increased yellow perch recruitment was documented since 2003 but it was the longevity of these year classes, (improved survival) as much or more than their magnitude of the year class, that allowed for the progress towards recovery. Questions facing managers are the sustainable level of double-crested cormorants in the region and the long term prognosis for the yellow perch fishery to fully recover to pre-double-crested cormorant levels.

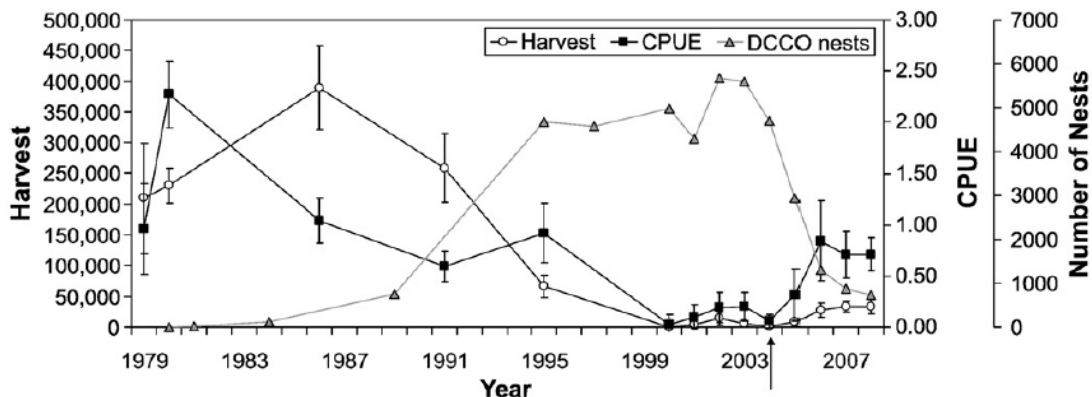


Fig. 2. Trends in open water (April–October) yellow perch harvest and angler harvest rate (fish per hour of effort or CPUE), and double-crested cormorant (DCCO) nest numbers for the Les Cheneaux Islands, Lake Huron as determined by creel survey and nest inventory counts, 1979–2008. Cormorant control was implemented in 2004 as denoted by arrow.

**Figure 23. Trends in open water yellow perch harvest from 1979 to 2009.**

Cvetkovic et al (2010) reported on the importance of macrophyte versus water quality factors in predicting fish assemblages in coastal wetlands in the Great Lakes. we show that plants are consistently better predictors of the fish community than are water quality variables in three separate trials: all wetlands in the Great Lakes basin (whole: 21.2% vs 14.0%; n=60), all wetlands in Lakes Huron and Superior (Upper: 20.3% vs 18.8%; n=32), and all wetlands in Georgian Bay and the North Channel (Georgian Bay: 18% vs 17%; n=70). This is the largest study to directly examine plant–fish interactions in wetlands of the Great Lakes basin.

Wagner et al (2010) studied lake whitefish dynamics and implications for management. The authors did not find relationships between spatial patterns in fish health indicators and estimates of natural mortality rates for the stocks. The research highlights the complexity of the interactions between fish nutritional status, disease dynamics, and natural mortality in wild fish populations. Additional research that identifies thresholds of health indicators, below (or above) which survival may be reduced, will greatly help in understanding the relationship between indicators measured on individual fish and potential population-level effects.

Bunnell et al. (2011 and 2014) explored the changing Lake Huron zooplankton community and the impacts of Bythotrephes on the lower food chain. Bythotrephes was the dominant planktivore and estimated to have eaten 78% of all zooplankton consumed. Bythotrephes consumption exceeded total zooplankton production between July and October. Mysis consumed 19% of all the zooplankton consumed and exceeded zooplankton production in October. Consumption by fish was relatively unimportant – eating only 3% of all zooplankton consumed. The study results provide no support for the hypothesis that excessive fish consumption directly contributed to the decline of Cladocerans and cyclopoid copepods in Lake Huron. Rather, they highlight the importance of invertebrate planktivores in structuring zooplankton communities, especially for those foods webs that have both Bythotrephes and Mysis. Together, these species occupy the epi-, meta- and hypolimnion, leaving limited refuge for zooplankton prey.

Roseman et al. (2013, 2015) reported on the offshore Lake Huron demersal fish community and trends between 1976 and 2014. Substantial numbers of wild juvenile lake trout were captured in 2012 and 2014, suggesting that natural reproduction by lake trout continues to occur. The 2012 and 2014 Lake Huron bottom trawl survey results indicate that an upward trend in demersal fish abundance was not sustained. The 2014 main basin prey fish biomass estimate for Lake Huron was 36 kilotonnes, less than half of the 2012 estimate (97 Kt). Estimated adult bloater biomass in Lake Huron increased slightly over the 2013 estimate but remains lower than the long-term average. YOY alewife, rainbow smelt, and bloater abundance and biomass decreased over 2013. Biomass estimates for deepwater sculpins, trout-perch, and ninespine stickleback in 2014 were lower than in 2013 and remained low compared to historic estimates. The 2014 biomass estimate for round goby was lower than 2013.



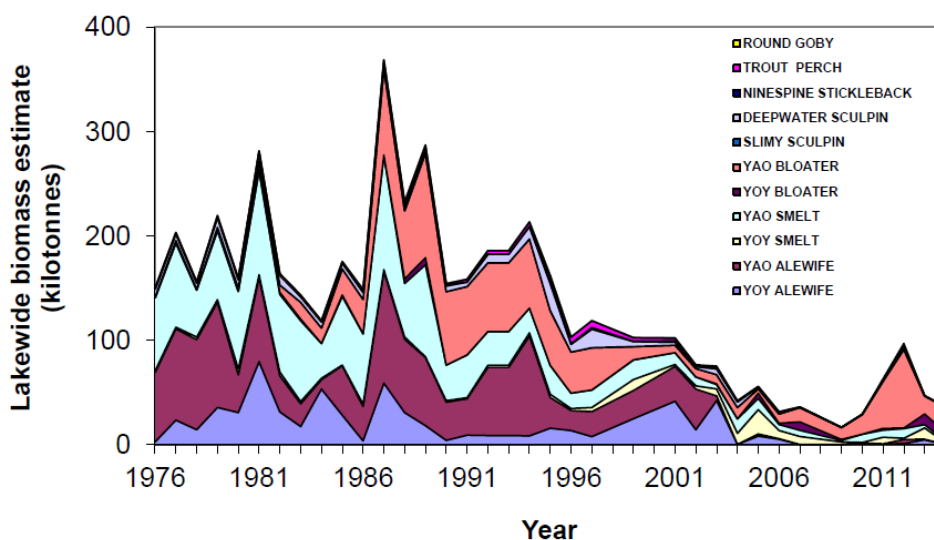


Figure 8. Offshore demersal fish community biomass in the main basin of Lake Huron, 1976-2014. Valid data were not collected in 1992, 1993, 1998, 2000, and 2008; biomass estimates for those years represent interpolated values.

**Figure 24. Offshore demersal fish community biomass in the main basin of Lake Huron 1976-2014.**

Pothoven et al (2013) evaluated changes in the zooplankton community before and after the alewife disappearance from Saginaw Bay. Abundances of *Bythotrephes* and age-0 yellow perch were both higher in 2009–2010 than in 1991–1996. Some changes such as increasing proportions of calanoid copepods reflect a more oligotrophic community and are potentially indicative of resource driven changes rather than direct or indirect impacts of the alewife disappearance.

He et al (2012) compiled lake trout population data from 1973 to 2010 for the main basin of Lake Huron. Lake trout in the main basin of Lake Huron are undergoing a transition from a hatchery stock to a wild stock, accompanied by an increased uncertainty in delayed recruitment. Future management should pay more attention to the protection of wild recruitment and the abundance of the spawning stock.

There is a need to measure mercury and other persistent contaminants as a function of fish age, especially with lake trout, because of management, ecosystem, and food web changes since 2000 that have caused lake trout and whitefish to reach much older ages than before. DNR and EPA are working on a solution that would allow the determination of age of each lake trout sampled for mercury contamination. DNR recently published a technique that permits determination of age for lake trout from an external structure (maxillary bones) rather than from otoliths (ear bones, which require incision into the fish and loss of tissue and fluids). The maxillary technique appears to give ages that are closely correlated with otolith (state of the art) ages without compromising the analysis of contaminant body burdens (Wellenkamp *et al.*, 2015).

Schaeffer et al (2012) utilized acoustic and midwater trawl surveys of Lake Huron to assess the pelagic prey fish community. Lake Huron now has almost two times greater pelagic biomass than Lake Michigan, but species composition differed. Alewife predominated in Lake Michigan, while pelagic biomass in Lake Huron was comprised of rainbow smelt, bloater, and to a lesser extent, emerald shiner.

Ivan et al (2011) studied walleye and yellow perch dynamics in Saginaw Bay. The results suggest that walleyes and yellow perch trend differently; while the relative abundance of age-0–2 walleyes generally increased and their mean length decreased from 1980 to 2008, the trends in yellow perch abundance and length differed among the young-of-year, yearling, and age-2 age-classes. Thus, we suggest that future

studies evaluating environmental determinants of year-class strength in Saginaw Bay evaluate age-0 walleyes and age-1 yellow perch. Finally, while age-0 yellow perch and age-0 walleyes appear to respond similarly to annual environmental conditions, the recent increase in walleye abundance and decrease in the mean size of age-0 yellow perch may have contributed to the reduced abundance of adult yellow perch via walleye predation and overwinter mortality.

Barbiero *et al.* (2011) studied the pelagic food web in Lake Huron and whether it has shifted to bottom-up control. The magnitude of the spring bloom in the open waters of Lake Huron has declined dramatically in recent years, beginning in 2003. May chlorophyll values, as estimated by SeaWiFS imagery, for 2003–2006 have been 50–60% of 1998–2002 values. Reductions in the spring bloom have been closely associated with abrupt declines in Cladoceran populations, as well as with declines in cyclopoid copepod populations. In addition, *Daphnia* population egg ratios in August exhibited a pronounced decrease between 2002 and 2003 and have remained depressed through 2005. Taken together, these data suggest a role for reduced food supply in the dramatic shifts seen in the Lake Huron crustacean zooplankton community since 2003. Additionally, summer chlorophyll values have shown signs of decline in 2005 and 2006 in spite of the historically low populations of Cladocerans, suggesting that control of summer phytoplankton populations in Lake Huron is determined by nutrient supply rather than grazing pressure.

He *et al.* (2015) and Johnson *et al.* (2015) point to the likelihood that walleye cannot be restored to levels called for in Fish Community Objectives (FCOs; DesJardine *et al.*, 1995). There is a growing awareness that the same may be true for lake trout recovery. While both species have become self-sustaining, the prey base appears to be limiting further population growth. Both species are far below population levels necessary to meet FCOs. Predation intensity is presently at least as high as when Chinook salmon were abundant (He *et al.*, 2015). Size at age of both walleye (Fielder and Thomas, 2014) and lake trout have declined sharply suggesting density-dependent, prey-limited conditions are now shaping growth parameters. He *et al.* (2015) and Johnson *et al.* (2015) recommend that top-down forces may be contributing to the depressed state of the prey community (in addition to bottom-up forces noted by Bunnell *et al.*, 2014).

One key uncertainty identified by these authors is the status of round gobies in Lake Huron. Round goby consumption by whitefish, lake trout, and walleye estimated by He *et al.* (2015) suggests that the prey assessment by USGS greatly underestimates goby abundance and biomass in Lake Huron (and thus most likely in Lake Michigan as well). He *et al.* (2015) also found that whitefish are the largest consumers of round gobies of all Lake Huron predators. Whitefish are far more numerous than lake trout and walleye and their transition to piscivory dramatically escalates predation rates in Lake Huron. None of the prey assessments in place in Lake Huron is directed at round gobies or is appropriate for estimating round goby abundance, yet round goby has replaced the alewife as the principal prey for most predators in Lake Huron. It will be impossible to adequately assess predator/prey balance in Lake Huron without a more accurate measure of goby abundance and biomass.

Barbiero *et al.* (2012) reported on the convergence of the trophic state and the lower food web in lakes Huron, Michigan, and Superior. Signs of increasing oligotrophication have been apparent in the open waters of both Lake Huron and Lake Michigan in recent years. Spring total phosphorus (TP) and the relative percentage of particulate phosphorus have declined in both lakes; spring TP concentrations in Lake Huron are now slightly lower than those in Lake Superior, while those in Lake Michigan are higher by only about 1 µg P/L. Transparencies in Lakes Huron and Michigan have increased, and in most regions are currently roughly equivalent to those seen in Lake Superior. Seasonality of chlorophyll, as estimated by SeaWiFS satellite imagery, has been dramatically reduced in Lake Huron and Lake Michigan, with the spring bloom largely absent from both lakes and instead a seasonal maximum occurring in autumn, as is the case in Lake Superior. Decreases in *Diporeia* in offshore waters have resulted in abundances of non-Dreissenid benthos communities in these lakes that approach those of Lake Superior. These changes have



resulted in a distinct convergence of the trophic state and lower food web in the three lakes, with Lake Huron more oligotrophic than Lake Superior by some measures.



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## 5

## 2012 CSMI Program Reports and State of Lake Huron

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### 5.1 2012 CSMI Agency Overview

#### 5.1.1 Michigan DNR

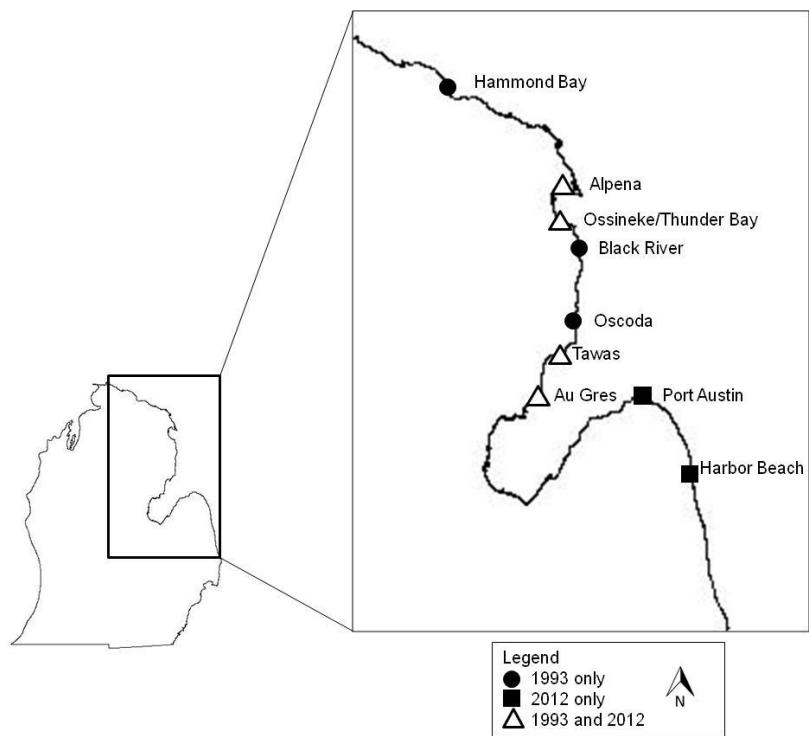
The Michigan Department of Natural Resources (DNR) 2012 CSMI funding was allocated in two directions:

- Beach zone investigations – subcontracted to Central Michigan University
- Nearshore fish community (from beyond beach zone to 30 m depth contour) – conducted by Michigan DNR Alpena and Lake St. Clair Fishery Research Stations.

The chief component of beach zone investigations was to compare species compositions and catch rates in beach seine netting between 2012 and a previous nearly identical survey conducted in 1993, prior to Dreissenid colonization. A graduate student project was completed and thesis delivered (Loughner *et al.*, 2014). A summary of the nearshore thesis research is below.

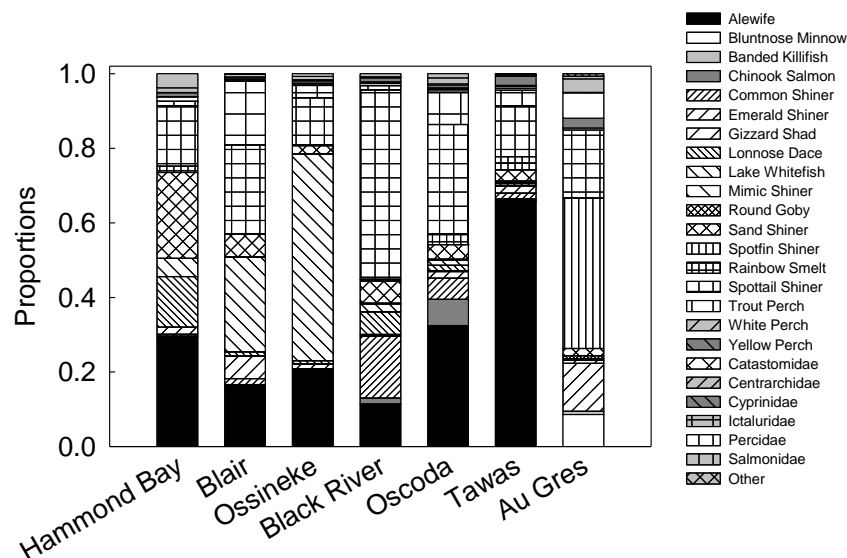
From Loughner et al (2014), Lake Huron has undergone dramatic shifts in fish community composition as a result of invasive species introductions and food web changes. In particular, Zebra Mussels and Round Gobies have greatly impacted near-shore fish communities. Our objective was to assess near-shore fish communities of western Lake Huron and compare species composition post invasion to species composition in 1993, prior to the invasion of Zebra Mussels and Round Gobies. Beach fish communities were sampled by nighttime beach seining during spring and summer 2012 in the western basin of Lake Huron along the Michigan shoreline. Our results show that overall the nearshore beach fish assemblage species composition of 1993 is different from 2012. There is a reduced number of species present in 2012, and the composition of species has changed dramatically from 1993. The species composition has shifted from an Alewife, Salmonid and Smelt dominated community to a Round Goby, Cyprinid, and Percid dominated community. The observed shift in species composition is largely due to the introduction of invasive species; however, anthropogenic impacts such as shoreline modifications and habitat alterations are also likely to be contributing factors.



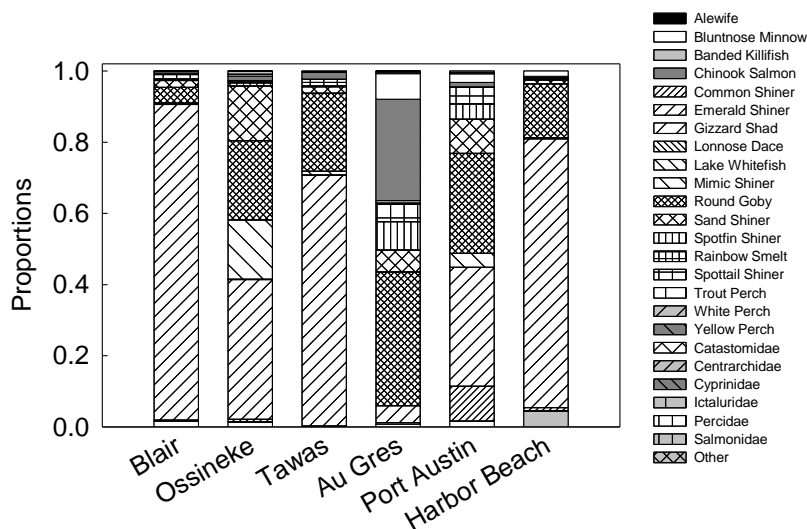


**Figure 25 Sampling Locations of MDNR transects**





**Figure 26. Proportions of species captured in spring 1993.**



**Figure 27. Proportions of species captured in spring 2012.**

The nearshore fish community study focused on two locations: Thunder Bay (North-central Lake Huron) and Lexington (“Thumb” area of Lake Huron). These two sites represent a broad littoral zone/protected bay environment with a large tributary (Thunder Bay) and a Main Basin shore site lacking protection or tributary (Lexington). The results were compared between stations and with Saginaw Bay where a long-term data series has been maintained and, for smallmouth bass, with a shallow station in Lake Michigan. The Principal Investigator (Johnson) for the DNR Alpena Fishery Research Station proposed a nearshore food web symposium for the 2014 International Association for Great Lakes Research (IAGLR) meeting and led the process of soliciting and screening papers. CMU moderated the session. The results of the

DNR work, including CMU's beach zone findings, were presented at the symposium, hosted at the May 2014 IAGLR meeting in Hamilton, Ontario. The abstracts of these papers are appended to this report.

A manuscript giving the results of the DNR's nearshore fish community study is in preparation and will be submitted to the *Journal of Great Lakes Research*.

#### IAGLR Abstracts

JOHNSON, J.E.<sup>1</sup>, WELLENKAMP, W.<sup>1</sup>, and ZELLINGER, J.<sup>2</sup>, <sup>1</sup>Michigan Department Natural Resources, Alpena Fisheries Research Station, Alpena, MI; <sup>2</sup>Michigan Department of Natural Resources, Lake St. Clair Fisheries Research Station, Mt. Clemens, MI. Effects of Changing Food Web and Nutrient Loading on the Nearshore Fish Community of Thunder Bay, Lake Huron.

In 2012 resource agencies combined to focus on spatial structure and composition of Lake Huron food webs. The focus of this presentation is the nearshore fish community in Thunder Bay, Lake Huron. Bottom trawl catches of age-0 whitefish fell to the lowest level in a 27-year time series and total trawl catch fell steadily after 1997. Alewife catches fell to near zero. Walleye catch rates in gillnets were relatively high in June but fell 86% by August. Smallmouth bass catch rates were far below those of other Great Lakes sites at similar latitudes. Age-0 yellow perch and other species apparently avoided daytime bottom trawls but were caught by night trawling and in micromesh gillnets. Few yellow perch older than age 1 were sampled. The Thunder Bay River was a significant source of nutrients to the bay during the 1960s-80s, but nutrient loads have fallen. There was no evidence that Thunder Bay's fish community benefited from nutrients of the River in 2012. Ecosystem re-engineering by Dreissenid mussels and proliferations of benthic algae may have negatively affected nearshore fish communities by depriving the water column of nutrients, particularly during spring when many species of larval fish require small zooplankton for first feeding. *Keywords: Fish behavior, Invasive species, Food chains, Nutrients.*

WILLS, T.<sup>1</sup>, JOHNSON, J.E.<sup>2</sup>, THOMAS, M.V.<sup>1</sup>, FIELDER, D.G.<sup>2</sup>, and ZELLINGER, J.<sup>1</sup>, <sup>1</sup>Michigan Department Natural Resources, Lake St. Clair Fisheries Research Station, Mt. Clemens, MI; <sup>2</sup>Michigan Department Natural Resources, Alpena Fisheries Research Station, Alpena, MI. Does "Nearshore Phosphorus Shunt" Translate to Higher Abundance of Nearshore Fish?

Invasive Dreissenid mussels and round gobies are thought to redirect energy flow from the pelagic to benthic zone and from offshore to nearshore, an outcome commonly referred to as nearshore/benthic shunt (NBS). Nutrients from tributaries are likewise subject to NBS. To test the hypothesis that NBS fuels heightened fish production in the nearshore we sampled two bays with differing tributary nutrient loading rates and one nearshore site with no tributary. Fish catch rates were lowest at Thunder Bay, the site with lower nutrient loading and highest at Saginaw Bay, where loading was highest, but both exhibited declines over time. Thunder Bay's catch rates declined since NBS and were lower than the site with no tributary. Walleye were evident in all areas but other research suggests walleye biomass has declined since NBS. Our findings indicate NBS is not translating into greater fish abundance, and productivity remains sequestered in forms not readily available to the fish community, such as dreissenids and *Cladophora* spp. Fish population indices were highest in proximity to the Saginaw River but there was no discernable benefit of proximity to the less productive Thunder Bay River. The effects of NBS were evidently detrimental to productivity of these nearshore fish communities. *Keywords: Invasive species, Food chains, Fish.*

#### 5.1.2 Michigan DEQ

The Michigan Department of Environmental Quality (MDEQ) recapped restoration efforts and progress in the Saginaw Bay watershed in a recent article in JGLR (Selzer *et al.*, 2014). Topics discussed include



actions to reduce sediment and nutrient loading from contributing watersheds, reducing elevated bacteria levels, protecting and restoring aquatic habitat, and remediating food web contamination. The authors identified five major action areas for future efforts: (1) targeting phosphorus load reductions, (2) linking watershed-based models with the Saginaw Bay Ecosystem Model 2 to replicate efforts underway in the Western Lake Erie Basin, (3) implementing large-scale conservation practices coupled with assessment and monitoring, (4) conducting additional research to understand what actions can be taken in nearshore ecosystems to reduce occurrence of nuisance algal and macrophytic growth, and (5) continuing and improving upon collaboration efforts between all stakeholders involved in restoring the Saginaw Bay region (Selzer *et al.*, 2014).

### 5.1.3 USGS

The USGS provided references to summarize recent research (Bunnell *et al.*, 2014; Bunnell, 2014; Riley *et al.*, 2014; O'Brien *et al.*, 2014; Roseman *et al.*, 2015). A summary of those papers is below.

Bunnell, D. B., R. P. Barbiero, S. A. Ludsin, C. P. Madenjian, G. J. Warren, D. M. Dolan, T.O. Brenden, R. Briland, O.T. Gorman, J. X. He, T. H. Johengen, B. F. Lantry, T. F. Nalepa, S. C. Riley, C. M. Riseng, T. J. Treska, I. Tsehaye, M. G. Walsh, D. M. Warner, and B. C. Weidel. 2014. Changing ecosystem dynamics in the Laurentian Great Lakes: bottom-up and top-down regulation. *BioScience* 64:26-39

A recent paper that included 20 co-authors (and spanned ten agencies and institutions) compiled ecosystem level indicators across all five Great Lakes, with the primary goal of identifying common trends and exploring the relative importance of bottom-up and top-down regulation. The time series revealed increasing water clarity and declining trends in phytoplankton, native invertebrates, and prey fish in at least 3 of 5 lakes since 1998. Lake Huron demonstrated the strongest evidence for bottom-up regulation, as phytoplankton, zooplankton, prey fish, and piscivores all revealed patterns consistent with limiting resources. Evidence for top-down regulation was limited to piscivores controlling prey fish in Lake Michigan. We hope these findings stimulate future mechanistic research to evaluate these correlative findings. Finally, our synthesis identified priority gaps in monitoring and knowledge for Great Lakes ecosystems.

2014. Bunnell, D.B. Update of USGS food-web research on Lake Huron during 2012 CSMI year. Presentation given at Great Lakes Fishery Commission Lake Huron Committee Meeting. Windsor ON March 24, 2014

Data not consistent with a nearshore shunt in Lake Huron. When spatial patterns occurred, highest biomass (zooplankton) was offshore. (Similar trends in lakes Michigan and Superior!)

Still being processed: benthos and fish diets.

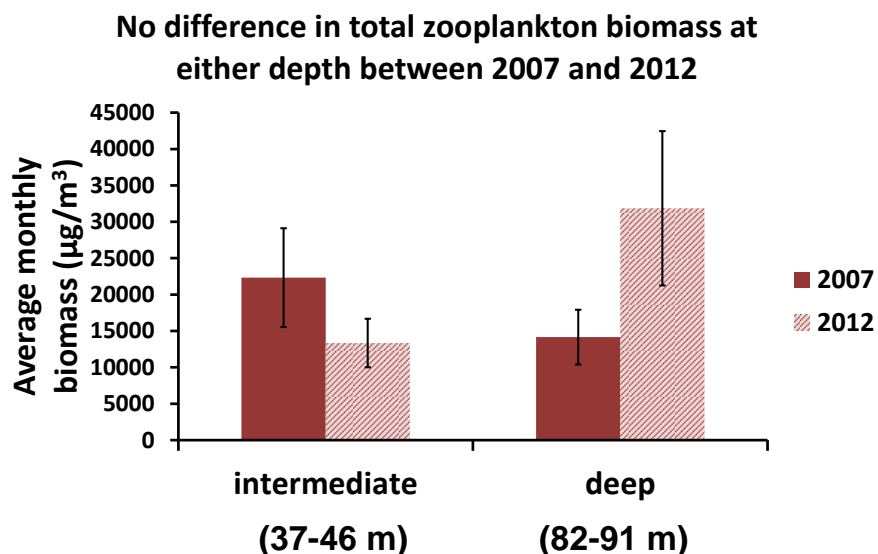
Future work:

Revisit bioenergetics modeling with vertical and horizontal distributions of planktivores and their zooplankton prey.

Submit manuscript showing *Bythotrephes* densities are ~50% lower in the day than at night (gear avoidance).



## Hammond Bay



**Figure 28. Average monthly biomass of zooplankton at Hammond Bay nearshore and offshore sites between 2007 and 2012.**

2014. Timothy P. O'Brien, David M. Warner, Steven A. Farha, Darryl W. Hondorp, Lisa Kaulfersch, and Nicole Watson. Status and Trends of Pelagic Prey Fish in Lake Huron, 2013. USGS. Compiled Reports to the Great Lakes Fishery Commission of the Annual Bottom Trawl and Acoustic Surveys, 2013. Presented at Great Lakes Fishery Commission Lake Huron Committee Meeting March 24, 2014, Windsor, Ontario

During 2014, prey availability for piscivores will likely be similar to that seen in other recent years. Alewife biomass remains low, and there has been no trend in pelagic fish biomass since 2004. The Lake Huron forage base still remains low compared to previous decades when alewife, rainbow smelt, and bloater were more abundant. Lake-wide pelagic biomass in Lake Huron in 2013 (6.1 kg/ha) was nearly identical to biomass in Lake Michigan (6.1 kg/ha) and similar to Lake Superior during 2011 (6.8 kg/ha). There is, however, a key difference between the three lakes. In Lake Michigan, alewife are still prevalent and comprise about 77% of the pelagic biomass, while in the other two lakes, the biomass of this species is negligible.

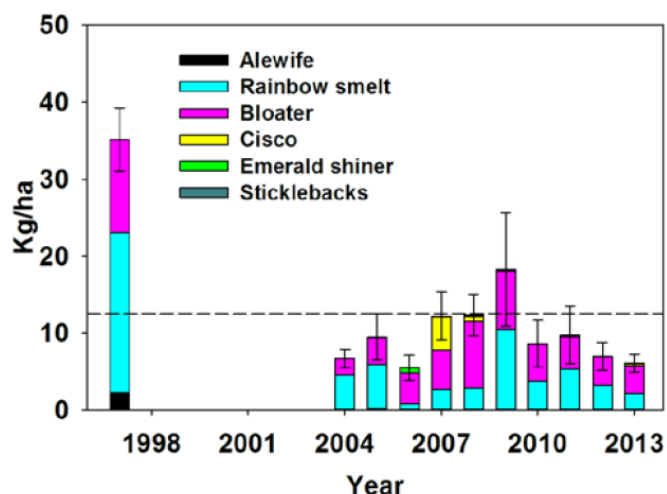


Figure 11. Lake-wide mean pelagic fish biomass in Lake Huron, 1997-2013. Error bars are 95% confidence intervals. The horizontal line denotes the 1997-2012 mean.

**Figure 29. Lake-wide mean pelagic fish biomass in Lake Huron, 1997-2013.**

2014. Stephen C. Riley, Edward F. Roseman, Margret A. Chriscinske, Taaja R. Tucker, Jason E. Ross, Patricia M. Armenio, Nicole Watson, and Whitney Woelmer. Status and Trends of the Lake Huron Offshore Demersal Fish Community, 1976-2012. Compiled Reports to the Great Lakes Fishery Commission of the Annual Bottom Trawl and Acoustic Surveys, 2013. Presented at the Great Lakes Fishery Commission Lake Huron Committee Meeting on March 24, 2014, Windsor, Ontario

The abundance of prey fish in Lake Huron has remained at very low levels since the collapse of the offshore demersal fish community (Riley et al. 2008), although survey catches in 2012 suggested that several species were beginning to increase in abundance. The estimated lakewide biomass of prey fish in 2012 was the highest reported since 2001, but the 2013 estimate is approximately half as high as 2012. The estimated biomass of YAO rainbow smelt and alewife in 2013 were lower than in 2012 and remained low compared to earlier data, and these populations were dominated by small fish. The reduction in the abundance of these exotic species is consistent with fish community objectives for Lake Huron (DesJardine et al. 1995), but does not bode well for Chinook salmon populations in the lake (Roseman and Riley 2009), which rely on these species as prey.

2015. Roseman, E.F., Chrisinske, M., Castle, D., Bowser, D. Status and Trends of the Lake Huron Offshore Demersal Fish Community, 1976-2014. Compiled Reports to the Great Lakes Fishery Commission of the Annual Bottom Trawl and Acoustics Surveys, 2014. pp. 73-85.

The USGS Great Lakes Science Center has conducted trawl surveys to assess annual changes in the offshore demersal fish community of Lake Huron since 1973. Sample sites include five ports in U.S. waters with less frequent sampling near Goderich, Ontario. The 2014 fall bottom trawl survey was carried out between 12 October and 3 November 2014 and included all U.S. ports, as well as Goderich, ON. The 2014 main basin prey fish biomass estimate for Lake Huron was 36 kilotonnes, less than half of the estimate in 2012 (97 Kt), and approximately 10 percent of the maximum estimate in the time series. The biomass estimate for adult alewife in 2014 was lower than in 2013 and much lower than levels observed before the crash in 2004. Estimated biomass of rainbow smelt also decreased and was the second lowest observed in the time series. Estimated adult bloater biomass in Lake Huron increased slightly over the 2013 estimate but remains lower than the long-term average. YOY alewife, rainbow smelt, and bloater

abundance and biomass decreased over 2013. Biomass estimates for deepwater sculpins, trout-perch, and ninespine stickleback in 2014 were lower than in 2013 and remained low compared to historic estimates. The 2014 biomass estimate for round goby was lower than 2013. Wild juvenile lake trout were captured again in 2014, suggesting that natural reproduction by lake trout continues to occur.

#### 5.1.4 NOAA-GLERL

Much of GLERL's 2012 CSMI effort in Lake Huron was centered on two major programs:

- **Mapping of bottom-dwelling organisms:** This sub-project continues work begun in Lake Huron in 2000 to assess trends (population sizes, spatial distribution, etc.) in lake-wide benthic populations, including zebra and quagga mussels.
- **Structure and function of the open water food web:** This sub-project examined horizontal and vertical distribution of plankton, larval fish, juvenile fish, adult fish, and the opossum shrimp along a long transect extending from shallow water in Thunder Bay to far offshore using a variety of advanced tools to examine fine-scale spatial distribution. The experiment was designed to relate changes in phytoplankton and light to impacts of invasive zebra and quagga mussels. This intensive field sampling is allowing detailed comparison to the Lake Michigan food web.

A few interesting results from the 2012 cruises are described below.

##### Benthic sampling:

In 2012, benthic samples were collected at 80 sites in the main basin of Lake Huron to assess trends in major taxa since 2007. Over this 5-year period, the mean density of quagga mussels declined at depths <50 m, but continued to increase at depths >50 m. At these latter depths, mean density increased 4-fold between 2007 and 2012 (220 m<sup>-2</sup> to 943 m<sup>-2</sup>). On the other hand, the amphipod *Diporeia* continued to decline. In 2012, it was not found at <50 m and mean density was only 160 m<sup>-2</sup> at depths >50 m. In 2000, mean density at this depth interval was 1,700 m<sup>-2</sup>. One surprising result was the continued high density of oligochaetes at <30 m. These detritivores may be responding to increased organic inputs to the benthic region as a result of the nearshore nutrient shunt by mussels into feces and pseudofeces.

##### Pelagic sampling:

Fine-scale vertical resolution of physical variables and biological variables was measured using the NOAA plankton survey system (PSS) along the Thunder Bay transect during April, July, and September. Samples were also collected and analyzed for nutrient concentrations and ratios (C:N:P), and zooplankton and larval fishes at fixed stations (10-m, 18-m, 45-m, and 82-m depths) in the epi-, meta-, and hypolimnion. Contrasting results of daytime and night transects are shown in Figures 31 and 32, respectively.

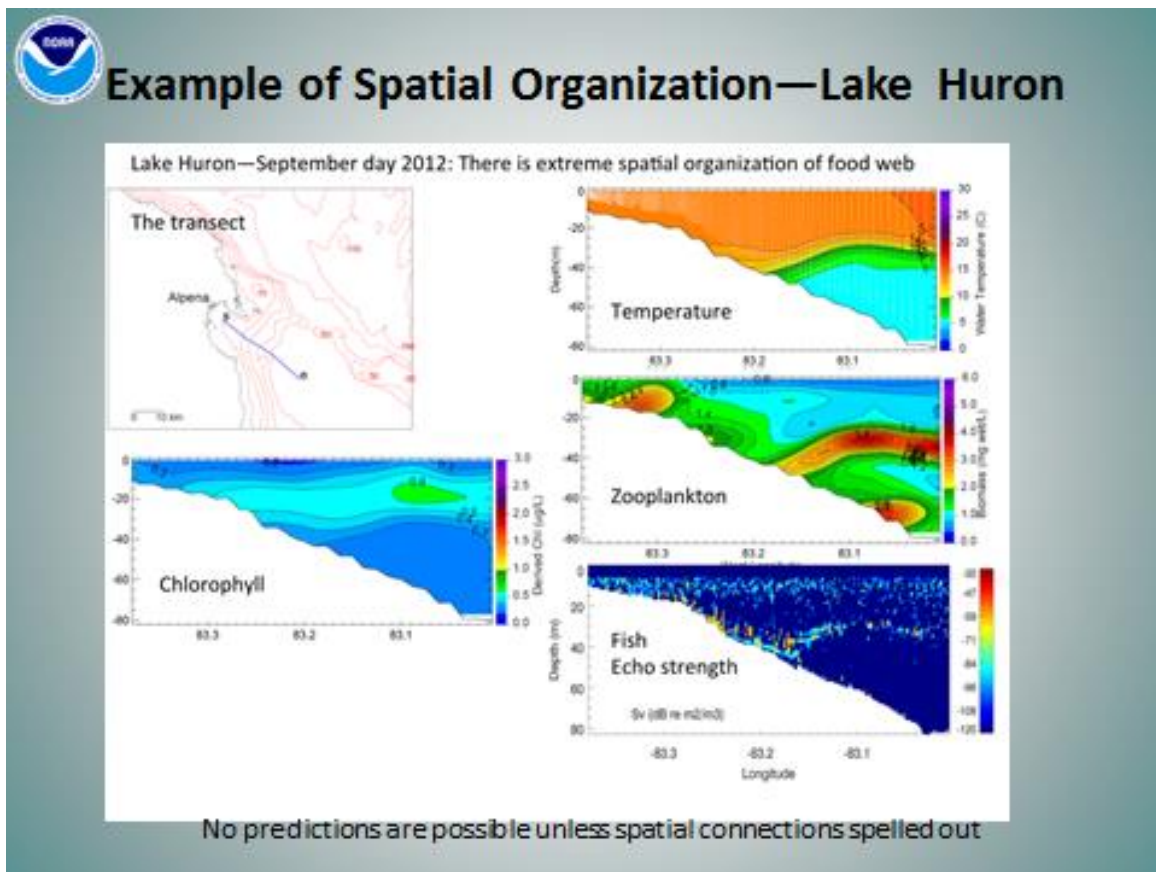
In April, nutrients and chlorophyll a were lowest at the nearshore sites, but in July they were higher at 18 m and 46 m than at other sites, and equal to other sites in September. Mass carbon to nitrogen ratios indicated little nutrient stress on phytoplankton. PSS and acoustic surveys of plankton and fish biomass indicated low chlorophyll a, zooplankton and fish biomass nearshore in April, but highest biomass near shore in July. Plankton and fish biomass were highly concentrated along base of the metalimnion in July and September.

Catches of fish larvae in ichthyoplankton nets were lower in April than July. In July, larvae densities were highest in the metalimnion at mid-depth and offshore sites. Growth rates estimated from otolith increments indicated newly hatched lake whitefish larvae caught in April grew slowly at nearshore sites

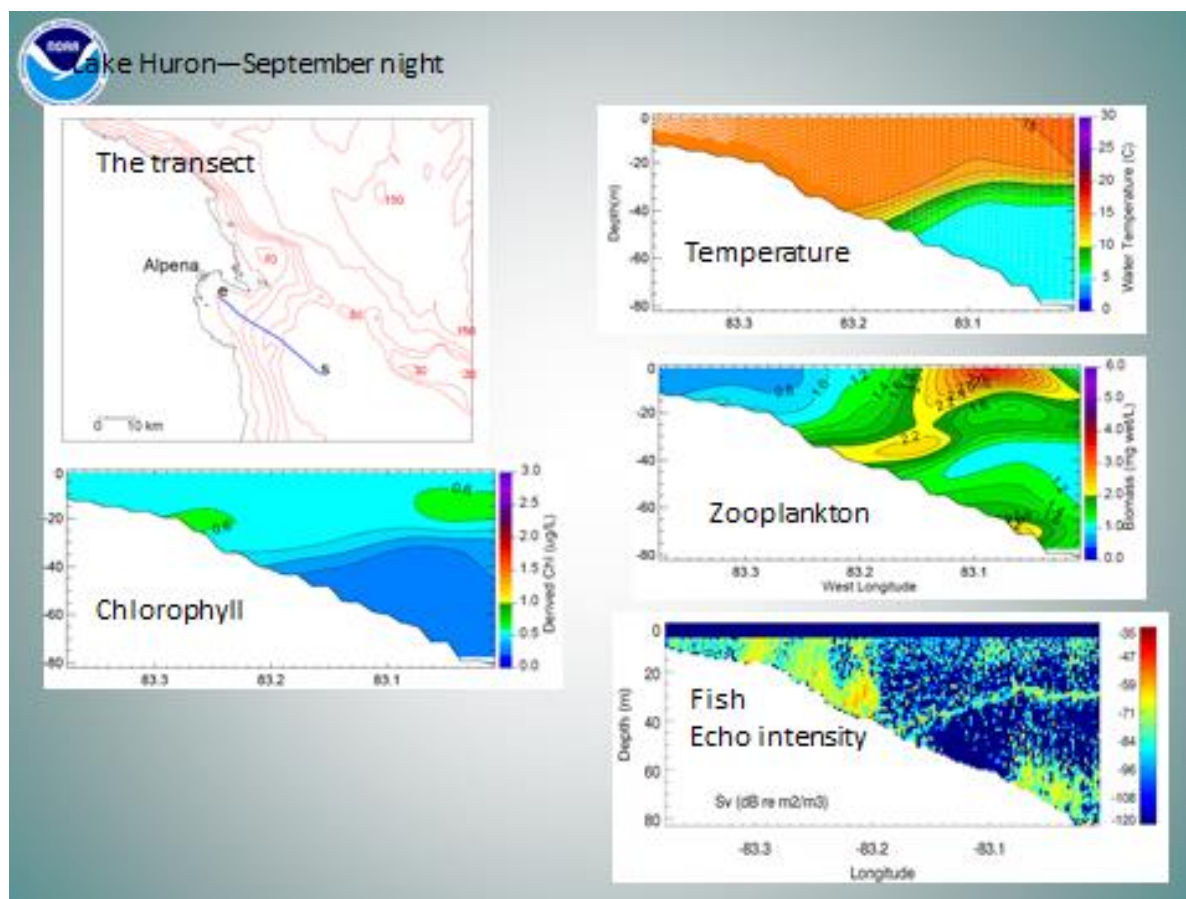




where plankton densities were lowest, whereas other larvae taxa hatched later in June and July grew faster at near shore and mid depth sites where plankton densities had increased. Stomach content analysis of fish larvae caught in July at near shore and mid-depth sites indicated larvae consumed *Bosmina* spp. and copepods. Availability and density of nutrients and zooplankton relative to fish larvae may explain the continued failed recruitment of lake whitefish in Thunder Bay. In Saginaw Bay, Pothoven et al. (2014) found that lake whitefish larvae were abundant and recruitment was successful, and the ratio of zooplankton density to lake whitefish larvae density was 30-fold higher than we found in Thunder Bay.



**Figure 30** The day time distribution of temperature, chlorophyll, zooplankton, and fish along the Thunder Bay transect during the day.



**Figure 31** The same transect sampled at night.

These and other observations show that zooplankton is organized in relatively narrow bands in deep water to possibly avoid visual feeding by *Bythotrephes* from above and by fish near the bottom during the day; at night they migrate into warm surface waters. Net tows show the same broad pattern, but only the PSS shows fine-scale resolution. Note also that chlorophyll concentrations are very low in both inshore and offshore regions. This same general trend in chlorophyll was seen in April and July, but chlorophyll concentrations were actually lower inshore than offshore. These trends are very different from the nearshore region of eastern Lake Michigan near Muskegon, where nutrient input from larger rivers stimulates nearshore growth of phytoplankton. The presence of quagga and zebra mussels close to shore in Lake Huron, in contrast to absence in nearshore waters near Muskegon, may be another reason for the difference. Similar to zooplankton and larval fish were generally found in the metalimnion during July. Measured larval growth rates were very low.

### 5.1.5 Environment Canada

Lake Huron data from the CSMI 2012 year are included in a few recent publications. Cruise reports also provide a summary of activities completed as part of Environment Canada's Great Lakes Surveillance Program (GLSP), including one spring and one summer cruise conducted on Lake Huron and Georgian Bay in 2012 (Figure 33). Dove and Chapra (2015) summarize recent offshore data and long-term trends for nutrients in all the Great Lakes, including Lake Huron, and document a general decline in phosphorus and associated oligotrophication, along with increases in nitrogen and silica (Figures 33 and 34). Measurements of legacy contaminants and contaminants of new and emerging concern, reported by Vernier et al. (2014), show generally declining trends of organic contaminants (PCBs, PAHs, pesticides,



etc.) in the Great Lakes, with Lake Huron concentrations among the lowest of all five lakes. Results for BPA, Triclosan and PFCs were very low or not detected. Citations and abstracts follow; internal reports and data files are also available for some results and additional analytes that are not yet published, including 2012 GLSP zooplankton data (contact for the latter: Kelly Bowen). Previous work that supports Lake Huron research on contaminants and other topics is summarized in Chapra *et al.* (2009) and Chapra *et al.* (2012a). Dove *et al.* (2012) presented analytical results for mercury using clean sampling methods that had not been employed previously that showed very low concentrations present in offshore waters of Lake Huron and most other Great Lakes. Recent modeling results and comparison with field data for mercury deposition complement these results (Cohen *et al.*, 2013).

Dove, A. & Chapra, S.C. 2015. Long-term trends of nutrients and trophic response variables for the Great Lakes. *Limnol. Oceanogr.* 60(2):696–721

**Abstract:**

Based primarily on data collected over the past four decades by Environment Canada, long-term trends of eutrophication-related variables are developed for the offshore waters of the Laurentian Great Lakes. Trends of spring concentration are reported for the major nutrient species: phosphorus [total phosphorus (TP), and soluble reactive phosphorus (SRP)]; nitrogen [total oxidized nitrogen ( $\text{NO}_3 + \text{NO}_2$ ), and ammonia nitrogen ( $\text{NH}_3$ )]; and silica [soluble reactive silica ( $\text{SiO}_2$ )]. Summer trends of surface chlorophyll *a* and Secchi depth are developed as indicators of lake trophic response. The results show that phosphorus has declined significantly in all the lakes, whereas nitrogen and silica have both increased. Along with documenting the impacts of the 1978 Great Lakes Water Quality Agreement phosphorus controls and the introduction of Dreissenids, the results demonstrate conclusively that the offshore waters are now overwhelmingly phosphorus limited, which supports the conclusion that controlling phosphorus remains the only viable option for managing the trophic status of the Great Lakes offshore waters.

Vernier, M., Dove, A., Romanak, K., Backus, S., Hites, R. 2014. Flame retardants and legacy chemicals in Great Lakes Waters. *Environmental Science and Technology*. Vol. 48 (16). pp. 9563-9572.

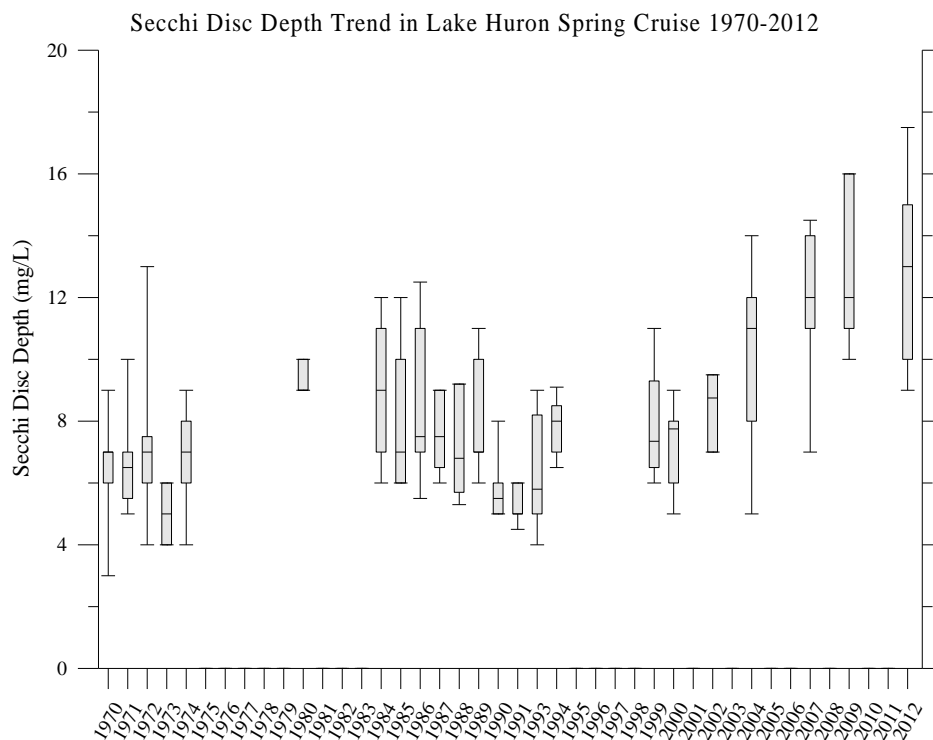
**Abstract:**

The Great Lakes have been the focus of extensive monitoring and research, but recent data on the aquatic concentrations of emerging compounds, such as flame retardants, are scarce. Water samples from 18 stations on the five Great Lakes were collected as part of Environment Canada's Great Lakes Surveillance Program in 2011 and 2012 using XAD-2 resin and analyzed for PCBs, organochlorine pesticides, PAHs, polybrominated diphenyl ethers (PBDEs) and emerging flame retardants, including organophosphate flame retardants (OPFRs). Total PCB concentrations ranged from  $623 \pm 113$  pg/L in Lake Ontario to  $117 \pm 18$  pg/L in Lake Superior. Among the organochlorine pesticides, the most abundant was dieldrin, with the highest average concentration of  $99 \pm 26$  pg/L in Lake Erie, followed by p,p'-DDD with an average concentration of  $37 \pm 8$  pg/L in Lake Ontario. Total PAH concentrations were higher in Lakes Erie and Ontario than in Lakes Michigan, Huron, and Superior. Total PBDE concentrations were highest in Lake Ontario ( $227 \pm 75$  pg/L), and the most abundant congeners were BDE-47, BDE-99, and BDE-209. Total OPE concentrations ranged between  $7.3 \pm 4.5$  ng/L in Lake Huron and  $96 \pm 43$  ng/L in Lake Erie.

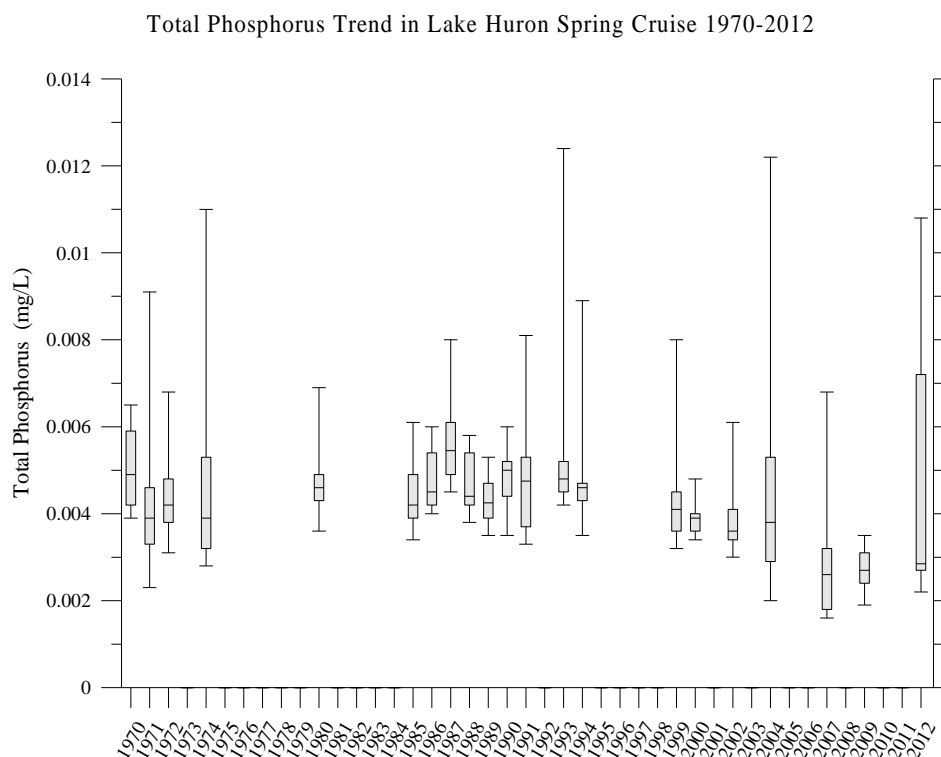




**Figure 32. Environment Canada Sampling Sites**



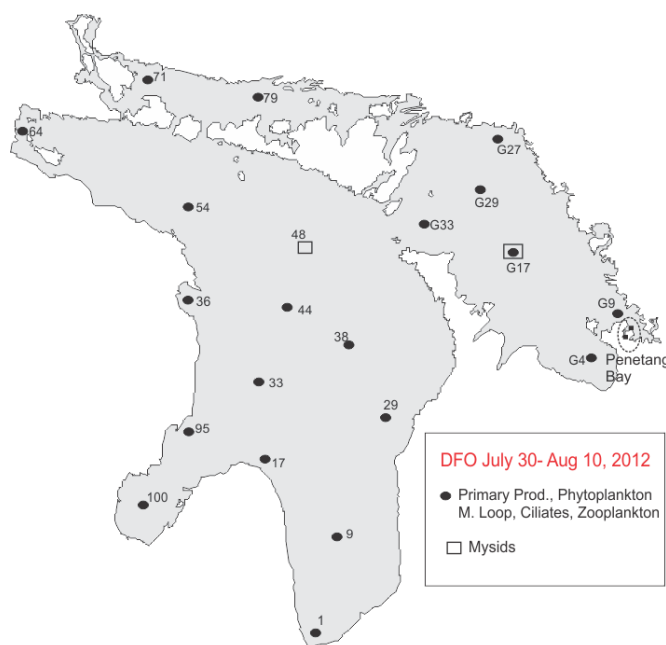
**Figure 33. Secchi disc depth trends during Lake Huron spring cruise 1970-2012 (note: axis units should be meters).**



**Figure 34. Total phosphorus trends during Lake Huron spring cruise 1970-2012.**

### 5.1.6 Department of Fisheries and Oceans

The Department of Fisheries and Oceans (DFO) collected phytoplankton and zooplankton samples on Lake Huron at the stations shown below. However at the writing of this summary, the results were not available.



**Figure 35. Location of DFO sampling sites.**

## 5.2 State of Lake Huron

A summary of the current state of Lake Huron is presented below. This section represents an overview of the major issues.

- Water level fluctuations are having an impact on coastal ecosystems, especially in Saginaw Bay and Georgian Bay. These water level fluctuations are being driven by climate combined with ongoing glacial rebound, especially in northern Lake Huron.
- Much of the lake nearshore waters are displaying symptoms of eutrophication while a significant oligotrophication of offshore waters is being documented. Several lake phenomena are contributing to this condition:
  - Nearshore phosphorus concentrations are highly variable in space and time;
  - Significant nearshore to offshore gradients of P and chlorophyll a are observed;
  - Cha et al. (2011) found that the proportion of tributary phosphorus retained in Saginaw Bay increased from approximately 46-70% when Dreissenids appeared, reducing phosphorus export to the main body of Lake Huron. The combined effects of increased phosphorus retention and decreased phosphorus loading have caused an approximate 60% decrease in phosphorus export from Saginaw Bay to Lake Huron. These results support the hypothesis that the ongoing decline of preyfish and secondary producers including *Diporeia* in Lake Huron is a bottom-up phenomenon associated with decreased phosphorus availability in the offshore to support primary production;
  - Severe declines in spring diatom biomass due to Dreissenid filtering are being observed; and
  - Continuous along-shore nearshore sensor tows (by USEPA GLNPO) show good correlation between land use and nearshore water quality.
- Several recent studies of zooplankton community composition and response to shifting food web dynamics provide indication of stresses in this component of the ecosystem:
  - Barbiero et al (2011) studied the pelagic food web in Lake Huron and whether it has shifted to bottom-up control. The magnitude of the spring bloom in the open waters of Lake Huron has declined dramatically in recent years, beginning in 2003. Taken together, these data suggest a role for reduced food supply in the dramatic shifts seen in the Lake Huron crustacean zooplankton community since 2003. Additionally, summer chlorophyll values have shown signs of decline in 2005 and 2006 in spite of the historically low populations of Cladocerans, suggesting that control of summer phytoplankton populations in Lake Huron is determined by nutrient supply rather than grazing pressure.
  - Barbiero et al (2012) reported on the convergence of the trophic state and the lower food web in lakes Huron, Michigan, and Superior. Signs of increasing oligotrophication have been apparent in the open waters of both Lake Huron and Lake Michigan in recent years. These changes have resulted in a distinct convergence of the trophic state and lower food web in the three lakes, with Lake Huron more oligotrophic than Lake Superior by some measures.
  - *Mysis* are facing starvation in Lake Huron; and
  - Bythotrephes account for 78% of all zooplankton consumption
- There appears to be a continued decline of *Diporeia* through 2007 – 2012, although the numbers for 2012 are not yet available;
- A continued decline of legacy toxics (PCBs, Hg) in sediments and food web has been observed;
- The state of Saginaw Bay has been well-documented by the NOAA-GLERL multi-institution multi-stressor study:



- Saginaw Bay TP and chlorophyll a do not meet current targets of 15 and 3.6 µg/L, respectively; and Saginaw Bay load target of 440 MTA is almost never met;
- HABs (*Microcystis* ) are still a problem in Saginaw Bay;
- Burrowing mayflies are recovering in Saginaw Bay;
- High concentrations of fecal bacteria have been measured in muck around Saginaw Bay;
- Saginaw Bay benthic primary producers include a variety of species: cladophora, spirogyra, chara, vascular aquatic vegetation. All contribute to muck on beaches;
  - Most growth is in the 2-4 m depth range;
  - Most limited by light and P.
- There has been a large increase in benthic algal mats along the southeast shoreline of Lake Huron from 1970s to 2007:
  - Cladophora have shown a strong correlation with Dreissenid biomass;
- Fish (muskellunge, northern pike) nursery habitat in Georgian Bay has been adversely affected by low water levels;
- Natural reproduction of lake trout has been observed through 2012;
- The overall health of the St. Marys River fish community compared favorably with relatively un-impacted sites from Lake Huron; and
- There still has been no measurable recovery of the alewife population since its collapse in 2003.



## 6

## Data Gaps, Emerging Issues, and Recommendations for 2017 CSMI Program

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### 6.1 Recommended components of 2017 CSMI program

Based on the above synthesis, the following bullets in this section comprise a list of activities that we would recommend for the 2017 CSMI program. These activities are based on the existing knowledge base on Lake Huron and the need to continue to develop that knowledge base for supporting management decisions. There is some overlap with what has already been suggested for 2017 CSMI summarized below in section 6.2.

- There is still a need to understand the reasons for recent shifts in zooplankton community structure
  - Roles of Bythotrephes and Leptodora, invasive predatory zooplankton
  - Top-down (predatory zooplankton, disappearance of alewife) vs bottom-up (i.e., phytoplankton food supply, oligotrophication) mechanisms?
- There is a need to determine the cause/s of Mysis starvation in Lake Huron.
- Continued work on understanding the causes for increases in benthic primary production, particularly in Saginaw Bay and along the southeast shoreline of the lake. In particular, the role of Dreissenids needs to be quantified.
- There should be continued monitoring of water, sediments, and biota concentrations of identified chemicals of mutual concern in the Main Basin, Georgian Bay, and the North Channel.
- There is a strong need for ongoing research and monitoring to better quantify and understand the cause-effect relationships for the nearshore-offshore gradients in the lake. These data and understanding can be synthesized in the Lake Huron ecosystem model recommended in section 6.3 below. This component of the ongoing work on nearshore-offshore gradients should include:
  - Continued nearshore continuous transect work with the EPA towed *in situ* sensor array;
  - Develop and monitor more nearshore to offshore transects as Bunnell did in 2012, but going forward select sites more adjacent to tributaries, also placing more emphasis on the vertical dimension of productivity;
  - Continue periodic spatially detailed inventory of Dreissenid densities in the lake (Tom Nalepa has done lakewide survey in 2012, but data are not available yet);
  - Continue remote sensing of nearshore productivity by organizations such as Michigan Tech Research Institute; and
  - Continue Canadian measurements and research on nearshore primary productivity in the southeastern part of the lake.
  - Similar work should take place in Georgian Bay and the North Channel. A conceptual model of how the Georgian Bay system works.
- Continue work relating coastal wetland flora and fauna community health and diversity to water level fluctuations, including ongoing study of Georgian Bay wetlands in response to lake levels



- There are several fisheries-related questions that warrant ongoing investigation related to the fish community structure and function and response to the changes in the lake's carrying capacity for this community:
  - Continue development of knowledge base of natural reproduction of Atlantic salmon in Saint Marys River;
  - Follow-up on the lake managers' perception that climate change will be a threat to a healthy fishery. The manager survey identified gaps in knowledge related to climate impacts on fish populations, trophic interactions, and habitat. Research should first focus on species of commercial and recreational interest, because management/restoration plans already exist and it is unclear how climate change could impact those plans;
  - Wagner et al (2010) studied lake whitefish dynamics and implications for management. The authors did not find relationships between spatial patterns in fish health indicators and estimates of natural mortality rates for the stocks. The research highlights the complexity of the interactions between fish nutritional status, disease dynamics, and natural mortality in wild fish populations. Additional research that identifies thresholds of health indicators, below (or above) which survival may be reduced, will greatly help in understanding the relationship between indicators measured on individual fish and potential population-level effects.
  - Ivan et al. (2011) studied walleye and yellow perch dynamics in Saginaw Bay. The results suggest that walleyes and yellow perch trend differently; while the relative abundance of age-0–2 walleyes generally increased and their mean length decreased from 1980 to 2008, the trends in yellow perch abundance and length differed among the young-of-year, yearling, and age-2 age-classes. Thus, we suggest that future studies evaluating environmental determinants of year-class strength in Saginaw Bay evaluate age-0 walleyes and age-1 yellow perch. Finally, while age-0 yellow perch and age-0 walleyes appear to respond similarly to annual environmental conditions, the recent increase in walleye abundance and decrease in the mean size of age-0 yellow perch may have contributed to the reduced abundance of adult yellow perch via walleye predation and overwinter mortality.
  - Continue adaptive management related monitoring of sea lamprey control program, especially in the Saint Marys River. This includes continued monitoring of the fish community in Saint Marys River and effects of invasives on that community;
  - Continue development and standardization of hydroacoustic methods for conducting and interpreting fish surveys;
  - Conduct surveys of round goby in coastal wetlands;
  - Continue studies to understand reasons for failure of recovery of alewife after the 2003 cold winter collapse?
  - Continue to document transition from hatchery stocked lake trout population to wild natural reproducing population
  - Many fishery managers believe that valuable information related to climate change, particularly long-term datasets, already exist but have not been made easily accessible or brought to their attention. Finally, in order to increase the awareness and use of their climate research, researchers should present at relevant meetings in addition to just emailing reports and publishing scientific manuscripts.
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## 6.2 Lake Huron Cooperative Science and Monitoring Questions and Needs: 2017 CSMI

A running tally of science and monitoring questions and needs to be considered for the 2017 year of intensive study are found below. They were assembled using the following information:

- Lake Huron Technical Committee (Sarnia, January 20-22, 2015)
- Lake Huron Technical Committee: Priority Research Questions (Nov. 2014 version)
- Mini-Conference on Lake Huron Food Web and Science Needs (MSU, Dec 2014)
- Previous science and monitoring priority setting workshops
- Personal communication

### 6.2.1 Habitat Connectivity:

- What long-term trade-offs for the Lake Huron fish community would result from removal of barriers that restrict movement of potadromous fishes? Which barrier designs or strategies would allow passage of non-jumping fish, such as sturgeons, suckers, and walleyes, while preventing passage of sea lampreys and other invasive species? Determine scope and extent of sea lamprey habitat above selected dams. Determine which barriers should be targeted for removal. (\*LHTC Priority; Previous CSMI priority, Biodiversity Conservation Strategy)
- What is the extent of dam-sequestered nutrients (refer to Lisa Fogerty's work and expand; 2012 focus).
- How do fluctuating water levels, habitat alteration/loss/fragmentation and climate change influence fish productivity and species diversity? (LHTC; Biodiversity Conservation Strategy)

### 6.2.2 Fisheries Related Priority Research (LHTC)

- How has fish production potential changed in Lake Huron as a result of shifts in energy cycling/pathways? What are the implications for fisheries and species diversity? (\*LHTC Priority)
- What factors control the distribution and structure of Lake Huron's prey fish populations, including cisco? (\*LHTC Priority)
- What strategies can be employed to expand cisco beyond its current range and limited population size in order for it to become a major prey item in Lake Huron? (LHTC)
- How do invasive species affect the productivity and stability of Lake Huron fish populations?(LHTC)
- What factors influence early life survival of lake trout and what is the relative importance of these factors on recruitment to the adult stage? (LHTC)
- What level of stock discrimination exists in Lake Huron's ecologically significant fish stocks, including lake trout, Lake Whitefish, walleye and cisco? How does stock intermixing affect the stability of exploited fish stocks? (LHTC)
- Improve lakewide estimates of fish production at different trophic levels and knowledge of seasonal growth patterns and .... (mortality??)
- Focused monitoring and research on priority management areas as per Environmental Objectives and Biodiversity Conservation Strategy
- Improve understanding of Walleye population, source populations, and nursery habitat.
- Establish additional radio-telemetry arrays around the Lake Huron basin to better understand migratory fish movement
- Conduct hydro-acoustic surveys in Georgian Bay to build on US information. Identify possible refugia for alewife and enhance cisco data.
- Has catchability in surveys and fisheries changed over time and, if so, how does this influence our assumptions about fish stocks? (LHTC)



- Is excessive predation (e.g., on early life stages) and lack of an alternative prey species now that alewives are gone, limiting yellow perch and smallmouth bass survival and the development of a fishery?(Jim Johnson)
- Can we prove that the failure of whitefish to reproduce is due to lack of spring plankton for first-feeding fry? Are other small-mouth-gape fish similarly affected by lack of food at first feeding? (Jim Johnson)
- Are findings at Lexington and Alpena in 2012 generally applicable to Main Basin ports? (Jim Johnson) (Jim Johnson)

### 6.2.3 Nutrient Cycling, Productivity, and Food Web Dynamics:

- Need to quantify the magnitude of energy/nutrients shunted along the gradient from nearshore to offshore (2012 CSMI; LHTC; MSU Conference). How does Georgian Bay differ from the Main Basin in terms of energy transport? How can regular surveillance monitoring play a role? Develop a conceptual model to explain nutrient transfer through the aquatic food web and determine if it differs between Georgian Bay and the Main Basin. (2012CSMI)
- Need to understand how energy/nutrients are being allocated between the benthic, mid-depth and pelagic zones of the main basin and the resulting food web structure. (2012CSMI)
- Need to better understand how the new nutrient cycle is affecting upper food web production (larval fish - zooplankton interactions, forage fish-predator fish interactions). A comparative study at locations around the lake, both nearshore and offshore, should be pursued. (2012CSMI)
- Conduct basin-wide benthic sampling and reporting and include the North Channel and Georgian Bay. Are changes in macroinvertebrates affecting the food web and diets? (LHTC)
- Update spatial and temporal trends of diporeia and mysis (LHTC)
- Focused effort on inner Saginaw Bay with regard to lower food web, sedimentation, reef restoration surveillance. (LHTC)
- Examine Cladophora community structure, spread, and relation with energy. Is there a nutrient sink unaccounted for? (LHTC)
- Determine if Dreissenids and gobies have taken over past pelagic production. (MSU-Mini Conference)
- Determine how to best to understand the total carbon budget or productivity lake wide, benthic, pelagic, inshore, offshore, all basins. Include thinking of the influence of nearshore fish species such as bass, emerald shiners, etc. and how fish move between and within systems. Consider use of carbon isotopes and acoustic arrays to address some of these questions. (MSU-Mini Conference).
- The limited frequency (within each year) of the zooplankton may be an underestimate of the contribution of some species. (Bunnell, 2013)
- Estimates of nutrients, benthic invertebrates, and zooplankton have been collected farther offshore than where prey fish biomass was estimated. This highlights a gap in nearshore monitoring and research that limits our understanding of how the watershed, nearshore, and offshore habitats are linked and influence one another. (Bunnell, 2013)
- Although the use of satellite-derived estimates of chlorophyll *a* provides a comprehensive glimpse into phytoplankton dynamics within the epilimnion that cannot be achieved through *in situ* sampling, this method fails to characterize the dynamics in deeper water, such as the deep chlorophyll maximum. (Bunnell, 2013)

### 6.2.4 Invasive Species:

- It seems likely that there is much variation across years and between ports/locations in how the near-shore (or mid-depth) sink works. For example, Dreissenids seem to have ebbed in biomass: is this a trend or simply a cycle, and if a cycle, can we develop some predictions as to how it will play out in the



future? Will the cycle of Dreissenid abundance become an important driving force determining year class strength for certain species? MDNR work in 2012 suggests that the effect of Dreissenids is exacerbated by low background levels of nutrient enrichment and size of littoral zone. For example, Saginaw Bay's fish community seems hardly affected by the Dreissenid invasion, while Thunder Bay, a nutrient poor area, suffered severely. Ports with close proximity to deep water may have responded differently than those with wide littoral zones. (Jim Johnson)

- Can we use stable isotopes to measure contribution of invasive species, particularly round gobies and hemimysis, to diets of important nearshore fish species such as yellow perch and smallmouth bass? (Jim Johnson)
- Update status on distribution, spread and abundance of Dreissenids and change in trend from zebra to quagga mussels in parts of the basin (LHTC)
- Is there a calcium budget for Lake Huron and do zebra and quagga mussels have an effect on the calcium budget? (LHTC)
- Address knowledge gap for round goby biology, importance as prey, abundance/ distribution/spread, and association with aquatic habitat types including tributaries (LHTC) Determine a suitable sampling program design for gobies. Determine role of gobies in energy shunt between nearshore and offshore system. Examine use of integrated assessment techniques using including different gear, video, and stomach analysis.
- Examine interplay between gobies, cladophora, botulism, and avian mortality e.g., southern Georgian Bay (LHTC)
- To what extent does fish community structure in Lake Huron influence juvenile sea lamprey survival? What are the implications for sea lamprey control efforts (LHTC)
- How do invasive species affect the productivity and stability of Lake Huron fish populations?
- What is the probability of surviving a sea lamprey attack for host species other than lake trout, particularly Lake Whitefish and cisco? (LHTC)

#### 6.2.5 Information Needs from Agencies and Studies for Improved Management

- Continue efforts to characterize land use and nutrient loading linkages and the resulting tributary loadings. (2012 CSMI)
- Transport of nutrients from watersheds through impoundments and effects of Dreissenids on nutrient transport through impounded tributaries. (2012 CSMI)
- Need to quantify the magnitude of energy/nutrients shunted along the gradient from nearshore to offshore. (2012 CSMI)
- Need to understand how energy/nutrients are being allocated between the benthic, mid-depth and pelagic zones of the main basin and the resulting food web structure. (2012 CSMI)
- Need to better understand how the new nutrient cycle is affecting upper food web production (larval fish - zooplankton interactions, forage fish-predator fish interactions). A comparative study at locations around the lake, both nearshore and offshore, should be pursued. (2012 CSMI)
- Need to establish baseline information on the physical (e.g. substrate, bathymetry, littoral cells, sediment transport), chemical, and biological features of the nearshore to guide management actions in the future. (2012 CSMI)
- Need to develop methods of measuring primary productivity that includes periphytic algae.
- The ecology of benthic communities, with emphasis on role of periphyton in nutrient cycling and as a source of secondary benthic production, needs to be better understood. (2012 CSMI)
- What nearshore areas represent areas of resiliency (to climate change, energy shifts, invasive species, and trophic changes), high ecological value, and what are the associated biological, physical, and chemical factors? (GLWQA 2012)



## Eastern and Southern Georgian Bay Science and Monitoring Priorities

The ability to manage the water resources and aquatic habitats and species of Georgian Bay has historically been compromised by a lack of coordinated and systematic monitoring and science by resource management agencies (exception being fish-related data). Concerns over lakewide changes in nutrient cycling and redirection of energy to the nearshore system, invasive species, and food web changes, as well as the recurrence of local and regional water-quality problems, prompted a science synthesis of south-eastern Georgian Bay (Charlton and Mayne, 2014). The completed report focused on phosphorus, cyanobacteria and harmful algal blooms, and science and monitoring priorities. Embayments with limited circulation/flushing and deep enough to stratify to produce oxygen depletion and phosphorus enrichment are in most need of concerted science and monitoring effort. There is also a paucity of nearshore and open water data for Nottawasaga Bay in southern Georgian Bay.

The following are the major science and information needs articulated by agencies and stakeholders:

- Explore the causal relationships accounting for patterns of variability in phosphorus and water quality (tributary loading, exposure, circulation, and flushing, thermal regime, anthropogenic development, invasive species) to separate anthropogenic from natural influences;
- Study the various watershed, ground water, tributary, septic and wetland phosphorus sources and contributions to Sturgeon Bay (an embayment with near-annual cyanobacteria blooms) and other isolated embayments and river mouths with known water quality problems;
- Determine the internal loads and fate of regenerated phosphorus in Sturgeon Bay and other enclosed embayments;
- Study the trends and factors responsible for low dissolved oxygen depletion and cyanobacteria and harmful algal blooms in enclosed embayments. Determine the role of iron in blooms formation;
- Study, synthesize and share information on natural physical process information (e.g., remote sensing and volumetric measures of bottom sediment, bathymetry, and circulation);
- Perform synoptic surveys of eastern Nottawasaga Bay to understand nearshore phosphorus concentrations and sources, fish communities, aquatic and terrestrial invasive species, and shoreline alteration impacts;
- Determine the composition of the Nottawasaga River plume and investigate sources of suspended sediments, all forms of phosphorus and *E. Coli*, to determine management actions;
- Continued coastal wetland research in Georgian Bay is needed in order to monitor the impacts of low water levels and increased development in Georgian Bay. Links should be made with phosphorus inputs, habitat provision/resiliency; specific focus of future research should include wetland inventories of the Georgian Bay archipelago as well as revisiting sites that were first monitored more than a decade ago.
- Identify and reassess historic spawning locations to determine if invasive species (dreissenids, round goby) have led to deteriorating habitat quality;
- Collect baseline information on Nottawasaga Bay nearshore system (aquatic habitat, nutrients, benthos, invasive species, algal biomass, river mouth plume dynamics and phosphorus loading).
- Determine whether or not the nearshore shunt applies to south-eastern Georgian Bay and how it functions.



## **Appendix A**

### **Lake Huron Science Needs as per Mini-Conference on Lake Huron Food Web (MSU, Dec 2014)**

**Conference Objective:** Determine role of piscivores in dramatic changes in the Lake Huron fish community, and also how these piscivores responded to the changes. In addition evaluate how we could reduce uncertainty, and what our capability is to predict the future role of piscivory.

- **Catchability of trawl and hydroacoustics:** How best to design a program to assess the prey fish community and assess what we need to know about fish to manage the fish community. Determine information needs from those studying other trophic levels? Address questions around consistency in catchability and precision. Consult with hydroacoustics experts. Consider integrated assessment and use of gear types and surveys.
- **Determine relative importance of nearshore to offshore energy shifts and transport:**
- Examine both inshore and offshore energy transport, especially in Saginaw Bay. How does Georgian Bay differ from the Main Basin in terms of energy transport? Determine how best to classify a species as being inshore or offshore and associated and determine, from a fish management perspective, the relative importance of inshore species (bass, yellow perch) or energy transport to the offshore species? Has there been a shift in productivity overall or a shift from offshore to nearshore? Gobies are found in both inshore and offshore systems and it's of interest to determine their role in energy transport.
- Determine if Dreissenids and gobies have taken over past pelagic production.
- Determine how to best to understand the total carbon budget or productivity lake wide, benthic, pelagic, inshore, offshore, all basins. Include thinking of the influence of nearshore fish species such as bass, emerald shiners, etc. and how fish move between and within systems. Consider use of carbon isotopes and acoustic arrays to address some of these questions.
- Investigate improvements to fish assessment program designs to better assess the current prey fish community.
  - Fill holes not covered by existing gears (top waters or bottom waters). Lots of fish in top layer. Fish are in deeper/offshore waters on bottom not sampled by trawl or hydroacoustic. Need to build an assessment program for gobies.
- **Address uncertainty in predator abundance including:** fish data, data quality, fishing mortality rates, reliability of harvest data, consideration of fish movement and increase use of acoustic arrays. Focus on whitefish and determine importance of bloaters to other fish diets given their biomass in Main Basin.

## **Appendix B**

### **Information Needs for Improved Management of Lake Huron**

*Developed by the Lake Huron Binational Partnership to inform the proposed Year of Intensive Monitoring in 2012*

Nutrient levels in the open waters of Lake Huron were historically driven by total tributary inputs, and overall productivity was largely driven by spring plankton blooms and abundant populations of benthic invertebrates, especially *Diporeia*, which lived the soft sediments of the lake. Surveillance, monitoring, and research efforts in Lake Huron have been guided by this conceptual model for the past several decades. As described below, Lake Huron is undergoing system-wide changes, apparently a result of dramatic shifts in nutrient cycling within nearshore and offshore regions. Investigative work in 2012 should clarify and quantify how nutrients move through the system, and the resulting impact on the food web, to allow governmental agencies to better manage the health and productivity of the lake. A particular focus on the nearshore region of the lakes is needed, since this area seems to be sustaining the current productivity of the Lake.

Current Understanding/Hypotheses of Lake Huron Nutrient Cycling and Productivity



Although tributary loadings are not thought to have changed dramatically, the colonization of both hard and soft substrates by Dreissenid mussels has radically altered nutrient cycling. It appears that nutrients are increasingly being retained in nearshore regions and shunted to the bottom of the lake.

In the nearshore environment, particles and associated nutrients are filtered out by abundant Dreissenid populations, bound up as tissue/shells, and re-released as pseudofeces which in turn are utilized by primary producers (algae, benthic plants, etc) in the nearshore environment. Algal fouling is now found in areas not typically associated with higher ambient nutrient levels, presumably caused by this “fertilizing” effect of mussel beds. In addition, anecdotal reports from researchers suggest that highly decomposed plant tissue is accumulating in the interstitial spaces of some cobblestone beaches, which may be another nutrient sink that has not been fully quantified.

In the offshore environment, quagga mussels are now found in high numbers. Their filter feeding activity in the constantly-cold, offshore environment is believed to remove nutrients/plankton from the water that historically drove the springtime diatom bloom. During the spring, waters are isothermal and thus well-mixed, giving benthic-dwelling Dreissenids access to diatoms produced throughout the water-column. In addition, commercial fisherman have periodically reported pulling up large amounts of plant material in their deepwater nets, yet another potential nutrient sink that has not been fully quantified. Thus, offshore nutrients also appear to be shunted to the benthic environment.

While many of these processes still need to be better described, they are the major components in the current conceptual model for nutrient cycling and productivity in Lake Huron. More needs to be done in 2012 to better describe the magnitude and seasonality of the individual processes.

#### Food Web Impacts

The impact of the altered nutrient cycle is not fully understood. For reasons still unknown, *Diporeia* populations have crashed throughout the lake, removing a major food source for the fishery. *Mysis*, the other large invertebrate found in the offshore, does not appear to be filling this niche (based on the only comprehensive study on record for Lake Huron, done in 2007), and may be declining. Forage fish populations have dramatically decreased since 2003, with non-native alewife now at extremely low levels. Pelagic salmon populations have also decreased and the remaining fish have lower body weight.

Meanwhile, fish species that are more nearshore oriented appear to be rebounding. Native walleye, yellow perch, and smallmouth bass are increasing in nearshore areas within Lake Huron. With the lower productivity of the open waters, the nearshore fishery may be of increasing importance for natural resource managers.

Efforts in 2012 should not only focus on determining changes in the lake since 2007 when the last major research effort occurred, but also more needs to be done to better describe the foodweb impacts of the altered nutrient cycle and to expand our understanding of the nearshore environment.

#### Information Needs for Improved Management of Lake Huron

- Continue efforts to characterize land use and nutrient loading linkages and the resulting tributary loadings.
- Need to quantify the magnitude of energy/nutrients shunted along the gradient from nearshore to offshore.
- Need to understand how energy/nutrients are being allocated between the benthic, mid-depth and pelagic zones of the main basin and the resulting food web structure.
- Need to better understand how the new nutrient cycle is affecting upper food web production (larval fish - zooplankton interactions, forage fish-predator fish interactions). A comparative study at locations around the lake, both nearshore and offshore, should be pursued.

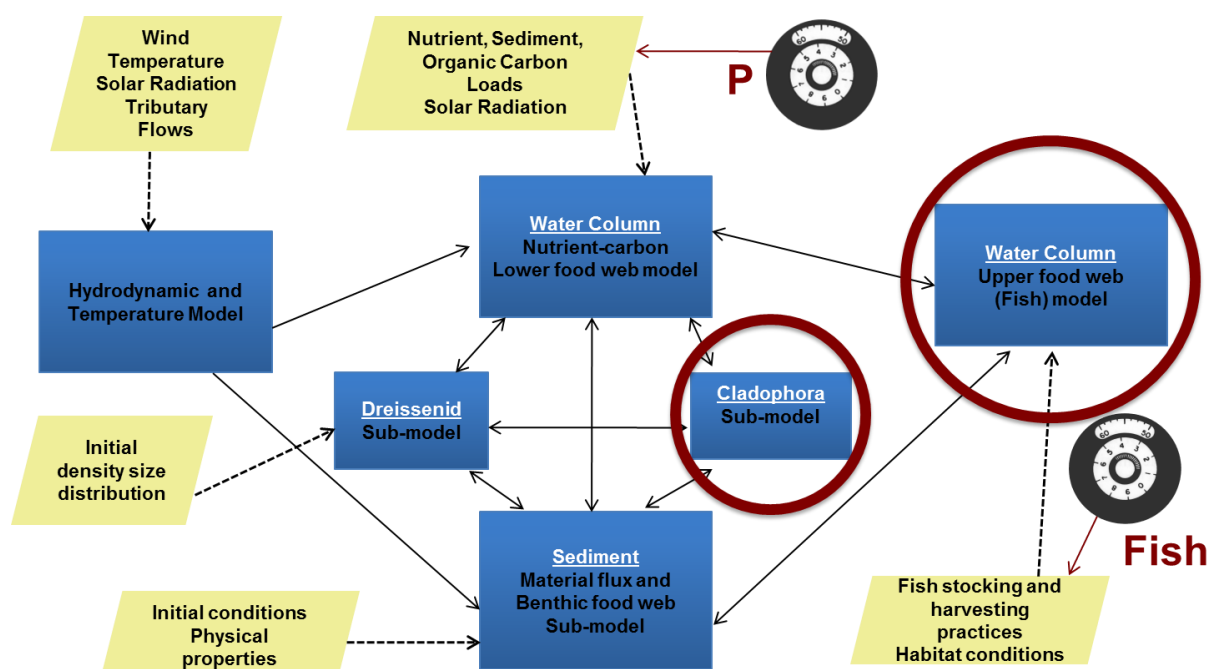
### **6.3 Model Need**

Given the above monitoring and research recommendations, we see a need to develop a comprehensive quantitative understanding of the lake’s trophic relationships on a spatial (nearshore, offshore, embayments) and seasonal basis. The synthesis of the related research and monitoring into a fine-scale





linked hydrodynamic- nutrient – lower food web – upper food web mathematical model can provide such a conceptual and quantitative understanding. A conceptual diagram of such a model is presented below. This is a model framework that could integrate much of the Lake Huron monitoring and research that has been conducted in the past 10-15 years, as well as the new information to be gathered in the 2017 CSMI program. It could be refined, re-calibrated, and re-applied every five years in an Adaptive Management framework that assesses the response of the lake to changing natural (e.g., climate effects on hydrology and temperature) and anthropogenic (e.g., nutrient loading changes, invasive species impacts). This operational modeling framework would serve as both a repository of knowledge about the Lake Huron ecosystem structure and function and as a decision support tool for adaptively adjusting management actions in the lake. Of course, it would require collection of all the input data (i.e., hydrometeorological conditions, nutrient loads, initial conditions for all state variables). But having done that, this model, for example, could help explain changes in the zooplankton community, contribution of Dreissenids to Cladophora blooms and the resulting nearshore-offshore trophic gradients. It could also be used to forecast the lake's response to nutrient load controls in the watershed. Most of the model's data needs are already being met by the existing Lake Huron field programs; therefore, development and application of



such a model would not require significant additional resources.

**Figure 36. Conceptual diagram of an ecosystem model for Lake Huron.**



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## Appendix A: Full Reference List

Below is a complete list of all the references that were reviewed as part of this project. Not all were summarized in the text above.

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## Appendix B: Annotated Bibliography

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## Appendix C: SYNTHESIS OF SCIENCE AND MONITORING IN LAKE HURON FROM 2007 – 2010

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**Appendix D:**  
**SUMMARY OF LAKE HURON BINATIONAL PARTNERSHIP**  
**MEETING TOBERMORY, ONTARIO**  
**OCTOBER 4-6, 2010**

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