TWO POSSIBLE FUTURES The primary piece of evidence that suggests the climate is changing now and is likely to continue to change in the future has to do with atmospheric concentration of carbon dioxide over the last one thousand years. The concentration remained relatively flat—just under 300 parts per million—until the early 1800s, after which it has been increasing steadily to the present level of just under 400 parts per million. At the present rate of increase, it is projected that the carbon dioxide concentration could rise anywhere from 550 to almost 1,000 parts per million, depending on whether human carbon dioxide emissions are controlled or not.

A general upward trend in global air temperature index has accompanied the rise in atmospheric carbon dioxide since 1850. The first 100 years of this record show a lot of variation and no real evidence of a consistent trend. Since the 1960s, however, a comparison of the rise in carbon dioxide and global air temperature shows a clear link between the two, and

THERMAL SENSITIVITY OF FISHES

Based on a presentation by Brian Shuter, Research Scientist, Ontario Ministry of Natural Resources; Adjunct Professor of Zoology, University of Toronto

atmospheric scientists tell us more carbon dioxide in the atmosphere means warmer air temperatures.

Natural forces alone cannot account for the increase in global temperature; only when human carbon dioxide emissions are factored into the equation do climate model simulations closely match the observed increase in global temperature.

With this understanding of how human carbon dioxide emissions is driving global warming, we can explore a couple of scenarios of what may occur in the future. One scenario assumes stringent fossil fuel conservation measures are put into place to reduce carbon dioxide emissions—call it the "Prius scenario," where everybody in the world switches to small fuel-efficient cars. Call the other the "Hummer scenario," where carbon dioxide emissions are not controlled and everyone continues driving large, low-mileage vehicles.

The Prius scenario still results in almost a doubling of carbon dioxide, after which concentrations level off. The Hummer scenario causes carbon dioxide levels to more than triple in the next 100 years, the consequences of which could be very interesting, to say the least.

EFFECTS ON LAKES IN OUR REGION Given these two possible futures, we can make some projections of what might happen to temperature and precipitation in the Great Lakes region. The effects differ greatly between the Hummer and Prius scenarios. For example, by 2100 the summer mean air temperature (June-July-August) is projected to increase roughly five degrees Fahrenheit under the Prius scenario, whereas the Hummer scenario causes average summer temperatures to rise 15-20 degrees, making our region a very warm place indeed. Precipitation is projected to generally decline during summer and increase in winter under both scenarios until the latter years of the century, when these trends start to reverse under the Prius scenario. Conservative estimates predict a 10 to 20 percent increase in annual rainfall by 2090.

As a rule of thumb, a 10 percent increase in rainfall is needed to maintain existing water levels with each degree rise in temperature. Therefore, for lakes in our region, even the Prius scenario means we can expect lower water levels, longer ice-free periods, an increase in summer surface water temperatures and a longer stratification period.

The projections for future water levels in this region have been controversial, but some consensus is building around the idea that they will drop. Ultimately, how much water levels go down depends on whether our region gets enough additional rainfall to keep up with the rising amount of water lost to evaporation as temperatures increase. Regardless of how little or how much the decline, it means less water for fish.

Small inland lakes in this region generally are ice-covered 90 to 100 days each winter, which keeps a lid on evaporation during that part of the year. This is expected to shrink by 45 to 60 days between 2030 and 2090 as a result of longer ice-free periods and warmer open waters in winter. For the Great Lakes, this means Lake Superior, which normally never has ice-free winters, could be having ice-free winters nearly half the time by 2090. By then, Lake Erie could be ice-free almost every winter.

We are seeing this already. Since about 1960, the duration of winter on Lake Erie—defined as the number of days surface water temperatures are below 39 degrees—is clearly getting much shorter, about 20 days shorter as of 2000. Mid-summer surface water temperatures are showing a steep rise. Similar trends are evident on each of the Great Lakes during the same period.

EFFECTS ON FRESHWATER FISH Surface water temperature governs many aspects of the behaviors of fish, and the ways in which many of the fish that live in the Great Lakes react to water temperature is well documented. This knowledge of the thermal preference and performance of different fish species enables us to make reasonable projections about what might happen to different species as temperatures become warmer.

If a fish is put in a tank of water that's cold at one end and warm at the other, it will swim around until it finds a spot with a temperature it likes. The temperature it chooses is called its preferred temperature. If a fish is held in water at different temperatures and given plenty of food to eat, its rate of growth increases as the temperature increases until it reaches a peak, after which growth rapidly slows down again. A fish's peak growth rate typically is within a few degrees of its preferred temperature. This is typical of freshwater fish that live here and elsewhere in Earth's Temperate Zone.

Fishes are characterized by their preferred temperatures and grouped according to whether they prefer low, medium or high water temperatures. These are called the cold-, cool- and warm-water thermal guilds. Members of the cold-water thermal guild like water temperatures under 60 degrees; these include lake trout, salmon, herring and smelt. The cool-water guild likes water in the 60- to 80-degree range and includes walleye, yellow perch, northern pike and crappies. Bass, bullheads, carp and bluegills are members of the warm-water guild and prefer waters 80 degrees and warmer.

Where these fish are found around the country relates to the thermal guild to which they belong. Lake trout, for example, are common in cold Canadian waters, while bass are common in the warmer waters south of Canada. This is how climate controls the distribution of fishes around North America. In other words, fishes that prefer cold temperatures will be found only where the water stays cold, and they will be absent from waters too warm for them to tolerate. The opposite is true for warm-water fishes.

Cold- and warm-water fishes may be found in areas where the temperature is outside their thermal preference, but they are relatively rare because they aren't as able to compete for food as cool-water species that are in their preferred temperature range. As this region heats up, fishes that prefer warmer water will be better able to compete and expand their range northward, and cold-water species will disappear from waters that become too warm for them. Besides lake trout, the losers in this scenario include brook trout, lake whitefish, round whitefish and burbot. Some winners include buffalo, carp, catfish and several species of sunfish.

LAKE ERIE WALLEYE ANALYSIS It's a little harder to predict the fate of cool-water species. Walleyes belong to this guild, and without a detailed analysis it isn't apparent where they will be negatively or positively affected.

Lake Erie has a world-class walleye fishery. If the small shallow east end of the lake warms up significantly, the walleye there are not going to be happy. On the other hand, if the small deep eastern end of the lake warms up, the walleye might not be terribly affected because they still have some deep, cold water there. The turbidity of Lake Erie may also change with warmer temperatures, which means the light environment as well as the thermal environment will change.

An analysis of these factors indicates a 35-degree increase in Lake Erie's surface water temperature and a six-foot drop in its water level would increase walleye habitat in the deep eastern basin by 32 percent, whereas habitat in the shallow western basin will decrease by 26 percent. This would cause Lake Erie's walleye population to decline in the western basin but increase in the eastern end of the lake.

EFFECTS ON FISH ECOLOGY

Climate change is expected to have four major effects on fish ecology:

- Change in overall fish production in particular aquatic ecosystems.
- Change in relative productivity of individual fish populations in a particular aquatic ecosystem.
- Large-scale shifts in the geographic distribution of species.
- Small-scale shifts in the spatial distribution of members of specific populations.

Consequences for the fisheries of the Great Lakes region include:

- Change in sustainable harvests for all fish populations in an ecosystem.
- Change in the sustainable levels of exploitation that can be directed at fish populations within an ecosystem.
- Change in mixture of species that can be sustainably harvested within a specific region.
- Change in location of profitable fishing grounds.
- Change in sustainable harvest for the population.
- Change in efficiency of fishing gear, leading to change in sustainable levels of fishing effort.

HOW TO HELP PRESERVE OUR FISHERIES

Shuter outlined six ways of adapting to climate change that could help reduce its effect on the fish populations of Wisconsin and other Great Lakes states:

- **Conserve water**—Increased demand for water for human uses may lead to severe reductions in the amount of suitable habitat available to fish.
- **Redirect fishing effort**—Focus on fish populations whose productivity is improved by climate change.
- **Protect vulnerable fish populations**—Protect those populations whose productivity is diminished by climate change.
- **Reduce the effects of other agents of stress**—Reduce water pollution and inputs of toxic contaminants, limit competition for water between humans and fish, and control access to our waters by invasive species.
- **Actively accelerate the northward shift of warm-water species,** and/or
- **Actively protect cold-water species from competition with warm-water species.**

It is clear that climate change is already underway. Some future change is unavoidable; however, *if limited*, the effects of this change on aquatic environments can be evaluated and plans and efforts made to address them. Any delay in controlling human greenhouse gas emissions will accelerate both the rate and magnitude of future change. This will make planning and mitigation difficult—and perhaps impossible.

Lake Superior, Wisconsin: Karen Rodriguez