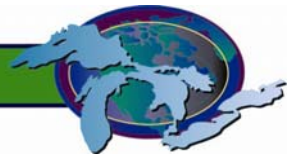

Surface Water Temperature

Overall Assessment:

Trend: Based on the date of the onset of summer stratification, Lakes Superior, Michigan, and Huron are all stratifying earlier and are thus classified as increasing. Based on the same metric, Lakes Erie and Ontario are classified as undetermined due to data unavailability. Data from the National Oceanic and Atmospheric Administration's National Data Buoy Center (NOAA NDBC) were used in this report.

Lake-by-Lake Assessment:

Lake Superior

Trend: Increasing

Rationale: The date of the onset of summer stratification in Lake Superior is occurring earlier at a rate of roughly 0.5+/-0.3 days per year. This rate is consistent between three NOAA NDBC buoys.

Lake Michigan

Trend: Increasing

Rationale: The date of the onset of summer stratification in Lake Michigan is occurring earlier at a rate of roughly 0.8+/-0.3 days per year. This rate is consistent between two NOAA NDBC buoys.

Lake Huron

Trend: Increasing

Rationale: The date of the onset of summer stratification in Lake Huron is occurring earlier at a rate of roughly 0.6 +/- 0.3 days per year. This rate is consistent between two NOAA NDBC buoys.

Lake Erie

Trend: Undetermined;

Rationale: Due to its shallowness, the overturn in Lake Erie naturally occurs earlier in the year than the rest of the lakes. However, the NOAA NDBC buoys are typically not yet deployed and therefore data is not available for this report.

Lake Ontario

Trend: Undetermined.

Rationale: Data is only available since 2002.

Purpose:

To assess trends in surface water temperature and to infer the impact of climate change on the Great Lakes region.

Ecosystem Objective:

The Great Lakes Water Quality Agreement Act's General Objectives state, "these water should be free from materials and heat directly or indirectly entering the water as a result of human

activity that...produces conditions that are toxic or harmful to human, animal, or aquatic life." Furthermore, this indicator relates to Annex 1 of the Great Lakes Water Quality Agreement which states, "there should be no change in temperature that would adversely affect any local or general use of the waters."

Ecological Condition:

The development of the temperature structure of a lake is a direct reflection of its regional climate. Upward trends in surface temperatures have been documented for the Laurentian Great Lakes (Austin and Colman, 2007) as well as lakes around the world (Schneider and Hook 2010). However, surface temperatures by themselves do not necessarily reflect the volumetric average temperature of a lake, and surface temperatures are subject to daily fluctuations, largely tied to variability in the wind field. The heat content of a lake (equivalent to the depth averaged temperature) is a much more robust measure of a lake's thermal condition, varying on seasonal and interannual scales, and hence a more useful measure of long-term change in lakes.

Subsurface temperature data is not available on a long-term basis necessary for determining lake heat content or trends therein. However, due to an unusual thermodynamic property of fresh water, we can determine the heat content using just a surface temperature in one specific circumstance. Specifically, when the surface water temperature reaches its temperature of maximum density (3.98C) in the spring (or early summer) the entire water column must also be at the same temperature. Subsequent to this, lakes tend to form stratification in which a layer of warm water sits on top of cooler water below; hence, this date is often referred to as the onset of spring stratification. While this only gives us a glimpse of the heat content, we can use the date at which this event happens as a proxy for interannual variability in heat content. In warm years, this event will occur early, and in cold years it will be delayed. In large, in partially ice covered lakes like Lake Superior, it has been shown that the timing of this event is strongly correlated to the average ice cover the previous winter.

Data from NOAA NDBC buoys in the Laurentian Great Lakes from 1979-2010 (as available) was used to examine trends in the timing of the onset of positive stratification and hence trends in heat content. Lakes Superior, Michigan, Huron, and Erie all show trends towards earlier onset of spring stratification, from 0.5 to 0.8 days earlier per year. In addition to this trend there is a great deal of natural interannual variability. Interannual variability between the lakes is roughly correlated, suggesting that the variability observed is a reflection of climate over the entire upper portion of the lakes. On top of the trend towards earlier overturn, a significant portion of the remaining interannual variability is correlated with the ENSO index.

Linkages

As the date of the onset of spring stratification becomes earlier, both average and maximum summer water temperatures tend to increase. Separate research (Austin and Colman, L&O 2008)

has shown that the length of the stratified season has increased from approximately 145 days to 170 days, an increase in the length of this season of about 18%.

In response to an increase in stratification period, and warmer bottom temperatures, oxygen depletion in the deep waters of the Great Lakes will likely decrease. Lower oxygen levels, in accordance with higher water temperatures will also support greater nutrient and contaminant release from bottom sediments. Specially, phosphorous release would be enhanced, mercury releases and uptake by biota would likely increase, and the release of some heavy metals would also increase (Kling at. al., 2003). As such, this report relates to the indicators of "Water Quality as Measured by Contaminants in Whole Fish," "Water Quality as Measured by Contaminants in Waterbirds," "Water Quality as Measured by Contaminants in Bald Eagles," and "Harmful Algal Blooms." This indicator is also related to the climate indicators of "Air Temperature," "Water Levels," and "Ice Duration."

Management Challenges/Opportunities

Response options that could be used to address climate change are classified into two categories, the first of which is adaptation, or "initiatives and measures designed to reduce the vulnerability of natural and human systems against actual or expected climate change effects." The other way in which climate change can be addressed is through mitigation, or technological change and substitution that reduce resource inputs and emissions per unit of output (Koslow, 2010).

Comments from the author(s)

Note on trends: the stated rates of change are average rates over the period 1979-2010; there is significant interannual variability on top of these trends.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validate or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respectable generator of data	X					
4. geographic coverage	X					

and scale of data are appropriate to the Great Lakes basin						
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					
Clarifying Notes						

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Contributors:
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Information Sources:

Austin, J.A. and S. Colman, Lake Superior summer water temperatures are increasing more rapidly than
regional air temperatures: a positive ice-albedo feedback. In press, Geophysical Research Letters, 2/2007

Kling, G., Hayhoe, J., Magnuson, J., Robinson, S., Shuter, B., Wander, M., et al. (2003). *Confronting Climate Change in the Great Lakes region: Impacts on Our Communities and Ecosystems.* Union of Concerned Scientists and the Ecological Society of America.

Koslow, M. (2010). *Improving the Odds: using Climate-Readiness Planning to Reduce the Impacts of Climate Change on the Great Lakes Ecosystem.* National Wildlife Federation.

Philipp Schneider, Simon J. Hook (2010) Space observations of inland water bodies show rapid surface warming since 1985, 1-5. In *Geophysical Research Letters* 37 (22).

List of Figures

Last Updated

State of the Lakes Ecosystem Conference (SOLEC) 2011

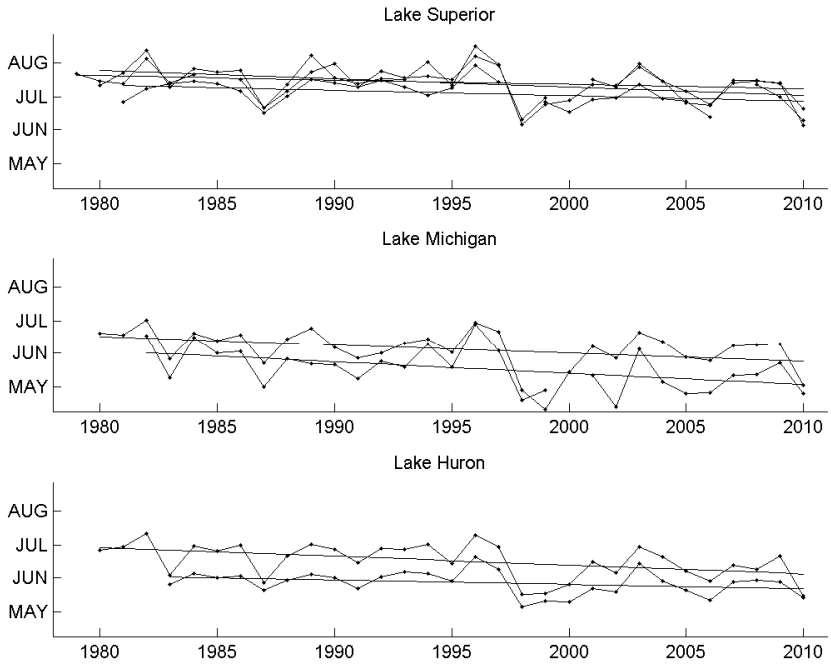

Figure 1.