

## Confronting Climate Change in the Great Lakes Region Technical Appendix

### Changes in Lake Productivity and Eutrophication

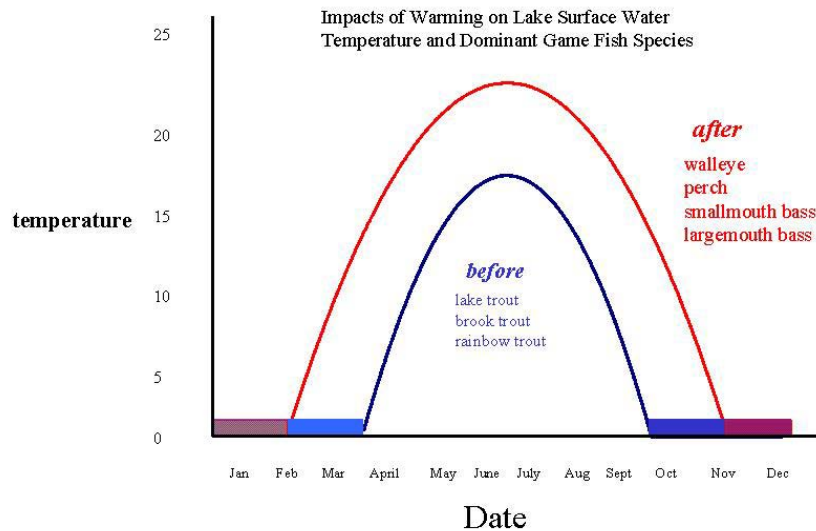
*This document is a technical appendix providing further detail on the water resource information in the Report on **Confronting Climate Change in the Great Lakes Region** available at <http://www.ucsusa.org/greatlakes/> (Kling et al. 2003). The authors most responsible for this section include (alphabetically) Lucinda Johnson, George Kling, John Magnuson, and Brian Shuter.*

#### Primary Productivity in Lakes and the Link to Climate Change

Primary production by algae in the water and on the bottom of lakes sets the level of food available for secondary producers, such as zooplankton and fish. Primary production is controlled by a combination of temperature, light (or the portion of the ice-free year when light is available), and nutrients. When nutrient availability is high, overall production varies with water temperature and the length of the ice-free period (Fee et al. 1992; Hewett and Johnson 1987; Plante and Downing 1989; Shuter and Ing 1997). When nutrient availability is low, overall production is set by the nutrient level and is relatively insensitive to changes in temperature (Dillon and Rigler 1974; Downing et al. 1990; Shuter and Ing 1997). It is likely that rates of primary production will be altered by climate change and may result in significant consequences for aquatic ecosystems and the human communities that use them. On the one hand, decreases in primary production will reduce food availability at the bottom of the food web, ultimately causing reductions in productivity of fish at the top of the food web. On the other hand, excessive increases in primary production will produce eutrophic (highly productive) conditions, exemplified by degraded water quality and noxious blue green algal blooms.

Our future climate will likely produce longer ice-free periods and higher surface water temperatures in lakes (*Figure 1*). Research in small lakes suggests that as ice-free periods increase so does primary production (Fee et al. 1992), and that an increase in water temperature of 10°C (18°F) may lead to a 4-fold increase in primary production (Regier et al. 1990). Such positive effects can be offset by decreases in light, as shown by a study of northern Wisconsin lakes that found lower primary production on cloudy days when less light was available for photosynthesis (Adams et al. 1993). In the future, cloud cover could either increase, as it has done in the Great Lakes Region recently, or it could decrease if aerosols decline. The uncertainty in scenarios for cloud cover makes the assessment of how light will affect primary production difficult.

**Figure 1.** *Warming will alter the annual cycle of surface water temperatures in lakes, ultimately impacting fish species. Blue = range in water temperature from ice-out in spring to last day of ice cover given current climate. Red = expected range in annual cycles after a 4°C (~7°F) increase in mean annual air temperature across the region. The curves shown are for a lake in the northern part of the region with a mean depth of 10m (~33 ft) and a mean annual air temperature of 2.5°C (36.5°F), prior to warming. The curves were derived from equations in Shuter et al. 1983.*



Nutrient availability could limit or even reverse the increases in primary production expected with longer, warmer ice-free periods. Predicted reductions in runoff and a general drying of watersheds (as are likely to occur under future climate change), will likely reduce inputs of both phosphorus and other dissolved materials (Magnuson et al. 1997; Schindler et al. 1996; Webster et al. 1996, 2000). In small, oligotrophic (unproductive) lakes, phosphorus loading from the watershed was shown to decline with decreases in summer precipitation (Dillon and Molot 1997), and in small lakes in western Ontario warm dry years were accompanied by reduced nutrient inputs to the lake, a longer stratification period, and the appearance of an open-water algal community dominated by species adapted to low nutrient conditions (Findlay et al. 2001). The impacts of longer stratification periods were also shown in a simulation study of Lake Michigan, which suggested that primary production would decline slightly because nutrient inputs to surface waters from the sediments would be reduced by the earlier onset of thermal stratification (Brooks and Zastrow 2002). These findings suggest that warmer and drier summers, or prolonged or stronger stratification, will lead to lower nutrient levels, thus lower primary production in many lakes (Boyce et al. 1993; Croley 1994; Peeters et al. 2002).

Changes in the species composition of the algae and in the seasonal pattern of productivity are also likely consequences of climate change. Climate warming will bring earlier ice-off and spring runoff, and this will change the timing of the spring phytoplankton bloom (Gerten and Adrian 2002). Also, longer periods of summer stratification tend to shift the phytoplankton community during the growing season to bluegreen algae because earlier stratification causes the diatom populations to decline. Overall, seasonal succession of the plankton is occurring earlier, in response to earlier ice breakup, earlier warming of temperatures, earlier stratification, and earlier onset of the interactions that drive seasonal plankton succession. These trends are expected to continue in the future.

In productive (eutrophic) lakes, if climate causes inedible nuisance species to dominate algal productivity (for example, bluegreen algae), or if the timing of algal production is out of synch with the food demands of fish, then all upper levels of the food

chain will suffer, particularly fish. In a comparison of two future climates for Lake Mendota, WI, a climate that was warmer and dryer with less wind versus a warmer, windier, wetter climate with more extreme rain events, the various processes that influence algal species and water clarity interacted in such a way that the final outcome of climate change on nuisance algal species is difficult to predict, and depends in part on other interactions in the food web such as the potential invasion of fish species that better graze the zooplankton (Gitay et al. 2001).

The likely impacts of climate change on overall aquatic productivity are summarized in *Table 1* (impacts on fish production are discussed in a separate appendix). We have moderate confidence that: reductions in productivity resulting from drying-out will be greatest for shallow lakes; reductions resulting from decreases in nutrient availability will be greatest for low volume or deep oligotrophic lakes (Dillon and Molot 1997; Findlay et al. 2001); lakes of moderate depth with relatively high nutrient levels may show increases in productivity permitted by longer, warmer growing seasons (Porter et al. 1996); and each of the Great Lakes is likely to exhibit great regional disparity in both the direction and magnitude of local changes in productivity.

**Table 1.** Summary of expected effects of climate warming on lakes and the impact of those effects on productivity. Impacts are derived assuming a warmer climate with reduced water levels (see Kling et al. 2003, Chapter 2).

Climate Driven Change	Individual Impact on Production	Most Sensitive Lake Type
- Drought-induced decrease in lake water volume	- Initial increase in production, followed by progressive decreases as the lake dries out.	- Small and shallow
- Drought induced decrease in annual input of nutrients (phosphorus) and dissolved organic carbon	- Decrease in production resulting from nutrient limitation	- Small and nutrient poor (oligotrophic)
- Increase in duration of summer stratification and decrease in winter mixing	- Decrease in production, produced by decreases in overall nutrient regeneration rate	- Deep and oligotrophic
- Increases in both ice-free period and maximum summer water temperature	- Increase in production	- Moderate in area, depth, and nutrient concentration

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