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ABSTRACT

The Ohio Sea Grant Education Program has produced this series of publications designed to help people understand how global change may affect the Great Lakes region. The possible implications of global change for this region of the world are explained in the hope that policymakers and individuals will be more inclined to make responsible decisions about global change policy issues. The individual information sheets, called "scenarios", describe the scientific community's prevailing interpretations of what may happen to the Great Lakes region in the face of global warming. The scenarios are written in terms the general public can understand and include the most recent information available on a variety of subjects. The Introduction, "Understanding Climate Models," is followed by 10 scenarios. Scenarios include: (1) "How Will Water Resources in the Great Lakes Region Be Affected?"; (2) "Will Biological Diversity in the Great Lakes Region Suffer?"; (3) "What Could Happen to Great Lakes Shipping?"; (4) "How Will Agriculture in the Great Lakes Region be Affected?"; (5) "Will it Affect Airborne Circulation of Toxins?"; (6) "What are the Implications of Low Water Levels in Great Lakes Estuaries?"; (7) "Will it Speed Eutrophication in the Great Lakes?"; (8) "What Could Happen to Great Lakes Recreation?"; (9) "How Could Fish Populations in the Great Lakes be Affected?"; and (10) "How Eill Forests in the Great Lakes Region be Affected?" (JRH)

ED 399 145

Global Change in the Great Lakes

SCENARIOS

Global Change in the Great Lakes Scenarios

Because global change issues are often difficult to understand, many people — including important decisionmakers — are hesitant to support global change policy suggestions by the scientific community. Instead, these people take a "wait and see" attitude toward global change which, unfortunately, defeats the purpose of any proactive suggestions the scientific community may offer.

The Ohio Sea Grant Education Program has produced the enclosed series of short publications designed to help people understand how global change may affect the Great Lakes region. By explaining the possible implications of global change for this region of the world, it is hoped that policy makers and individuals will be more inclined to make responsible decisions about global change policy issues. The publications, called "scenarios," describe the scientific community's prevailing interpretations of what may happen to the Great Lakes region in the face of global warming. The scenarios are written in terms the general public can understand, they include the most recent information available on a variety of subjects, and their content has been reviewed for accuracy by a panel of experts.

List of Titles

Introduction	Global Change in the Great Lakes: Understanding Climate Models
Scenario #1	Global Change in the Great Lakes: How Will Water Resources in the Great Lakes Region be Affected?
Scenario #2	Global Change in the Great Lakes: Will Biological Diversity in the Great Lakes Region Suffer?
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Scenario #9	Global Change in the Great Lakes: How Could Fish Populations in the Great Lakes be Affected?
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Global Change in the Great Lakes
Understanding Climate Models

Throughout the past decade, advances in computer and communication technologies have allowed people in the world's more developed countries to generate, access, and share enormous amounts of information. Private satellite dishes and cable television, for example, convey real-time images of people, places, and events throughout the world; and personal computers allow people to access databases and data management programs from the privacy of their homes and offices.

An important component of this communications revolution has been the media, which have been instrumental in helping the public keep up with — and, in some instances, understand — developments in the world around them. In their quest to provide people with up-to-the-minute information, the media have drawn all sorts of important issues into the public forum for debate. Perhaps no body of knowledge has been more affected by the media's aggressive investigation of new information than science.

Once almost entirely confined to scientific journals, scientific controversies have found their way into everyone's daily life, thanks to the media. People have come to expect that when they read or listen to news reports, they are likely to be informed of the results of one scientific study or another. Instead of reporting scientists' final consensus on an issue, however, the media often follow a scientific question through months or years of debate. While this ensures that the public is kept informed of the progress of research, it also lends to the public's confusion over issues on which experts cannot seem to agree.

The Global Warming Debate

A current example of confusing scientific debate centers around scientists' interpretations of what the Earth's climate will be like in the next century.

Most members of the scientific community agree that if concentrations of certain greenhouse gases increase, global climate will change. Few, however, agree on when these changes will occur and how extensive they will be.

Greenhouse gases such as carbon dioxide, methane, and water vapor occur naturally in the atmosphere and help warm the earth by absorbing infrared radiation emitted by the Earth's surface. If this did not happen at all, the planet would be uninhabitable. At issue is the role of human activities such as deforestation and the burning of fossil fuels in amplifying the greenhouse effect by increasing greenhouse gas concentrations in the atmosphere. If current trends in emissions continue, scientists predict that a 1.5 to 4.5°C warming of the Earth will probably occur near the middle of the next century. If this warming occurs, it could have significant effects on such climate variables as precipitation and wind patterns. These, in turn, will affect agriculture, water resource availability, regional weather conditions, and many other things that directly affect human life and the world as we know it.

A few scientists, however, are not convinced that the Earth will experience a significant amount of warming as a result of an enhanced greenhouse effect. According to them, the Earth's physical processes are flexible enough to accommodate the additional greenhouse gases emitted by human activity. They believe the world's oceans, for example, are capable of absorbing and storing much more CO_2 than they currently do. If a slight global warming does occur, these scientists believe its effect on humanity will be minimal.

The key to understanding the global warming debate is to understand how it is possible for scientists to generate different interpretations of future climate on Earth. Then, by recognizing the strengths and weaknesses of scientists' climate research, the debate over global warming becomes easier to follow.

Climate Models

To predict future global climate, scientists start with information about the present climate and try to make reasonable assumptions about what will happen in the next century. Then, they use computerized climate models to assimilate this information and come up with a description of future climate.

> ***"A current example of confusing scientific debate centers around scientists' interpretations of what the Earth's climate will be like in the next century."***

> ***"The key to understanding the global warming debate is to understand how it is possible for scientists to generate different interpretations of future climate on Earth."***

We use models in our everyday life to represent a variety of objects, processes, and systems. Because models are only *representations* of real things, however, we do not expect them to be exactly like the things we try to imitate. We know, for example, that while a model train may have the same shape as a real train, it is much smaller and cannot transport the same amount of cargo.

Even though models are not precise replicates, they still provide useful information. Dummies used in car crash simulations, for example, are far from being human, yet the information they provide engineers helps car manufacturers design safer vehicles. Similarly, global change models used today may not function exactly like the real climate, but the information they generate helps scientists understand the possible implications of global climate change.

For a climate model to function as realistically as possible, there are a number of physical laws, such as the law of conservation of energy, that scientists must incorporate. Climate variables associated with these laws include precipitation, temperature, and wind patterns, all of which interrelate and help determine how the total Earth system functions. Scientists express these laws and variables as mathematical equations, which are entered into a computer along with information on past and present global conditions. To this, scientists add their reasoned assumptions.

The simplest climate models are one- and two-dimensional simulations that try to predict the average climate across the Earth as a whole, but not regional variations. A major flaw is that they cannot incorporate many of Earth's important physical processes. The types of models most often used today are three-dimensional models known as General Circulation Models (GCMs). These allow scientists to investigate a large number of climate variables simultaneously, and results can be applied to specific regions of the Earth — such as the Great Lakes.

Because GCMs are predominantly concerned with atmospheric circulations, scientists often start with GCM information, then add data from smaller models of physical processes such as ocean circulation or cloud formation. This process is sometimes referred to as the *coupling* of climate models.

The Reliability and Validity of Climate Models

The reason there is so much disagreement in the scientific community about global climate change is that the reliability and validity of the climate models currently being used are questionable on several counts.

Testing Climate Models

To determine how well a climate model works, modelers "validate" their models by comparing them to the real world. In other words, models are provided with information about today's climate as input and are expected to produce data that closely resembles today's climate. Critics claim that some of the climate models used today have not been validated, and that those that have are not accurate.

Spatial Resolution

Modelers generally divide the world into a number of three-dimensional columns of air that extend upward from the surface of the Earth. Temperature, pressure, precipitation, and other properties of each column are translated into mathematical equations and fed into a computer along with modelers' assumptions. The equations are solved for each column of air and the computer generates a description of what global climate in these regions will be like in the future. Unfortunately, computer speed and other constraints limit the number of columns into which modelers can divide the Earth. As a result, the average size of these columns of air is 300 miles on each side — roughly the size of the state of Wyoming. This poor *spatial resolution* makes it nearly impossible for modelers to predict regional differences in such variables as precipitation, temperature, and wind velocity. Our experience tells us, however, that on any given day the weather in one part of a state may be very different than in another.

One way to improve the spatial resolution of GCMs would be to use faster, more powerful computers. Unfortunately, modern machines cannot accommodate the thousands of equations necessary to make this possible. According to physicist James Trefil of George Mason University, if modelers reduced the size of atmospheric columns used in a GCM from 300 to 30 miles per side, the best of today's computers would take 40 years to generate a prediction of future climate. Ironically, such calculations would come too late to be of much assistance to scientists and policymakers interested

Major Features of Three General Circulation Models (GCMs)*

GCM	When Calculated	Model Resolution (Lat. x Long.)	Temperature Increase for Doubled CO_2 (°C)	Increase in Global Precipitation (%)
Goddard Institute for Space Studies (GISS)	1982	8 x 10°	4.2	11.0
Geophysical Fluid Dynamics Laboratory (GFDL)	1984-85	4 x 8°	4.0	8.7
Oregon State University (OSU)	1984-85	4 x 5°	2.8	7.8

* Assuming that CO_2 doubling will occur in the middle of the next century.

Source: U.S. Environmental Protection Agency (1989)

in making proactive decisions. However, recent advances in technologies such as superconductivity make scientists hopeful that a new breed of computers will evolve that can make high resolution GCMs possible.

Assumptions

Another reason people question the reliability of climate models is that although scientists agree on some of the initial conditions to set for climate models, they often make different assumptions about other physical processes related to their models. While there is a consensus on how temperature and wind velocity should be measured, for example, there is no standard way to compute things like cloud height, the movement of sea ice, or surface *albedo* (the ratio between the light reflected by an object and the total light falling on its surface). Scientists do not yet know enough about these physical processes to gather and interpret information about them consistently. Depending on their assumptions about these different physical processes, climate modelers can come up with very different interpretations of the future, as evidenced by the GCMs of the three leading global change research institutions, shown above.

The more physical processes modelers try to incorporate into their models, the more assumptions they have to make about processes related to climate. The number of assumptions multiplied, then, when scientists link models together or use output from one model as input for another model. Since not all modelers' assumptions about climate are correct, the more assumptions involved in a model, the greater the error. The key to improving climate models is to gain a better understanding of the physical processes that drive the individual components of climate.

Characteristics of Some Variables Involved in Climate Modeling

To appreciate the complexity of climate models, here are a few examples of the kinds of variables that modelers must incorporate into their models.

Oceans

The primary function of oceans in regard to climate is to absorb, release, and distribute atmospheric heat on the Earth's surface. Modeling the oceans presents a particularly difficult challenge for scientists because relatively little is known about the physical processes that affect ocean circulation. For example, scientists have not been able to agree on how to calculate the vertical and horizontal mixing of currents, and they have trouble incorporating information about upwellings into their models. (An *upwelling* is a phenomenon that occurs in oceans and lakes when wind blowing across warm surface water pushes that water away from shore. When this occurs, cold, nutrient-rich water from below is forced to the surface.)

Another important function of oceans is to absorb CO_2 from the atmosphere, but no one knows how much can be taken up. As mentioned earlier, some scientists believe that there is little threat of global warming as a direct result of increased atmospheric CO_2. They think excess CO_2 emitted by human activity will be removed by oceans. Other scientists, however, are quick to point out that the amount of carbon the oceans are able to absorb is a direct function of ocean temperature. Because cool water is capable of absorbing more atmospheric CO_2 than warm water, these scientists are concerned that even a small increase in ocean temperatures in the future will disturb the carbon balance and enhance the greenhouse effect. To make an accurate assessment of the role oceans play in carbon absorption, scientists need to gain a better understanding of the entire carbon cycle: the process whereby carbon is transferred between land, water, living things, and the atmosphere.

> ***"The more physical processes modelers try to incorporate into their models, the more assumptions they have to make about processes related to climate."***

Clouds

Another important climate variable that is difficult to assess is the role of clouds. Depending on their composition and their location in the atmosphere, clouds can perform a variety of functions. By trapping and reflecting the longwave radiation emitted by the Earth's surface, clouds function as insulators, helping keep the Earth warm. Clouds can also trap and reflect the shortwave radiation emitted by the sun. In this case, clouds act as cooling mechanisms and prevent the Earth from becoming unbearably hot.

Despite these significant functions, however, scientists have a difficult time incorporating information about clouds into their models because cloud behavior is difficult to measure, let alone predict. Some researchers have hypothesized, for example, that if the Earth warms, there will be an increased rate of evaporation, which will lead to the formation of more clouds. If these clouds reflect a large amount of incoming shortwave radiation from the sun, they will help cool the Earth and reduce warming. On the other hand, if they trap and reflect longwave radiation, warming could increase.

As with atmospheric circulation models, resolution is a major problem for scientists trying to model both clouds and ocean circulation. Like the atmosphere, clouds and oceans are affected by all sorts of regional climate conditions that make it difficult to predict the future climate at specific points on the globe.

Volcanoes

Many people may not associate volcanoes with climate, but historical records suggest that volcanic eruptions can have significant effects on world climate. Volcanoes can discharge enormous amounts of fine particles and aerosols into the atmosphere, which can decrease the amount of sunlight that is able to reach the Earth's surface. When this happens, the Earth can cool by several tenths of a degree for years, perhaps decades. Examples of this phenomenon are found throughout time, from the volcanic acids deposited in the Greenland ice sheets over a thousand years ago to more memorable eruptions such as Mount Pele and Krakatoa.

Some researchers suggest that the reason the Earth has warmed by 0.3° to 0.6°C in the past 100 years is that there has not been significant volcanic activity. Without the natural cooling that accompanies intense volcanic activity, the Earth has warmed.

Policy Decisions in the Face of Global Warming

According to Trefil, there are three basic responses to the global warming debate that today's leaders can adopt. First, decision makers could adopt a "wait and see" attitude by waiting until scientists can produce indisputable evidence that global warming is or is not continuing to happen. The obvious shortcoming of this policy is that by the time such results become available, it may be too late for policymakers to take steps to help reduce the consequences of global warming if it does, indeed, continue.

Another response would be for policymakers to "assume the worst and act accordingly." This response would require immediate policy decisions designed to drastically reduce human activities that affect climate. Such policies might include a ban on the use of fossil fuels or a halt to deforestation. This would be the best response to help reduce the effects of global warming, but it would bring economic hardship to millions of industries and people.

Finally, decision makers could adopt a "no regrets" policy. "The idea here is to undertake immediately those actions that make sense whether the warming predictions are right or not," said Trefil. In other words, even though scientists cannot definitively agree on whether or not global warming will continue, they do generally agree that human activity is at the heart of many other problems throughout the world. If steps are taken to correct *known* problems such as acid deposition, deforestation, and fossil fuel dependency, they will have the added benefit of helping reduce emissions of greenhouse gases. Although this "middle of the road" approach may seem appealing, it may not initiate the types of policy decisions that would adequately address severe global warming if it were to occur.

Some critics argue that climate models should not be used as guides for making public policy decisions about global warming because these models currently do a poor job describing how the Earth's physical processes work. Despite the models' shortcomings, however, they are still useful in helping scientists assess what the *possible* implications of continued global warming could be.

To appreciate the importance of climate models, consider another type of model relied on daily: weather models. Before people leave their homes in the morning, they generally listen to weather forecasts in order to determine what clothing will be most appropriate for the day and what sorts of outdoor activities the weather will permit. People trust these forecasts enough to make these kinds of decisions, but they do not trust them completely — people accept that weather forecasters are sometimes wrong about the weather. Still, the weather reports give us a pretty good idea of what to expect — and that's better than nothing! By the same token, climate models may not be very trustworthy at present, but they can help us imagine what future climate may be like and help us design contingency plans based on the scenarios they predict.

Whether global warming actually occurs as predicted, it is important for people to be knowledgeable about what the future could hold. Even a one- or two- degree temperature change could have significant implications for humanity. This is why The Ohio State University is preparing educational materials for teachers, students, and the public. In addition to the Global Climate Change Scenarios describing potential impacts on the Great Lakes, Sea Grant and the National Science Foundation (NSF) support the development of curriculum activities for secondary schools. Funds from the Eisenhower Program and NSF support teacher enhancement workshops in Ohio and throughout the United States. These efforts help to assure that future decision makers will understand climate change and the possible effects of continued global warming on the Earth system.

Although the global warming debate can be difficult to follow at times, people should keep in mind the fact that our questions about the Earth's physical processes have always evolved faster than our understanding. As our computers become more powerful and scientists' knowledge of Earth systems grows, chances are we will develop more reliable climate models. The dilemma is that decisions need to be made *now* if we want to address the future problems that may be associated with global warming. ⊕

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For information about the scenarios or global warming, contact the Ohio Sea Grant Education Program, The Ohio State University, 29 W. Woodruff, 059 Ramseyer Hall, Columbus, OH 43210, 614/292-1078. To place an order, send $6 (or $9 if ordering from outside the U.S.), in U.S. dollars, to Ohio Sea Grant-Publications, The Ohio State University, 1314 Kinnear Road, Columbus, OH 43212-1194, 614/292-8949. Make checks payable to The Ohio State University.

Global Change in the Great Lakes
How Will Water Resources in the Great Lakes Region be Affected?

Scenario #1

The Great Lakes are indeed great. Containing about 100 million cubic kilometers of water, they represent the largest freshwater system in the world. Some 40 million people live within their basin, a region bordered by eight states and two provinces. Because of proximity, many residents depend on these vast bodies for power production, recreation, irrigation, drinking water, and transportation.

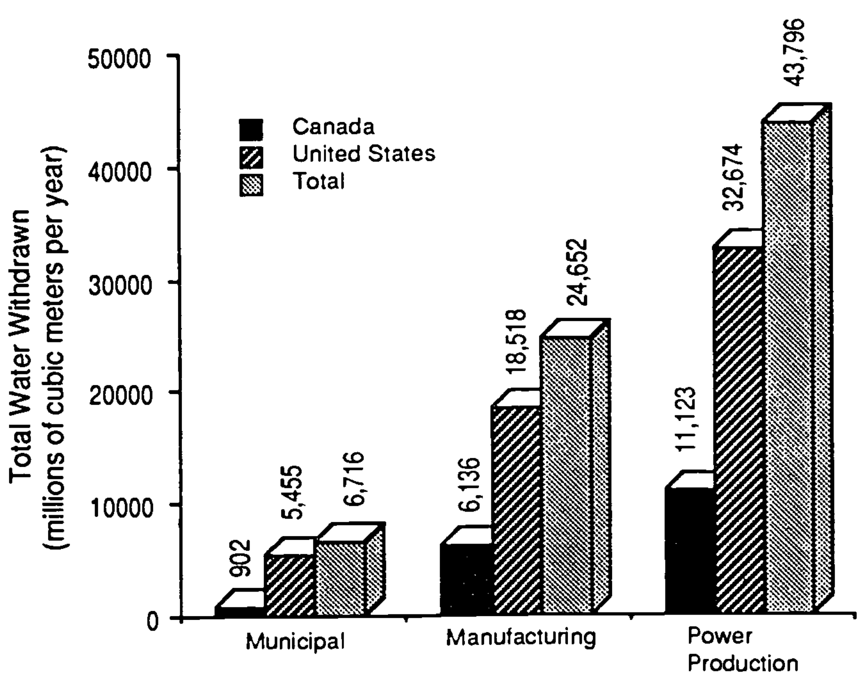
Of this vast supply, approximately 75 billion cubic meters of water are removed from the lakes each year for municipal, industrial, or individual purposes. While most of this water is returned to approximately the same location, more than 4 billion cubic meters is consumed through evaporation, growth of plants, incorporation into products, or other processes.

The Demand for Water

The demand upon regional water resources is increasing at a tremendous rate. According to national trends, by the year 2020:

- power generation in the United States will require 15 times more land and 13 times more cooling water than at present;
- the use of industrial water will increase eightfold;
- the use of irrigation water will increase fivefold;
- urban land use will double;
- twice as much sewage capacity will be needed; and
- the population in the Great Lakes Basin will double.

Water Withdrawal in the Great Lakes Region



Source: Environment Canada and U.S. Environmental Protection Agency (1987)

What Global Warming Could Do

Should global warming occur, its effects on Great Lakes water resources would be substantial. According to scientific estimates, within the next 50 to 75 years the temperature of the Earth may increase by as much as 1.5 to 4.5°C. The primary cause is expected to be the ongoing accumulation of greenhouse gases in the atmosphere. To put these figures in perspective, global temperatures have only altered about 5°C since the last ice age. If warming trends continue as predicted, they will cause climatic conditions throughout the world to shift poleward, affecting each region in numerous complex ways.

In terms of water, climatic changes would increase demand in the Great Lakes Basin area by increasing evaporation, changing humidity and precipitation patterns, and drying up some local supplies. Also, western and southwestern states may agitate to divert water from the Great Lakes to regions experiencing scarcity.

Lake levels are likely to be directly affected by these factors, as evidenced in Lake Erie's recent history. In 1985 and 1986, high water records were set and flooding occurred; but in the fall of 1986 less precipitation coupled with high evaporation rates were recorded, causing the lake level to drop. In 1987 and 1988, a drought amplified these factors and lake levels fell below average.

Even slight drops in lake levels are significant. For example, a 2.5 cm decline in Lakes Michigan and Huron is equivalent to more than 36 billion cubic meters of water — enough to supply the needs of a city the size of Cleveland for over 88 years.

Another effect of global warming could be an accelerated rate of *eutrophication* — or aging — of the Great Lakes. Lakes and

Projected Impacts of Global Warming on Great Lakes Hydrology

Snowmelt	Decrease
Runoff	Decrease
Soil Moisture	Decrease
Lake Evaporation	Increase
Overlake Precipitation	Increase
Lake Surface Temp.	Increase
Ice Cover	Decrease
Net Basin Supply	Decrease
Lake Levels	Decrease

Source: Cohen (1989)

other bodies of standing water naturally progress from *oligotrophy* (being cool, deep, and having limited amounts of life) to *eutrophy* (being warm, shallow, and having an abundance of life). Unless there is enough flow to wash out accumulating sediments, *senescence* will be reached, completing the evolution of open water bodies to wetlands, then to moist lowlands.

Accelerated warming of the lakes could also heighten the impact of zebra mussels on the region. These bivalves and the plankton on which they feed thrive in warm water. Since their accidental introduction into Lake St. Clair, the zebra mussel has colonized all the Great Lakes. Encrusting all available hard surfaces in concentrations as high as 70,000 individuals per square meter, zebra mussels clog municipal and industrial water intakes, damage boat engines, create extra drag on boat hulls, and foul docks. Lake Erie's food chains may also be threatened. In preliminary laboratory studies at The Ohio State University, zebra mussels increased their feeding activity with increasing temperatures. For their thumbnail size, they filter an unusually large amount of water: clearing about a liter a day of plankton and suspended sediments. Early results indicate that zebra mussels accumulate a high percentage of environmental toxins in their bodies, which could be passed on to predators such as fish or diving ducks.

What We Can Do

Concern for protecting the water resources of the Great Lakes basin from excessive diversion, consumption and withdrawal is nothing new. The Boundary Waters Treaty of 1909, the Great Lakes Water Quality Agreement of 1978, and the Great Lakes Charter of 1985 address these issues. Protecting a precious supply of water, however, is not easy. Policy questions linger: Do states in which a water resource is located have more rights than downstream users; and does the first state to put the resource into beneficial use have priority over others?

By gathering data on the demands upon and capacities of the Great Lakes, the Great Lakes Commission (GLC), an eight-state agency, is trying to identify absolute water needs of the eight states and two provinces in order to make well-founded suggestions for the future. Approved by Congress in 1968, the GLC's purpose is "to promote the orderly, integrated, and comprehensive development, use and conservation of the water resources of the Great Lakes Basin."

It is impossible to know exactly what the effects of global warming may be upon the Great Lakes, but we should realize that a complex network of demands upon these lakes already exists. Optimum management is becoming essential. Furthermore, we must do away with the *egosystem* approach to the management of our water resources in which our needs and wants are the driving factors. Instead, we should adopt an *ecosystem* approach where the integrity of the environment is maintained above all else. ⊕

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Global Change in the Great Lakes
Will Biological Diversity in the Great Lakes Region Suffer?

Scenario #2

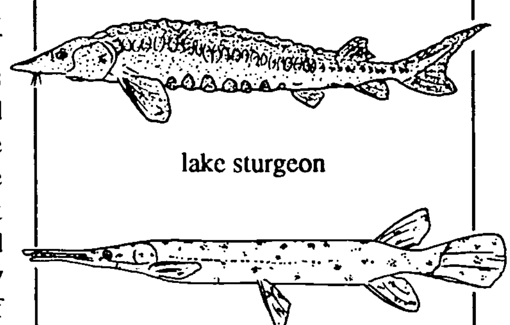
When asked to name a few natural resources, most people are quick to identify those resources commonly used in everyday life: forest products, water, minerals, and so on. One important resource often overlooked, however, is biological diversity.

Simply defined, biological diversity is the variety of life on Earth. Although it can be viewed in many ways, three basic levels can be identified. First, one can describe the genetic diversity between individuals of the same species. A peek in any family photo album reveals that even closely related organisms are rarely identical. Second, species differ from one another. Imagine for a minute all the different types of birds you know. Third, biologists make distinctions between ecosystems. Just within the United States, there are environments as different as painted deserts, alpine meadows, and mangrove swamps.

No one knows exactly how many species inhabit the Earth. Ten million is considered a conservative estimate. To date, only about 1.5 million animal and 300,000 plant species have been recorded by scientists. Clearly, we humans have only an elementary grasp of these with whom we share the planet. Sadly, we may never know. Experts estimate that at least one million species will become extinct by the end of this century. Even the mass extinction that ended the dinosaurs' reign may not have occurred as swiftly.

Maintaining biological diversity is important to humans for several reasons. The National Park Service refers to the arguments in favor of preservation as the four E's: ethics, ecology, economics, and esthetics. One could say that plants and animals have an intrinsic right to exist; it is immoral for humans to decide what species should survive and what should be exterminated. In addition, each species is a living component of its ecosystem and its loss would disrupt a network of interrelationships. A third argument is that many species have untapped economic value. For example, the medicinal qualities of some plants have been used to develop drugs to combat human heart disease and childhood leukemia. Also, by preserving variety within species, we insure a rich pool of genetic information that can help researchers engineer more resilient domestic breeds. Finally, other members of the living world have esthetic value because of their beauty, symbolic meaning, or intrinsic interest.

Rare Lake Erie Fish



lake sturgeon

spotted gar

Source: Trautman (1981)

Threats to Biological Diversity in the Region

Many factors contribute to the loss of biological diversity, but the main culprit is habitat destruction caused by human activity. In the Great Lakes region, these include deforestation, deterioration of water quality, the drainage of wetland areas, and contamination by chemicals such as pesticides and polychlorinated biphenyls (PCBs).

Laws have been passed in Great Lakes states and provinces that help reduce habitat destruction caused by chemicals and other pollutants, plus many public and private conservation programs have been established to help restore and preserve the habitats of rare species. Despite progress in identifying and amending some of the causes of habitat destruction, researchers are concerned about how global change issues such as the "greenhouse effect" and its resulting climate changes will affect the precious natural areas that remain.

The Possible Influence of Global Change

Because of the wide variety of species inhabiting the Great Lakes region and the diverse problems that already face them, the effects of global change — especially global warming — are of particular concern to resource managers.

Most scientists agree that the average temperature of the Earth is increasing with the buildup of "greenhouse gases" in the atmosphere. Although no one knows how much temperatures may rise, experts estimate that it could be between 1.5 to 4.5°C over the next few decades.

Global warming in the Great Lakes region would likely mean increases in

Focus

Species Introduction and Reintroduction

If global warming occurs as scientists predict, resource managers will have to make some difficult decisions about their role in shaping the species composition of natural areas. For example, should southern trees be introduced into the Great Lakes region to speed their migration? Should varieties that have been genetically engineered to withstand pests and drought be planted in the wild?

Already, programs to reintroduce extirpated species have begun in some locations. Starting in 1988, the Ohio Division of Wildlife began a series of river otter reintroductions to try to repopulate state waterways. Likewise, the Bureau of Endangered Resources in Wisconsin has reintroduced former natives such as the peregrine falcons, trumpeter swans, and pine martens to that state.

air and water temperatures, greater precipitation, and accelerated evaporation rates. These factors could cause lake levels to drop by several meters. As a result, regional estuaries and wetlands could decline, reducing valuable spawning and breeding grounds for fish and birds, respectively. Water quality in the lakes would decline as pollutants concentrated, making some areas intolerable to certain species.

Climatic conditions in the future could shift ecological regions poleward. Generally speaking, the southwestern desert could replace the grain belt (of which the Great Lakes region is a part) and the grain belt could shift into Canada. The composition and abundance of forests could change too. For example, deciduous forests could move into land now covered by boreal (northern evergreen) forest, and boreal forest could blanket tundra.

It is important to remember, however, that most species that compose the ecosystems with which we are familiar would not relocate together. Instead, unusual combinations would arise. Some plants and animals with only marginal distributions in the Great Lakes region at present could expand their territories under new conditions. Likewise, others would find either the climate or the changing interrelationships between species unfavorable. Moving to more suitable sites might not be possible for many species if global warming occurs as rapidly as predicted. Human activities that alter the landscape, such as agriculture and city-building, or natural topographical features such as the Great Lakes themselves, would be barriers to migration. In addition, it is plausible that the Great Lakes region would experience an influx of foreign plants and animals able to aggressively out-compete remaining natives.

How Can Biological Diversity be Preserved?

Although it is difficult to estimate the magnitude of global warming effects on natural habitats, it is important that steps be taken now to ensure the survival of the region's native plants and animals. Already, decision makers in the Great Lakes region are adopting policies meant to restore, preserve and maintain natural areas. These include reintroduction programs and multiple use planning initiatives. In addition, there are several things that individuals can do to preserve biological diversity:

- Help stop greenhouse gas accumulation in the atmosphere by reducing fossil fuel consumption at home, at work, and at school. Whenever possible, elect to use public transportation, carpools, or a bicycle.
- Become a member of conservation organizations that lobby on environmental issues, or write your own letters to governments and businesses.
- Volunteer to help restore and maintain natural habitats in your community.
- Finally, keep abreast of current environmental topics, then share your knowledge with others. ⊕

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Ohio Sea Grant College Program

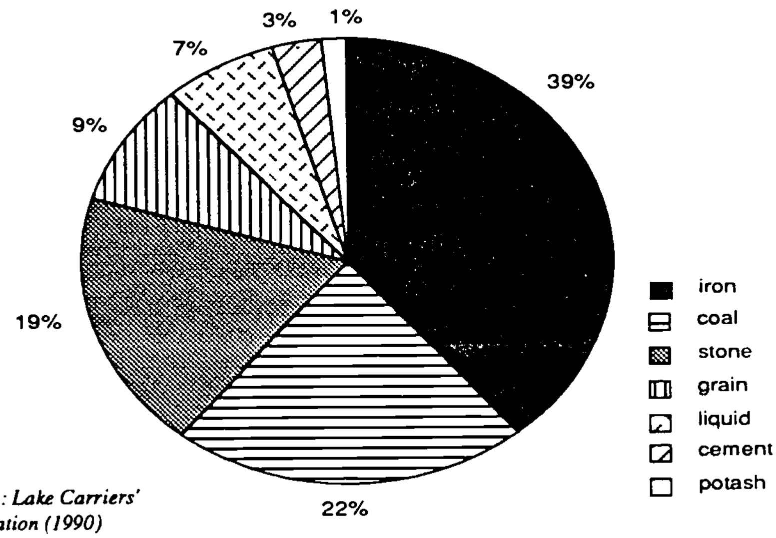
Global Change in the Great Lakes

What Could Happen to Great Lakes Shipping?

Scenario #3

The Great Lakes have been an important link in North American transportation systems since the first Native Americans navigated the region's waters. Today, nineteen states and two provinces currently use the Great Lakes, their locks, and the St. Lawrence Seaway for transportation and commercial activity. In addition, over 200 merchant and foreign flag vessels participate in commerce at 83 ports. Goods traveling through the waterways may be exchanged on worldwide markets.

Great Lakes Bulk Commerce – 1990

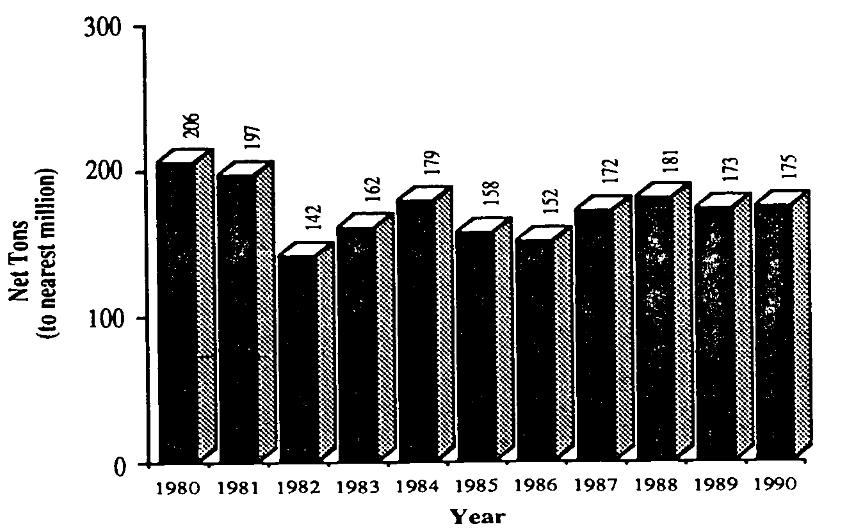


Source: Lake Carriers' Association (1990)

Iron ore, coal, and limestone are the primary cargoes moved through the Great Lakes. In contrast, the region's manufactured and agricultural exports are largely transported by rail or inland waterways because the shallowness of Great Lakes ports and channels prohibits ocean-going ships. The size of the lakes and their winter ice cover discourage some smaller vessels.

Nevertheless, during a typical 10-month navigation season, shipments of all dry- and liquid-bulk cargoes top 160 million tons. In boom years like 1979, more cargo crisscrosses the Great Lakes than passes through the Panama Canal.

Total Amount of Bulk Products Shipped on the Great Lakes



Source: Lake Carriers' Association (1988, 1990)

Possible Effects of Global Warming

Although global warming would probably extend the navigation season by two months, this benefit is expected to be overshadowed by lowered lake levels. According to predictions by the Center for the Great Lakes, the average air temperature could increase 1 to 4.5°C by the year 2055. Despite potentially greater annual precipitation, this warming would increase evaporation rates from land and water, reducing the water supply in the basin.

The *draft* of a boat is the depth of water displaced when it is afloat. If lake levels drop, ships will have to carry lighter loads in order to sit higher in the water. With less carrying capacity, more trips would have to be taken to move the same amount of goods as before, making transportation more time consuming.

Overall, in the course of a shipping season, a 1-inch reduction in draft could reduce U.S. merchant fleet carrying capacity by more than 420,000 net tons. Within each Great Lake, however, the effects of water level changes on shipping would be different. For example, a half-meter drop in Lake Superior would result in a 5 percent decrease in cargo capacity, a 6 percent increase in transportation costs, and a 15-day increase in transportation time. Because of its shallowness, Lake Erie would experience even more extreme conditions. A one-meter drop in Lake Erie is expected to decrease cargo capacity by 14 percent, increase costs by 14 percent, and necessitate an additional 50 days for cargo delivery.

Another factor to consider is that lower lake levels would mean that ports and connecting channels such as the Welland Canal would need to be dredged deeper and more often. Additional dredging in polluted sites would be expensive since the disposal cost of contaminated sediments is high. Also, if water levels fall below the point where dredging can maintain current project depths, dock foundations may be weakened. As a result, equipment for loading and unloading goods may have to be lowered, or vessel structures raised.

Focus

The Effect of Low Water Levels on Ship Carrying Capacity at the Sault Ste. Marie Locks in Michigan

For each inch of draft, a 1,000 ft.-long supercarrier on the Great Lakes can carry up to 267 net tons of cargo per trip. In July 1986, the mean draft of supercarriers at the Sault Ste. Marie locks was 28' 1". This allowed the 1,000 ft. vessels to carry up to 69,664 tons of iron ore per trip. Because the average supercarrier makes 45 trips during the shipping season, each 1,000 foot vessel was able to transport nearly 3.1 million tons of iron ore in 1986.

During the drought of 1988, however, water levels dropped and supercarriers lost 17 inches of draft. This meant the supercarriers could carry a maximum of 65,064 tons of cargo per trip. Over the shipping season, this meant each 1,000 ft. vessel lost 205,000 tons of carrying capacity compared to the amount shipped in 1986.

Source: Lake Carriers' Association (1988)

Planning for the Future

It is important that people understand the potential effects of climate change on Great Lakes shipping, so they are prepared for the economic consequences. If conditions alter substantially, lake carriers may need to consider redesigning some of their fleet. However, some reluctance is to be expected. As Glen Nekvasil of the Lake Carriers' Association phrased it, "A decision to build a $130 million ship can't be based on a theory."

Increased shipping costs would directly affect the industries that depend on the Great Lakes to transport their products. In turn, steel producers, grain farmers, and other area business people would have little choice but to pass their costs on to consumers. As Stewart J. Cohen of the Canadian Climate Service said, "appropriate responses must be made to climate changes as they affect Great Lakes transportation that will allow consumers to continue to enjoy the benefits of these services at a reasonable cost and with minimum interruption." ⊕

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Global Change in the Great Lakes
How Will Agriculture in the Great Lakes Region be Affected?

Scenario #4

Much of the Great Lakes region is farmed: 42 percent of all land is used for agriculture and 10 percent for pasture. The eight states alone produce nearly a quarter of the total agricultural output in the United States, and raise approximately 18 percent of the cattle. Other agricultural products in the region include corn, soybeans, grapes, and tobacco. Any changes in temperature or precipitation patterns within the region may affect agricultural productivity and, in turn, the livelihoods of many people.

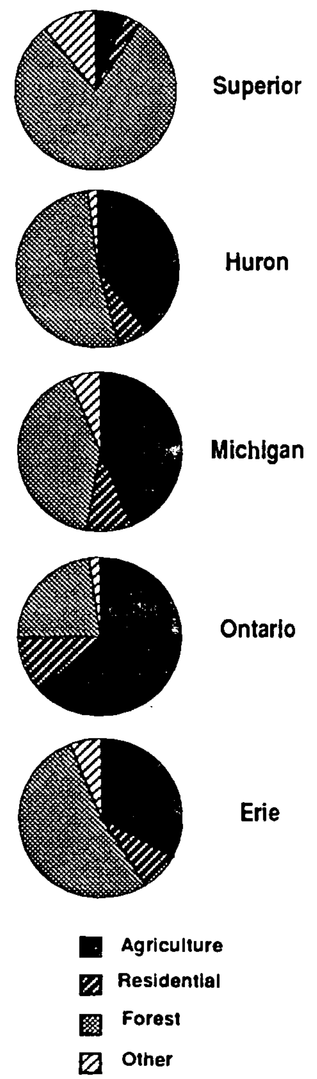
Potential Benefits of Global Warming

Should global warming occur, it could have three major benefits to agriculture in the Great Lakes region. First, the higher temperatures may extend or shift the range of certain crops. The continent's corn belt, for example, could relocate to the northern states and Canada. In total, some Great Lakes states and provinces could have a one or two percent increase in agricultural acreage, while the figures for states to the south may decline.

Second, agricultural regions in middle and high latitudes could also experience a longer growing seasons as a result of global warming. A greater number of frost-free days would permit earlier planting and harvesting.

Third, if the amount of CO_2 in the atmosphere were to increase as most scientists predict, more carbon would be available to plants for food (carbohydrate) production. As a result, the rate of photosynthesis may increase in some species, producing higher crop yields when and where conditions are favorable. For example, corn and sugarcane respond very mildly to elevated levels of CO_2 while wheat, potatoes, and beans may increase their growth and yield by 10 to 50 percent. Gains will probably vary within the Great Lakes region, occurring more in the north than in the south.

Land Use in the Great Lakes Region



Source: Environment Canada and U.S. Environmental Protection Agency (1987)

Potential Drawbacks of Global Warming

Although these potential benefits of global warming seem significant for Great Lakes agriculture, they may not outweigh the inherent problems.

CO_2 Enrichment and Soil Quality

While some crops may yield more produce under higher CO_2 levels, *food quality* would deteriorate with increasing CO_2. For example, experiments have shown that pests need to consume more plant material to satisfy their nutrient requirements when the plants have been raised under high CO_2 levels.

Another consideration is that plants grown with CO_2 enrichment will have higher nutrient requirements unless they fix their own nitrogen. In Canada, however, the soils in the northern portion of the Great Lakes Basin are thinner and less fertile than in the south. For this reason, the total agricultural production in the northern Great Lakes region may not increase significantly.

Pests

Warmer climatic conditions could increase the activity and the geographic range of unwanted insects and plants. For instance, tropical organisms that cause diseases in crops and livestock may expand into what are currently subtropical and temperate zones. In addition, insects could produce more generations per year and have higher overwinter survival should global warming occur.

Unfortunately, 14 of the world's 18 most troublesome weeds tend to thrive under higher levels of CO_2. Therefore,

Average Climate Change in the Great Lakes Region by Latitude

	36-40°		40-44°		44-49°	
	T(°C)	Ppt (mm)	T(°C)	Ppt (mm)	T(°C)	Ppt (mm)
May	2.4	12.5	3.6	9.4	3.6	8.9
June	6.4	–6.6	7.0	–9.2	9.4	–45.0
July	7.4	–10.7	8.0	–39.6	9.4	–30.8
August	4.2	7.7	4.3	0.8	8.1	–13.5

Source: Ritchie, Baer, and Chou (1989)

plants that do not respond dramatically to increased levels of CO_2 may have to contend with bigger, more aggressive competitors.

The net result could be that farmers feel compelled to use more herbicides against noxious weeds, more insecticides against unwanted insects, and more fertilizers to stimulate plant growth. In turn, the use of these chemicals would likely raise the cost of food production, and water runoff from chemical-laden farms would generate additional nonpoint source pollution.

Increased Evaporation

The apparent advantages of warmer temperatures and increased precipitation in the Great Lakes region may be offset by an increase in evaporation from plant, soil, and lake surfaces. This could pose two types of problems for farmers: less soil moisture could stress crops, lowering yields; and a meter or more drop in lake levels could mean less water for irrigation.

The situation would be even worse in the southern United States. Strapped by more frequent droughts, distant farmers could increase pressure on Great Lakes policymakers to divert water from the basin, testing the resolution of the Great Lakes Charter.

Another issue is that lower lake levels would alter shorelines, possibly blocking the access of ships with large drafts. This would increase transportation costs for grain producers and manufacturers. Shipping is currently the cheapest way to distribute bulky goods.

Climate Variability

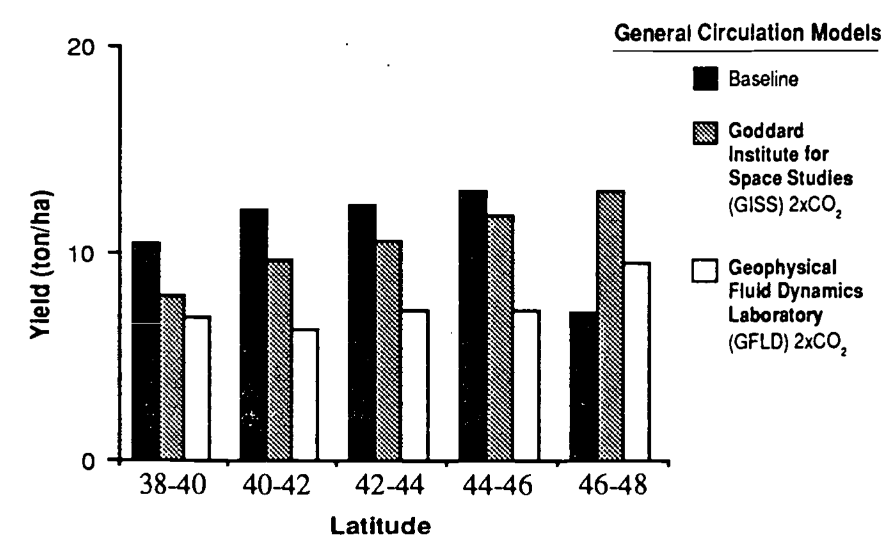
Finally, increases in atmospheric CO_2 will probably result in greater climate variability. While farmers accept yearly precipitation and temperature fluctuations as normal parts of agricultural production, future conditions could increase the frequency of extreme, climate-related events.

For example, years of above-average precipitation may be interspersed with years of drought; severe storms may increase in frequency and intensity; and sudden cold snaps may damage crops which have not been hardened by cold spring and fall temperatures. These variables, combined with the potentially greater effects of insect pests and noxious weeds, could increase the risk of crop failure and, in turn, the risk of economic hardship to farmers.

The Future is Now

While the conditions for maintaining the current crop mix may worsen, farmers who adjust their production activities in accordance with climatic changes are likely to profit. In particular, farmers should capitalize on opportunities to grow new crops in the Great Lakes region. For instance, the Land Evaluation Group at the University of Guelph has suggested that extended growing seasons and milder

The Average Irrigated Corn Yield in the Great Lakes Region



Source: Ritchie, Baer, and Chou (1989) winters would make the production of many horticultural crops feasible throughout Ontario.

Although researchers are examining what can be done now to protect agricultural productivity in the face of rising CO_2 levels, they must first gain clearer insight into such global processes as ocean circulation, cloud formation, and heat exchange mechanisms. Carbon dioxide models have been helpful in simulating what might happen to plant species under increased levels of CO_2, but little research has examined the combined effects of increased CO_2 and climate factors such as precipitation patterns.

Through a better understanding of these processes, researchers can develop more accurate models to help predict how global warming will affect Great Lakes agriculture. With this information, individuals in agricultural industries can begin to prepare for what is now an uncertain future. ⊕

Focus

Comparative Agricultural Opportunities

Because the effects of global warming are expected to vary geographically, it is important for agricultural producers to consider how future climate could influence regional production opportunities. By estimating the relative position of current crops in future agricultural markets, they can determine which crops have the greatest potential for maintaining and strengthening trade ties with other countries. The Land Evaluation Group, for example, has been studying how production opportunities for wheat and grain corn may increase or decrease throughout the world.

	Wheat	Grain Corn
Canada	▲	▲
North and Central America	▼	▼
South America	▼	▼
Europe	▼	▼
Africa	▼	na
USSR	▲	▲
Asia	▼	na
Oceania	▼	na

▲ indicates an increase in production opportunities
▼ indicates a decrease
na = not available

Source: University of Guelph (1987)

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Global Change in the Great Lakes
Will it Affect Airborne Circulation of Toxins?

Scenario #5

In the 30 years since Lake Erie was dubbed the "dead" Great Lake, the U.S. and Canadian governments have done much to improve the quality of the region's terrestrial and aquatic environments. While progress has been made, for example in enacting phosphorous restrictions, serious problems remain.

To date, Great Lakes resource managers have been relatively successful in reducing the amount of *point source pollution* in the region, but most *nonpoint source pollution* continues unabated. Point source pollution discharges directly from specific locations, such as outlet pipes, whose owners can usually be identified and held responsible for any effluent. In contrast, *nonpoint source pollution* is diffuse. Within an area, numerous potential polluters may exist, yet chemicals (e.g. pesticides in agricultural runoff) cannot be traced to a particular site because inputs are so dispersed.

Distant Sources of Airborne Toxins

The atmosphere is a common pathway by which toxins are distributed throughout the Great Lakes, accounting for about 20 to 25 percent of the total loadings. In fact, for some harmful chemicals, up to 90 percent of what reaches the upper lakes does so from the sky.

Unfortunately for scientists and lawmakers, airborne toxins know no borders. Since they freely cross international, provincial, state, and county boundaries, research and regulation are complex tasks: How can someone track down the source of contaminants in a raindrop or a breath of air? Airborne toxins originating thousands of miles away can precipitate into the Great Lakes region in dust, rain, or snow. Long-range transport is possible because air from across the North American continent funnels over the region. In fact, no matter which way the wind blows, the Great Lakes are downwind of pollution sources.

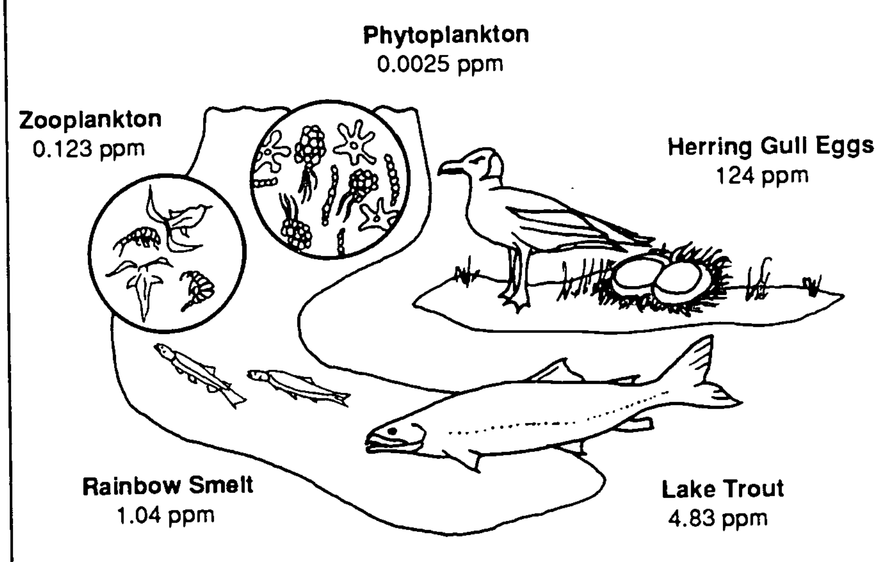
In modern times, the large surface areas of the Great Lakes have become vast depositories for airborne debris. Toxins in the air are mixed into the water by wind and wave action. Some will stay in suspension and eventually flush out of the lake, while others will settle to the bottom and remain indefinitely in the sediments. On average, water retention times range from 2.7 years in Lake Erie to over 170 years in Lake Superior.

Biomagnification and Bioaccumulation

Toxic particles entering in the Great Lakes via the atmosphere are taken up by many resident plants and animals. The amount of toxins absorbed by an organism depends in part on its lifespan. The longer an organism lives, the more time it has to *bioaccumulate* poisonous substances. By the time a large lake trout or salmon is reeled into the boat, the number of toxic particles in its body could be a million times the concentration that originally contaminated the water.

Another factor is *biomagnification*, the process by which noxious substances become increasingly concentrated as they pass through the food chain. When one organism feeds on another, the consumer takes up any toxins in its prey.

Biomagnification of PCBs



Source: Environment Canada and U.S. Environmental Protection Agency (1987)

FOCUS
The Health Effects of Some Common Toxins

Name	*Use*	*Health Effects*
DDT, dieldrin, aldrin	Of these pesticides, DDT was banned in the United States in 1971, and others are now restricted.	Bioaccumulate in animals, possibly causing reproductive disorders and cancer in humans.
PAHs (polynucleated aromatic hydrocarbons)	Have a variety of industrial uses. Category includes petroleum.	Can cause cancer and chromosome damage in wildlife (e.g. fish) and humans.
PCBs (polychlorinated biphenyls)	Banned almost completely in 1979, PCBs were used in insulation for electrical capacitors and transformers, and as a plasticizer.	Bioaccumulate in wildlife (e.g. fish) and humans. They are a probable carcinogen in humans.
Heavy Metals (mercury, lead, arsenic, cadmium, etc.)	Have a variety of industrial uses. For example, some are ingredients in gasoline, paints or pesticides.	Bioaccumulate in animals. Human consumption of contaminated food can cause a variety of health problems: mercury can cause brain damage and birth defects; lead can cause anemia, fatigue, and irreversible brain damage; and cadmium can cause kidney damage.

Source: Hilleman (1988)

Consequently, the higher an organism is in the food chain, the greater the number of toxic particles it is likely to contain and the more hazardous it becomes for others to eat.

Public Health Hazards

Of the 11 critical Great Lakes pollutants identified by the International Joint Commission, 10 are transported by air. The list includes polychlorinated biphenyls (PCBs), dioxins, dieldrin, mercury, and lead: all singled out because they bioaccumulate, they biomagnify, and their effects are irreversible. Although progress has been made in controlling these toxins, current levels continue to be unacceptable in some locations.

Researchers have been studying people and wildlife to better understand the risks critical pollutants may pose to Great Lakes inhabitants. Findings include:

- Pregnant women who eat PCB-contaminated fish may give birth to babies who weigh less, are shorter, have smaller head circumference, and show more behavior and neuromuscular problems than babies born to other mothers.
- The cumulative effects of toxic pollutants have been blamed for various cancers in Great Lakes fish. In Lake Ontario, for example, catfish foraging in polluted sediments have an abnormally high rate of facial tumors.
- PCB and dioxin poisoning are thought to be related to reproductive failure in Lake Michigan tern and cormorant colonies. Scientists found that three-quarters of the tern eggs studied did not hatch, while chicks that did were dead within 12 days. In addition, many young cormorants emerged with malformed bills, feet, heads, or internal organs; plus some were missing eyes or skull bones.

Airborne Toxins and Climate Change

Many researchers predict that the Earth will experience global climate changes within the next century. In the Great Lakes region, changing climatic conditions could make airborne toxics even more hazardous than they are today.

The effects of global warming in the Great Lakes region will likely include increased temperatures, evaporation, and incidence of severe storms. This combination of factors would mean that airborne toxins could travel further on air currents before falling to Earth. Therefore, while the Great Lakes are currently receiving toxins from Central and South America, airborne substances could originate from even more distant locations in the future. Likewise, toxins generated in this region may be transported greater distances around the globe.

On the other hand, a more energetic hydrological cycle could *reduce* the amount of time toxins are airborne. How higher temperatures will affect the volatility of compounds is another major question.

Concentrations of pollutants in the Great Lakes would also increase if water levels decreased as a result of global warming. Nearshore areas would be stirred more often and more deeply by storms, resuspending toxins that have been buried in sand and mud for decades.

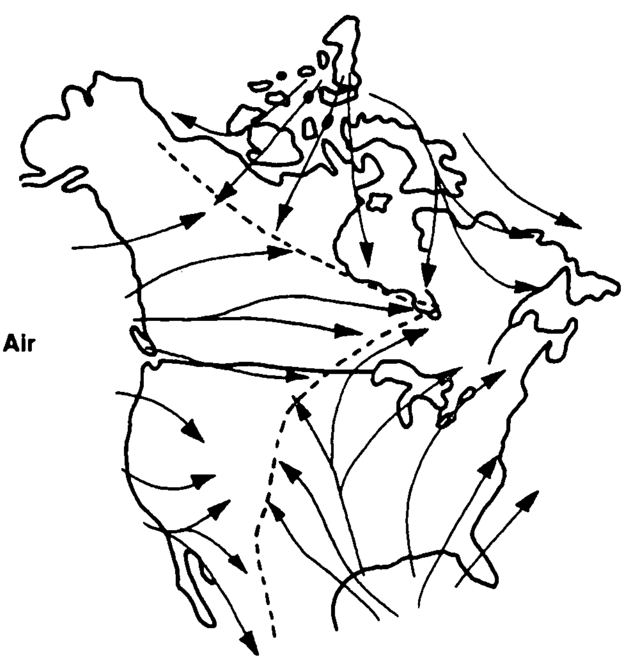
Exposure of toxic sediments in present-day wetlands could threaten migratory waterfowl and shoreline wildlife. Plant and animal species living in the Great Lakes region may not be able to tolerate subsequent changes in their environment. Their health and ultimately their survival may be threatened.

Compounding these problems could be the continued production and use of many hazardous substances. Even without global change effects, atmospheric concentrations will continue to increase unless current policies and practices are altered. However, should global warming occur, existing stress on organisms and their ecosystems would be magnified — making *any* toxin potentially more dangerous.

Global Implications

Because airborne toxics can be carried almost anywhere in the world by the atmosphere, identifying and controlling these substances is truly a global responsibility. Isolated attempts to address global change issues will not be effective. Instead, world leaders need to adopt an integrated and cooperative approach, recognizing the interactive nature of ecosystems. To better understand how the physical, chemical, and biological components of earth systems may be affected by global change, interaction between researchers in many disciplines is also imperative. ⊕

Surface Wind Flow Across North America
July Patterns



Source: Subcommittee Acid Rain. 1981. Still Waters: The Chilling Reality of Acid Rain. Ottawa. Reprinted in Sierra Club et al. (1988)

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Global Change in the Great Lakes

What are the Implications of Low Water Levels in Great Lakes Estuaries?

Scenario #6

A variety of wetland environments dot the Great Lakes region, providing numerous species with habitat and breeding grounds. Swamps, marshes, and bogs are familiar to many outdoor recreationists, yet few people are knowledgable about estuaries.

Estuaries are commonly identified as places where freshwater meets sea, and where water levels rise and fall with the tides. Although the Great Lakes are considered inland seas, they are so far from the ocean that tidal influences are nearly unobservable and salt concentrations are insignificant. Nevertheless, the chemically distinct waters located at the mouths of Great Lakes tributaries are considered estuaries. Because of their proximity to open water, estuaries are sensitive to changes in lake levels. Should global warming occur, these valuable wetlands would be seriously affected.

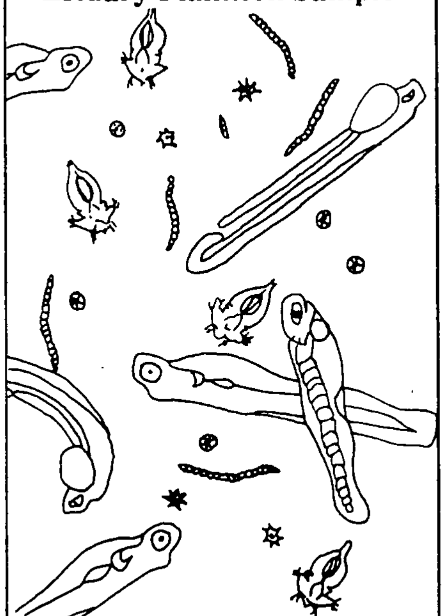
The Importance of Great Lakes Estuaries

To appreciate the importance of estuaries, it is necessary to understand their biological characteristics, and their role in cleansing and regulating regional water supplies.

Although the casual observer may not realize it, the estuary landscape is composed of a patchwork of wet and dry areas. Plants are sensitive to these variations and differ with elevation.

Diverse plant communities, in turn, support a diversity of animals. As in other ecosystems, energy from plants fuels the estuary food web. The process begins when herbivores eat plants directly, and carnivores eat the herbivores. At all stages, decomposers such as bacteria digest dead tissues and make nutrients available again to plants so they can photosynthesize.

Estuary Plankton Sample



Source: Fortner and Mischler (1985)

In addition, vegetation creates cover for animals as they rest, feed, seek mates, or rear young. Estuary plants are particularly important to the reproductive success of many resident and migratory species. Deep layers of submersed plants and sediment provide protective breeding and nursery grounds for fish and other aquatic animals, while trees along the border provide nesting sites for birds.

Estuaries also improve water quality. Wholly or partially submersed vegetation slows the flow of incoming streams, encouraging the deposition of suspended materials. Some of the nutrients and toxins that settle onto the mud may then be taken up by plants. As a result, the water leaving an estuary is often cleaner and clearer than the water that enters. Unfortunately, some of the pollutants will continue to cycle, concentrating into increasingly hazardous doses as they advance through food chains.

Lastly, estuaries and surrounding wetlands act as natural flood control mechanisms because their water absorbing capacities are tremendous. When storm surges and seiches drive lake water against the shore, estuaries take in the storm water then slowly release it. An added benefit is that estuary vegetation secures soil, reducing shoreline erosion caused by wave action.

The Status of Wetlands in the Great Lakes Region

Wetlands are endangered environments that are rapidly disappearing in the Great Lakes region. Since the 1950s, millions of wetland acres have been drained or otherwise destroyed. Causes include agricultural development, highway construction, irrigation and flood controls, and hydroelectric and water supply projects.

Today, only 30 percent of the original estuaries, marshes, and other wetlands remain in the Great Lakes region. The Great Black Swamp that once covered a large portion of northwestern Ohio and neighboring states is a notable casualty.

The governments of the countries, states, and provinces bordering the lakes manage many of the remaining marshes and their tributaries. Still, most wetlands are now in the hands of hunting clubs and other recreational users. Efforts are underway to map remaining critical habitats in order to insure better protection.

The Future of Wetlands in the Great Lakes Region

The National Oceanic and Atmospheric Administration (NOAA) estimates that water levels in the Great Lakes could drop between 1 and 2.5 meters as a result of global warming. This range is based on predictions that the evaporation rate will increase and tremendous urban growth in the region will place additional demands on lake resources.

If lake levels drop, wetland environments will migrate lakeward, shrinking or eliminating many protected plant and animal habitats. Some species may adapt to these changes, but others will either experience population declines or relocate. In turn, wetland loss would create a "ripple effect" through the food web. Even salmon, a deepwater species, would be affected since they feed on alewives and smelt, which spawn in wetlands.

The reproductive failure of fish and ducks that breed in estuaries would impact human activities such as hunting, sport fishing, and commercial fishing. This is likely to have a direct effect on the economy of the Great Lakes region.

Another potential consequence of the lakeward migration of wetland habitats is that people will want to develop the new waterfront property. If this happens and water levels rise in the future, buildings situated on the shoreline would suffer extensive damage, and any landward migration of new wetland habitats would be blocked. Unfortunately, it is unlikely that emergent plants would colonize the bottom mud of offshore areas because it is either too sandy or too rocky.

Policy Choices

Whether lake levels rise or fall in the future, estuaries and other Great Lakes wetlands will feel the impact of increased human activity and demands on resources. Lake levels should be monitored continually, so scientists can use current as well as historical data to interpret the effects of global warming.

Only through the proper management of life-sustaining wetlands can decision makers preserve the natural, economic and recreational value of the Great Lakes region. Resource managers must act quickly to protect the integrity of remaining wetlands. Predicted changes in world climate may further reduce the number and quality of regional wetlands. Policymakers must decide whether people should be allowed to develop former wetlands, and they must design appropriate strategies to carry out their initiatives. ⊕

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Ohio Sea Grant College Program

Global Change in the Great Lakes

Will it Speed Eutrophication in the Great Lakes?

Scenario #7

Eutrophication is a natural aging process for bodies of standing water. Over time, many *oligotrophic* (cold, deep, barren) lakes and ponds gradually become *eutrophic* (warm, shallow, fertile). If there is not enough flow to flush out accumulating sediments and organic material, the sequence ends at *senescence*, in which former bodies of water become wetlands, then moist lowlands.

Human activity can accelerate the rate of aging, effectively shortening the life of a lake or pond. In the Great Lakes, nutrient loading and siltation from agricultural runoff are major causes of *cultural eutrophication.*

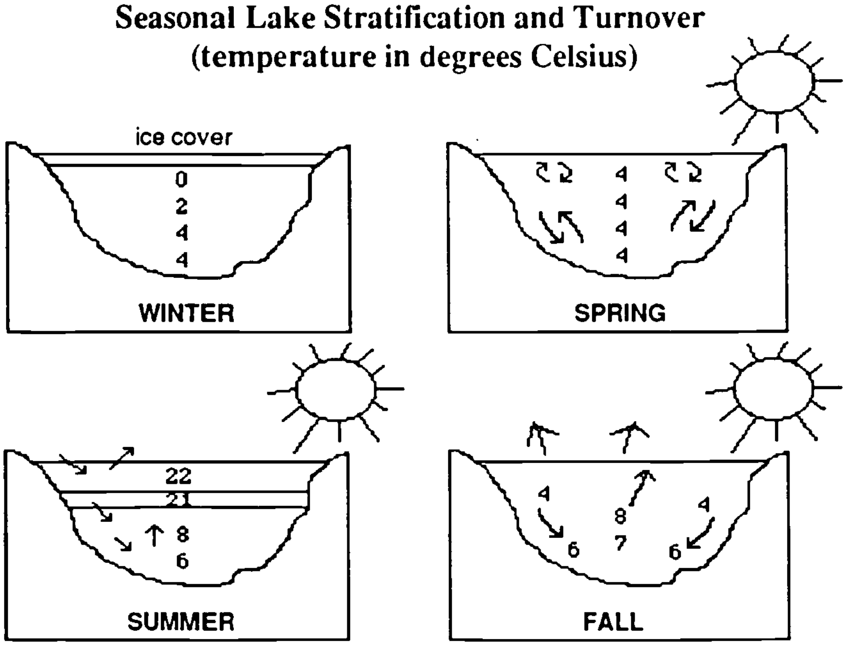
Because Lake Erie is the warmest, shallowest, and most biologically productive Great Lake, human-induced changes are of particular concern to resource managers. The Eastern and Central Basins of Lake Erie are especially vulnerable to cultural eutrophication because they can stratify during the summer months.

Lake Stratification

Stratification occurs when a lake develops the "layered look." In early summer, the sun's rays penetrate surface waters, creating a warm upper zone. Below lies a cool lower layer, separated from above by a narrow transitional zone called the *thermocline*. Although dissolved oxygen levels increase with decreasing temperatures, the bottom layer is isolated from its major source of new oxygen — the air. As a result, deep-dwelling organisms including many fish may exhaust their summer breathing supply. If dissolved oxygen levels reach zero, the water is considered *anoxic*. Resident organisms must relocate or else they will die before the fall turnover replenishes the lake bottom.

When seasonal stratification produces anoxic conditions in the Eastern and Central Basins, Lake Erie's biological characteristics change and the rate of eutrophication is accelerated.

Seasonal Lake Stratification and Turnover (temperature in degrees Celsius)



Source: Environment Canada and U.S. Environmental Protection Agency (1987)

Implications of Global Warming

If global warming occurs, changes in the *thermal structure* (temperature layers) of the Great Lakes could speed up eutrophication.

Using a model of Lake Erie's Central Basin, Blumberg and Di Toro examined how changes in thermal structure affect resident aquatic life. Next, information from the thermal structure model was applied to a eutrophication model to investigate how changes in thermal structure affect dissolved oxygen levels.

The eutrophication model was calibrated and verified using data from two base years: 1970 and 1975. These years were selected because they represent the two water quality extremes that can exist under present climate conditions. In 1970, the thermocline was deep, and over 60 percent of the bottom layer in the Central Basin was anoxic. In contrast, the thermocline in 1975 was shallow, and less than 10 percent of the bottom layer was anoxic.

Blumberg and Di Toro's findings indicate Lake Erie could have longer periods of stratification, and more algal growth as a result of global climate change. Specifically, the stratified season in the Central Basin may start earlier and end later, causing the basin to remain layered for two to four months longer than at present. In addition, the temperature difference between the Central Basin's upper and lower layers is likely to be greater, meaning even less dissolved oxygen will be exchanged across the thermocline during the hottest season.

Because the position of the thermocline appears to be sensitive to changes in windspeed, changes in wind patterns as a result of global warming could have an effect on lake stratification.

The position of the thermocline in a lake affects the relative volumes of water in the upper and lower layers during stratification. Some scientists predict that wind speeds will increase in the future, mixing dissolved oxygen and nutrients in the upper layer more thoroughly and deeply. This action will cause the thermocline to form deeper in the Central Basin during the stratified season. As a result, there would be a greater proportion of water in the upper layer than in the lower layer, further decreasing oxygen availability to bottom-dwelling organisms. For example, if the thermocline is lowered by two meters, the volume of water in the lower layer would be reduced by 20 percent and the amount of dissolved oxygen would be significantly less.

Furthermore, Blumberg and Di Toro predicted that the warmer lake temperatures of the future will have a significant effect on eutrophication in the Great Lakes.

If water temperatures rise, bacterial activity will increase, increasing the demand for oxygen. In addition, warmer temperatures, higher evaporation rates, and changing precipitation patterns may cause lake levels to drop. This could increase the extent and severity of stratification in Lake Erie. Conceivably, other Great Lakes may also begin to layer during future summers.

What Can Be Done?

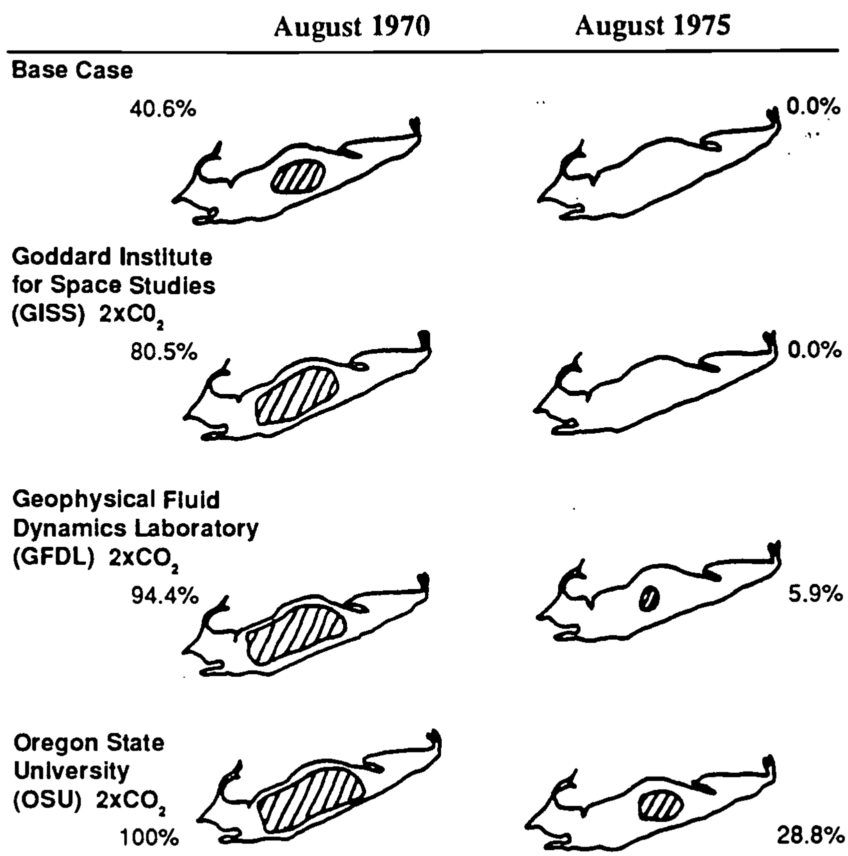
In the past two decades, much progress has been made in identifying and controlling the sources of cultural eutrophication. Canadian and U.S. governments have passed pollution control laws that have significantly improved the quality of water in the Great Lakes. A remaining problem, however, is identifying sources of *nonpoint source pollution.*

By definition, nonpoint source pollution is diffuse, making it difficult for regulators to trace inputs to particular sites. Many businesses (e.g. farms) and facilities (e.g. sewage treatment plants) add nutrients to the Great Lakes. During the 1960s and 1970s, Lake Erie had the most severe difficulties.

Excess nitrates and phosphates allow algae to grow in abundance, creating what is called an *algal bloom.* The extensive mats of blue-green algae floating near the surface of a lake eventually die and sink. In breaking down this extra material, decomposers on the lake floor can deplete the oxygen in the deep water. Even without natural changes like global warming, this is a serious problem.

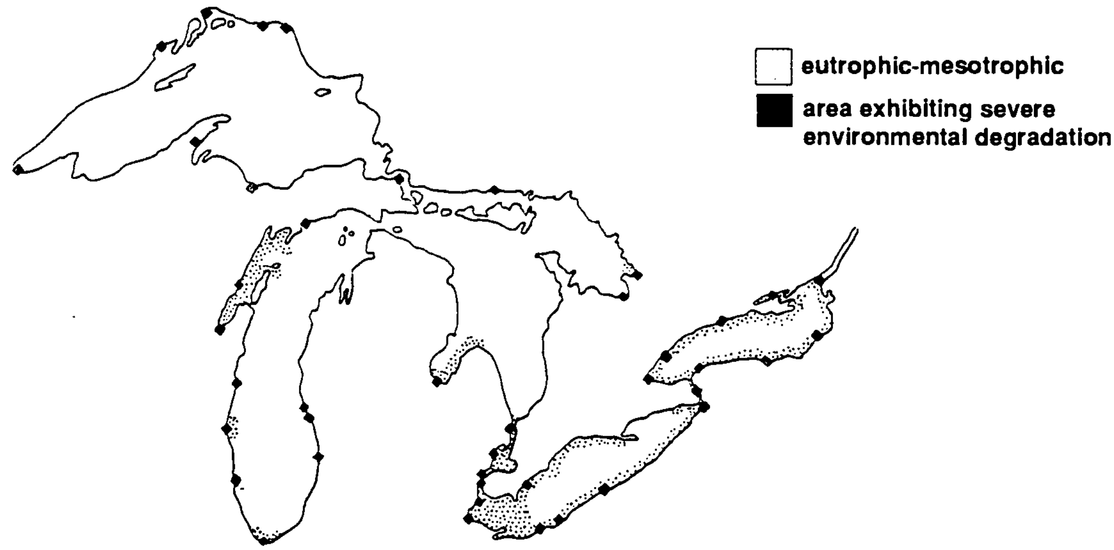
The Average Percentage of Anoxia in Lake Erie's Central Basin

Data from two contrasting base years were used to make projections about future water quality. As the three leading General Circulation Models indicate, global warming could have a considerable effect on dissolved oxygen levels in Lake Erie but the size of the anoxic area could vary widely from year to year.



Source: Blumberg and Di Toro (1989)

Great Lakes Trophic Status and Areas of Concern



Source: Environment Canada and U.S. Environmental Protection Agency (1987)

If global warming will mean a greater number of organisms competing for decreasing amounts of oxygen in increasingly toxic surroundings, it is likely that *all* species in and around the lakes will be affected in one way or another. Although humans cannot reverse or arrest eutrophication, with proper use, management, and protection, basin residents can reduce the effects of cultural eutrophication — prolonging the life of one of the world's most important water resources. ⊕

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Ohio Sea Grant College Program

Global Change in the Great Lakes

What Could Happen to Great Lakes Recreation?

Scenario #8

Because the economies of Great Lakes states and provinces depend heavily upon income from travel and tourism, the potential effects of global warming on regional recreational opportunities are of great interest to the resource managers. According to studies sponsored by the U.S. Environmental Protection Agency, global warming could significantly alter the climate of the region: increasing water temperatures, decreasing snow and ice cover, and lowering lake levels. The ramifications of these changes with respect to recreation are likely to be both negative and positive.

Changing Recreational Opportunities

If global warming occurs, the Great Lakes region will experience longer summers and shorter winters. This would provide enthusiasts with more time to enjoy warm-weather activities such as boating, camping, windsurfing, and swimming; but less time for cold-weather activities such as snowmobiling, ice skating, ice fishing, and skiing.

Whether or not the region attracts more or fewer recreationists will depend on the types of facilities available in the future, as well as the changing resources elsewhere. Clearly, winter sports participants may have to travel farther north into Canada to find favorable climatic conditions. In contrast, if increasing evaporation rates combined with unpredictable precipitation patterns shrink small water bodies and forests in other regions, more people may visit the Great Lakes.

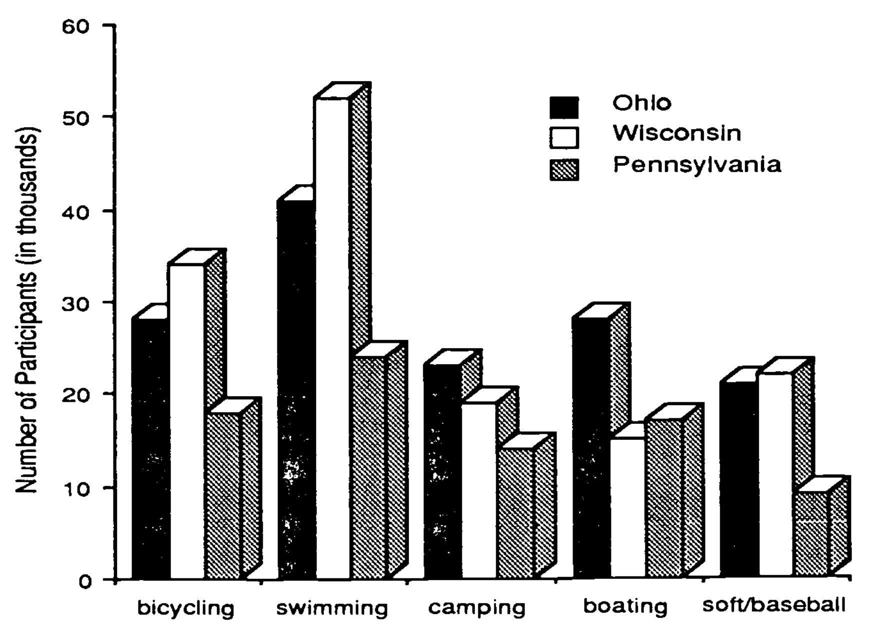
Climate change will also shape local ecology in ways that impact regional recreation. For instance, increases in Great Lakes water temperatures would affect fish populations. Climate models project that even coldwater fish will have more extensive thermal habitats in the future, yet heightened competition between and among species may offset these advantages. Conceivably, warmer water could allow new species—some of which are more aggressive predators than native fish—to invade the Great Lakes. Likewise, there may not be enough productivity lower in the food pyramid to support larger or more numerous top predators such as walleye or lake trout. Obviously, if any coldwater fish were lost or less desirable species introduced, enthusiasm for sport and commercial fishing in the Great Lakes could seriously diminish.

Lower Lake Levels

A major consideration is that higher evaporation rates in the Great Lakes due to global warming may lower water levels. The consequences for recreation activities would be largely negative:

- Although adjacent wetlands may move with the shoreline, many swamps and marshes in the region could dry up if lake levels drop. This would result in the loss of valuable habitat — particularly breeding sites — for birds and fish. Recreational activities such as fishing, hunting, and birdwatching would suffer.
- Receding water levels in some areas could move shorelines far from the hiking trails, camping grounds, scenic roads, and pic-

Current Outdoor Activities in Three Great Lakes States



Source: Great Lakes Commission (1989)

nic areas whose uses are typically enhanced by proximity to water.

- Boating is the most economically important recreational activity in the Great Lakes region. If global warming occurs, low water levels would make it difficult for boats to gain dock and berth access, and channels would have to be dredged deeper and more often to maintain access to open water.
- Finally, if water volumes in the Great Lakes decrease, concentrations of pollutants will increase. The result would be a rise in water quality concerns. For example, greater intake of toxins, either directly or through the food chain, would endanger the health of popular game fish (e.g. salmon and trout) and the humans who eat them.

What Can Be Done to Prepare for the Future?

No one knows the extent to which global warming may affect the Great Lakes region, yet it is important that we prepare now for the potential consequences.

Specifically, resource managers need to anticipate possible changes in fish populations and further loss of wetlands. Individuals in travel and tourism industries, on the other hand, should consider how to diversify the types of facilities and services offered regionally so as to accommodate longer summer and shorter winter seasons. Potentially, the Great Lakes could become a more attractive vacation destination. Care will need to be exercised, however, to ensure that larger crowds do not deteriorate the region's aquatic and terrestrial environments. Enormous challenges are also presented by the possibility of shifting shorelines and lower lake levels. In the future, the demand for water and water access may be even higher, placing recreation more directly into competition with other resource uses.

FOCUS
Downhill Skiing in Ontario

Understanding the potential effects of global warming on the Great Lakes region is crucial for business people and community planners whose livelihood depends on winter tourism. Downhill skiing is one recreational activity that attracts people to certain areas only when there are favorable climatic conditions. If snow does not fall during the peak season, the social and economic impact on resorts and their surrounding communities can be devastating.

Recently, the influence of double CO_2 levels on the average monthly precipitation and temperature in two Ontario ski areas was projected using the GFDL and GISS climate models. In both scenarios, winter temperatures will increase and precipitation will be normal to 15 percent above normal, but the net snowfall will decrease due to greater evaporation and sublimation rates. The GFDL model predicted that the reliable season (>75% chance of snow cover) and the marginally reliable season (50 to 75% chance of snow cover) at the Lakehead, a northern resort, will decrease from 111 to 72 days and from 131 to 91 days, respectively. The GISS model estimated even greater reductions. Fortunately for local businesses, the key holiday periods — Christmas and the February college break — will remain within the reliable season.

In contrast, the ski industry will be virtually eliminated in the South Georgian Bay area. According to GISS predictions, there will be no reliable or marginally reliable season. Similarly, only a marginally reliable season of 40 days will remain by GFDL calculations.

Given this information, the challenge for tourist-dependent communities will be to diversify the services and activities offered to visiting recreationists. In both parts of Ontario, winter financial losses could be offset by profits from the longer summer season.

Source: Wall (1988)

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Global Change in the Great Lakes
How Could Fish Populations in the Great Lakes be Affected?

Scenario #9

Since the last glacier retreated about 10,000 years ago, hundreds of fish species have colonized the Great Lakes. Although some invaders have migrated elsewhere or become extinct, others have become the current lake residents. Ironically, two variables — human activity and climate change — that have had a great influence over fish populations in the past are becoming increasingly interrelated today.

Human Activity

Humans primarily affect fish populations by inhibiting their reproduction. During the 1820s, many migratory species, such as muskellunge, lost their spawning grounds in the Great Lakes region when settlers began building dams, draining wetlands, and converting forests into farm land. This habitat destruction, combined with the subsequent overharvesting of adults, has caused certain fish populations to go into serious decline. Now a regionally endangered species, sturgeon has never recovered.

In addition, humans have shaped Great Lakes fish populations by accidentally introducing exotic species. For example, the construction of the Welland Canal between Lake Erie and Lake Ontario allowed sea lamprey to travel into the upper lakes, where they heavily parasitized lake trout. More recently, larvae of the infamous zebra mussel are believed to have hitchhiked from Europe to Lake St. Clair in the ballast water of at least one transatlantic ship. Today, these prolific bivalves are reducing the plankton populations that support lake food webs and fouling the rocky habitat of some fish.

Pollution has also been an ongoing problem. Despite progress in cleaning up the Great Lakes, humans continue to dump toxic chemicals and other noxious waste into the aquatic environment. As a result, some fish species have been excluded from certain areas, while others have endured health problems.

First Appearances of Exotic Species in Lake Erie

Rainbow smelt	1932
Sea lamprey	1921
Alewife	1931
White perch	1953
Spiny water flea	1985
Zebra mussel	1988

Source: Evans and Gannon (1988) and the Ohio Department of Natural Resources

Climate Change

Scientists are concerned that human activities such as deforestation and the burning of fossil fuels may cause the Earth to warm by as much as 1.5 to 4.5°C over the next century. While it is true that global temperatures have fluctuated by several degrees throughout geological time, this rate of increase is predicted to surpass those of previous periods. In the past 30 years, carbon dioxide levels have risen by 11 percent, and now each year chlorofluorocarbon gases — which may affect the ozone layer and global climate — rise by 5 to 6 percent. The primary question is whether many plant and animal species can survive such drastic alterations in climate.

Effects on the Lakes

Because they are particularly sensitive to changes in their environment, fish are useful biological indicators. Researchers hope that by studying the effects of global warming on this one group of animals, the future state of the Great Lakes can be predicted. To accomplish this goal, the problem has been examined from several angles.

Thermal Habitat

Fish in the Great Lakes generally live in one of three broad thermal habitats: coldwater fish prefer temperatures around 15°C, coolwater fish prefer temperatures around 24°C, and warmwater fish prefer temperatures around 28°C. Although fish can tolerate suboptimal conditions, each species has a specific ***thermal niche*** in which it can attain maximum growth. By definition, a species' thermal niche is its median preferred temperature plus or minus 2°C.

In the scenarios of the three major global climate models, both the length of the growing season and the amount of suitable thermal habitat are expected to increase for most Great Lakes species. For instance, researchers expect yellow perch and lake trout to occupy more depths over more days of the year as a result of global warming.

Given these changes, some fish may migrate as much as 200 km north of their present geographic ranges. Specifically, 27 species from the southern United States would probably invade the Great Lakes via various tributaries, and others from the Atlantic Ocean may enter via the St. Lawrence Seaway. Greater colonization and dispersal by exotics could restructure Great Lakes food webs in the future.

Prey Availability

Warmer water temperatures over the year would speed up fish metabolism. Whether or not this would accelerate growth rates within the three thermal habitats would depend upon prey availability.

If prey populations do not increase with increasing water temperatures, fish may not be able to find enough to eat to meet their higher daily requirements. Competition for food is expected to intensify under these conditions. As a consequence, fish growth in Lake Michigan, for example, could decrease by 10 to 30 percent. Warmwater species would experience the most severe impacts.

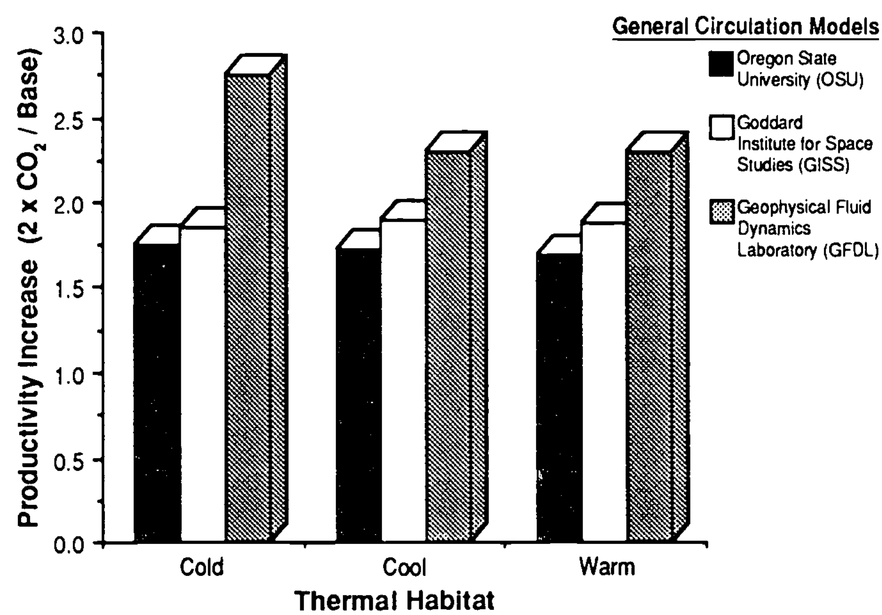
Fortunately, scientists estimate that phytoplankton production will increase 1.6 to 2.7 fold under a doubled CO_2 scenario. Greater phytoplankton production would provide more forage for zooplankton which, in turn, would provide more forage for young fish. With more to eat, cool and coldwater fishes could grow 20 to 70 percent bigger and warmwater fishes in warm areas 220 to 470 percent bigger.

The negative side of this scenario is that predation may not control the growth of certain phytoplankton populations under global warming conditions. Plankton-eating fish prefer green algae to blue-green algae (cyanobacteria), and blue-green algae have traditionally been a problem in Lake Erie and other shallow waters.

When blue-green algae populations multiply rapidly then die en masse, decomposers on the lake floor must consume large quantities of dissolved oxygen to break down the remains. This can cause sections of the lower lake to become anoxic in the late summer until the fall turnover renews oxygen supplies.

The net result is that bottom-dwelling fish such as perch, walleye, and catfish will suffocate unless they relocate during these oxygen-deprived periods. Invertebrates such as mayfly larvae that live in a lake's substrate are not as mobile, and often die when water quality becomes poor. Because invertebrates are important food sources for fish, declines in their populations create a ripple effect throughout the food web.

Increases in Great Lakes Phytoplankton Production



Source: Magnuson et al. (1989)

Hydrologic Cycle

If the average temperature in the Great Lakes region increases, the entire *hydrologic cycle* will be affected. The hydrologic cycle is the transfer of water molecules between air, land, and bodies of water.

With a rise in temperature, the precipitation patterns in the Great Lakes region would change. Some areas may experience more rainfall, while others may experience more drought. Greater precipitation could produce flooding of lowland areas, worsen soil erosion, and increase the amount of chemical runoff from agricultural fields.

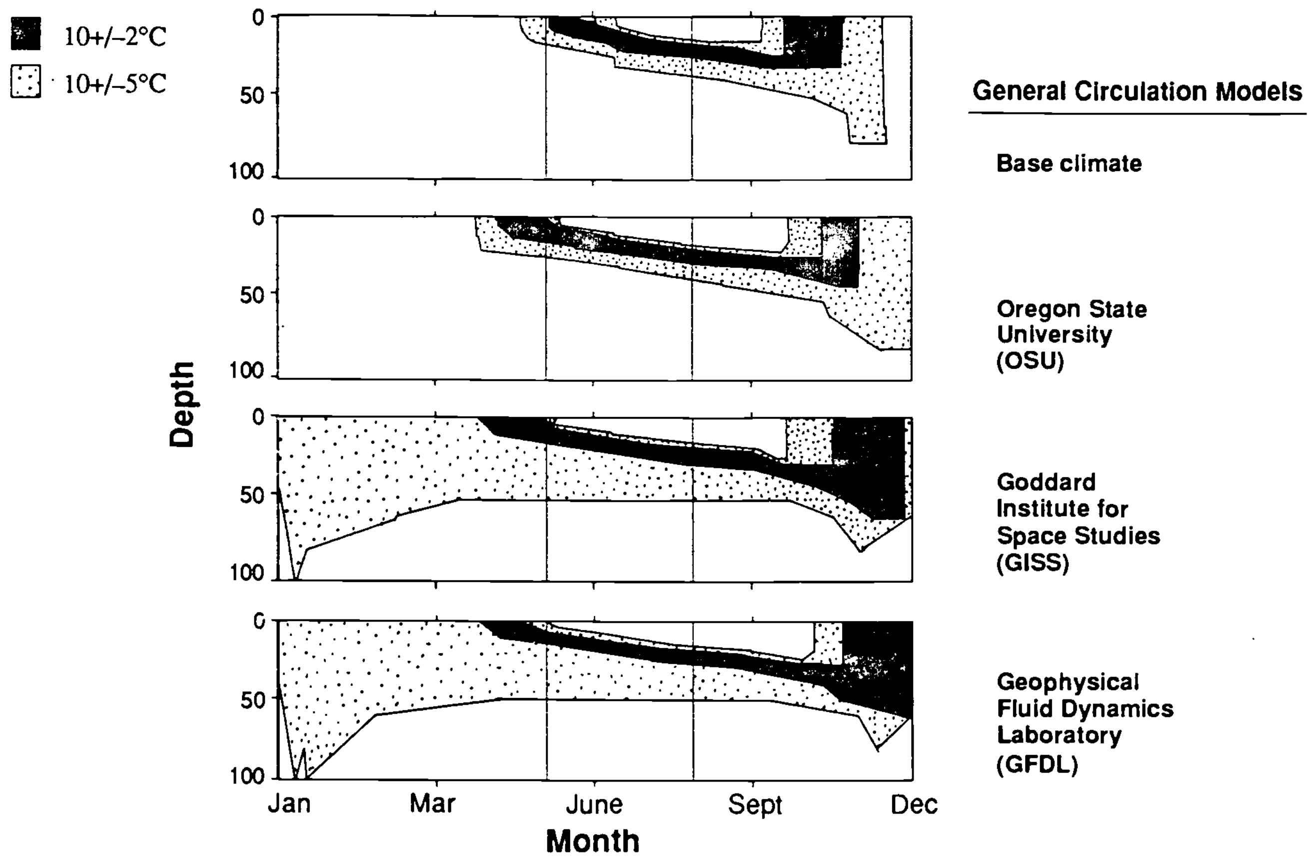
More runoff could be hazardous to the 139 species and subspecies of fish that live in the lakes and their tributaries. For example, additional sedimentation would further degrade the habitat of fish (e.g. walleye) that prefer rocky, not silty, lake bottoms.

Higher temperatures would also mean that more water is evaporated from lake surfaces. This loss would probably exceed any gains from precipitation, causing mean lake levels to fall 0.3 to 0.8 m and the water outflow to decrease by over 20 percent. If this happened, ports would have to be dredged more frequently and more deeply. This would resuspend sediments in nearshore waters, once again exposing resident plants and animals to toxic materials that had settled to the lake floor.

The first effects of climate change would be felt in water bodies with relatively small volumes. For instance, scientists predict that the surface temperature of Lake Erie, the shallowest of the Great Lakes, could rise by 5°C during the summer and the rate of the hydrologic cycle could speed up 7 to 15 percent.

In addition, increased evaporation may decrease the flow of water between tributaries and the lakes, making spawning habitats less accessible to some fish species; and increased precipitation could temporarily raise water levels in some locations, damaging those spawning habitats.

Changes in the Thermal Habitat of a Coldwater Fish (Lake Trout) in Southern Lake Michigan



Source: Magnuson et al. (1989)

Warmer stream temperatures will be beneficial to species, such as white perch whose young-of-the-year have a high overwinter mortality rate. Coolwater and warmwater fish may extend their ranges into Lake Superior streams that are currently too cold. On the other hand, species such as rainbow trout that require cool and coldwater habitats for spawning may not fare as well in southern areas.

The Future of Great Lakes Fisheries

Should global warming occur, the proliferation of many fish populations would generally benefit commercial and recreational fishing in the Great Lakes. There would be more employment in the commercial fishing and tourism industries, plus renewed interest in preserving water quality.

On the other hand, the effects of global warming on regional wetlands, eutrophication, toxic pollution and exotic species require additional study. It is possible that these negative factors could outweigh the positive ones.

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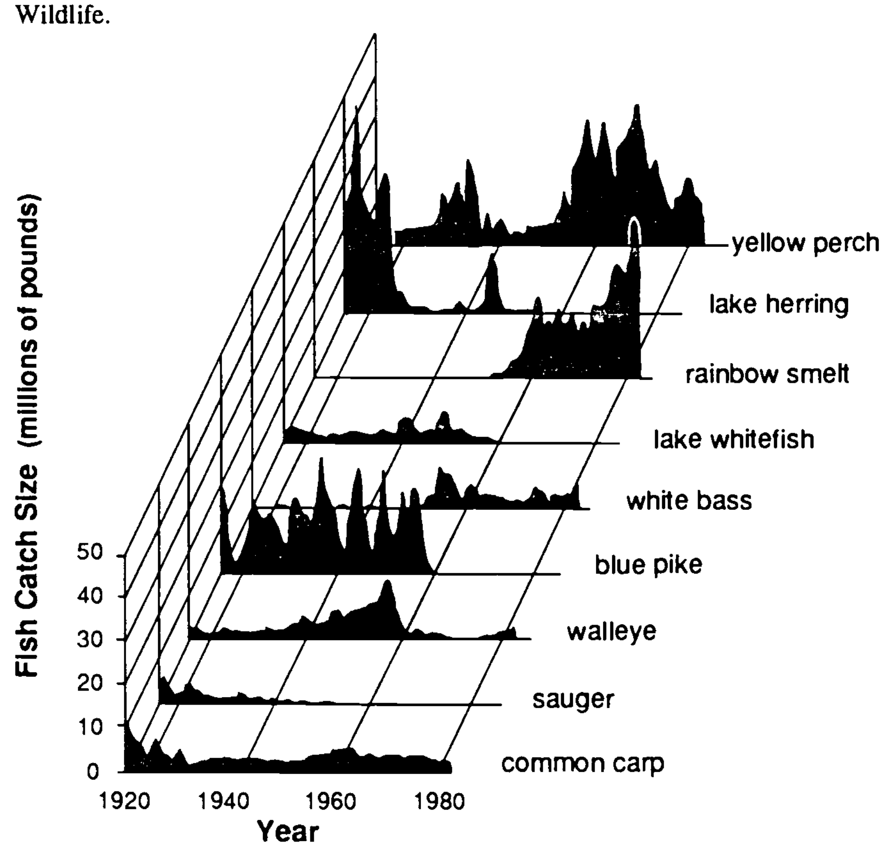
Focus

What Commercial Fish Harvests Tell Us

Researchers sometimes use records of commercial fish harvests to describe how fish populations have changed over time. Unfortunately, this is not always an accurate method of determining the abundance of species because there are many factors that can affect how much of a particular species is caught each year. For example, inaccuracies may be caused by changes in fishing gear, changes in market price, omission of sportfish harvests, or not reporting illegal harvests. Below is a record of commercial fish harvests in Lake Erie from 1920 to 1985, compiled with the assistance of the Lake Erie Fisheries Unit, Ohio Division of Wildlife.



Source: Evans and Gannon (1988), figure by Hartman of the U.S. Fish and Wildlife Service.

The *Global Change in the Great Lakes Scenarios* were prepared by the Ohio Sea Grant College Program (grant NA90AA-D-SG496, project E/AID-2) in cooperation with The Ohio State University's School of Natural Resources and Department of Educational Studies. Barbara K. Garrison and Arrye R. Rosser, Series Editors. Rosanne W. Fortner, Project Director.

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Ohio Sea Grant College Program

Global Change in the Great Lakes

How will Forests in the Great Lakes Region be Affected?

Scenario #10

Over long periods of time, the composition of forests naturally changes with changing climatic conditions. For instance, during the Ice Ages, North American forests were subject to great shifts in temperature, which caused tree species such as hemlock to migrate into previously uncolonized areas.

When climate changes occur slowly, a diversity of plants and animals can respond either by adapting to new conditions or by migrating to more suitable locations. However, when climate changes occur rapidly, some species cannot adjust fast enough, and their populations suffer decline or extinction.

Today, scientists are concerned that the world's climate seems to be warming at a rate unprecedented in history due largely to human activities such as fossil fuel burning. In the next 100 years, the average temperature of the Earth is expected to increase by 1.5 to 4.5°C. While global warming may increase the amount of suitable habitat for some species, it will probably have devastating consequences for many North American trees.

Why Do Forests Matter?

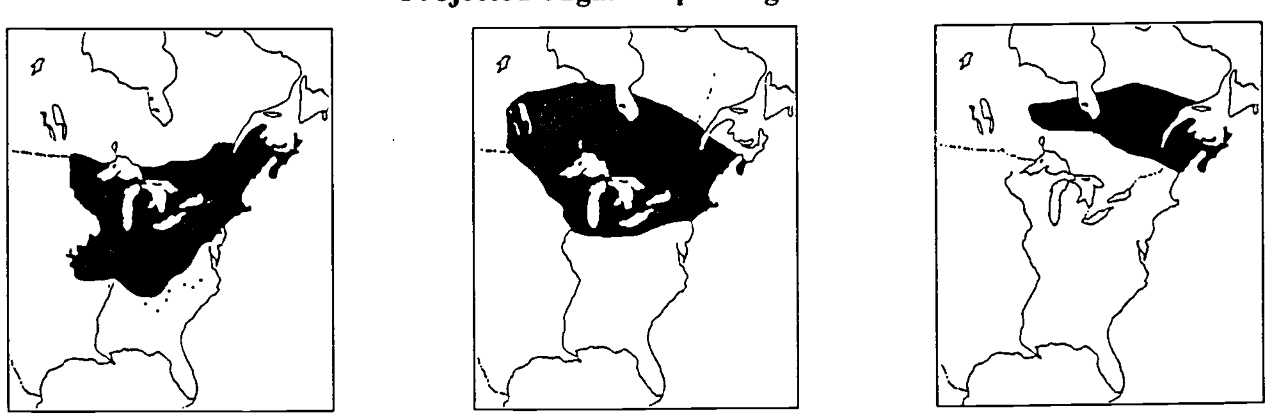
In addition to providing raw materials and recreational opportunities for humans, forests perform many important ecological functions:

- Forests provide protection against erosion by holding rocks and soil in place, and by regulating water flow. Excess water is stored within the vegetation and forest floor, then slowly returned to the system.
- Leaves, needles, and the forest floor filter many pollutants (e.g. pesticides, fertilizers) from the atmosphere.
- Trees remove carbon dioxide from the air, store carbon in their tissues, and release oxygen into the air. Alive or dead, woody tissues can keep carbon from cycling for several centuries.
- Forests help reduce noise pollution by dampening sound.
- Tree are excellent windbreaks, protecting neighboring fields and other open habitats.
- Forests are home to a diversity of life, providing resources such as shelter and food to their inhabitants.

Forest Migration

If global change occurs as predicted, the northern latitudes could experience warmer climates than presently exist. The result could be a northward displacement of ecological zones. For example, the southwestern desert could replace the grain belt, and the grain belt could shift into Canada. In the arctic region, tundra could disappear almost entirely and the landscape could become blanketed by boreal (northern evergreen) forest. In turn, southern deciduous forests could move into what is currently the boreal zone.

Projected Sugar Maple Migration

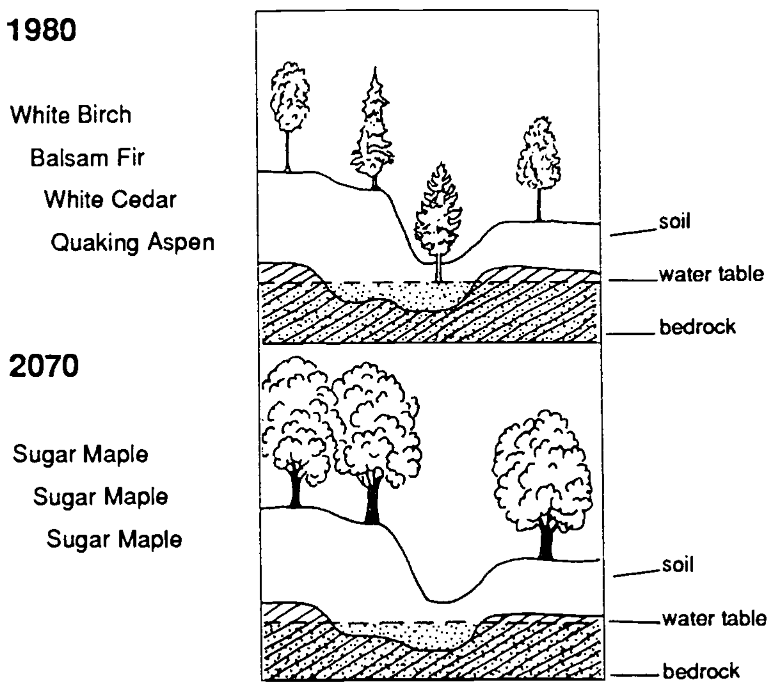


General Circulation Models

Present	Goddard Institute for Space Studies (GISS) 2 x CO_2	Geophysical Fluid Dynamics Laboratory (GFDL) 2 x CO_2

Source: Zabinski and Davis (1989)

How the Forests of Northern Minnesota Could Look if CO_2 Levels Double



Source: Botkin, Nisbet, and Reynales (1989)

The primary concern is that these shifts in habitat distribution may occur so quickly that ecosystems will not be able to keep up. To illustrate, fossil records have shown that the American beech averaged about 20 kilometers per century during past migrations. If estimates are accurate, the beech habitat will shift northward by 700 to 900 kilometers within the next century. This means the beech would have to migrate 40 times faster than before: an unlikely prospect.

Even if species such as beech, yellow birch, sugar maple, and hemlock could quickly colonize more northern latitudes, they may not be able to adapt to the different soils or day lengths in Canada. Furthermore, the presence of urban areas and extensive farmland in the southern Great Lakes states would impede migration. Vast expanses of land with few trees put a strain on seed dispersal mechanisms. There is also a limit to how much a forest can propagate in one year. Those unable to rapidly reproduce themselves may suffer decline over several generations.

Because these changes will occur slowly in human terms, the effects on northern forests may not become noticeable until 2040, or possibly as late as 2090. In the meantime, the established trees in the forest canopy could appear the same, giving the illusion that all is well. However, changes in precipitation patterns may affect the frequency with which adult plants flower and fruit, lessening the chance of offspring survival. As a result, when the presently established trees become overmature and begin to die off naturally around 2090, there will be fewer young trees to take their place. Symptoms of general malaise would appear too late to alert the majority of the Midwest populace in time to avert a crisis.

Future forest composition will also be influenced by natural disasters. Although scientists predict that rainfall in the Great Lakes region will increase under the global warming scenario, an accelerated rate of evaporation will cause the region to experience drier conditions overall. This could increase the frequency and extent of forest fires. According to Dr. Steven Zoltai of Forestry Canada, "the regeneration of old species that originated under a cooler climate is likely to fail after a fire. Thus, forest fires will probably be agents of rapid change, allowing the spread of pioneer species adapted to the new climate. Because of differential migration rates, the vegetation will consist of a strange mix of species, combinations for which we have no precedents."

Other Reasons for Forest Decline

In addition to global warming, there are a number of other factors that could contribute to the deterioration of forest health in the northern latitudes.

Since the late 1970s, scientists have documented evidence of forest decline in central Europe and parts of North America. Some tree species are experiencing thinning crowns, premature aging of foliage, loss of needles, and decreases in fine-root biomass. At numerous locations in the eastern United States and southeastern Canada, for example, red spruce, and balsam fir have been exhibiting a decreased growth rate and increased mortality rate for the past 20 to 25 years. Although scientists cannot pinpoint the exact cause of forest decline, several pollutants are suspect.

Acid Rain

Acid precipitation is largely due to the presence of two classes of chemical compounds (sulfur and nitrogen oxides) in the atmosphere. The primary culprits, sulfur dioxide and sulfur trioxide, are produced in large quantities by the burning of fossil fuels, particularly in coal-fired power stations. When these pollutants combine with moisture and oxygen in the atmosphere, they form sulfurous acid (H_2SO_3) and sulfuric acid (H_2SO_4), respectively.

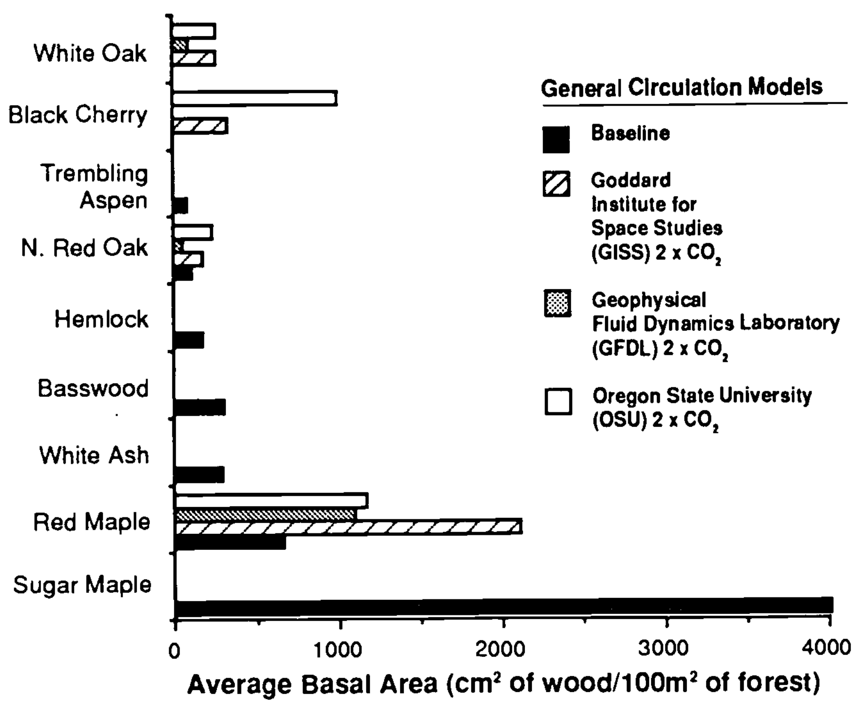
In contrast, nitrogen oxides are produced in large part by power plants and high-compression automobile engines. If temperatures are high, atmospheric nitrogen reacts with oxygen to form nitrous oxide (NO), which oxidizes again to form nitrogen dioxide (NO_2). When nitrogen oxides meet water, they produce a strong acid — nitric acid (HNO_3).

Researchers believe acid rain contributes to forest decline by mobilizing dissolved toxic metals (e.g. aluminum) that leach nutrients from the soil, and by directly damaging leaf cuticles. In addition, the greater soil acidity prevents the mineralization of litter by inhibiting the work of decomposers. This means that nutrients cycle more slowly through the ecosystem. As a result of these processes, tree growth rates are reduced and tree health is generally weakened. Trees become more susceptible to stress from disease, changing climatic conditions, and insect pests.

Heavy Metals and Organic Compounds

Other pollutants contributing to forest decline may include heavy metals and organic compounds. General stress may also be a factor. At this time, however, little research has been conducted to assess the effect these factors have on forest vigor.

Possible Changes in Tree Species and Size: Mount Pleasant, Michigan



Source: Botkin, Nisbet and Reynales (1989)

Economic Implications

If forest decline continues in North America as a result of global warming and pollution, it could have severe implications for forest industries in the Great Lakes region.

The forests in the northern part of the Great Lakes region consist mainly of maple, beech, and other northern hardwoods. Forestry is currently considered a growth industry here, providing several thousand jobs in timber harvesting and manufacturing. In Wisconsin alone, over 283,000 jobs are forestry related.

Softwood species such as pines, firs, and birch are currently harvested in the region for the production of pulp, paper, and construction supplies. If the climate in the Great Lakes region changes to the degree that scientists expect, these species would decline and would be replaced by hardwood species. As a result, the commercial forest industries could suffer. Although hardwood species are good for the production of furniture, they take longer to reach maturity. In addition, facilities that currently process hardwood species for pulp, paper, and other products would have to be adapted for hardwood species, or converted to handle furniture manufacturing.

A second Great Lakes industry expected to be economically influenced by global warming is recreation and tourism. Forests enhance recreational activities, such as hiking and camping, which attract thousands of visitors to the region each year. Depending on how forests in the region change, the aesthetic — and economic — value of these habitats could increase or decrease.

What Can We Do?

Because humans are limited in their ability to predict the future, there is great uncertainty — and apprehension — associated with global change. The potential consequences of the predicted trends could drastically alter the physical characteristics of the Great Lakes region, which in turn affect the resident human and natural communities.

Although evidence of climatic warming and forest decline has already been documented, it is not too late to protect Great Lakes forests. First, serious attempts should be made to reduce the chemical damage to forests via the atmosphere. Acid rain has steadily eroded the health of vigorous forests throughout the industrial world. This atmospheric pollution can only quicken the demise of trees undergoing climate-related stress. People can also make a conscious effort to reduce the amount of fossil fuels used, slowing the rate of CO_2 accumulation in the air.

Second, community leaders and decisionmakers in areas that are likely to suffer severe forest decline should act *now* to identify appropriate new tree species to colonize their regions. This will require research into which species are likely to thrive in various regions under present and future conditions. Conceivably, it could be necessary for humans to transplant tree seedlings in order to hasten the natural migration rate.

Finally, all policymakers should plan with the assumption that global warming is likely to occur. As Dr. Barry Smit of the Land Evaluations Group at the University of Guelph pointed out, it would be a grave error to conduct forestry and agriculture activities with the belief that warmer, drier years in the next few decades are rare anomalies not related to global warming. ⊕

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