SYNTHESIS OF SCIENCE AND MONITORING IN LAKE HURON FROM 2007-2010

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Front Cover Photo: Charlie Roswell, Purdue, conducting nearshore fish research on Saginaw Bay, Lake Huron. July 2009. Photo Credit: E. Verhamme.

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EXECUTIVE SUMMARY

In preparation for the Cooperative Science and Monitoring Initiative (CSMI) 2012 field year in Lake Huron, the Lake Huron Binational Partnership is holding a planning meeting in Tobermory, Ontario from October 4-6, 2010. This report serves as background for this meeting and a departure point for the participants to indentify future management needs and to plan their activities for 2012 and over the next five years of the CSMI cycle.

The report summarizes and attempts to synthesize, from a management perspective, the considerable science and monitoring work that has been conducted on Lake Huron over the past 4-5 years, including the 2007 Lake Huron field year and subsequent research and monitoring since then. Included in sections 2 and 3 of this report is 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 has been acquired over the past five years, there continue to remain information gaps that should be considered in planning science and monitoring activity over the next five years. Among them are:

- 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 (~ >20m 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 have recently been raised. One of the most talked about emerging issues is climate change, and research includes 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 are planned across the Great Lakes looking specifically at the issue of climate change in the context of ecosystem and societal impacts.

Research related to the sinkholes in Lake Huron is attempting to determine the importance of this recently discovered ecosystem as an emerging issue.

The Great Lakes research community continues to identify more chemicals of emerging concern in Great Lakes waters. Recent chemicals of concern include polybrominated diphenyl ethers (PBDEs) and pharmaceutical and personal care products (PPCP). Others include 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 is 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.

1. INTRODUCTION

The purpose of this report is to present a synthesis of the research and monitoring conducted in Lake Huron since 2007, the last major binational Lake Huron field year. This synthesis is being prepared in preparation for the next Lake Huron intensive field year, which is being conducted in 2012 as part of the binational Cooperative Science and Monitoring Initiative (CSMI). The CSMI process is a five year process that is comprised of two years of planning for an intensive field year in the third year of the process. Year 4 is reserved for laboratory analysis of samples acquired the previous year, and year 5 is for data analysis and reporting. The CSMI process is an ongoing cycle that builds on knowledge gained from previous efforts. Accordingly, a report of the knowledge gained from the 2007 Lake Huron intensive field year and subsequent science and monitoring will provide a sound basis for discussion of future information needs.

Unlike the other Great Lakes, which follow the LaMP process for addressing lake-wide environmental issues, the Lake Huron community has formed the Lake Huron Binational Partnership (Partnership) to prioritize and coordinate environmental activities in the basin. To prepare for the field year in Lake Huron, the Partnership is holding a planning meeting in Tobermory, Ontario from October 4-6, 2010. This report serves as background for this meeting and a departure point for the participants to indentify future management needs and to plan their activities over the next five years of the CSMI cycle.

1.1 BACKGROUND ON LAKE HURON BINATIONAL PARTNERSHIP

Officially formed in 2002, the Lake Huron Binational Partnership is a coalition of federal, state, and provincial agencies that have environmental responsibilities in the Lake Huron basin. The purpose of the Partnership is to prioritize and coordinate environmental activities in the Lake Huron basin. The Partnership identified three initial priority issues in 2002 that would benefit from the binational effort. These issues are: contaminants in fish and wildlife, biodiversity and ecosystem function, and fish and wildlife habitat. With respect to these issues, there are several key management questions that the Partnership is addressing. These include:

- How have contaminants affected fish and wildlife, and are the fish and wildlife healthy and safe to eat?
- How is the lake ecosystem changing with regard to its structure and function and what has caused the changes?
- What kind of invasive species are present in the lake and how do they affect the ecosystem?
- How is the food supply for fish populations changing, and what effects will those changes have?
- How can we protect and restore critical habitat for plants, fish, and wildlife?
- How does loss of wetlands from shoreline alterations and development pressure affect fish and wildlife?

In addition to these binational issues, the Partnership also shares information between countries on domestic issues, such as progress in delisting of Areas of Concern within the basin, and fouling of beaches by algae and bacteria.

With regard to these issues and other emerging issues the Partnership prepared an action plan in 2004, and 2008-2010 Action Plan in order to track progress, provide information on current research and monitoring, and identify future needs (Lake Huron Binational Partnership, 2008).

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 2007 in preparation for the Partnership 5-year planning process, which begins at the Partners meeting in Tobermory, Ontario on October 4, 2010. This report also includes references to work before 2007, because some results became available in the 2007-2010 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 2007 field year 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. SUMMARY OF 2007 LAKE HURON FIELD YEAR

In January, 2008 members of several U.S. and Canadian agencies met to discuss the sampling that had been conducted on Lake Huron in the summer of 2007. Environment Canada (EC) and USEPA-GLNPO continued to do their routine sampling in the open waters of the lake in the spring (both), summer (EPA), and fall (EC). While those data are not presented in detail here, several summary plots are presented to put Lake Huron in the context of other Great Lakes. Several special studies were identified at this meeting that had been conducted by the USEPA Mid Continent Ecology Division (MED), USGS, and NOAA. Some of these studies are presented below, while others are discussed along with their findings in Section 3 of the report.

2.1 SPECIAL STUDY OVERVIEW

A special study by the USEPA-MED utilized a towed sensor array to develop a high resolution map of water quality in the nearshore waters of Lake Huron (Yurista et al., 2010). This data will be used to investigate the relationships between nearshore in-situ measurements and land-use patterns in adjacent watersheds. In addition, multiple tows taken throughout the summer will reveal if any seasonal patterns in water quality in the nearshore region. The study area extended along the 20 m depth contour on the U.S. shoreline between Port Huron, MI and the St. Marys River outlet. Preliminary analysis shows that it is possible to predict (with linear models) the nearshore chlorophyll and zooplankton concentrations given land use and other intrinsic characteristics. The results are not yet published, but preliminary results are shown below for model and data predictions of chlorophyll (Figure 1) and zooplankton (Figure 2).

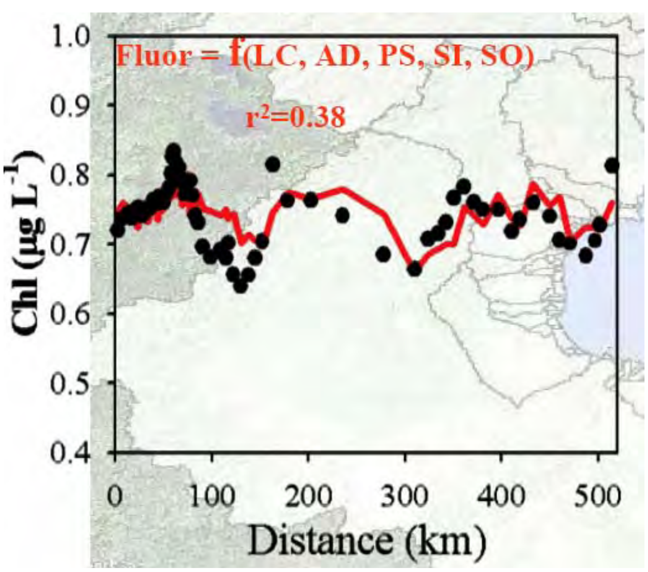

Figure 1. Predicted (red) and measured (black) chlorophyll concentration along a transect extending from Port Huron, MI (left side) to the St. Marys River outlet (right side).

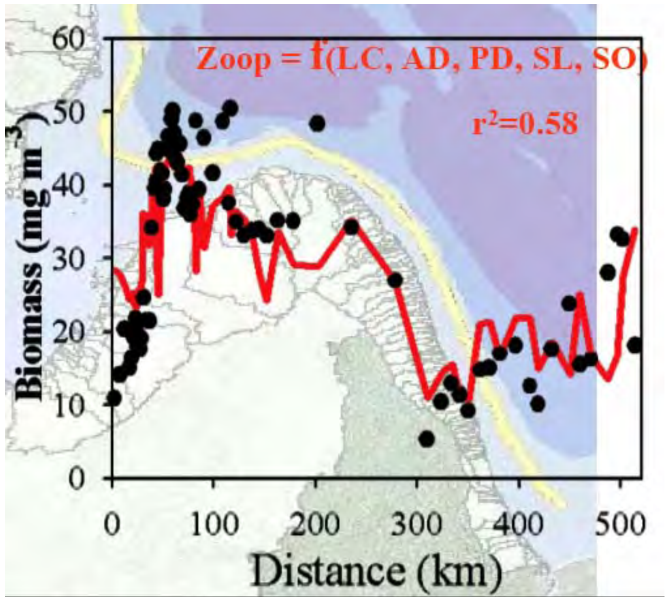

Figure 2. Predicted (red) and measured (black) zooplankton biomass along a transect extending from Port Huron, MI (left side) to the St. Marys River outlet (right side).

During the January, 2008 meeting members of the USGS, USEPA, and NOAA discussed a focused study of the food web of Lake Huron that was conducted in 2007. With funding from the USEPA, the USGS sampled transects off of two ports (DeTour and Hammond Bay) in northern Lake Huron (Daley et al., 2009). In addition researchers from NOAA (Pothoven, 2010) sampled a transect off of Harbor Beach, MI in southern Lake Huron. The goal of both projects was to determine if recent declines in zooplankton were due to increased predatory consumption. Both research groups monitored water quality, zooplankton, and benthos. A more rigorous analysis of the fish, zooplankton, and benthos (diets, stable isotopes, and lipids analysis) was undertaken by the USGS. The health of larval fishes was also studied in the context of resource availability. While the study is still ongoing preliminary results show that the food web remains dramatically altered and is consistent with data collected in 2003 (discussed in Section 3). Densities of prey fish, zooplankton, and benthic invertebrates remain near record lows. The USGS plans to apply a bioenergetics model to determine if the declines could be due to resource availability.

Another dataset identified during the 2008 conference call was a basin-wide survey of benthic invertebrates by NOAA. This study is discussed further in Section 3 in the benthos section under research by Nalepa (2009). Results show a dramatic decline in *Diporeia* and an expansion of dreissenids to deeper depths.

Also mentioned during the conference call was an intense research project being conducted by NOAA and others on Saginaw Bay (Stow et al., 2008). This 5 year project (beginning in 2007) is funded by the NOAA Center for Sponsored Coastal Ocean Research. While the primary objective of the project is to develop an Adaptive Integrated Framework (AIF) to bring scientists, managers, and stakeholders together, the project is also collecting an extensive chemical and biological dataset on Saginaw Bay. Several of the components of the project are mentioned in Section 3.

The project has collected data from the Saginaw River and its tributaries (nutrients) and from stations across Saginaw Bay (nutrients, benthos, fish, benthic algae) in 2007 and continuing through 2010. Some of the research has been published (Cha et al., 2010; DeMarchi et al., 2010) with more publications scheduled as the project nears completion in 2012. Preliminary results will be presented at the Tobermory meeting.

2.2 CONVENTIONAL CHEMICALS

This section presents trends in water chemistry from the USEPA-GLNPO website (http://www.epa.gov/glnpo/monitor.html) which compares the lake-wide average trends in water quality for all of the Great Lakes (Figures 3 to 7). As a whole, Lake Huron is experiencing an increase in the spring chloride, and nitrate/nitrite concentrations. Levels of total and dissolved phosphorus have been declining over time and are very similar to the open waters of Lake Superior. Lake-wide chlorophyll values are lower today than in the late ‘80s and early ‘90s, and are similar to values measured in Lakes Michigan, Superior, and Ontario.

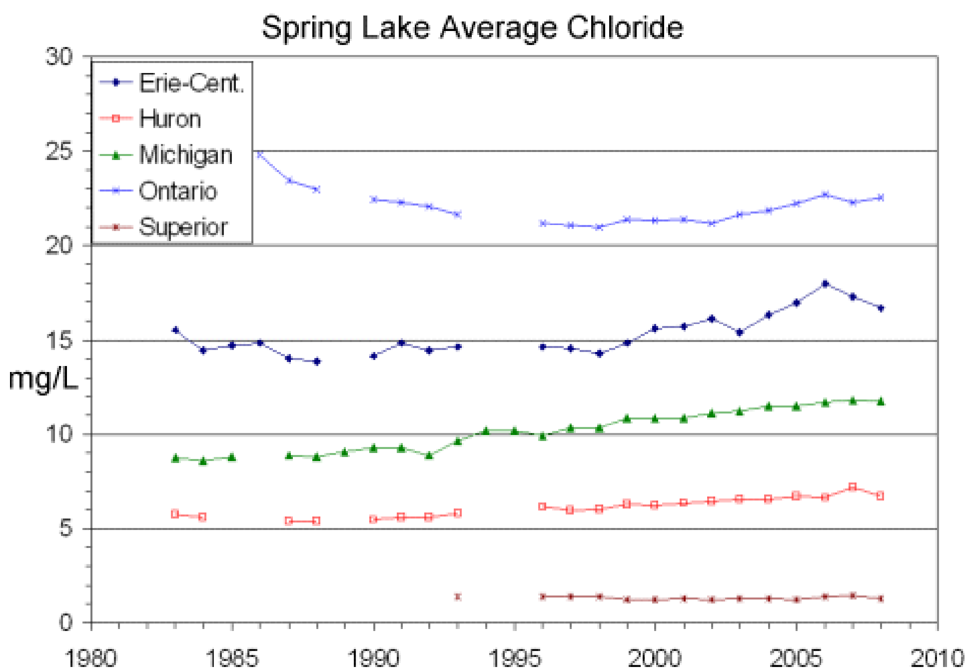

Figure 3. Lake-wide average spring chloride.

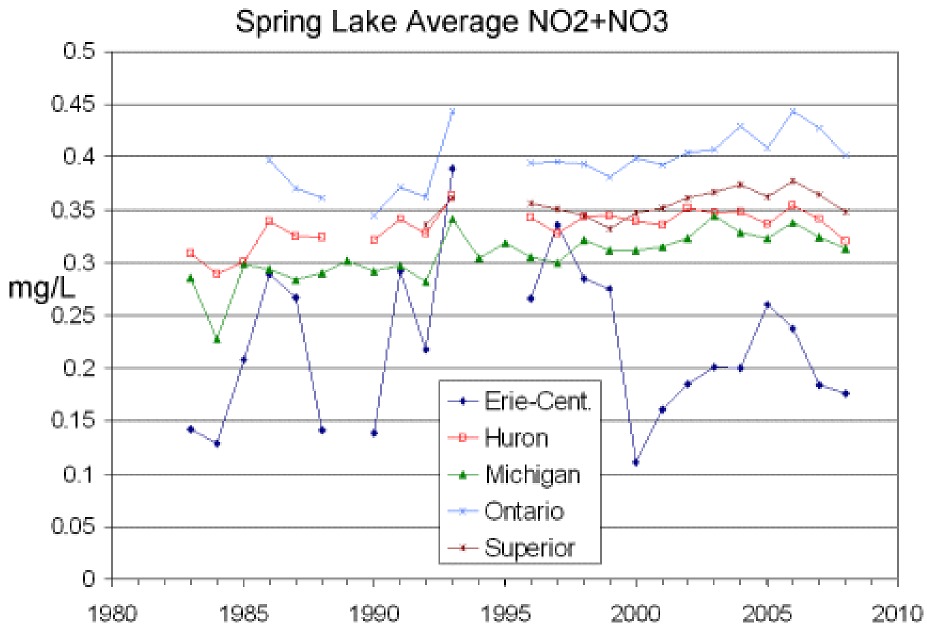

Figure 4. Lake-wide average spring NO2+NO3.

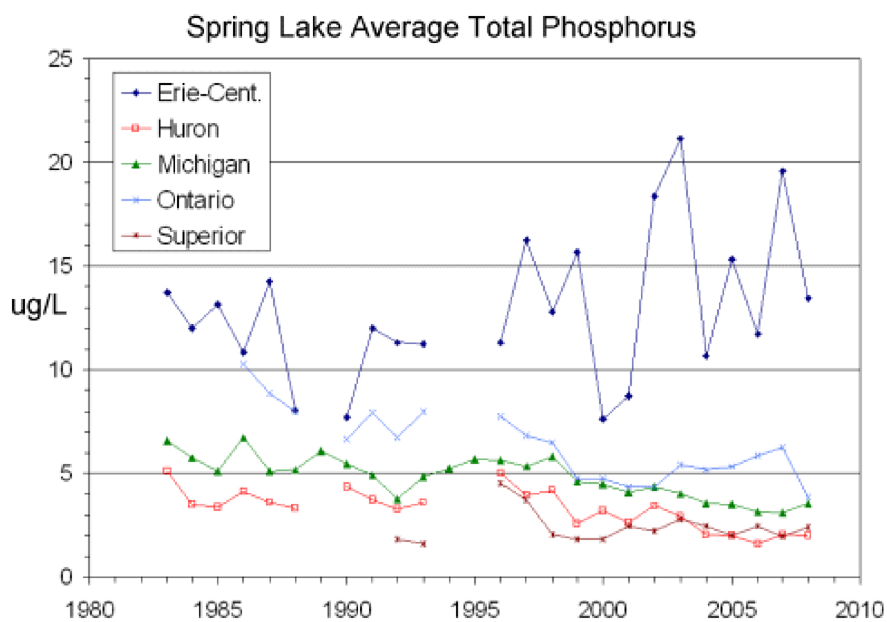

Figure 5. Lake-wide average spring total phosphorus.

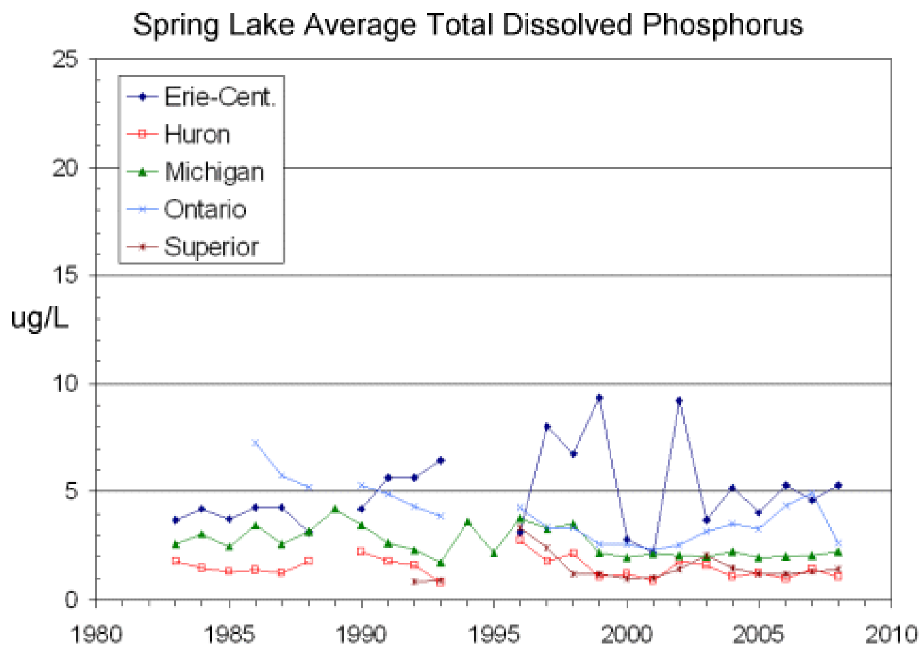

Figure 6. Lake-wide average spring dissolved phosphorus.

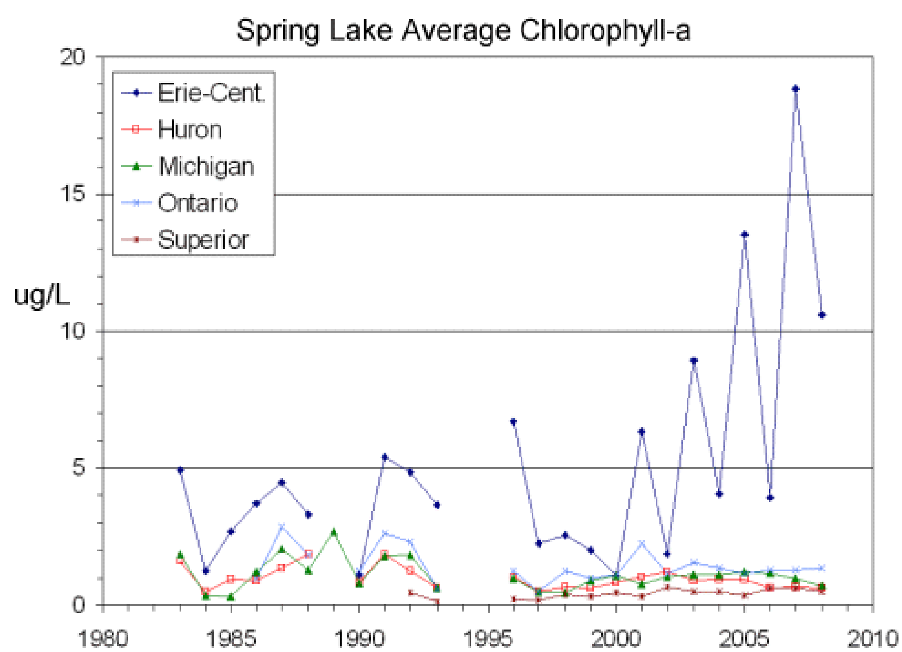

Figure 7. Lake-wide average spring chlorophyll.

Additional open water chemistry and nutrient data for Lake Huron was presented in Barbiero (2009) (Figure 8). In addition to displaying the declining trends in total phosphorus and chlorophyll *a*, a noticeable increase (more than double) in the Secchi depth was observed between 1995 and 2006. An upward trend in the dissolved silica was also observed over the same time period.

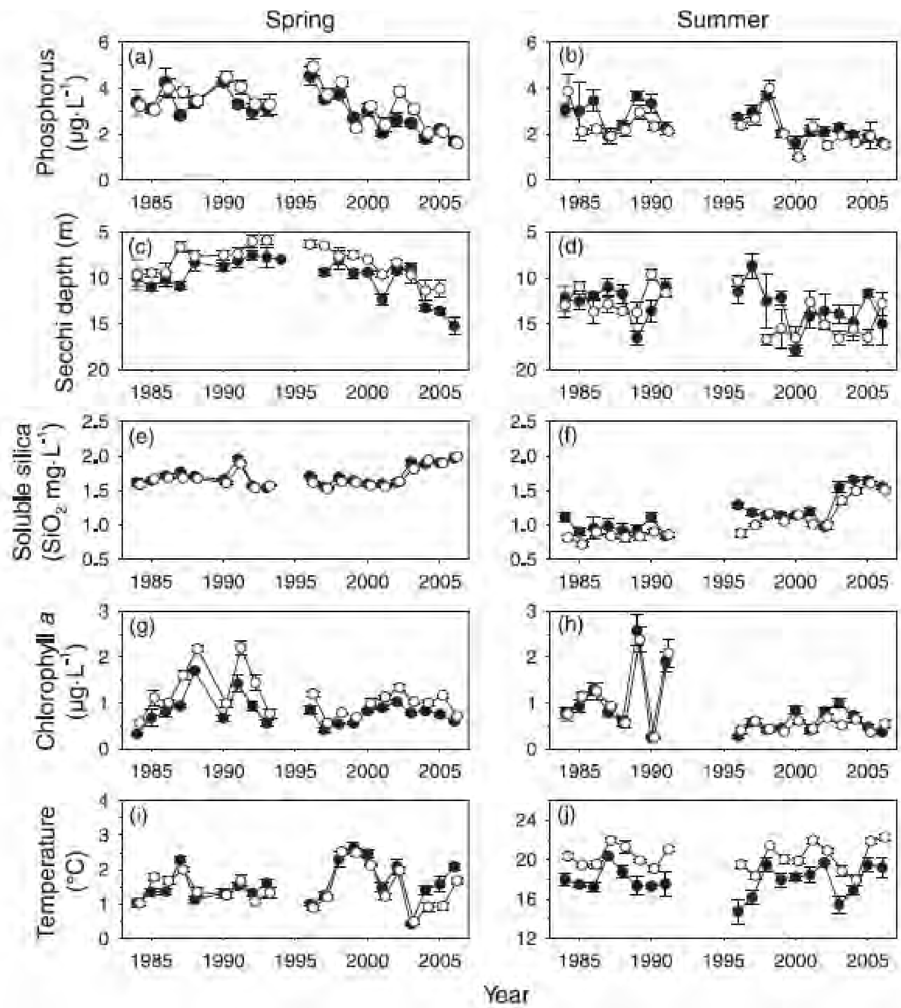

Figure 8. Spring and summer water quality trends in northern (solid) and southern (open) Lake Huron (Barbiero et al., 2009).

Monitoring data for Lake Huron was also summarized as part of the State of the Lakes Ecosystem Conference (SOLEC) in 2009 (Environment Canada & USEPA, 2009). Shown in Figure 9 is the annual spring average total phosphorus concentrations from monitoring by Environment Canada (blue) and the USEPA (red). The SOLEC total phosphorus open water target of 5 ugP/L is shown as a horizontal line. In recent years, the open water has been well below the 5 ugP/L TP target.

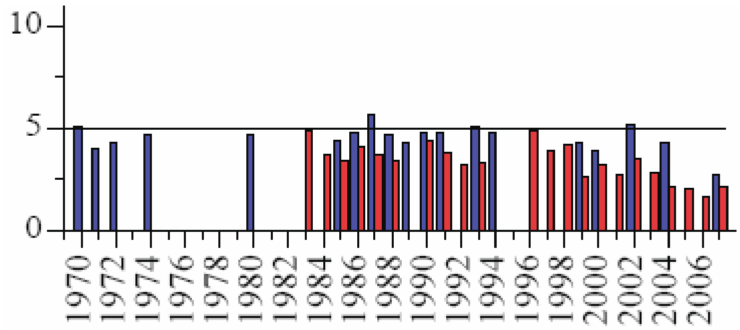

Figure 9. TP (ug/L) trends in Lake Huron (red=EPA, blue=EC).

2.3 TOXIC CHEMICALS

Time trends in several toxic compounds were presented in the 2009 SOLEC report (Environment Canada & USEPA, 2009). Figure 10 below indicates that there has been no decrease in lake trout PCB levels in 2007 compared to 2005-6. Nor has mercury in adult walleye shown any recent trends (Figure 11). Other plots are presented in the SOLEC report for other toxic compounds.

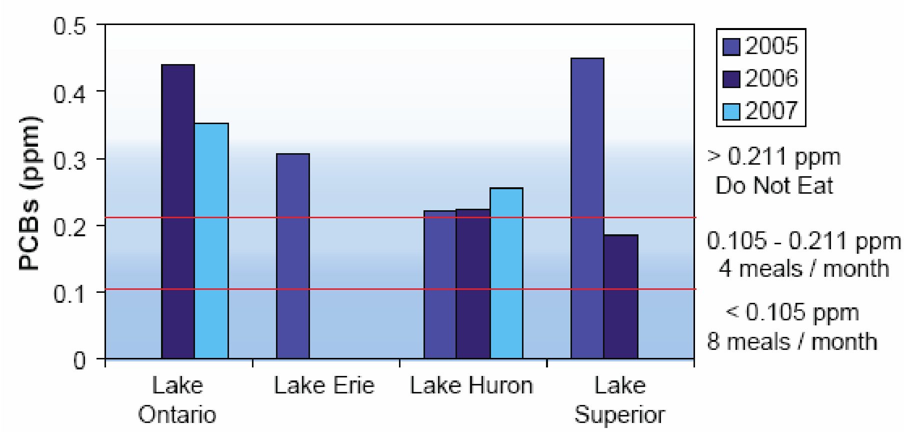

Figure 10. Total PCBs in lake trout and OMOE fish consumption guidelines.

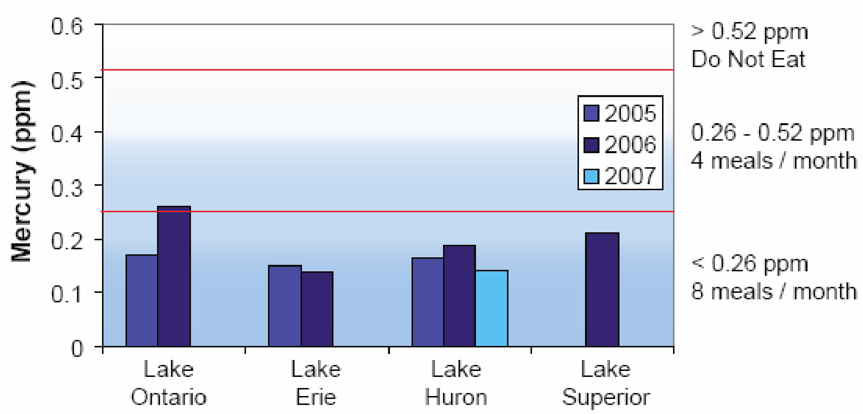

Figure 11. Mercury in walleye and OMOE fish consumption guidelines.

Long term trends in PCB concentrations in lake trout have been tracked for all the Great Lakes by GLNPO (Carlson & Swackhamer, 2006) and for all but Lake

Michigan by Environment Canada (Figures 12 and 13). These data show exponential declines in total PCBs through the early 2000's, especially for Lake Michigan and Ontario. The lack of a measurable decline through the mid-2000's in many of the lakes may suggest that PCB levels are approaching a steady-state condition with the present PCB loads to the lake. Continued monitoring of PCBs is necessary to confirm this hypothesis or to detect a slower response to declining PCB loads.

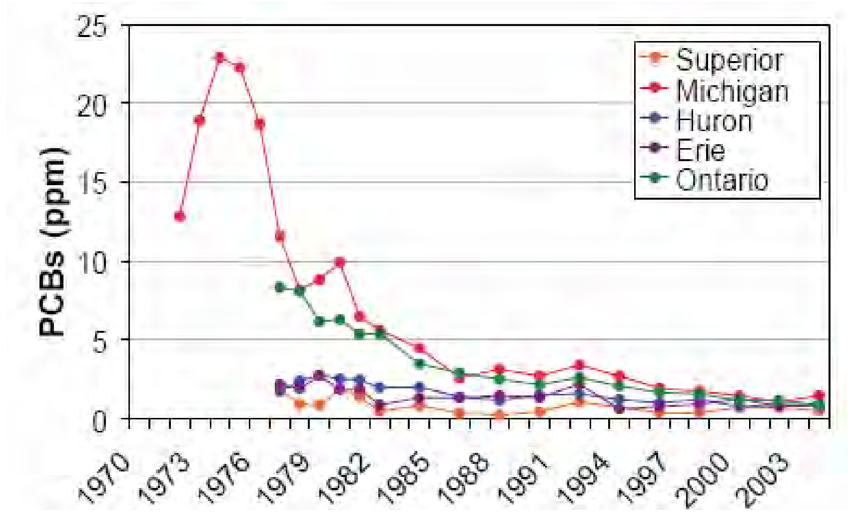

Figure 12. Total PCBs in odd year fish from 1972 to 2003.

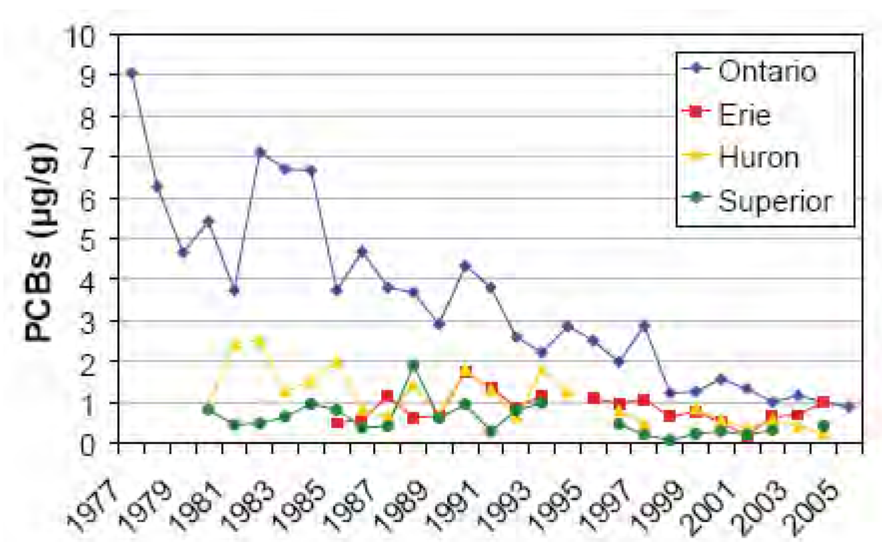

Figure 13. Total PCBs in whole lake trout.

3. SUMMARY OF SCIENCE AND MONITORING BY TOPIC AREA

This section will synthesize research and monitoring findings over the past 3-5 years as they pertain to the action areas mentioned in the Action Plan. This section is divided into two sub-sections: aquatic ecosystems, which cover research related to bacteria, *Cladophora*, Harmful Algal Blooms (HABs), benthos, nutrients, plankton, zooplankton, physical processes, sinkholes, and water levels; and fish related science and monitoring.

3.1 AQUATIC ECOSYSTEMS

3.1.1 Bacteria

Research related to bacteria has focused on refining methodologies to identify point and non point sources of contamination at bathing beaches around Lake Huron. Another recurring problem at bathing beaches is that the sand itself may harbor bacteria that can cause a higher than expected bacteria concentration in surface waters.

Traditional Bacterial Source Tracking (BST) methods involve collecting bacteria samples from a range of possible contamination sources and comparing the DNA signature from the pool of sources to ambient water samples collected at a beach. Recent research by Lyautey et al. (2010) on fecal bacteria in southern Ontario has shown that the library of source samples should be specific to a geographic area and time range, otherwise the accuracy of BST methods limits the ability to pinpoint a specific source. The accuracy of BST methods can also be improved by eliminating DNA signatures that are common among several sources.

Additional source tracking research was conducted by Kon et al. (2009) along the eastern shore of Lake Huron in the Eighteen Mile River watershed. Comparison of BST samples collected at the Ashfield Township Beach to a library of potential sources showed that over 60% of the bacteria contamination was originating from agricultural sources in the watershed and only 3% of the contamination was from human sources. A significant finding of the research was that 15% to 22% of the bacteria samples could be traced back to Environmentally Adapted Strains (EAS) of bacteria that can replicate outside of animal hosts. EAS bacteria have been found elsewhere in the Great Lakes and should be considered in all source tracking projects.

Further research on the persistence of *E. Coli* in the natural environment was conducted by Wheeler et al. (2006) at the Conger Lighthouse Beach near Port Huron, Michigan. Using bacteria and autoclaved (sterile) sand from the beach they were able to show that bacteria concentrations can increase by 5 orders of magnitude (up to $2x10^5$ CFU/g) in two days and stay at that concentration for up to 35 days. Laboratory and in-situ incubations produced similar results when autoclaved sand was used. However, ambient concentrations of E. coli were always less than 100 CFU/g, suggesting that there are natural controls on bacterial growth (such as predation and competition for nutrients).

3.1.2 *Cladophora*

The recent reemergence of *Cladophora* in nearshore areas of the Great Lakes has sparked a renewed interest in *Cladophora* related research. Some of that research is being conducted in the nearshore areas of Lake Huron.

In preparation for SOLEC 2008, a special research summary was written about *Cladophora* (Auer & Bootsma, 2008). The summary states that *Cladophora* has become a nuisance in Lakes Erie, Ontario, and Michigan at levels similar to what was seen in the 1970s. The summary goes on to state that the recent increase in *Cladophora* is likely due to increased transparency (linked to Dreissenids), which has increased the growth potential of *Cladophora* by 50%. This is enough to offset the gains that have been made to reduce loads of nutrients to the Great Lakes. A second hypothesis is that nutrients are being accumulated more in the nearshore region of the Great Lakes due to filtering and deposition by dreissenids. While some researchers have observed *Cladophora* problems in isolated areas there isn't any lake-wide or basin-wide surveillance system to grasp the full extent of the problem. The authors recommend additional monitoring and modeling to identify the most effective means of managing nuisance *Cladophora* growth.

One of the authors of the SOLEC summary on *Cladophora*, Dr. Marty Auer, has been working with other researchers to refine the Great Lakes *Cladophora* Model (Tomlinson et al., 2010). This model is designed for application across the gradients in light and nutrient status seen in nearshore areas of the Great Lakes. The model uses knowledge gained from work done in the early 1980's (Auer & Canale, 1982) by the authors. The model was tested against data from Lake Huron (Harbor Beach, MI) collected in 1979 and then validated against data collected in 2006 on Lake Michigan (Milwaukee, WI). An application of the model showed that increases in water transparency in Lake Michigan had extended the depth of *Cladophora* colonization by < 60% (from a depth of 6m to over 12 m), which led to a doubling of annual net production. The model also showed that soluble reactive phosphorus (SRP) concentrations need to be below 1 ugP/L in order to limit the growth.

There are currently three ongoing projects in Lake Huron which are studying nearshore benthic algae. All projects are collecting ambient water quality data and surveying benthic algae nearby and then each one is focusing on a specific research question.

The first project is being led by Dr. David Burton of the University of Waterloo, with support from the Ontario Ministry of the Environment (Todd Howell) and others (Howell & Barton, 2010). This group is focusing on the Point Clark, Ontario region which is plagued with shoreline fouling from *Cladophora*, *Chara*, and other periphyton from shallow and deep areas. The purpose of the project is to collect chemical, physical, and biological data from the region and to survey the extent of benthic algae with the goal of identifying the most effective means to limit and manage future growth.

The second project is part of a multidisciplinary project on Saginaw Bay being lead by NOAA-GLERL with the nearshore benthic algae component being led by researchers at Michigan State University (Peters et al., 2010). As with the previous study, the benthic algae in Saginaw Bay are made up of several species, which all can contribute to beach fouling. The goal of this project is similar to the last, except that the results will compliment other portions of the larger project to simulate the transport of nutrients from the watershed to the bay.

The third project is being led by researchers at Michigan Technological University (Dr. Martin Auer and Aaron Dayton) and focuses on measuring gradients in phosphorus concentrations near dreissenids beds in Saginaw Bay (Dayton & Auer, 2010). Preliminary results indicate that near bottom SRP levels are 2 to 3 times greater under low wind conditions than further up (~30 cm) in the water column. Monitoring will continue in 2011. The hypothesis is that there is a positive feedback loop between *Cladophora* and Dreissenids.

3.1.3 Harmful Algal Blooms

Harmful algal blooms (HABs) continue to plague portions of the Great Lakes including the shallow embayments of Lake Huron during the summer months. Recent research has focused on monitoring the extent of blooms, studying the impacts of blooms, and developing new methods to detect concentrations of toxins. Two of the literature sources summarize the current state of HABs research at the Great Lakes level. The first one is a background document written prior to the SOLEC 2008 conference (Watson & Boyer, 2008) and the second one involves two of the same authors (Ridal et al., 2008). The SOLEC background paper mentions that over one third of Areas of Concern have taste and odor impairments. Of additional concern is that remedial action plans usually rely on proxies instead of direct data to make assessments of taste and odor impairments caused by HABs. On a lake-wide basis, the SOLEC paper identified Lake Huron as having a “mixed” status with respect to HABs, meaning that it’s a problem in some areas, but not others. Of concern is that some researchers have identified Lake Huron as having higher microcystin production capacity than HABs in western Lake Erie (Dyble et al., 2008).

A few years ago, NOAA established the Center for Excellence for Great Lakes and Human Health. The center has three research priority areas including reducing beach closures, drinking water, and HABs (NOAA GLERL, 2010).

Research conducted by Lekki et al (2009) utilizes remote sensing to map the concentrations of a HAB in Saginaw Bay and in the western basin of Lake Erie. The project tested two airborne platforms that can be retrofitted onto planes, unmanned planes, and balloons to quickly assess the extent of an algal bloom. The researchers worked in conjunction with water based measurements to calibrate the hyper spectral imaging system and were able to estimate the algae concentration. Further research is planned to refine the atmospheric correction factors.

One of the problems associated with identifying a HAB is that current laboratory detection methods are either fast, but have high detection limits or slow, but provide lower detection limits. In recent research by Gregson et. al. (2006) a new method is explored that is both fast and accurate at measuring microcystin hepatoxins (MC). The method was optimized to test MC concentrations as low as 0.025 ug/L from untreated surface waters. This is well below the public health criteria of 1 ug/L.

3.1.4 Benthos

The macro benthos has historically been a key component in lower food web of Lake Huron, but as research has shown, the benthic community is in decline and doesn't show any signs of recovering.

Monitoring by USEPA-GLNPO has shown that between 1997 and 2009 *Diporeia* abundance had dropped significantly (Barbiero et al., 2010b). In 1997 *Diporeia* were present at all stations with a lake-wide average of 3,500 /m^2. By 2009, *Diporeia* were only present at the deepest sites (> 90m) and with abundances ranging from 191 to 720 /m^2. The trends seen in Lake Huron are very similar to what occurred in Lake Michigan during the same time period. A figure from the paper is reproduced below

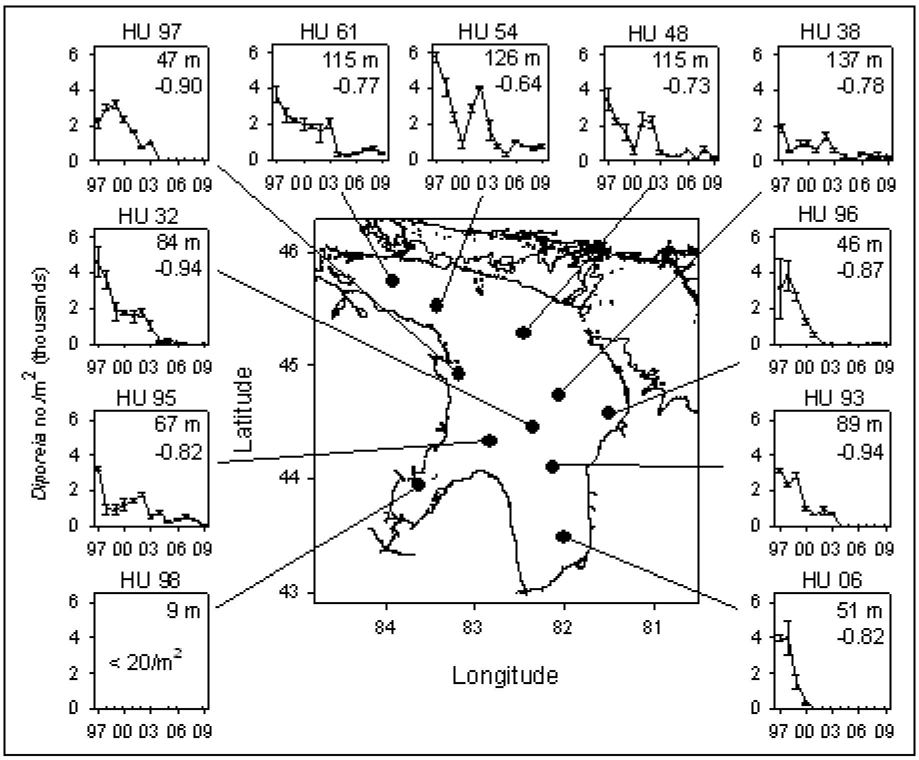

Figure 14. *Diporeia* densities in Lake Huron, 1997-2009.

Error bars indicate one standard error. Station designations are given above each plot; stations depths are given within each plot. Rho values associated with Spearman rank sum correlations with year are shown below station depth where significant (α = 0.05) trends were found. < 20/m^2 indicates average annual densities were below this value during the course of the study.

Another agency that has monitored the benthos in the open waters of Lake Huron is the USGS. Between 2001 and 2007 all native benthos experienced declines in abundance and *Diporeia* disappeared from all sites less than 46 m with significantly reduced numbers at 73 m (French, 2010). Declines at the 46 m site coincided with the arrival of quagga mussels at this depth. On average, densities of *Dreissenids* increased at the 27, 46, and 73 m sites over the 2001 through 2007 period.

The decline in benthos in Lake Huron is supported by historical evidence from NOAA that the benthos was much richer in the 1970s compared to the levels measured recently in the last decade by the USEPA, USGS, and NOAA. Nalepa et al (Nalepa et al., 2009) compared recent (2000 and 2003) benthic densities to data collected by others in 1970 across Lake Huron. While the 2000 data indicated a mixed trend where only *Diporeia* declined markedly from 1970 levels at the shallower depths (18 to 32 m), comparison to the 2003 data showed a drastic decline across all major taxa (*Diporeia,* Oligocheata, Sphaeriidae, and Chironomidae). The only exception was at the deepest sites (> 90m), which is similar to the USEPA conclusions. Re-sampling of the sites in 2007 showed the same trends, where the density of *Diporeia* continued to decline and quagga mussels increased, but this time the deeper depths were also affected with a decline of *Diporeia* of 57% from the 2003 sampling.

Dreissenid mussels are usually regarded as a “dead end” in the lower food web because it is believed that few predators exist to recycle food up to higher level organisms. In a recent paper (Madenjian et al., 2010) the authors make the statement that populations of waterfowl and fish consume significant quantities of *Dreissenids,* enough to limit growth in Lake Huron. The authors estimate that lake whitefish predation on dreissenid mussels was eight times higher in Lake Huron versus Lake Michigan. Future food web models will need to include the dreissenids-whitefish trophic link. This paper suggests that native fish populations are adapting to a new, but lower quality food source.

Another research topic that may be of interest is the potential return of burrowing mayfly nymphs to Saginaw Bay. Recent research by Schloesser (2010) investigates historical populations of burrowing mayflies through sediment cores. While nymphs vanished from Saginaw Bay in the 1950’s, recent pollution abatement programs and evidence of mayfly swarms suggests they are returning to the levels similar to that seen before the 1950s. This trend is similar to what was seen in western Lake Erie, where mayflies have fully recovered.

3.1.5 Nutrients

As part of a project funded by USEPA-GLNPO, Dr. David Dolan at the University of Wisconsin-Green Bay has been assimilating nutrient loading data for every Great Lake (Dolan, 2010). While the data is yet unpublished, a summary of the annual total phosphorus load to Lake Huron is shown below (Figure 15).

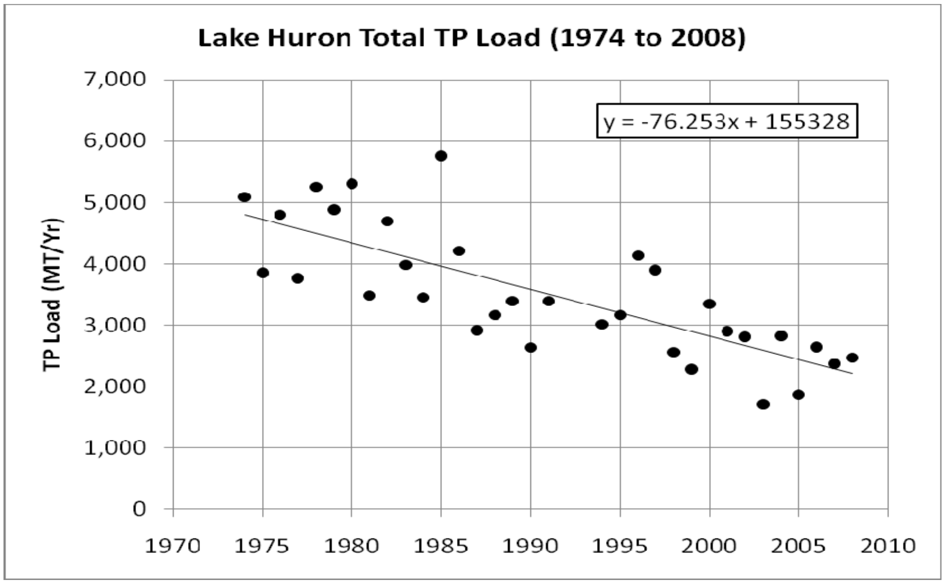

Figure 15. Annual load of total phosphorus to Lake Huron from 1974 to 2008.

More recently, Dr. Dolan's research has been able to break down the total phosphorus load by geographic area (Figure 16) and by major source categories (Figure 17) within Lake Huron.

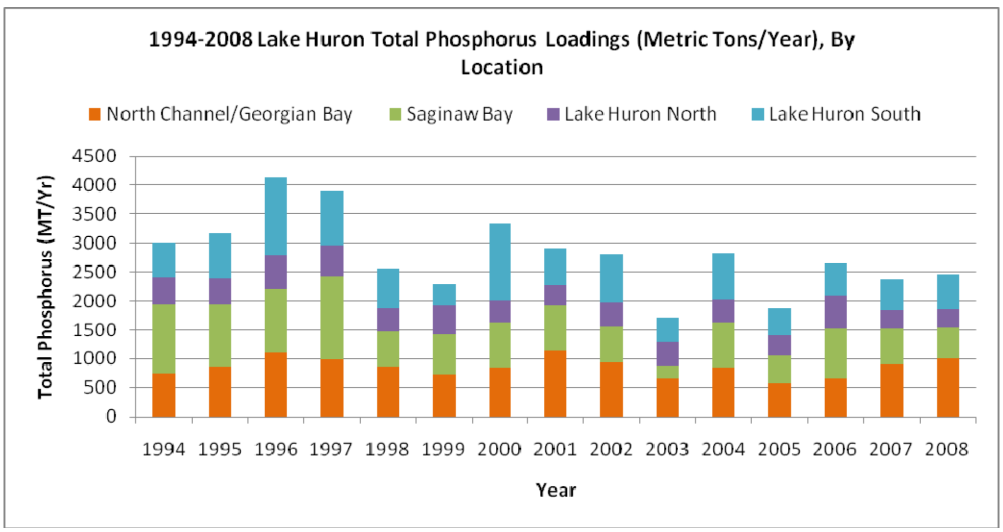

Figure 16. Annual load of total phosphorus to Lake Huron by geographic area from 1994 to 2008.

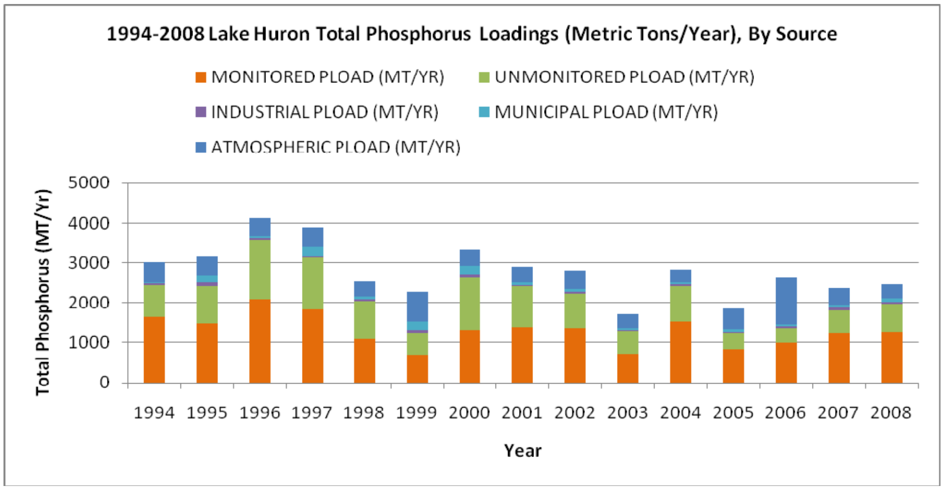

Figure 17. Annual load of total phosphorus to Lake Huron by major source category from 1994 to 2008.

Other phosphorus loading research is being conducted in the Saginaw Bay watershed be several researchers (Tao et al., 2010b; DeMarchi et al., 2010; He & DeMarchi, 2010; Cha et al., 2010; Tao et al., 2010a). The goal of the project is to develop revised estimates of the TP load to Saginaw Bay through various methods including simple regression models and a more complex watershed model. A plot of the annual TP load from the Saginaw River is shown below in Figure 18. Additional data was collected in 2008, 2009, and 2010 to further quantify the load contribution from the major tributaries to the Saginaw River. A breakdown of the annual contribution from the major source categories is also shown below in Figure 19. The “Saginaw/Bay” stands for the load contribution to the Saginaw River from the City of Saginaw, MI down to the mouth of the river including Zilwaukee, Bay City, and Essexville, MI.

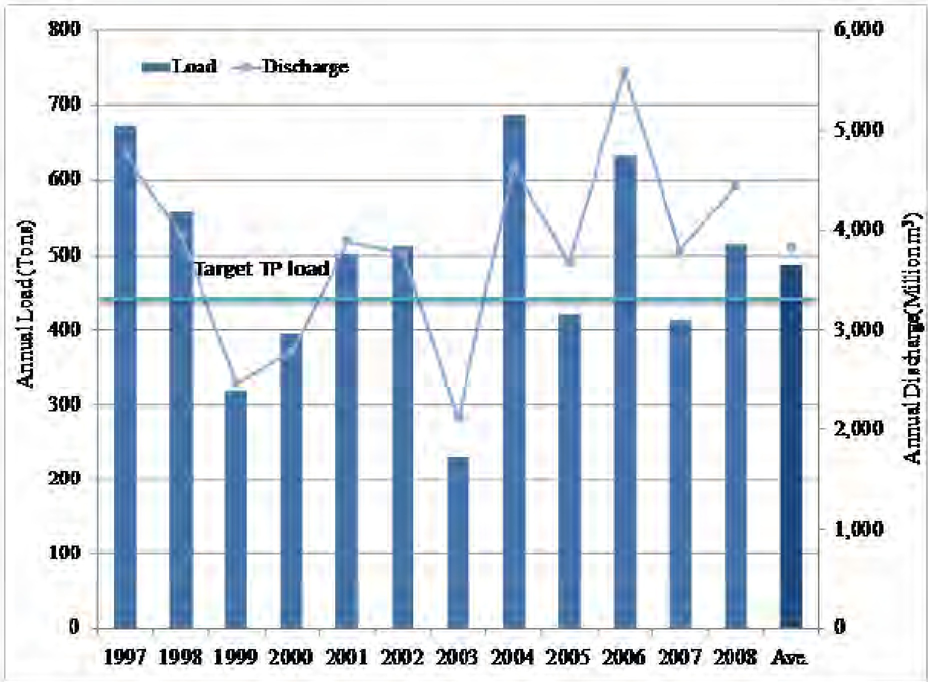

Figure 18. Saginaw River TP load to Saginaw Bay.

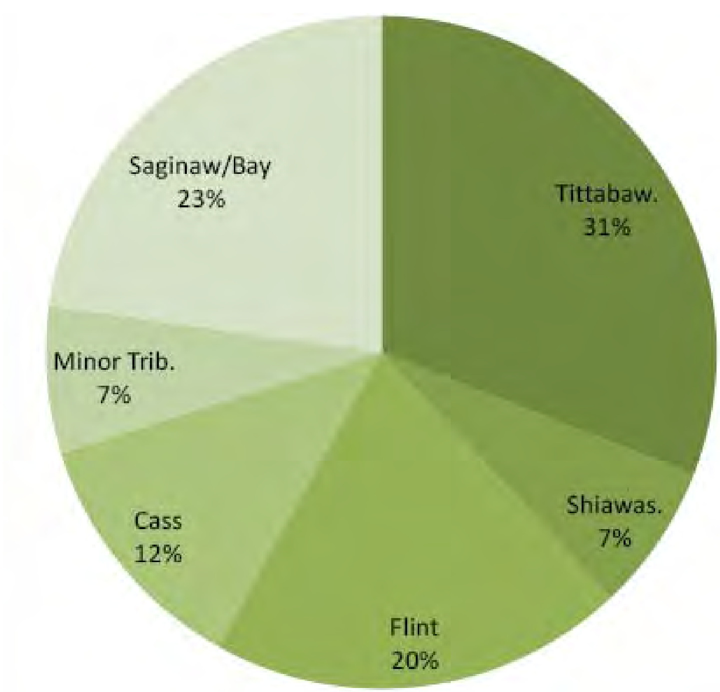

Figure 19. Breakdown of TP load to the Saginaw River (1997 to 2008 avg).

The nearshore regions of the Great Lakes received special attention at the SOLEC 2008 conference and one of the focus areas was nutrients (Kelly, 2008). In particular, data from Lake Huron showed that nearshore waters had higher total P and chlorophyll. The author also noted that nearshore areas tended to have a higher TP:Chl ratio than the offshore waters, suggesting that nearshore TP is equated with less algal biomass. The author also highlighted the need for consistent monitoring of the nearshore region to assess long and short thermal changes in the ecosystem.

One program that is attempting to develop a consistent monitoring program across the coastal regions of the United States is being funded by the USEPA's Office of Water through the implementation of a National Coastal Survey (Kohlhepp, 2010). There are 250 stations across the Great Lakes (US side only) that will be sampled every 5 years beginning this year (2010). In addition to nutrients and general water quality parameters, limited benthic and sediment samples will also be analyzed. A map of the Lake Huron stations is shown below in Figure 20.

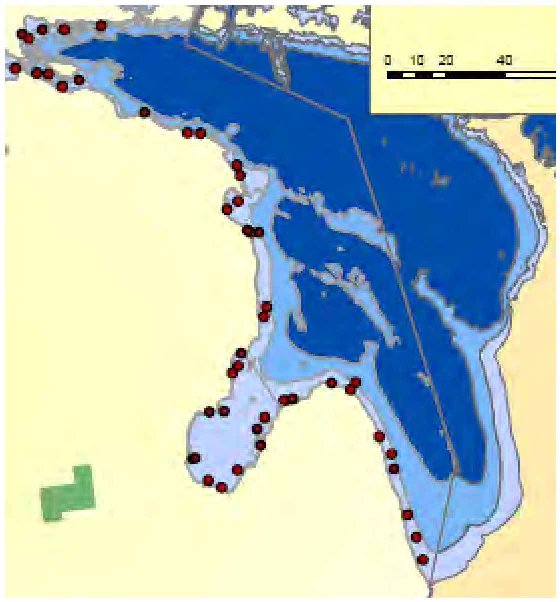

Figure 20. Map of Lake Huron National Coastal Survey stations for 2010.

3.1.6 Plankton

Research by the USEPA has shown that the spring algal bloom in Lake Huron has declined dramatically beginning in 2003 (Barbiero et al., 2010a). This is the same year that a dramatic decline in *Diporeia* began as well. Concentrations of May chlorophyll, as measured by remote sensing (SeaWiFS) from 2003 to 2006, have declined > 50% over 1998 to 2002 average values. Monitoring data showed the decline was primarily due to the loss of colonial diatoms. The loss of spring diatoms has been closely associated with additional declines in zooplankton from 2003 to 2005. Together, the loss of the spring bloom and reduced zooplankton abundance suggest a loss of food supply in the pelagic region. A plot of the chlorophyll (SeaWiFS) and phytoplankton biomass by major taxa group is shown below in Figure 21.

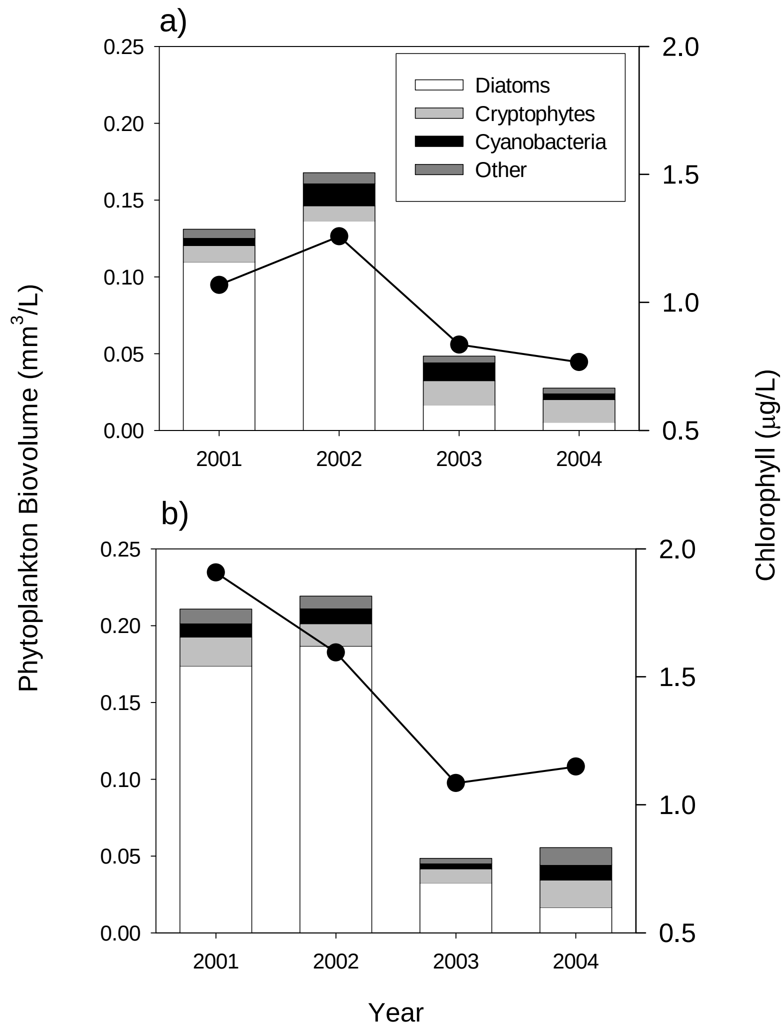

Figure 21. Spring phytoplankton biovolume and corresponding SeaWiFS estimated chlorophyll for the (a) northern, and (b) southern basins of Lake Huron, 2001-2004.

A more detailed study of the environmental drivers behind phytoplankton response is being carried out in Saginaw Bay by Millie et al. (2010). Their research has shown that the late-summer phytoplankton bloom is correlated to meteorological patterns, river flows, and annual phosphorus load. A gradient in phytoplankton abundance, nutrients, and transparency, was observed between stations closer to the Saginaw River and extending out in the outer Saginaw Bay. Additional research by Millie (Millie et al., 2006) used artificial neural networks to predict chlorophyll a concentrations in Saginaw Bay. The trained networks were able to estimate chlorophyll concentrations well and could be embedded within other water quality models to simulate algal response to water quality changes.

While it has been over a decade since dreissenids first colonized Saginaw Bay, recent research into data collected during the initial colonization (1990 to 1996) has shed light on the direct impacts of the invasion on the phytoplankton community (Fishman et al., 2009). The changes in phytoplankton community composition were indicative of increased water clarity and eutrophic conditions. After 1994, *Microcystis sp.* dominated algal assemblages. The shifts in community composition confirmed that dreissenids have a direct (filtration) and indirect (nutrient cycling) impact on plankton. Another impact is increased water clarity which will tend to favor more light tolerant species such as *Microcystis* spp.

Model simulations by Bierman et al. (2005) and again by Fishman et al. (2009) also demonstrated that these mechanisms are capable of shifting the community composition in Saginaw Bay. An ongoing research project on Saginaw Bay is developing a finer scale ecosystem model based on the Bierman model (DePinto et al., 2010).

3.1.7 Zooplankton

A recent invasive species in the Great Lakes, the bloody-red mysid (*Hemimysis anomala*), is the most recent non-indigenous species from the Ponto-Caspian region. However, the exact origin within the Ponto-Caspian region is not known. Research by Questel (2010) was able to narrow the origin of the *Hemimysis* in Lake Huron to the Mittellandkanal in Germany. The genetic signature of *Hemimysis* in the other Great Lakes likely originated from Lake Schwerin (Germany) for Lake Erie, Ontario, and the St. Lawrence River; and the Danube River for Lake Michigan. These results indicate that there were multiple source areas for the *Hemimysis* invasion into the Great Lakes.

As mentioned earlier, dramatic changes occurred in the open waters of Lake Huron in 2003. The spring diatom bloom was greatly reduced and populations of *Diporeia* were in decline as well. Additional monitoring by the USEPA showed an abrupt decline in cladocerans populations (Barbiero et al., 2009). The two historically dominant cladocerans (*daphnia* and *bosmina)* were mostly absent from the northern region of the lake and had greatly reduced numbers in the south. Declines of 90% were common at most stations. The authors hypothesize that reduced food supply and increased predation pressure from species that historically relied on *Diporeia* were the root causes of the decline. A plot of the results is shown below in Figure 22.

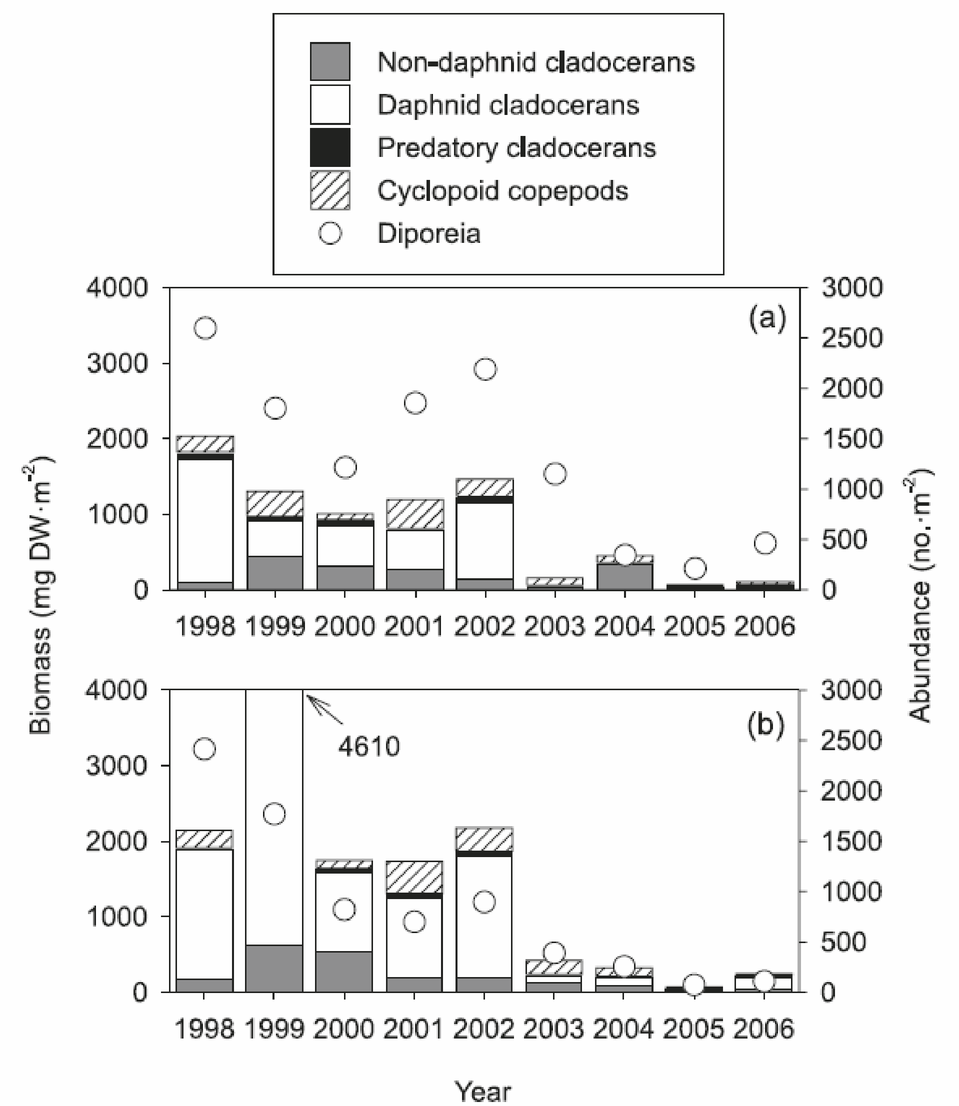

Figure 22. Biomass and abundance of zooplankton and *Diporeia* in Lake Huron.

Figure 21 above is a stacked bar plot (left axis) of areal August non-daphnid cladoceran biomass (excluding predatory cladocerans), daphnid cladocerans biomass, predatory cladoceran biomass, and cyclopoid copepod biomass (adults and copepodites); scatter plot (right axis) of *Diporeia* areal densities for the (*a*) northern and (*b*) southern basins of Lake Huron, 1998–2006.

A more detailed study of Lake Huron zooplankton was carried out by Bowen et al. (Bowen & Arts, 2010) in 2007. While the results are yet unpublished the authors indicate that calanoids dominate the zooplankton community especially in the spring and summer. Cladocerans are present throughout the growing period, but have a higher presence in the fall. Rotifers have very low densities in spring. Results of this study will be released soon.

Another zooplankton species sampled in 2007 was *Bythotrephes* by Pothoven (Pothoven et al., 2010). The authors found that the density of *Bythotrephes* was inversely proportional to fish densities. A reduction in predation was also linked to an increase the average body length.

3.1.8 Physical Processes

With relatively simple equipment (a series of thermistors) Wells (2010) was able to document the complex thermal patterns that exist in the Fathom Five Park in Lake Huron and in nearshore waters around the Great Lakes. This research highlights the dynamic nature of the thermocline during the stratified period and how the depth of it can vary significantly due to internal waves. Temperature swings of up to 10 °C per hour were observed where the depth of the thermocline was changing rapidly due to an internal wave. This information is useful to resource managers as temperature affects the growth and survival of many aquatic organisms.

While the previous research project was able to document local changes in temperature, work by Beletsky (2009) aims to model the hydrodynamic and thermal conditions of Lake Huron. Model results show significant inter-annual variability of summer lake temperature and circulation patterns. In addition a finer scale nested grid of Saginaw Bay became operational in 2009 to support the forecasting of the Saginaw River plume into inner Saginaw Bay.

Although the next study was not directed at the Great Lakes the authors demonstrated that the best method to estimate evaporation in the ice-free season is through the water balance method (Yao, 2009). This is done by calculating the volumes of all of the other components of the water balance (inflow, outflow, volume change) and determining evaporation as the remainder of the outflow portion.

3.1.9 Sinkholes

Recent underwater explorations have exposed regions of high biogeochemical activity in several submerged groundwater vents, or sinkholes, in Lake Huron. These sinkholes contain high sulfate and low dissolved oxygen concentrations and have sharp physical and chemical gradients. Several studies discuss how the physical and chemical conditions in these sinkholes create unique habitats for microorganisms (Biddanda et al., 2009).

An assortment of methods including aerial photography, physical-chemical mapping, time series measurements, remotely operated vehicle (ROV) surveys, diver observations, and bathymetric mapping were used to obtain an understanding of sinkhole features and to understand the interaction between system's groundwater flow and Lake Huron. Groundwater of relatively constant temperature hugs the sinkhole floor, creating a diverse ecosystem, including photosynthetic purple cyanobacteria mats (Ruberg et al., 2008).

Nold et al. (2010) generated clone libraries and RNA sequences of *Archaea* and *Eukarya* species from sediment cores sectioned into five distinct layers from the Middle Island sinkhole in Lake Huron. The upper layer was dominated by nematodes (*Tobrilus gracilis*), ciliates (*Frontonia vernalis*), and tardigrades (*Isohypsibius granulifer*). The second layer shared clones with the upper layer but also included seed shrimp (*Cyprididae* sp.) and copepods (*Leptodiaptomus* sp.). Clone libraries for the deepest layer were dominated by sequences similar to known methanogens (*Methanosphaerula* and *Methanosaeta*) and uncultivated *Archaea*, including non-thermophilic *Crenarchaeota*. Phylogenetic trees indicate diversity in eukaryotic and archael lineages (Nold et al., 2010).

A 70-cm long sediment core recovered by divers in September 2008 from a sinkhole off Middle Island in Lake Huron was analyzed by Paddock et al (2009). The sediment accumulation rate was estimated to be 300 mg cm^{-2} yr^{-1}, which is at least an order of magnitude higher than rates observed in open areas of the lake. Approximately 52% of the organic carbon and 62% of the nitrogen deposited in the sediment was estimated to be released into the overlying water (Paddock et al., 2009).

The rate of groundwater mixing in a series of sinkholes in Lake Huron was quantified using Radon-222 as a tracer. Because radiochemical tracers decay with known half-lives, they are often used to estimate the relative ages of processes such as mixing. Mixing times calculated as part of this study may also be applied to non-conservative constituents to estimate removal, uptake, or oxidation rates (Klump et al., 2010).

3.1.10 Water Level

Research regarding Great Lakes water levels and historical fluctuations has increased in recent years due to decreases in annual average water levels compared to the above-average levels experienced throughout much of the 70s, 80s and early 90s. Long-term studies indicate that an overall downward trend in lake levels is an expected response to warming temperatures due to climate change (Lenters, 2004).

Lake Michigan-Huron water levels were in a declining trend between 1997 and 2007 (Stow et al., 2008). A plot of the annual average water level for all of the Great Lakes for that period is shown in Figure 23 below (Stow et al., 2008). Currently, Lake Huron is about 24 cm higher than it was at the same time in 2007 and about 40 cm above its period-of-record low for this time of year. (pers comm. C. Southam, Canadian Hydrographic Service, Environment Canada)

Low levels have raised concern that the Great Lakes are beginning to be affected by climate change. Although this hypothesis is consistent with recently reported water temperature increases in Lake Superior, other hypotheses are under consideration. These include glacial isostatic rebound (the rise of land masses that were once depressed by ice) and anthropogenic induced erosion in the St. Clair River (Stow et al., 2008).

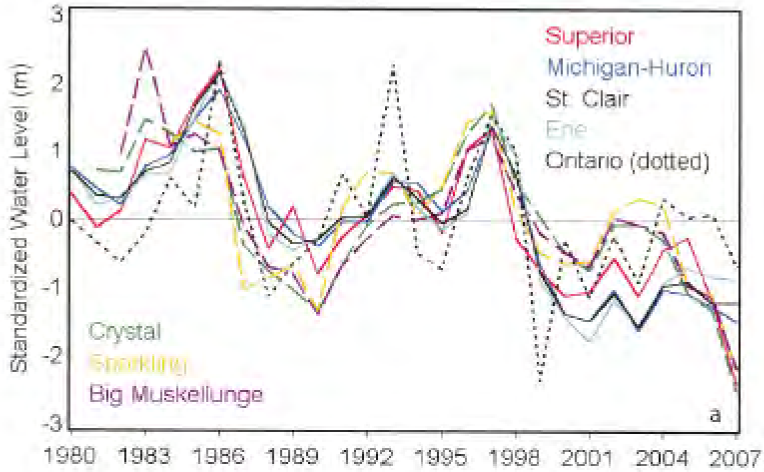

Figure 23. Standardized annual average water level from the Great Lakes.

It should be noted that in the context of historical water level trends, the recent decline is similar to other periods; however, the decadal average (2000-2009) is the lowest on record (Figure 24). The plot below was created using the monthly average (1918 to 2009) water level data published by the USACE (http://www.lre.usace.army.mil/).

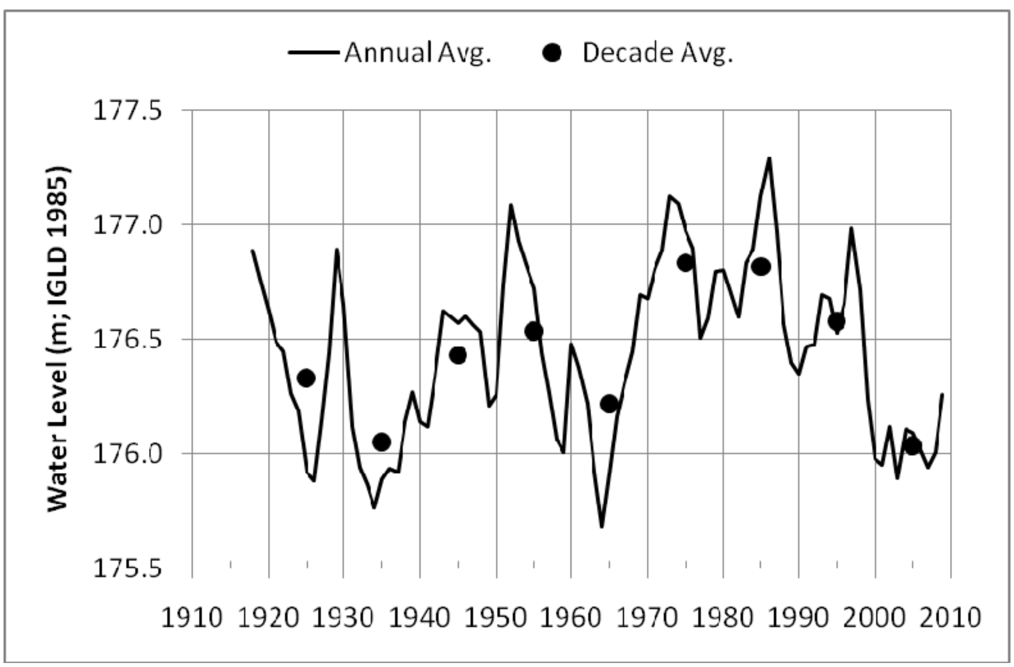

Figure 24. Plot of annual and decadal average water level for Lake Michigan-Huron.

Water level data from 1860 to 2006 representing Lakes Michigan and Huron were evaluated by Sellinger, et. al (2008) to evaluate changes in long-term and seasonal patterns. Seasonal Trend decomposition using Loess (STL) and Dynamic Linear Models (DLM) were used. STL results indicate a sustained decline around 1900 with a periodicity of approximately 30 years. A correspondence with sunspot activity was also revealed. DLM results show a relationship with precipitation over a three-year lagged timeframe. The DLM also highlights lake level declines from 1973 to the present, which may have been obscured by increasing precipitation into the 1990s. This decline may be attributed to increases in evaporation (Sellinger et al., 2008).

Lenters (2001) studied long-term trends in the rate-of-change in monthly mean Great Lakes water levels from 1860 to 1998. Trends indicate changes in the seasonal cycle of Great Lakes water levels. Lakes Michigan and Huron show negative trends in February to March and positive trends from November to December. Lakes Michigan and Huron have a weaker seasonal cycle than the other Great Lakes. Trends have been found for all great lakes, both regulated and unregulated. For example, regulating an increase in Lake Superior water levels causes Lakes Michigan and Huron to drop (Lenters, 2001). Lenters (2004) later analyzed Lake Superior water levels from 1948 to 1999. The seasonal cycle has decreased in amplitude by 20%. Analysis of the water budget indicates that the change is primarily the result in trends in runoff and over-lake precipitation. The water budget trends are primarily related to climate variations rather than lake regulation (Lenters, 2004).

Another study completed recently investigated the impacts of the St. Clair River on the water levels of the upper Great Lakes (International Upper Great Lakes Study, 2009). The report concluded that between 1963 and 2006 the difference in water level between Lake Erie and Lake Huron declined by 23 cm (9 inches). An increase in the conveyance (cross sectional area) of the St. Clair River accounted for 7 to 14 cm of the decline, while glacial rebound accounted for 4 to 5 cm, and changes in climatic patterns accounted for the remaining 9 to 17 cm. The authors note that climatic patterns accounted for 58 to 76 % of the decline in the last decade. The report also concludes that there has been no significant erosion of the St. Clair River bed since 2000.

3.1.11 Wetlands

To date, greater than 50% of Great Lakes coastal wetlands have been lost to development and agriculture over pre-settlement levels (Uzarski et al., 2010a). Coastal wetlands serve many physical, chemical, and biological functions (Uzarski et al., 2010a). Research has focused on alterations in hydrology and invasions of non-native plant species, which have changed coastal wetland structure in recent years.

The McMaster Coastal Wetland Inventory (MCWI) was created from satellite imagery from 2002 to 2008. Wetlands were manually delineated in GIS as coastal marshes and upstream wetlands. Within the northern Georgian Bay, there are 12,629 distinct wetland units comprised of 5,376 ha of low marsh, 3,298 ha of high marsh, and 8,676 ha of upstream habitat. The MCWI provides the most current and comprehensive inventory of wetlands in the region (Wojcik, 2010).

Great Lakes coastal wetlands experience fluctuating water levels. When levels are below normal, previously inundated areas are exposed. This provides an opportunity for riparian property owners to manipulate wetland structure and decrease wetland area. Schock et. al (2010) hypothesizes that this habitat alternation has significant impacts on fish and invertebrate communities living in these areas. Biota were sampled from disturbed and control sites using nets and community structure was analyzed (Schock et al., 2010).

Uzarski et. al (2010) sampled invertebrate communities within plant zones in Lake Huron. Community composition was related to hydrology using non-metric multidimensional scaling and Pearson correlation. With habitat, water quality, and depth held nearly constant, Great Lakes water levels still had an impact on invertebrate communities. Results suggest that hydrologic regimes impact the ecosystem in ways not previously considered (Uzarski et al., 2010b).

Aquatic plants were sampled from five coastal wetlands in northern Lake Huron in July 1996, 1997, and 1998. Mean water levels ranged from 176.37 to 177.19 during those years. Plant species abundance responded to water level changes. Results indicate that temporary flooding and drying in response to water level fluctuations are critical in maintaining a diverse plant species population in the wet meadow zones of the marshes. Short-term water level changes do not affect the relative spatial position of major plant zones nor the relative abundance of emergent species in the deepest zones (Gathman et al., 2005).

The aggressive non-native variety of *Phragmites australis*, or common reed, has infested many areas in the St. Clair Delta. Its growth threatens the biological diversity and wildlife habitat provided by natural wetlands. Two studies were conducted from 2001 to 2005, in order to develop techniques for restoring native wet-prairie plant communities and Great Lakes marsh habitats. Herbicides, prescribed burns, mowing, and flooding were used. A combination of herbicide application followed by a sequence of flooding, dewatering, burning, and flooding provided the most reliable control of phragmites (Kafcas, 2007).

An ongoing research project is attempting to develop a comprehensive map of the *Phragmites* infestation on the U.S. side of the Great Lakes by 2011 (Bourgeau-Chavez & Brooks, 2010). The project will use a combination of remote sensing (synthetic aperture radar) and field documentation to identify known and potential *Phragmites* locations. So far three field teams have visited over 600 locations in the Great Lakes Basin, with a majority of them occurring along the western shore of Lake Huron in northern lower Michigan. More information on the project is available at http://www.mtri.org/phragmites.html

3.1.12 Wildlife

Double-crested cormorant populations have increased dramatically throughout the Great Lakes region since lows in the 1970s. This has resulted in an increasing frequency of interactions between cormorants and people. These interactions have raised questions about the potential effects on fisheries, aquaculture, island vegetations, other colonial-nesting waterbirds, and fishing-related tourism in the region. Stakeholder concerns play an important role in management decisions; however, there is considerable disagreement regarding the perceived extent of risks posed by cormorants (Muter et al., 2009b).

Muter et. al (2009) adapted the notions of “victim” and “perpetrator” to the context of cormorant-related risks. Over the last thirty years, articles have evolved from depicting cormorants as recipients of risk (i.e. from pesticides, disease, and management) to sources of risks (i.e. to fish populations, vegetation, and tourism). Stakeholder groups pushing for cormorant management have increased in number over time. The changing nature of media coverage, coupled with the increase in stakeholder groups, suggests that human-cormorant conflicts remain hostile and contentious (Muter et al., 2009a).

The yellow perch fishery of the Les Cheneaux Islands (LCI) in Lake Huron collapsed in 2000, due in part to the increase in cormorants in the region. In 2004, a management program including egg-oiling and lethal culling began in order to reduce cormorant foraging on yellow perch in the region. A variety of data collection methods were used including aerial counts and telemetry surveys. Management led to a 74% reduction of cormorants from 2004 to 2007 (Dorr et al., 2010).

Ridgway et. al (2006) analyzed over 20 years of double-crested cormorant population data (1979-2001). Results indicate that in the North Channel and Georgian Bay of Lake Huron, density-dependent population regulation occurs. Rapid population increases of cormorants in Lake Huron have largely ceased; however, changes in fish abundance may result in future changes in carrying capacity, there were 11,445 nests in the North Channel and 10,815 nests in Georgian Bay, respectively (Ridgway et al., 2006). Ridgway (2010) also employed line transect distance sampling in aerial surveys of cormorants along the coasts of Georgian Bay and the North Channel in Lake Huron. Detection of cormorants varied based on group size, location (land, water, or flying), and season. Most cormorants were detected loafing on shore among many islands defining the region. Density in 2004 ranged from 2.3 cormorants per km^2 to 1.21 cormorants per km^2 in late August. This study indicates that aerial surveys employing distance sampling can be useful in monitoring the distribution and abundance of water birds in the Great Lakes (Ridgway, 2010).

3.2 FISH

The fisheries research priorities for Lake Huron were established through coordination by fisheries managers and scientists at the Great Lakes Fishery Commission (GLFC) and the Binational Executive Committee (BEC) of the Partnership, their supporting technical committees, and other Great Lakes researchers. The Lake Huron Technical Committee (LHTC) established Fish Community Objectives (FCOs) in 1995 that have provided valuable guidance for Lake Huron fisheries managers and researchers (Lake Huron Technical Committee, 2007). The BEC has also coordinated numerous lake-wide activities with a focus on supporting pollution reduction and protecting high quality habitat that support the protection and restoration of the lake fishery (Lake Huron Binational Partnership, 2008).

It is important to continue to revisit the *Overall Objective* from the FCO report (DesJardine et al., 1995), because it continues, until updates are adopted, to provide overall direction for the protection and enhancement of the fisheries resources in Lake Huron.

> *" Over the next two decades, restore an ecologically balanced fish community dominated by top predators and consisting largely of self-sustaining indigenous and naturalized species capable of sustaining annual harvests of 8.9 million kg."* (DesJardine et al., 1995).

More recently in *The State of Lake Huron in 2004*, (Bence & Mohr, 2008) stated that, "Major shifts in predator and prey biomass and community structure have moved the community in the direction envisioned in the FCOs". Although the changes are not fully understood, the impact of the shifts on the 1995 FCOs warranted a revisit and update of the lake objectives.

Recommendations for future research within Lake Huron from this summary report include:

- Revisit the appropriateness and attainability of the 1995 FCOs,
- Continue research on lower trophic level processes and the food-web responses,
- Continue to promote sea lamprey control as they impact the top-predator community,
- Identify high-priority habitats,
- Improve the direct management of native species.

Finally, the LHTC (Lake Huron Technical Committee, 2007) developed environmental objectives (EOs) for Lake Huron that are protective of the structure and function of the fish community at the ecosystem level. These EOs (LHTC, 2007) include:

- **Spawning and Nursery Habitats**: Maintain, protect and restore the integrity and connectivity of wetland spawning, nursery and feeding areas throughout the Lake Huron basin. Protect and restore connectivity and functionality of tributary spawning and nursery areas throughout the Lake Huron Basin. Protect and restore reef spawning areas throughout the Lake Huron Basin.
- **Shoreline Processes:** Protect and rehabilitate nearshore habitats and reestablish the beneficial structuring forces of natural water exchanges, circulation, and flow that they provide.
- **Food Web Structure and Exotics**: Protect and where possible enhance or restore fish community structure and function by promoting native species abundance and diversity and avoiding further exotic species introductions. In particular, protect and restore keystone predators to control exotic species and cultivate a food web favorable to reproduction of native species.
- **Water Quality**: Protect and restore water quality throughout the Lake Huron basin, especially in the Areas of Concern, and reduce or remove contaminant burdens from the fish community in order to avoid reductions in fish production and native species biodiversity, and to maintain fishable,

swimmable, aesthetically unaltered waters for the enjoyment of future generations.

As a way to support the focus the BEC and their committees on the fisheries objectives for Lake Huron, the following are a sample of additionally significant ongoing research from an extensive review of the published literature in the Lake Huron basin or are directly relevant. It is likely that other significant contributions exist as unpublished efforts, but the following are those recently published that are considered particularly noteworthy.

In Strecker et al. (2010) the authors assessed the spatial and temporal variation of traits in coastal fish in Lake Huron from 2001 to 2005 in response to biotic and abiotic factors. The authors found that air temperature and vegetation were significant variables in most years. These two variables are likely to be impacted by climate change through changes in average annual temperatures and water levels. Overall the trait based framework developed by the authors is useful in highlighting the interactive effects of environmental variables over a large spatial scale.

On the topic of climate change, Jones et al. (2006) presents evidence that water temperatures have risen in Lake Erie between 1965 and 2000 and their models suggest that the regional temperatures of tributaries and Great Lakes will rise substantially during the 21st century. While the authors don't make a direct linkage between the warmer temperatures and fish populations, they do suggest that an integrated modeling approach using mechanistic models can provide useful in predicting plausible habitat responses, and thus predictions on fish population dynamics.

Jones and Irwin (2008) propose to use a decision analysis approach which includes a food-web model of the Lake Huron coldwater fish community to assist managers in identifying alternative harvest strategies for multiple species. The approach involves key regional stakeholders (including managers, biologists, fishery industry members, and other experts) and will help develop performance statistics for establishing economic and ecosystem tradeoffs and decisions on FCOs.

Riley and Adams (2010) found that the benthic ecology of the western main basin of Lake Huron is undergoing profound changes across a large spatial scale. These changes are affecting the habitat use of offshore demersal fishes by shifting them towards shallower environments and shifts appear to be directly related to recent invasions of exotic species.

Dunlop et al. (2010) used hydro acoustics to characterize temporal dynamics of fish schools in northern Lake Huron from 2000 to 2004. The use of hydroacoustics may serve as another valuable tool in stock assessments and they found dramatic changes in fish school numbers and characteristics over the 5-year period. Their research found that the changes coincided with a reduction in alewife as well as environmental parameters like temperature, reinforcing the complex and dynamic relationship between biotic and abiotic parameters in the system.

Peterson et al. (2009) used long-term biomonitoring data on lake trout (Salvelinus namaycush) collected from Lakes Erie, Ontario, Huron, and Superior to investigate latitudinal and temporal trends in body mass and energy density of this top predator. Their results found that competition between the stocked pelagic forage species is leading to a bioenergetics bottleneck within the food chain as the prey base has shifted towards becoming more limiting in recent years. The study provides primary evidence that Great Lakes lake trout populations are unable to acquire and assimilate energy from pelagic prey as efficiently as they did historically in these lakes, because of competition.

Warner et al. (2009) conducted multivariate analyses of acoustic biomass data and abiotic variables from the years 1997, 2004, 2005, and 2007, to conclude that the smaller basins in Lake Huron are likely important contributors to lakewide fish biomass, production, and dynamics. The researchers suggest that for existing biomass levels, efforts to understand ecology, population dynamics, and lakewide abundance need to incorporate the effects of depth and geographic variation on fish distributions and ecology of Lake Huron fishes.

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4. INFORMATION GAPS BY ACTION AREA

During the literature review and data gathering phases of this report several researchers commented on information gaps that they had identified during their research project. While not an exhaustive list, the items below represent gaps that may be important to managers. These gaps should be taken in context with the priorities of the Partnership to determine if any of these items below warrant additional research.

In a discussion of nearshore issues, Kelly (Kelly, 2008) noted that it was difficult to determine if nearshore (~ > 20m depth) regions of the Great Lakes had experienced significant water quality changes because very few long term datasets exist for this region.

In discussions with members of the MDNRE, they identified an information gap related to fish community dynamics in the nearshore waters of Lake Huron (excluding the major embayments).

Some of the focused research in 2007 focused on identifying the cause of the dramatic decline in offshore benthos and zooplankton. To date that research has not answered those questions specifically. This information gap still exists. When combined with the nearshore information gap presented above it is unclear as to the connections between the nearshore and offshore waters of Lake Huron. A better understanding of the ecological processes controlling the observations of increased eutrophication symptoms in the nearshore waters (e.g., return of *Cladophora* blooms) and significant decrease in phosphorus levels and lower food web productivity in the offshore waters. This includes understanding the significance of nearshore-offshore transport. Clearly, more work needs to be done to determine the relative contributions of invasive species (and resulting changes in ecosystem structure and function) and changes in phosphorus loadings to these observations.

Although most of the discussion in Tobermory will focus on monitoring, Dr. Alderstein of the University of Michigan commented that having a coordinated strategy for data analysis and reporting (of results and data inventories) would help to focus the next round of monitoring (personal communication, September 2, 2010). Her information gap specifically is a complete understanding of the research done to date in Lake Huron by government and research institutions.

During the Saginaw Bay project (Stow et al., 2008) it became clear that a large gap in the State of Michigan fish assessment database is the over-winter survival of age-0 fishes. The state does annual fall surveys, but it is tough to connect the dots between years without knowing the status of the recruitment class at the beginning of the year. Closing this information gap would aid in population and individual modeling to determine the causes for survival of one species over another.

Other ecosystem information gaps include:

- 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; and
- 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.

There is also 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. This is also listed as an emerging issue in the next section.

Finally, 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. While there has been some research and monitoring done with regard to this issue as part of the IUGLS, there is still uncertainty with regard to long-term responses in fish and bird habitat conditions, conditions which are essential for bird biodiversity and fish spawning and nursery services.

5. EMERGING ISSUES

This section identifies several emerging issues with respect to Lake Huron management and science that have come up in other Great Lakes discussions or have received special attention from researchers due to its potential to have a larger impact on water quality in the future.

One of the most talked about emerging issues is climate change. To some researchers this may involve analyzing future predictions of climate or it may involve studying historical trends to identify extremes high and low conditions. The only common theme amongst the science community is it change will occur. In the context of other stressors (like urbanization, deforestation, invasive species, etc..) climate change may seem like the most "distant" of all the stressors, but the fact is that climate change is already affecting the aquatic ecosystem. Several studies are planned across the Great Lakes looking specifically at the issue of climate change in the context of ecosystem and societal impacts. While climate change is not a new issue, it often takes a backseat to more hot button issues.

Research related to the sinkholes in Lake Huron could be considered an emerging issue due to the recent discovery of this unique ecosystem. From looking at the sinkhole section of this report (in Section 3) it is clear that this relatively isolated ecosystem has received considerable research attention, which is likely to continue in the future as the general public takes an interest in it.

The Great Lakes research community continues to identify more chemicals of emerging concern in Great Lakes waters. Recent chemicals of concern include polybrominated diphenyl ethers (PBDEs) and pharmaceutical and personal care products (PPCP). Others include 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 is an emerging issue. The shoreline region is often home to many endangered 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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APPENDIX A

COMPLETE BIBLIOGRAPHY OF ALL REFERNECES COMPILED FOR THIS REPORT BY SUBJECT AREA

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Appendix A
Reference List – by Topic, Alphabetized

Invasive Species

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