Confronting Climate Change in the Great Lakes Region
Technical Appendix

Fish Responses To Climate Change

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 principal contact author for this background paper is Brian Shuter, and other authors responsible include (alphabetically) Lucinda Johnson, George Kling, and John Magnuson.*

Temperature and Water Quantity

The body temperature of a fish is essentially equal to the temperature of the water where it lives. Typically, each species exhibits a characteristic preferred temperature – the temperature that individual fish choose to live in when given a choice. Rates of food consumption, metabolism, and growth rise slowly as the preferred temperature is approached from below, and drop rapidly after it is exceeded until reaching zero at the lethal temperature.

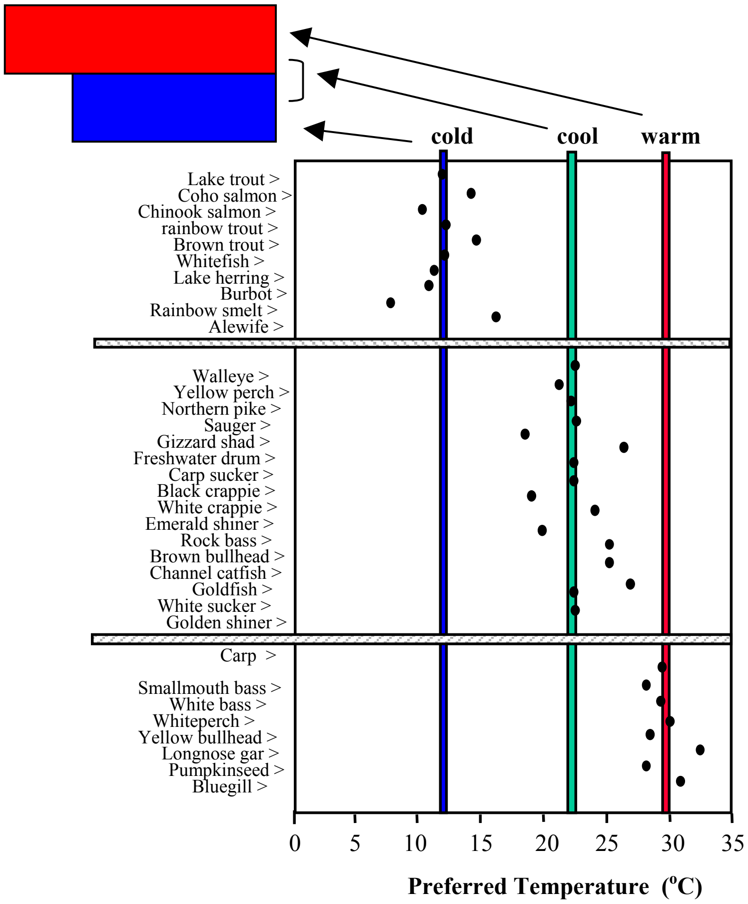

***Figure 1**. Common fish species of the Great Lakes region, grouped into thermal guilds (cold –blue, cool-green, and warm-red) according to their preferred temperatures. The colored bars identify the median value of the preferred temperatures for the species listed in each guild. The arrows indicate the preferred summer location for each guild in a typical stratified lake.*

Common species of fish can be grouped according to their preferred temperatures into "guilds" (*Figure 1;* Hokanson 1977; Magnuson et al. 1979; Magnuson and de Stasio 1997; Magnuson et al. 1990). For a given species, these guilds define the daily activities that sustain the lives of individuals (e.g., feeding and predator avoidance) and the seasonal activities that maintain the existence of populations (e.g., reproduction and parental care).

Given the vital importance of water and temperature to fish, they will respond strongly to natural variations in climate that involve changes in water volume, water flow, and water temperatures. Responses to such environmental changes fall into two broad categories: (1) changes in fish distributions, including shifts in the large-scale centers and boundaries of individual species and species groups, and shifts in the distributions of individual population members at local scales, and (2) changes in the overall production of the entire fish community in a particular region and changes in the relative productivity of individual populations within a community.

Changes in Fish Distribution

Individual fish actively select and rapidly change living areas based on suitable temperatures, oxygen concentrations, and food availability. Cold-water fish will actively avoid temperatures that exceed their preferred temperature by 2 to 5°C (3.6 to 9 °F) (Magnuson et al. 1979), and seek out refuge areas of cooler water such as groundwater or seepage areas and headwater streams (Meisner 1990; Gunn et al. 2002).

Boundaries of the zoogeographic range of species are determined in part by the interaction of thermal tolerance and behaviour of the fish with local climate. The potential effects of climate warming on such boundaries include expansion, contraction, or shift of species ranges. For freshwater fish, physical constraints such as drainage patterns, waterfalls, and land-locked areas play a large role in determining the location of zoogeographic boundaries, and in the rate at which a species may respond to the release of a climate-determined boundary. For example, the invasion of Lake Ontario by white perch from the Atlantic coast was prevented by thermal constraints until the 1930's. Then a series of warm winters over a 20-year period permitted this species to spread through the Hudson River and Erie barge canal waters and enter Lake Ontario by 1950 (Johnson and Evans 1990). There have been many studies of the potential impacts of climate warming on the distribution of fish species in the Great Lakes region (*Table 1*).

***Table 1**. Fish species will likely extend or retract their ranges in ways that are related to thermal tolerance, behavior, and climate shifts. This presents a summary of observed, predicted, and possible changes in zoogeographic boundaries of fish species in the Great Lakes basin. Changes for both lake and river environments are presented.*

Distributional Change	**Species**
Extension at northern limit	- perch, smallmouth bass: predicted ~500 km extension of existing boundary across Canada with 4 ºC (~7 ºF) increase in mean annual air temperature (Shuter and Post 1990) - smallmouth bass, carp: predicted ~500 km (~ 310 miles) extension of existing boundary in Ontario with ~ 5 ºC (~9 ºF) increase in mean annual air temperature (Minns and Moore 1995) - minnows (8 species), sunfishes (7 species), suckers (3 species), topminnows (3 species): predicted extension into Great Lakes basin possible with warming (Mandrak 1989)

Retraction at southern limit	- whitefish, northern pike, walleye: predicted retraction because of northward shift in sustainable yields expected to result from climate change (Minns and Moore 1992) - lake trout and other coldwater species: predicted in small small shield lakes by because of expected smaller hypolimnetic refuges with lower O_2 levels (Stefan et al. 1996, 2001; Schindler et al. 1990, 1996) - brook trout: predicted for lower elevations streams throughout the southern edge of the range because of expected increases in groundwater temperatures (Meisner 1990)
Barrier release and range expansion	- white perch: observed invasion and spread through Great Lakes Basin when 1940's warming of Hudson River and Erie barge canal waters effectively removed thermal barrier and permitted access (Johnson and Evans 1990) - striped bass: predicted that warming may permit this species to invade the Great Lakes basin and thus expand its range eastward (Coutant 1990)

Populations living near the edge of the species range often exhibit greater year-to-year variation in abundance than populations living near the center of the range (Myers 1998; Shuter et al. 2002). Thus, when a southern boundary retracts northward, populations with historically stable abundances may become more variable. Populations living at the northern edge of the zoogeographic range tend to exhibit lower growth rates and greater sensitivity to exploitation. Thus, when a northern boundary extends northward, populations near the old boundary may become less sensitive to exploitation and exhibit more stable abundance.

Many studies have developed forecasts of the potential northward expansion of the distribution of smallmouth bass, a typical warm-water species that is native to the southern part of the Great Lakes basin (Shuter and Post 1990; Minns and Moore 1992). Recent work has focused on documenting the consequences of that expansion for native fish communities in newly invaded lakes (VanderZanden et al. 1999; MacCrae and Jackson 2001; Jackson and Mandrak 2002). This work documents a range of substantial negative effects including local extirpation of many native minnows and negative impacts on native top predators, particularly lake trout. This work clearly demonstrates the ecological disruptions that will occur throughout the region as coldwater species disappear and warm and cool-water species vie to take their place in a warmer world.

These disruptions are likely to be compounded by invasions of other aquatic organisms, many of which are capable of totally restructuring existing food chains (e.g., Ricciardi 2001) with significant consequences for native fish communities. The zebra mussel and European carp invasions in the Great Lakes region are perhaps the best examples of such a major disruptive event. Climate warming is likely to permit zebra mussels and common carp to expand their existing ranges northward in the Great Lakes region.

In addition to changes in fish species distributions in the Great Lakes region, higher summer surface water temperatures and increased summer anoxia in deeper waters may lead to greater release of heavy metals (Dollar et al. 1991) and methyl-mercury in aquatic environments, and consequently higher mercury levels in fish (Bodaly et al. 1993; Heyes et al. 2000; Scheuhammer and Graham 1999; Yediler and Jacobs 1995). This will have negative impacts on the fish populations themselves, and on any human populations dependent on them for food.

Changes in Fish Productivity

Comparing freshwater lakes from the Arctic to the tropics, the overall production of fish is strongly correlated with the mean annual air temperature (Schlesinger and Regier 1982). Within smaller geographic regions, variation in fish production in lakes is most closely associated with differences in nutrient availability and lake morphometry (Ryder 1982; Downing et al. 1990; Leach et al. 1987). Within a lake, the productivity of a fish population is related to the amount of water present and its thermal suitability. The amount of suitable living space available is a time-weighted average of the volume of water with temperatures close to the preferred optimum but less than the lethal limit. Studies of both freshwater (e.g., walleye, lake trout, whitefish; Christie and Regier 1988) and marine species (Friedland et al. 1993) have demonstrated that the abundance and productivity of fishes increases with increased time spent at the optimal temperature. There is also a trade off between the positive effect of increased temperature on production and the negative effect of reduced lake volume from drying. For example, given a scenario where annual air temperature rises ~3°C (~5°F) and lake level drops ~1 m (~3 ft), available data from North American lakes (Ryder 1965; Matusek 1978; Schlesinger and Regier 1982) suggests that fish production will decrease in lakes with a mean depth of 3 m (~10 ft) or less, and production will increase in lakes with a mean depth greater than 3 m (~10 ft) (Shuter *unpublished*).

Production of several species of sport (lake trout, walleye and pike) and commercially harvested fish (whitefish) in the region currently varies with the amount of thermally suitable habitat (Christie and Regier 1988), and it is predicted that climate warming will cause large decreases in the amount of thermally-suitable habitat for lake trout in many inland lakes (Stefan et al. 2001). This would effectively eliminate lake trout from almost all shallow lakes in the region because of ‘summerkill,’ a lethal combination of high surface water temperatures and decreased bottom water oxygen. This is consistent with earlier work (Magnuson et al. 1990; Magnuson and de Stasio 1997) that predicted cold-water fish living in large, cold lakes will be the most secure against the negative impacts of climate change. In contrast, Stefan et al. (2001) predicted less ‘winterkill’ of warm- and cool-water fish living in shallow inland lakes because shorter ice cover times would eliminate winter oxygen deficits.

The impacts on fish production from changing temperatures and species ranges vary with different species. For example, it is likely that most northern lakes would become more thermally suitable for walleye, a typical cool-water species in Ontario, and only a few southern lakes would become less suitable, largely owing to summer temperatures reaching levels outside the optimal range for growth (Shuter et al. 2002). However, despite this overall improvement in thermal conditions, sustainable harvests from individual populations could still decline, given possible declines in water levels or nutrient availability.

Impacts On Fisheries

Climate-driven changes in fish populations and communities will produce a variety of impacts on existing fisheries (*Table 2*). Most of these impacts will stem from two primary mechanisms: (1) the overall sustainable harvest of fish will rise and fall with shifts in overall aquatic productivity, and (2) sustainable harvests from a specific population in a specific location may increase substantially or fall to zero depending on how new climate conditions and species-specific thermal characteristics interact.

Table 2. *Changes in climate will have impacts on fish ecology and consequences for fisheries.*

Impacts on fish ecology	Consequences for fisheries
- Change in overall fish production in a particular aquatic ecosystem	- Change in sustainable harvests for all fish populations in the ecosystem
- Change in relative productivity of individual fish populations in a particular aquatic ecosystem	- Change in the relative levels of exploitation that can be sustainably directed against the fish populations of the ecosystem
- Large scale shifts in geographic distribution of species	- Change in mixture of species that can be sustainably harvested within a specific geographic area - Change in location of profitable fishing grounds
- Small scale shifts in the spatial distribution of members of a specific population	- Change in sustainable harvest for the population; - Change in efficiency of fishing gear, leading to change in sustainable levels of fishing effort

Given such impacts, effective human adaptation to the impacts of climate change on fish and fisheries should involve explicit efforts to protect those native fish communities that are most vulnerable to climate driven invaders (e.g., Jackson and Mandrak 2002). It should also involve reallocation of harvest from those populations that are adversely affected (e.g., lake trout populations in southern, inland lakes) to those populations that are positively affected (e.g., walleye populations in the north and smallmouth bass populations throughout the region). However, there are strong inertial forces in both ecological systems and harvest systems that complicate this simple picture. In ecological systems, concurrent shifts in productivity and thermal conditions will cause significant restructuring of the fish community. This period of restructuring can be prolonged and will be characterized by great uncertainty in the sustainable harvests of any fish species. In harvest systems, there are human preferences for particular species that are difficult to change. These preferences will tend to prolong exploitation of populations that should be protected. The risk associated with these internal lags is that unsustainable exploitation levels will be maintained on adversely affected populations, leading eventually to both population and fishery collapse. Such risks will increase as the rate of climate change increases (for further discussion in Kling et al. 2003).

Generalities and Heterogeneity of Response

While climate change has a broad footprint across the globe, the response of aquatic ecological systems to climate change will differ greatly across regions. This heterogeneity in response is expected at two spatial scales. First, variation in climate and expected changes in climate will vary across the larger scale of the entire Great Lakes Region. Second, there is variation among aquatic habitats because the habitats vary over even small distances and different habitats filter the climate signal differently (Magnuson et al. 1990; Magnuson et al. 1997). A number of examples are presented here, but others should be expected:

- Warming will have greater effects on streams and small inland lakes than on large, stratified lakes, because the large lakes usually have refuges of deep, cold, oxygenated waters below the surface layer for cold-water fishes.
- Upland streams, currently permanent ponds, and lakes are more likely to become wetlands, dry lands, or intermittent waters than lower main-stem rivers and drainage lakes.
- Lakes with associated wetlands will likely have a decrease in dissolved organic carbon inputs while those without such wetlands will see little change.
- Developed urban and suburban lands with many roofs, roads, and parking lots (i.e., impervious surfaces that do not allow infiltration of water) will have greater flooding resulting from any storm events than will similar landscapes with less human development.
- The altitudinal position of waters in the landscape and in the hydrological flow system, the extent of human development, and the size of the water body and its watershed will greatly influence the response of lakes and streams to climate change.
- In addition to the rural and urban development patterns, the glacial history of an area will also mediate hydrologic responses to changing climatic conditions, where groundwater-dominated areas will respond more slowly than those areas fed solely by surface waters.

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