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The Future of Great Lakes Resources

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The Future of Great Lakes Resources

A Report on the Activities of the University of Wisconsin Sea Grant Institute

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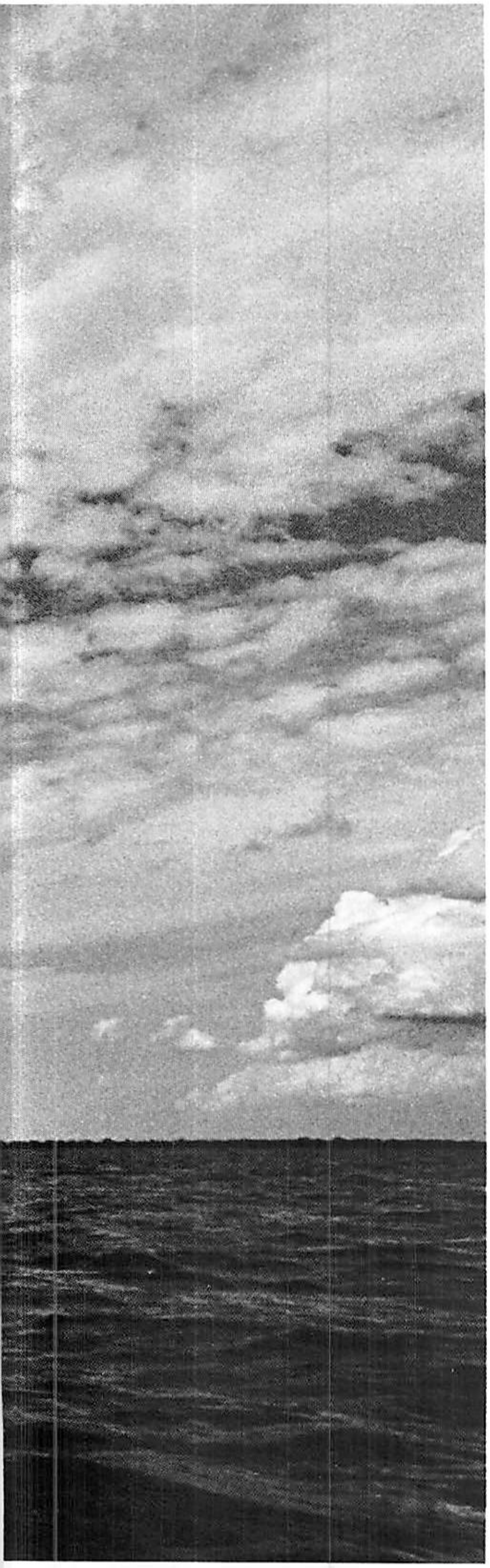


Sea Grant and the Great Lakes

Robert A. Ragotzkie
Director, Sea Grant Institute
University of Wisconsin–Madison

About 6,000 years ago, the retreating Ice Age glaciers left the North American continent a magnificent gift—five sparkling freshwater seas we today call the Laurentian Great Lakes: Superior, Huron, Michigan, Erie and Ontario.

Stretching a thousand miles across the heartland of the United States and Canada, the Great Lakes cover a total area of more than 95,000 square miles—more than all the New England states combined. Together, they constitute one-fifth of the available freshwater on the face of the Earth, an estimated 65 trillion gallons.

So awesome are the Great Lakes in size, early European explorers were amazed to find they were freshwater, rather than saltwater. These seas are clearly lakes, but owing to their size, they display many oceanic characteristics. Great Lakes resources are also as diverse as those of saltwater seas, and human use of these resources is as intense—or more so—than along the most densely populated seacoasts.

The lakes are a unique and valuable resource in the most heavily populated and industrialized region of the U.S. They are expected to provide clean drinking water for 25 million U.S. citizens, high-quality water for a wide variety of manufacturing plants, cooling water for electric power plants and recreational opportunities for over 60 million people. They also provide an efficient and inexpensive water transportation system for iron, coal, limestone and grain. They support an immensely productive fishery, which is exploited by both commercial and sport fishing, and they are a sink for domestic and industrial wastes. All together, these Great Lakes resources are the backbone of the industrial and population heartlands of the U.S. and Canada.

With heavy use has come abuse. Today, it is clear that the Great Lakes are subject to the same array of pressures as the oceans, particularly in the coastal regions. But as closed bodies of water with relatively shallow basins, the Great Lakes have a much smaller capacity to absorb and resist these pressures, and conflicts of resource allocation and environmental degradation have occurred much sooner and more rapidly than in the oceans.

As ecosystem changes occurred, water quality declined and fisheries collapsed, the need for pollution abatement, fishery management and control of coastal development was clear and immediate. The societal responses have been sharp and often controversial, but overall the people of the Great Lakes region have begun to recognize the need for management of the Great Lakes as a whole.

Because the Great Lakes and their resources are shared by the U.S. and Canada, by eight states (New York, Pennsylvania, Michigan, Ohio, Indiana, Illinois, Wisconsin and Minnesota), by the Province of Ontario and by several native American tribes, their management is complex. Over the years, a variety of international, interstate, intrastate and state-local institutional arrangements have been developed. In many respects, management strategies for the Great Lakes have evolved faster and reached a more advanced stage than those for managing the oceans.

While we have made great strides forward in understanding the complexity of the Great Lakes, we still have a long way to go.

After decades of abuse and neglect, there has been a remarkable turnaround in our attitude toward the Great Lakes. In the last 15 years, we have recognized many of the problems besieging the lakes and have taken measures to correct them. The amount of nutrients entering the lakes has declined, leading to improved water quality. The Great Lakes fisheries have improved dramatically, thanks to major rehabilitative efforts and control of the predatory sea lamprey.

Despite our successes to date, we remain concerned about the threat of toxic substances that contaminate the lakes. Because of their behavior in the lakes, these substances—PCBs, furans, mirex, toxaphene, dioxins and a number of others—pose a potential hazard to human health. But their sources are widespread and their fates in the lakes are exceedingly hard to trace.

Over the years we have gradually begun to understand that the Great Lakes as an ecosystem must include people. The lakes are not isolated, nor can they be. We are all a part of the system. Recognizing this rather obvious truth has led us to new approaches for dealing with the Great Lakes. Instead of dealing with a particular chemical or particular species of fish, we must consider how the whole system works and then try to prevent damage to any part of it.

This report on the activities of the University of Wisconsin Sea Grant College Program features a series of papers originally presented in May 1983 as part of the UW Sea Grant Institute's 15th anniversary symposium, "The Future of Great Lakes Resources." These reviews illustrate the importance of the whole-ecosystem approach. They show us that, while we have made great strides forward in understanding the complexity of the Great Lakes, we still have a long way to go.

Wisconsin Governor Anthony Earl describes the importance of the Great Lakes to the state and region, and how Sea Grant and other university research has helped develop policies for wise management of the Great Lakes.

Economist Richard Bishop shows how the Great Lakes fisheries have recovered from the dark days of lamprey devastation and windrows of dead alewives on the beaches. The fisheries have made a remarkable comeback, thanks to fish stocking, lamprey control and other management activities. Maintenance and enhancement of the Great Lakes fishery, however, depends on continued public and private support.

Fisheries biologist James Kitchell traces the management processes that have yielded major new fisheries and helped resurrect some commercial fisheries that depend on the predator-prey relationships in the lakes. While the benefits are tremendous, the potential for management mistakes is also real and of unbelievable consequence.

Limnologist David Edgington takes a broad new look at eutrophication of the Great Lakes and the role of nutrients in water quality. In analyzing how the lakes function, he advocates an ecosystem approach—looking beyond just chemical pollution of the water to include the health of the whole system, including predator-prey relationships of the food web.

Water Chemist Anders Andren tells us that a significant—sometimes the major—portion of many chemical contaminants entering the Great Lakes fall from the air, and he warns that reducing atmo-

Sea Grant's research vessel, RV/AQUARIUS.

spheric inputs is going to be a difficult problem for society to deal with.

There is no question that recent cleanup and research efforts have helped turn around an alarming rate of deterioration of the Great Lakes. Billions of dollars in economic benefits for the region have resulted from these efforts. But will water quality continue to improve? Will the fisheries continue to flourish? Will the lakes continue to respond to our management?

Continued research and surveillance of the Great Lakes are essential to answering these questions. Without these efforts, the costs of which can be measured in millions of dollars, the result of our investment of billions of dollars to protect and maintain the quality of the lakes will never be known.

Two important goals of the University of Wisconsin Sea Grant College Program are to seek solutions to marine problems and to make the people of Wisconsin and the nation aware of the lakes' and oceans' tremendous resources and potentials. The main emphasis of our Sea Grant program has been on the resources and problems of the Great Lakes, though much of our research and information activities are national, even international, in scope. The activities supported range from fundamental research to quick-response projects. The intent of all projects is to provide information that will allow industry, government and the public to make wiser use of marine resources, to find solution to problems that threaten the sustained use of these resources, and when possible, to enhance their value.

It is the integration of research, technology transfer and education at all levels that constitutes the unique character and power of the Sea Grant Program. The Wisconsin Sea Grant College Program works in cooperation with various industries and municipalities, including the paper industry, fish processors, Joyce Foundation, National Fisheries Institute, Green Bay Metropolitan Sewerage District, commercial fishermen, sport fishermen, charter boat operators, marinas, ship builders and shippers, and the region's ports. An active network of Sea Grant institutions, especially among the programs of the Great Lakes Sea Grant Network, assures that useful information and methods developed by these participants will be transferred through other universities and applied in other parts of the country.

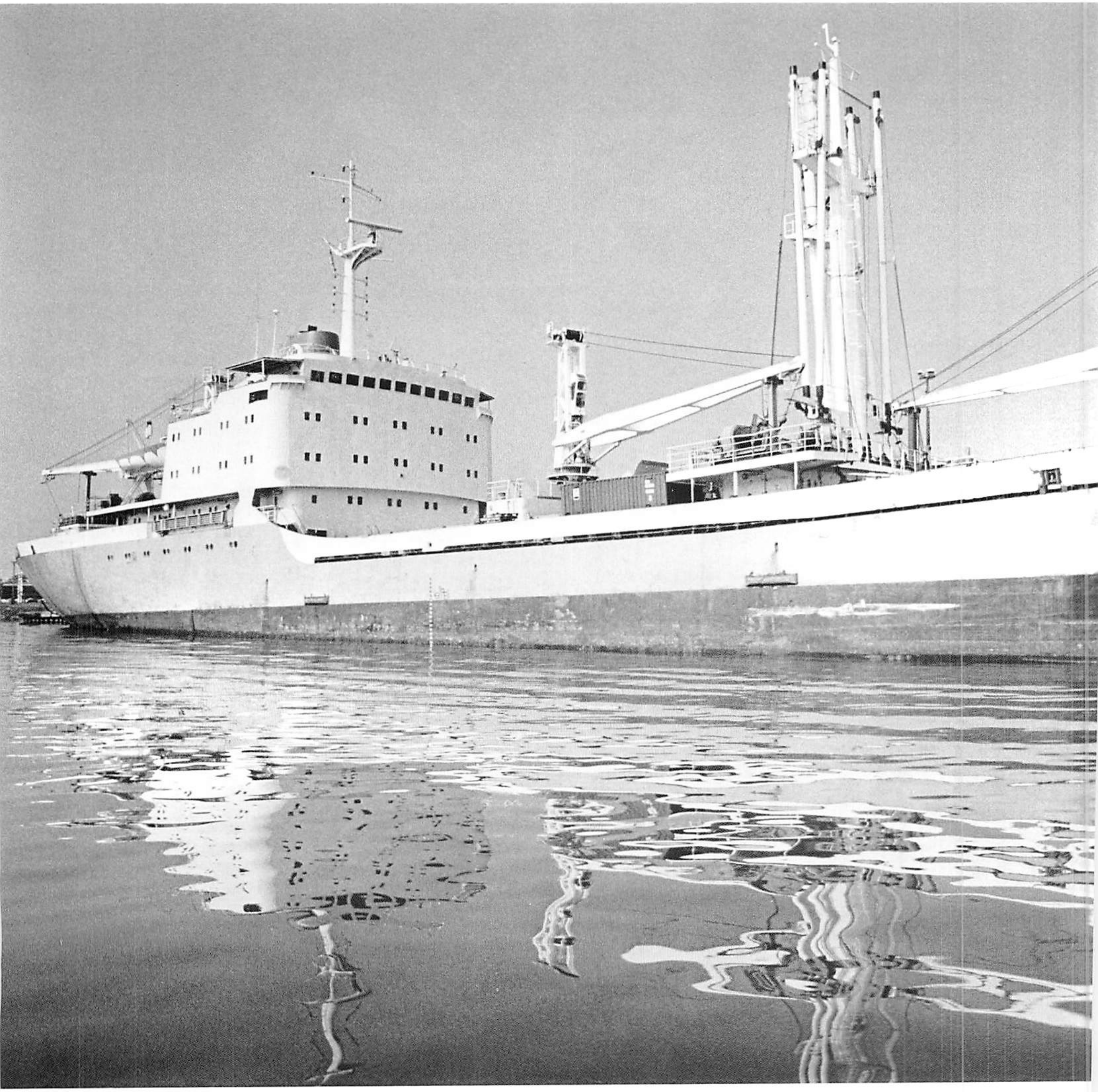
Continued research and surveillance of the Great Lakes are essential.

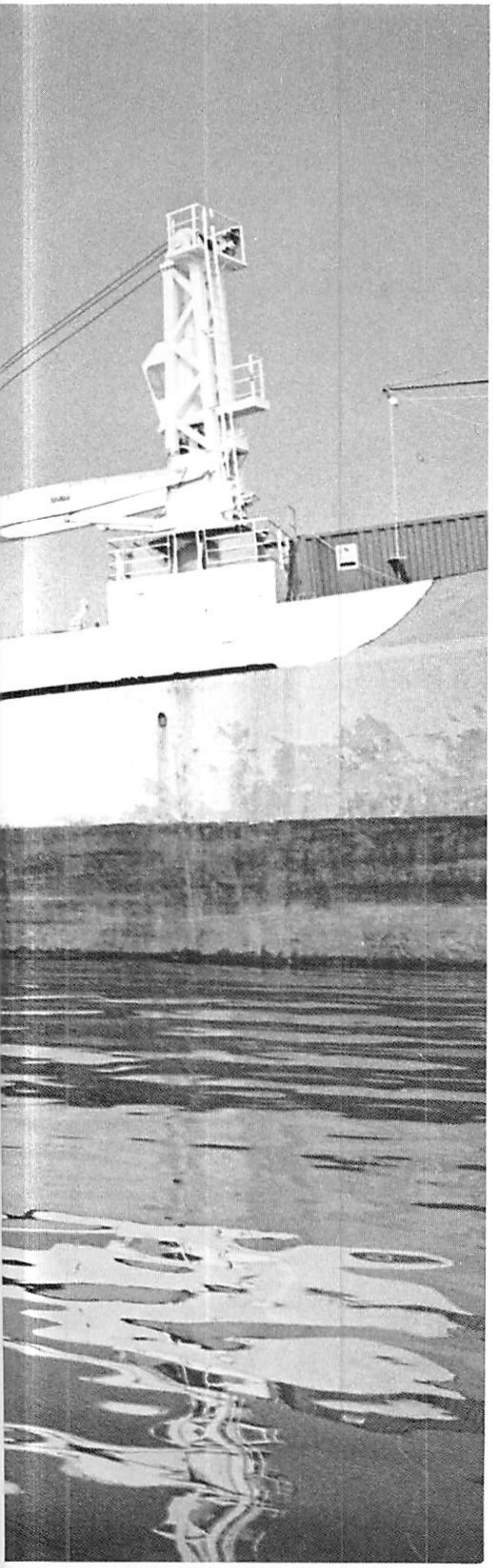
It is imperative that we build upon this kind of work and the momentum Sea Grant has built up here in Wisconsin, in the Great Lakes basin and across the country.

Clearly, we will need to manage the Great Lakes in ways that will ensure their continued high quality and biological productivity. Their resources of clean water, diverse and valuable fisheries, and varied recreational opportunities are going to be much more valuable in the years to come, and the study of these inland seas and their resources requires techniques and approaches analogous to those used for the world ocean. The result, prudent stewardship of these renewable resources, will pay rich dividends in the future.

It is our hope and our intent that the University of Wisconsin Sea Grant College Program will continue to play its part in this stewardship, as it has for the past 15 years.

. . . the Sea Grant Network is by far the largest coordinated effort going into research on the Great Lakes at this time. We should all be glad that it is here to serve us . . .





The Great Lakes and the Wisconsin Idea

Anthony S. Earl
Governor of Wisconsin

A year ago, I spoke here as a candidate for governor. I am delighted now to be back as governor to discuss one of the central topics affecting our state's welfare and one that is very close to my heart as a former state Secretary of Natural Resources.

The Great Lakes are America's inland seas and among Wisconsin's most precious resources. One-fifth of all U.S. industry is located around the Great Lakes, and about one-fifth of our nation's population lives in the Great Lakes region and depends on the lakes for drinking water.

In Wisconsin, we rely on the Great Lakes to support industry, to attract tourists, to offer opportunities for sport and commercial fishing, and to provide recreation for our families. The Great Lakes are a part of our character as a state. They make us distinctive, and they hold much for our future.

Recognizing this, the Wisconsin state government and the University of Wisconsin have revitalized "The Wisconsin Idea" in recent years to unite their efforts in behalf of the preservation of our Great Lakes resources.

Sea Grant, University Extension, the Department of Natural Resources, the Department of Transportation, the Public Service Commission, the Coastal Management Program, the Department of Development and the Department of Agriculture have combined scientific research, policy research and policy implementation activities to develop wise approaches to Great Lakes management in Wisconsin.

One of the best examples of "The Wisconsin Idea" in action was the approach I came here to discuss last year—the cooperative effort of Sea Grant, the DNR, municipalities, paper companies and other private industries to ease the massive pollution problems of the Lower Fox River Valley.

Here was a situation where traditional pollution control techniques would not have worked or would have been prohibitively expensive. But we worked out a program to set certain allocation levels for various waste discharges—in effect, to establish limits on rights to pollute based on discharge location, water temperature, time of the year, etc.—and then to give the dischargers great flexibility in meeting these standards. This approach has worked, and it is an example of how the University of Wisconsin can act as a research arm of the state in achieving resource management and conservation.

Another example is the cooperation between Sea Grant and the DNR in doing the necessary research and stocking to rejuvenate the Great Lakes fisheries in Lakes Michigan and Superior. This cooperative effort means a real boost to Wisconsin's economy.

Still another example would be in the area of dredge disposal, where the Department of Natural Resources, the Department of Transportation and Sea Grant combined scientific research and policy implementation to dispose of clean dredged material in a new kind of beach nourishment project in Kewaunee. The cost of this project was $65,000, and it resulted in cost savings of $335,000. Because the federal government is pushing more of the costs of dredging onto localities, programs like Wisconsin's may be the only hope of many communities to maintain their harbors.

The Great Lakes Sea Grant Network is an excellent example of what we hope to achieve on the governmental level.

I have already made efforts to see that Wisconsin does not stand alone in dealing with the issues that confront us. At the last National Governors' Association conference in Washington, D.C., a newly expanded Council of Great Lakes Governors was created, and they decided to headquarter the council in Wisconsin. I will chair this council for two years. We will be dealing with many issues common to the upper Midwest, but one of the most important will be our common resource, the Great Lakes.

I hope that we can organize a strong regional policy on our Great Lakes management and that this political interlink will be matched by university research networks. The Great Lakes Sea Grant Network is an excellent example of what we hope to achieve on the governmental level. I am aware that—because of cutbacks in federal funding for such programs as the Great Lakes Basin Commission and the Great Lakes Environmental Research Lab—the Sea Grant network is by far the largest coordinated effort going into research on the Great Lakes at this time. We should all be glad that it is here to serve us, and we look to it to play a key role in the future.

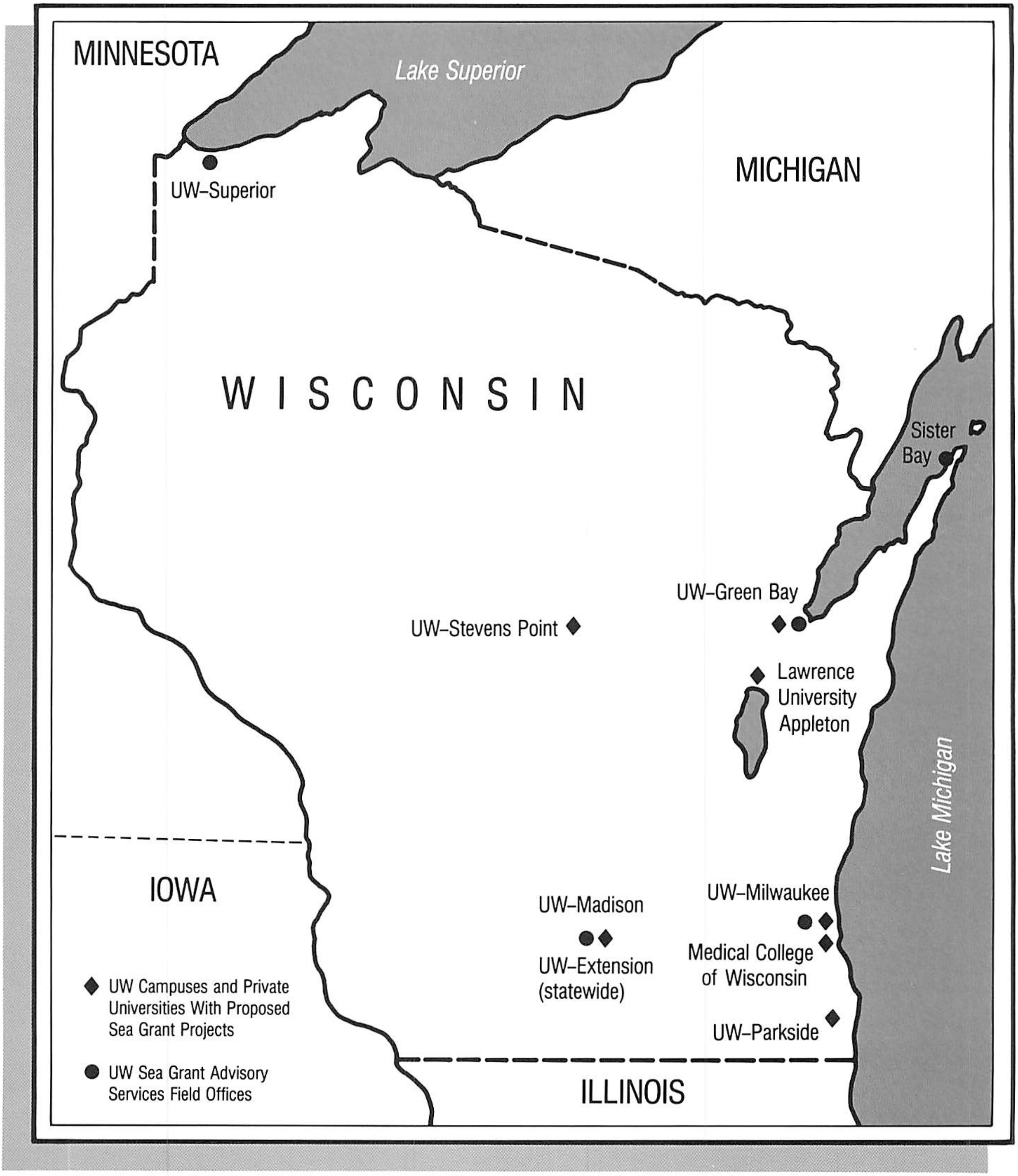
The economic future of Wisconsin and the other states of the region is closely tied to the resources of the Great Lakes.

I am hoping, by the way, that both Sea Grant and the State of Wisconsin, through the Coastal Management Program, will have more money to invest in Great Lakes management issues as a result of congressional action. We are supporting those legislative efforts and hope they produce a benefit for Wisconsin.

I believe Wisconsin deserves a benefit, because Wisconsin has already shown that it cares about its Great Lakes. The state's commitment can be seen in many forms, including the Harbor Assistance Program now in place in the Department of Transportation, the Water Regulation and Zoning Laws now administered by the DNR, the Great Lakes Trout and Salmon Stamp now being issued to support a continued high level of fish stocks, and the recent passage by the State Assembly of the ban on phosphates. All of these show a real state concern for the diversity of effort required to keep our precious Great Lakes resources intact.

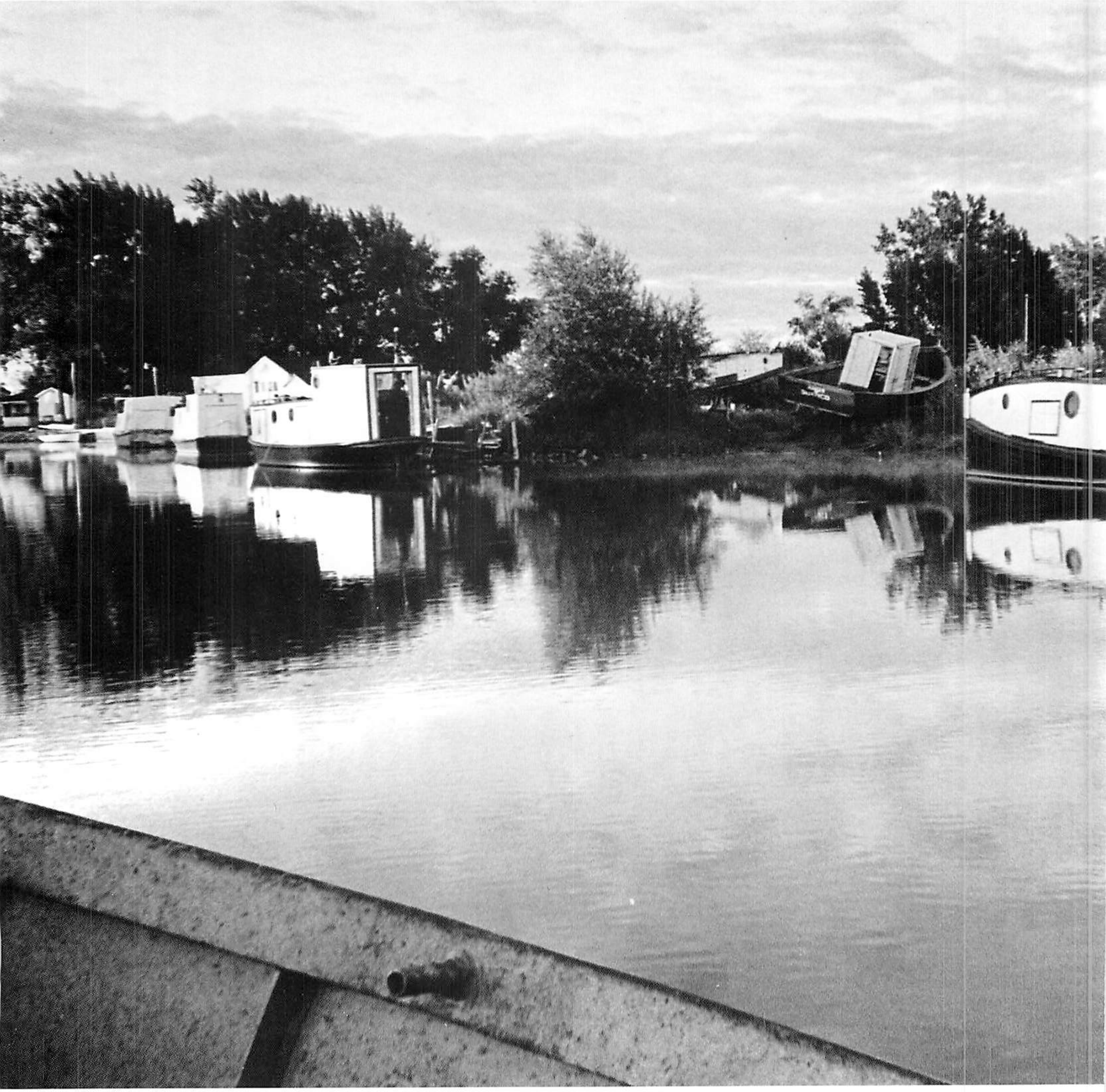
The economic future of Wisconsin and the other states of the region is closely tied to the resources of the Great Lakes. In the years to come, we will be required to make difficult decisions that involve balancing environmental concerns with economic growth. We will also have to renew decaying waterfront areas, monitor and maintain water quality, and assure that the benefits of the Great Lakes are shared equitably.

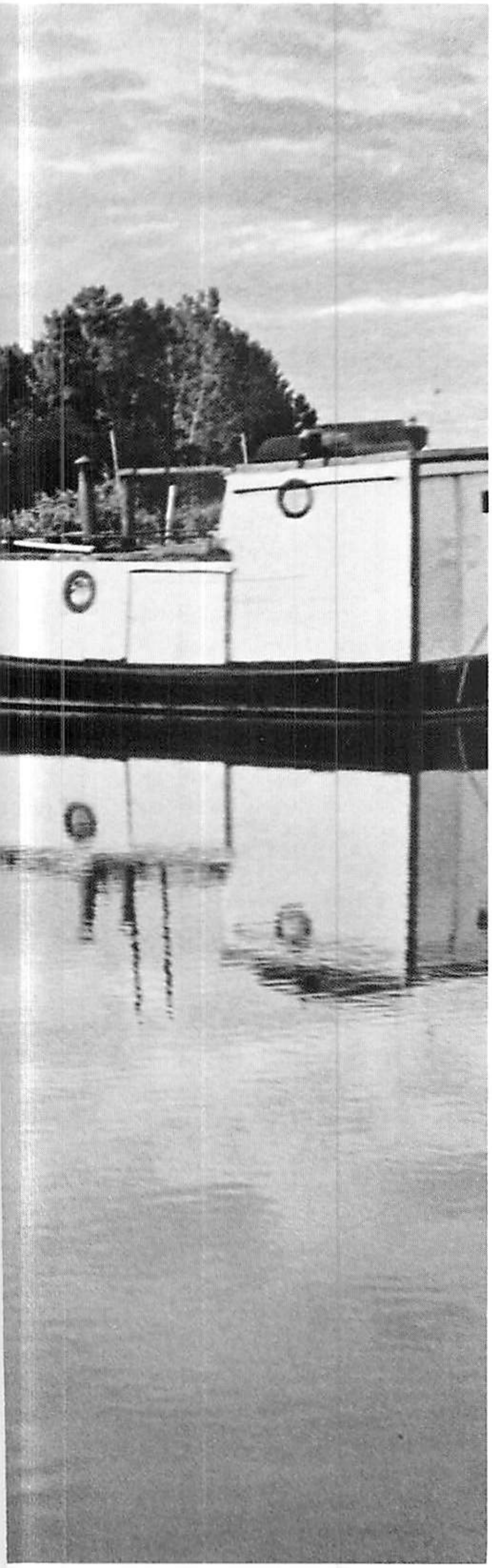
Alone, these requirements would be overwhelming to us. But if state government and the university continue their excellent pattern of cooperation, and if Wisconsin joins with the states and provinces that share in the Great Lakes, I have every reason to hope that the future will be good for us as we seek both opportunity and refreshment along our "sea" shores.



One of 29 Sea Grant Programs nationwide, the University of Wisconsin Sea Grant Institute is a member of the Great Lakes Sea Grant Network, which also includes Minnesota, Illinois-Indiana, Michigan, Ohio and New York.

Clearly, care must be taken through research and monitoring to assure the wholesomeness of both sport and commercial catches, and the protection of the Great Lakes from harmful chemicals.





Wisconsin's Great Lakes Fisheries: An Economic Perspective

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Two experiences I had recently in other states will perhaps help us view Wisconsin's Great Lakes fisheries in a broader context.

First, during a trip to Alaska last year, I had an opportunity to fish for king salmon. As we trolled in the famous Inside Passage, my host pointed out that our limit for the day would be just one salmon each, and the minimum size was 28 inches. He, of course, had heard of the salmon fishing in Lake Michigan and asked about our current limit: It was five fish per day and a minimum size of 10 inches.

Second, while in New York on business last winter, I took a little time out to do some "fishery research." It is common knowledge around Wisconsin that the Jewish holidays affect the demand for lake whitefish, a major contributor to our commercial catch. I cornered the maitre d' of a delicatessen and asked him about gefilte fish. Yes, whitefish was used, along with carp and walleye. I explained that this was particularly interesting, because my Midwestern Jewish friends had not heard of using whitefish for that purpose. "The answer," he replied, "is simple. New Yorkers are the most particular people in the world about what they eat."

These experiences dramatize the tremendous comeback that Wisconsin's Great Lakes fisheries have made since the 1950s and 1960s. During that period, the sea lamprey invasion did extensive damage to the lake trout populations in Lakes Michigan and Superior. Whitefish were very scarce most of the time. Lake herring populations collapsed and have not recovered. In the mid-1960s, the yellow perch population declined greatly. Toward the end of the 1960s, tons of unwanted alewives washed up in windrows along the shore of Lake Michigan.

By the early 1980s, the picture had improved greatly. Basing comparisons of Alaska and Wisconsin sport fisheries only on bag limits would be tenuous, but it is still fair to say that the Great Lakes now have a world-class salmon and trout fishery. The Great Lakes also have a nationally significant commercial fishery that produces high-quality freshwater fish products. It will help in assessing their future prospects to translate these general observation about the current fisheries into economic terms. Let's begin with sport fishing.

The statistics to be presented here combine some results from my own research program with recently release survey data from the U.S. Fish and Wildlife Service.[1,2,3] Table 1 provides a summary.

An estimated 411,000 people, 16 years of age and older, fished in Wisconsin waters of the Great Lakes in 1980. This means that 23 per cent of all the anglers in the state fished at least one day in the Great Lakes. Both survey data and Great Lakes Stamp sales indicate that there are about 220,000 participants in the trout and salmon fisheries. That leaves more people in the warm-water fisheries than I realized previously, and not much is known about them. As one would expect, there is substantial participation in perch fishing, plus others who target on smelt and walleyes. All the participants combined—warm water and cold water—recorded 2.7 million recreation days during 1980. This was 9 percent of all the fishing days occurring within the boundaries of the state.

Such large amounts of participation translate into large economic values. Our work indicates that the net social benefits generated by sport fishing in Wisconsin waters of the Great Lakes is somewhere in the neighborhood of $60 million annually. This is the net value that anglers place on the opportunity to fish in these waters. It is over and above the $2.5 million annually spent on public programs, including stocking, regulation, sea lamprey control and other management efforts. It is also over and above what anglers spent on their sport. For Wisconsin Great Lakes anglers, the amount spent was $49 million in 1980.

Turning to the commercial side, the relevant statistics are summarized in Table 2. During 1982-83, some 220 people held state licenses to fish commercially in Wisconsin waters of Lakes Superior and Michigan. They reported employing 418 crew members on a full or part-time basis. Reported investments totaled $13.1 million, including vessels, gear and real estate. The value of the combined total reported catch was $3.9 million in 1981, the most recent year for which data are currently available. My best estimate is that the social net benefits for commercial fishing would lie between $3 million and $5 million annually.

TABLE 1: Wisconsin Great Lakes Sport Fishing Facts (Annual)

1980 Participants	411,000
1980 Days of Participation	2,715,100
1980 Expenditures	$49,100,000
1978 Public Costs	$ 2,500,000
1980 Net Social Benefits	$60,000,000

The net social benefits generated by sport fishing in Wisconsin waters of the Great Lakes is somewhere in the neighborhood of $60 million annually.

Table 3 breaks the total catch in dollars down into the different species. Important food fishes include chubs, whitefish, yellow perch, smelt and fat trout.

Chub fishing in Lake Michigan has been excellent over the last few years. Chubs are popular as a smoked fish.

Lake whitefish have been doing quite well for about 10 years, but concerns for the stocks are growing, as we shall see in more detail shortly. In addition to its use for gefilte fish for East Coast residents, whitefish is popular in the Midwest and East as a fresh fish. It supplies the popular fish boils in Door County, Wis., and elsewhere, and it is also often smoked.

Yellow perch are still an important part of the state's annual commercial catch, but that fishery has not been as productive in recent years as in the past. Perch has long been popular in Wisconsin for Friday night fish fries, and large quantities are also imported to Wisconsin from Lake Erie.

Smelt are common, at least seasonally. While markets for smelt are still limited, they appear to be growing.

Fat trout—a relative of the traditionally caught "lean trout"—were insignificant five year ago, but are emerging as an important part of the Lake Superior catch.

Alewives also made an important contribution to the 1981 catch. The $400,000 value of this catch in

1981 represents about 18 million pounds. Alewives are used to make fishmeal (a poultry feed), fish oil, pet foods and fertilizer. PCB contamination of alewives has led to a drop in meal and oil production, but the PCB levels in Lake Michigan fish appear to be declining.

These figures indicate that both the sport and commercial fisheries are now making significant economic contributions to the state and nation. As our attention turns to the future, it is important to recognize that these fisheries are not free gifts of nature. Many depend directly or indirectly on human management. The present trout and salmon sport fisheries would probably not exist at all without stocking, sea lamprey control and law enforcement. Though less obvious at first glance, the warm-water sport fisheries and the commercial fisheries are linked to human management as well.

At least six major sets of issues must be dealt with if we are to succeed in maintaining and enhancing the productivity of Great Lakes fishery resources in the future: sport fishing issues, commercial fishing issues, Indian fishing rights, sport-commercial fishing conflicts, commercial fishing-DNR conflicts and contaminant issues.

The salmon and trout sport fishery we have 10 or 20 years from now will depend on management of the forage base, stocking policies and lamprey control. Jim Kitchell will address current concerns about the forage base in the next paper. I will only underscore the importance of what he says. A large share of Wisconsin's $60 million annual benefits from sport fishing rests on the continued viability of the forage base, particularly in Lake Michigan. To ignore this fact is to risk having the trout and salmon fisheries tumble like a house of cards.

Stocking is one aspect about which a great deal is known. Fish can be raised and stocked at reasonable cost. Nevertheless, there are still important stocking issues to be considered. For one, we must begin to ask whether the point will be reached soon where it is no longer economically feasible to try to reestablish naturally reproducing lake trout stocks in Lake Michigan. Exotics are doing well, are popular with anglers and may be more accessible to them.[4] I admit the question is biologically and economically complex, but it must be raised unless more success in trout reproduction is achieved soon. Other issues relate to the mix of species, especially the relative roles of chinook and coho salmon and prospects for a much larger walleye catch from Green Bay.

It is easy—and dangerous—to take sea lamprey control for granted. If the sea lamprey control program suffers too heavily from the budget-cutters, or if the lampreys become tolerant of chemicals currently used to control them before new lampreycides are developed, or if harmful effects to humans of currently used lampreycides are discovered, the results could be economically disastrous. A well-financed, long-run program of control and supporting research appears to have strong economic justification, but may be difficult to maintain in today's political climate. User fees may have to be increased.

TABLE 2: Wisconsin Great Lakes Commercial Fishing Facts

	Lake Superior	Lake Michigan	Total
1982-83 Licenses	21	199	220
1982-83 Capital Investment	$1,600,000	$11,500,000	$ 13,100,000
1982-83 Crew Members	26	392	418
1981 Average Days Fished	74	66	- -
1981 Total Value of Catch	$ 500,000	$ 3,400,000	$ 3,900,000
1981 Net Social Benefits	- -	- -	$3-5,000,000

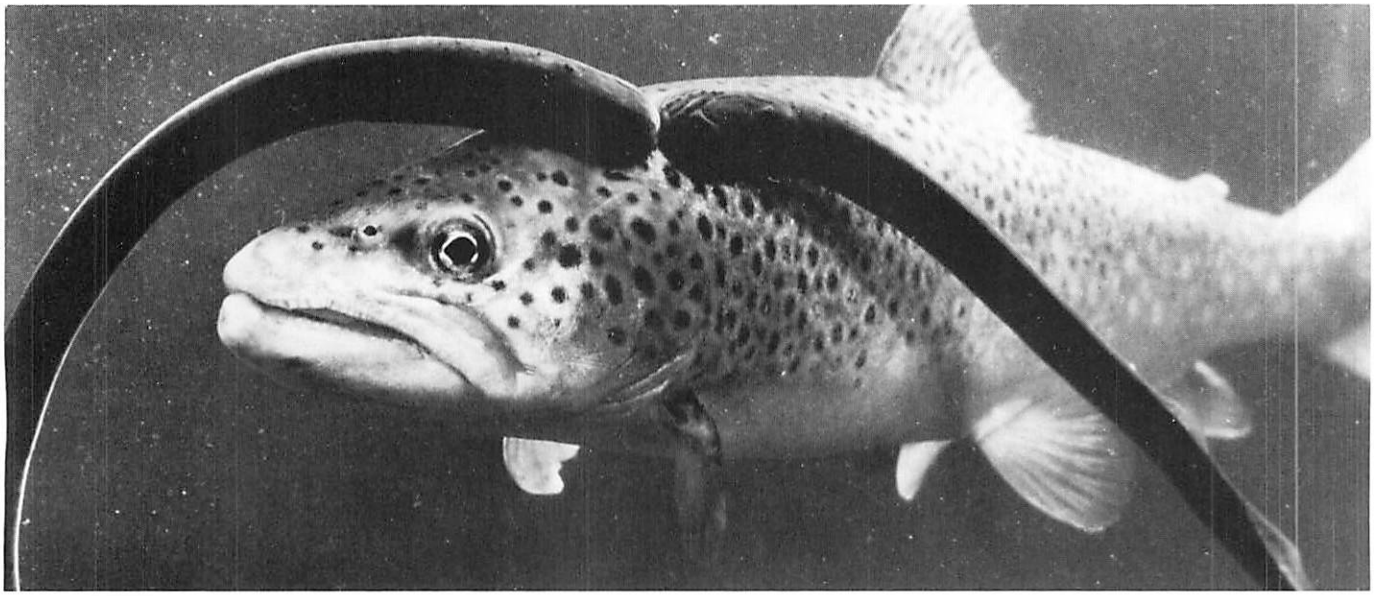
> **It is easy—and dangerous—to take sea lamprey control for granted.**

The major issue in commercial fishing is management. While the way has not always been smooth, my feeling is that we have made significant progress toward sound management of the commercial fisheries since the passage of the 1977 law (Chapt. 418, Laws of Wisconsin). Still, in the near future, decisions will have to be made regarding how the costs of fish management are to be equitably shared. Cutbacks in federal support have meant that an ever-increasing share of the support for commercial management has had to come from other sources, including sport fishing revenues. How this problem is dealt with will do a lot toward shaping the commercial fishery that will exist in Wisconsin 10 years from now. In particular, future commercial fishing fees will influence the viability of the state's small, part-time fishing firms.

The fishing rights of the Red Cliff Tribe of Chippewa Indians—whose reservation occupies the northern tip of the Bayfield Peninsula on Wisconsin's Lake Superior coast—were established under early treaties and have been reaffirmed more recently in court decisions. Within certain limits, Indian licensees have the right to fish without control by the state. Management of the same resources by two separate political entities (the state and the tribe) has the potential for disaster for both sides. Nevertheless, a very promising agreement between the state and the tribe has been reached. So far, the cooperative arrangement has worked well, but continued effort will probably be needed if problems are to be resolved in an equitable way.

Unfortunately, a similar Indian fishing rights agreement has not been reached in Michigan. The security of whitefish stocks exploited in Wisconsin waters of Green Bay and Lake Michigan is linked to what happens in Michigan waters. Biologists are becoming increasingly concerned about the heavy rates of exploitation being imposed on these stocks by tribal and state-licensed commercial fishermen in Michigan waters.

The sport-commercial fishing conflict issue is easy to see when Wisconsin's $60 million net benefits from sport fishing are compared with the $5 million maximum estimated net benefits of commercial fishing. Some may be tempted to argue that commercial fishing should be eliminated or greatly curtailed where any conflict at all exists between the two groups. But such evaluations are too simplistic. Economic comparisons of sport and commercial fishing are much more difficult to make. The benefit figures discussed here are *total* figures; the case for curtailing commercial fishing in favor of sport fishing must rest on the resulting *changes* in these totals. That is, in economic terms, the net increase above $60 million in sport fishing benefits would have to exceed the reduction in commercial fishing benefits that would be caused by restrictions on commercial fishing.



Two sea lamprey feeding on a brown trout.

TABLE 3: Dockside Value of Wisconsin Catch by Species

By Species	Superior	Michigan	Total
Chubs	$ 75,206	$1,464,345	$1,539,551
Whitefish	171,983	841,944	1,013,927
Alewives	0	405,591	405,591
Yellow Perch	0	364,439	364,439
Smelt	5,892	185,885	191,777
Lake Trout, Fat	118,533	0	118,533
Lake Trout, Lean	85,602	0	85,602
Other	24,317	125,523	149,840
TOTALS	**$481,533**	**$3,387,727**	**$3,969,260**

Our economic tools for measuring such changes are not well-developed. The problem is further compounded by uncertainty on the biological side. Suppose, for example, that the use of gill nets is greatly reduced. One would have to know how much such a regulation would reduce the net benefits of commercial fishing, what the effect would be on sport fish populations, how changes in sport fish populations affect the amount of sport fishing and the success rate for anglers, and the monetary benefits associated with changes in the success rate in sport fishing. It is very difficult to put all these pieces together.

The Great Lakes fisheries have proven their ability to be highly productive and will continue to provide opportunities for large economic rewards.

In a recently published paper,[5] we argued that if fears among biologists about the Lake Michigan forage base prove valid, the economic benefit-of-the-doubt should probably go to sport fishing. Commercial fishing for alewives ought to be curtailed under this scenario. However, after further reflection, it turns out that we probably viewed the problem a bit too simplistically. Publication of papers takes time, and meanwhile Kitchell and others have learned more about the interaction between salmon and trout and alewives. The extent to which alewife stocks serve as forage for salmon and trout varies greatly, depending on the location and time of year. For example, the commercial alewife harvest on southern Green Bay might be maintained or increased without affecting sport fish populations. Cutbacks in commercial fishing might become necessary in the rest of Lake Michigan, however.

Lake Michigan commercial fishermen unloading whitefish catch.

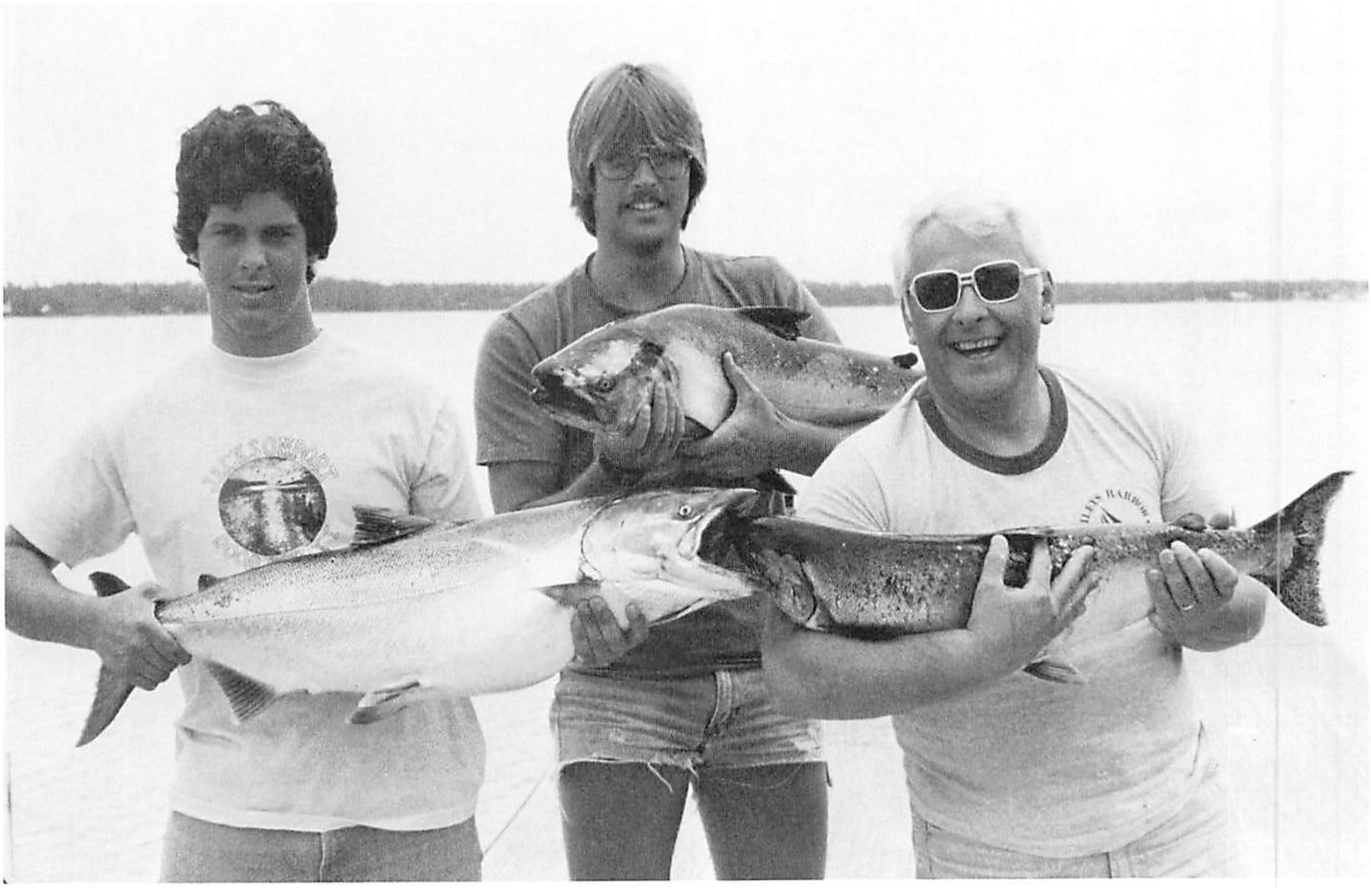
Things may look different 10 years from now. At present, I am not convinced that substantial curtailment of commercial fishing would yield large economic dividends to sport fishing. Where localized conflicts are obvious, the types of regulations currently used—such as area and season closures appear adequate to deal with the problem.

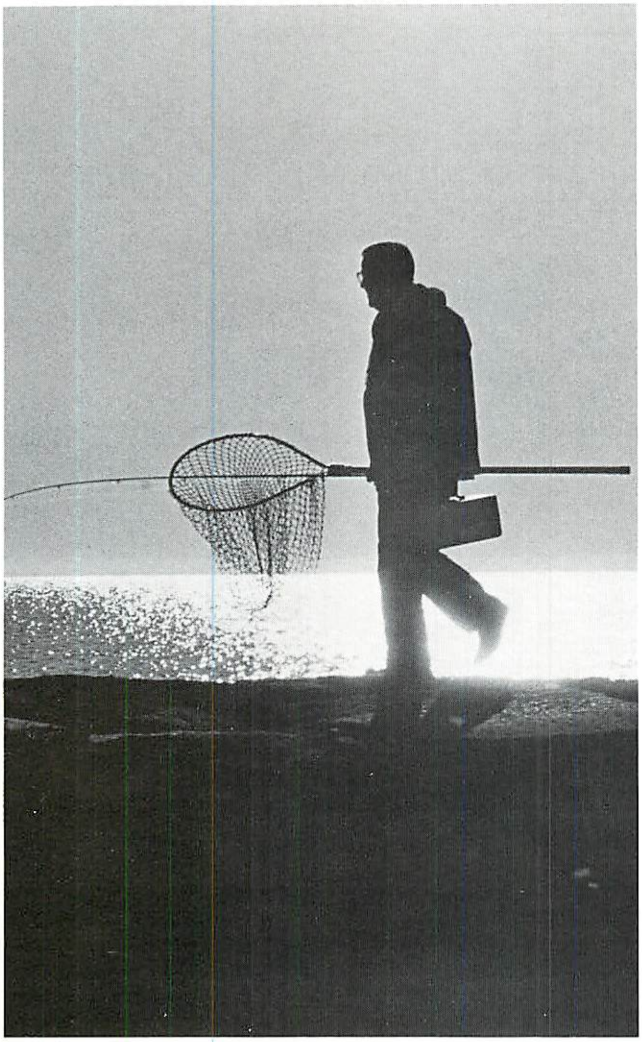
At present, I am more concerned about the conflict between commercial fishermen and the Wisconsin Department of Natural Resources. Some people at the DNR are convinced that the commercial fishermen are out to get as much out of the resource as they can, as fast as they can, legally or illegally. Many commercial fishermen bear hard feelings about past DNR management decisions, particularly those relating to lake trout. They also question whether most of the detailed regulations promulgated by the DNR over the years are doing anyone any good. A significant number of commercial fishermen are convinced that the DNR has a hidden agenda for eliminating commercial fishing altogether. In my opinion, these attitudes have contributed greatly to the illegal activities of commercial fishermen that have come to light over the last 25 years. The overall result is a very unhealthy environment for the industry and the agency.

> **Fishermen need to have a larger voice in making the rules that affect them.**

> **. . . these fisheries are not free gifts of nature.**

If a solution exists, it will require hard work by both sides. Part of such a solution may lie in a firmer understanding of the biology of the lakes. Many disagreements in past years have focused on issues of biological fact. Fishermen will have to listen more to biologists, and biologists will have to listen more to fishermen. Secondly, fishermen need to have a larger voice in making the rules that affect them. The creation of the Commercial Fishing Boards under the 1977 law was a significant step in the right direction. Where state control must be maintained, there needs to be greater recognition of the fact that commercial fishing has special problems beyond biology. The economic implications of alternative regulations need to be considered also. By the same token, commercial





fishermen need to more clearly recognize that the DNR has its own responsibilities and problems.

The ultimate goal of efforts to resolve this conflict should be to convert the adversarial relationship existing today into a one of a public agency and a clientele group. The alternative, I fear, will be the disappearance of commercial fishing as we know it. An intermediate alternative to complete elimination might be some sort of contracting system like those employed for rough fish removal in inland lakes and for timber sales, but such a system would require a major restructuring of the industry with much human hardship. Are such drastic changes in the public interest? I do not find the argument compelling.

. . . the Great Lakes now have a world-class salmon and trout fishery.

Lastly, on the contaminants issue, our experience with DDT and probably PCBs as well have taught us that contamination, even by persistent chemicals, need not spell permanent economic ruin. Everyone hopes that no new contaminants will appear in larger proportions of Great Lakes catches, yet fears remain and rumors circulate. Clearly, care must be taken through research and monitoring to assure the wholesomeness of both sport and commercial catches and the protection of the Great Lakes from harmful chemicals.

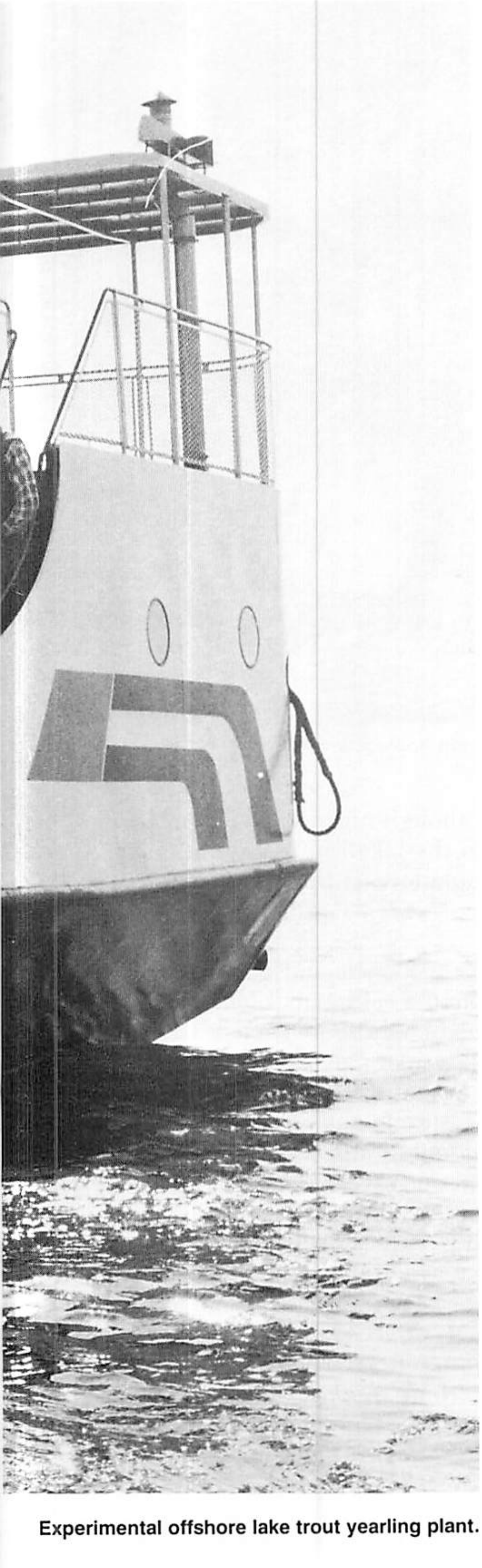
This list of issues has necessarily been superficial. My whole paper could have been devoted to any one of them. It is appropriate, however, to try to see the whole forest rather than individual trees at this celebration of Wisconsin Sea Grant's 15th anniversary, because it serves to highlight Sea Grant's important role in the future of the Great Lakes fisheries. The Great Lakes fisheries have proven their ability to be highly productive and will continue to provide opportunities for large economic rewards. Capitalizing on these opportunities will not always be cheap or easy. Sea Grant research and advisory service activities can do much to help.

It must be kept in mind that the economic scores I have given are not final. Nature, not economics, always bats last. Sea Grant biological researchers have a proven record, and their input will be badly needed in dealing effectively with forage base issues, developing sound information on the interactions at the biological level between sports and commercial fishing, designing better methods of monitoring how the stocks are doing, and fulfilling a broad array of other needs.

Beyond biology, the issues confronting the Great Lake fisheries have human dimensions. Whether the topic is the optimal mix of sport fish species, how to accommodate state and Indian fishing rights while protecting fishery resources, doing something about this commercial fishermen-DNR conflict or other issues, Sea Grant can help through promoting progress in the social sciences with Great Lakes applications and through Advisory Services personnel helping people to deal with their problems and to take advantage of their opportunities.

With sustained Sea Grant research and extension efforts, in cooperation with state, federal and other governmental units and the private sector, it will be fascinating to review our accomplishments and the important issues confronting us in 1998, at Sea Grant's 30th anniversary.

To make reliable stocking decisions right now, we have to anticipate the available forage base two to six years down the road . . .



Experimental offshore lake trout yearling plant.

Keeping Score: The Great Lakes Predator-Prey Game

James F. Kitchell
Center for Limnology
University of Wisconsin–Madison

Richard Bishop, the author of the preceding paper, is a fisheries economist, and his admission that "nature, not economics, always bats last" is interesting. My job as an ecologist, then, is to try to tell who's now at bat, what the score is so far and how things look for the next inning.

First, I'll provide a brief historical perspective for each of the Great Lakes, and then I'll report on some of the specific work done recently on Lake Michigan. This information is based on data from a variety of agencies, university research programs and other sources. The management policies that were initiated in the last three decades on Lake Michigan will bring about changes and effects that are likely to develop later in the other Great Lakes, so research on Lake Michigan may have applications to future problems throughout the Great Lakes system.

The general history of the Great Lakes goes something like this. Niagara Falls historically formed a major barrier between Lake Erie and Lake Ontario. Access *to* Lake Ontario through northerly waters was also restricted by the continent's topography. Despite these obstacles, however, major changes in the Great Lakes—the exploitation and ecological perturbations brought on by Western civilization—swept from east to west, from the Atlantic Ocean to the furthest reaches of Lake Superior. The construction of the Erie and Welland canals unexpectedly accelerated this process, providing the sea lamprey and other exotic organisms with access to the entire Great Lakes system.

The sequence of remedial action, however, followed a reverse course—starting in the western lakes and working east. Guided by a kind of triage mentality, these programs focused on regions where treatment promised to be not only effective, but decisive as well. Sea lamprey controls started first on Lake Superior and gradually reached Lake Ontario, where today it is in full force. Similarly, the renewed emphasis on stocking salmonids that followed the imposition of lamprey controls began first on Lake Superior with the lake trout rehabilitation program. Pacific salmon stocking began first on Lake Michigan and then swept east. Only recently has it reached its full potential in Lake Ontario.

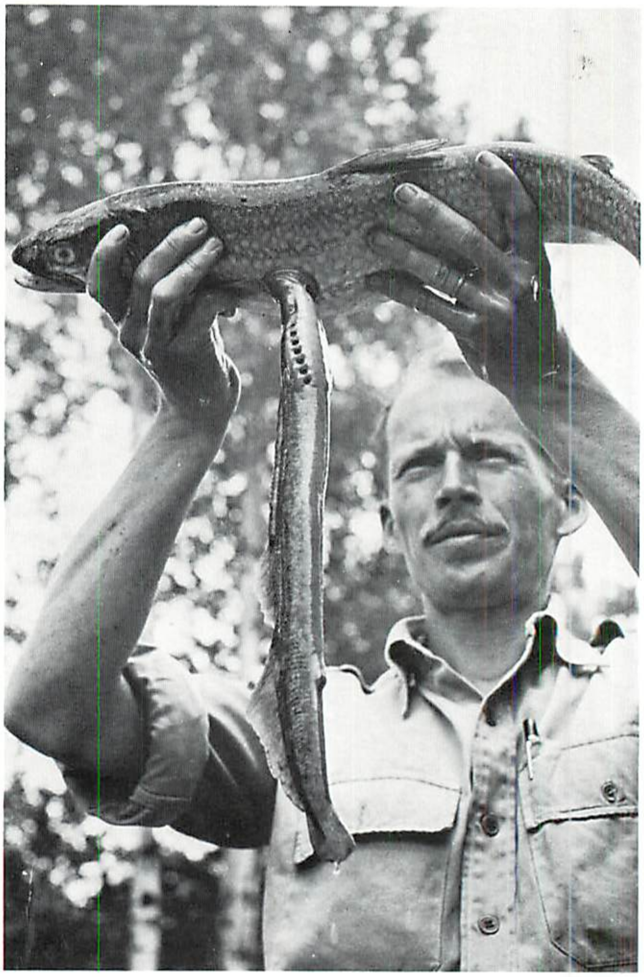
In these dramatic events, the leading actor was the sea lamprey. The onslaught of this parasitic ocean fish was devastating. They were far larger and more voracious than any native lamprey species in the Great Lakes. Native fish populations—many already heavily overexploited by commercial fishing—were especially vulnerable. Within six months, a sea lamprey can increase its weight 30-fold and does so at the expense of its victim—usually the largest, most noble and therefore most valuable fishes in each of the Great Lakes. A single attack wound inflicted by a lamprey can kill an adult lake trout.

A second set of invasions during this period began less dramatically but in the long run may prove to be equally important. These were the exotic fishes that were introduced—both inadvertently and, in some cases, purposely—to the Great Lakes. The notorious alewife may have been unwittingly introduced to the Great Lakes when American shad were stocked in Lake Erie. Alewife populations rapidly expanded into all of the Great Lakes except Superior. In that coldest of the Great Lakes, another exotic fish, smelt, achieved the same dominance.

The overwhelming invasion of the alewife had dramatic effects. Fisheries biologists were forced to take interest in more than those noble animals at the top of the lakes' food chain. The very underpinnings of the lakes' productivity—that is, the food that feeds the forage base that feeds the piscivores—became a subject of real concern. In Lake Michigan, for example, the abundance and size of its zooplankton changed radically as a consequence of the alewife population explosion. After a colossal die-off of alewives in Lake Michigan in 1966-67, the populations of large zooplankton increased dramatically.

In these dramatic events, the leading actor was the sea lamprey.

This fluctuation in the abundance of large zooplankton—particularly when it went down—had major effects on many lesser-known native Great Lakes fishes. Due in part to the scarcity of large zooplankton and in part to heavy exploitation, the once-abundant lake herring virtually disappeared from Lake Michigan. The emerald shiner—an even less-known fish, though historically one of the most abundant fish in the lake—now survives only in small, isolated populations at the mouths of rivers.



Former FWS biologist Vernon Applegate examines lamprey attached to a lake trout.

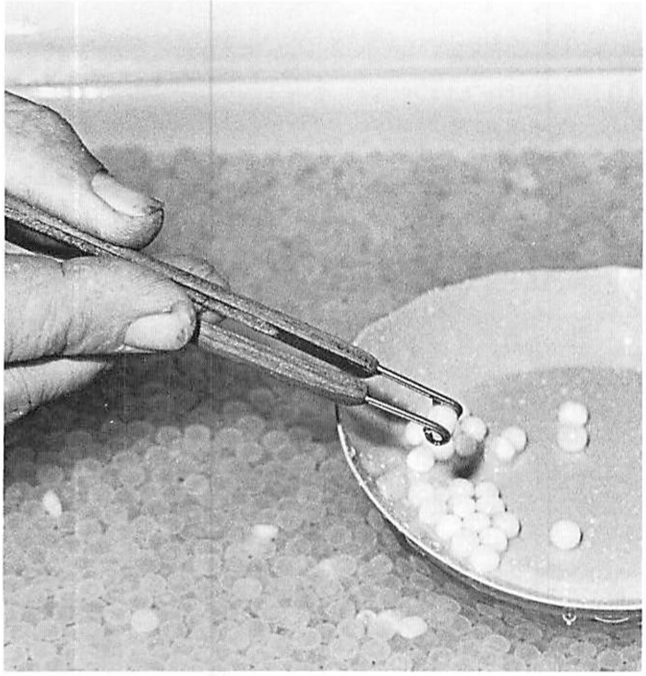
Actually, the effect of the alewife and smelt invasions appears to have had a component besides simple competition for food. Alewife and smelt predation on the eggs and larvae of native species may very well have had a dramatic effect on these resident fishes. Before the alewife and smelt invasions, the Great Lakes had equal numbers of fishes that laid their eggs either in open waters of the lake or on the bottom substrate. But after the alewife and smelt populations had peaked, only one relatively common pelagic spawner remained, while those fish that spawned on or near the substrate survived with little change. That difference underscores the fact that the interactions observed are probably manifestations of something more than competition—they imply a complex set of interactions at various stages in the life histories of this group of fishes we euphemistically call "forage fish."

Monitoring the growth of fish is equivalent to monitoring growth in a savings account.

The general history for each of the Great Lakes, then, has the following components in common. Long ago, there were abundant populations of lake trout and a whole suite of endemic ciscoes ranging across nearshore to offshore depths. Eventually, these fishes were subject to exploitation by commercial fishing and to the devastation of sea lamprey predation as this ocean invader proceeded up through each of the lakes. As sea lamprey populations increased and fishing continued unabated, the lakes' native fish populations collapsed. For the lake trout, the collapse was total in all but Lake Superior. Many of the large native ciscoes disappeared from all five Great Lakes.

Sea lamprey then moved inshore and found other prey. They continued to increase until extensive chemical control programs brought their populations in check and held them at very low levels. Since then, management agencies have established stocking programs designed to rehabilitate lake trout stocks and promote Pacific salmon.

Meanwhile, at the next trophic level, that which supports all of this, the native planktivorous fishes were presumably doing rather nicely—until, in the absence of predators, the alewife populations exploded. Eventually, the alewife populations fell; they now remain at levels less than half their maximum abundance, and recently we've seen increases in the native planktivore populations.


Fertilized lake trout eggs.

The primary interactions—those of particular importance—are among the the alewife, the smelt and the bloater chub. The first two are now the primary forage species in the lakes. The bloater chub is the one native species that remains in some abundance and provides a continuous commercial fishery. These three species interact in complex ways and are the subject of considerable Sea Grant-sponsored research.

The food web that now operates in each of the lakes has several general characteristics. At the top of it all is the sea lamprey populations, the control of which is essential. Next are the populations of Pacific salmon and lake trout, which are maintained almost exclusively by hatchery production and stocking, with the exception of some native lake trout stocks in Lake Superior. Further down are smelt and alewife, the primary forage base for the stocked salmonid populations. The smelt and alewife compete with native planktivorous fishes, which are also preyed upon to a modest extent by lake trout. The lower links in the food chain are the concern of Dave Edgington, the author of the next paper in this report, and they have to do with zooplankton, phytoplankton, nutrients and sunlight—everything that powers the system from below.

Though nutrient support in this trophic web essentially comes from below, researchers at the UW-Madison Center for Limnology have been interested since the mid-1970s in how control over the system is exerted from above. We have been developing bioenergetics models as a way of evaluating the impact of a fish predator on its resources. We applied these models specifically to Lake Michigan as a way of estimating the intensity of predation in the lake and to then evaluate what the effects of increased predation might be on the forage base. That should then tell us something about our management options and limitations.

Relatively simple in concept, energetics models are just mass balance equations: What goes *in* must, in some way, come *out*. Among the things that come out is an energy storage term—growth. Monitoring the growth of fish in a given environment is equivalent to monitoring growth in a savings account.

Ross Horrall examines incubation trays at an experimental lake trout hatchery.

This approach is preferable to the typical fisheries population dynamics approach, which essentially counts the numbers of fish, because individual fish growth is remarkably plastic. Three-year-old coho salmon, for example, can have tenfold differences in growth rate, depending on their environment. As might be suspected, they play very different roles as predators in the systems where they grow. Their potential contributions to future generations are just as disparate.

Growth, then, is the most responsive indicator variable and as such can be used to evaluate predator-prey interactions, because a large animal clearly eats more over the course of its life than a small one. We applied this knowledge specifically to Lake Michigan for three reasons: first, it's close by; second, the UW Sea Grant Institute supports work in Lake Michigan, and third and most important, it is in Lake Michigan where this predator-prey manipulation has been conducted for the longest period of time and has the greatest momentum. That long history of management and experimentation is very instructive.

Evaluating predator-prey interactions is relatively straightforward. We simply evaluate how a fish grows. Using a growth curve familiar to fisheries biologists, we plot the size of the animal at each year of age. From diet data, we determine what they eat as they become larger and older. For example, the average lake trout in Lake Michigan when young eats a mixture of small fish and invertebrates; but as it grows larger, it eats mostly adult alewives.

The energetics processes that regulate growth are also strongly influenced by water temperatures, so we create for each species a thermal history that accounts for the temperature preference of the fish during the summer months. Lake trout, for example, stay at depths with 10-12°C temperatures during midsummer; other fishes prefer other temperatures. Anglers use the temperature preference of fish as a means of locating them. For us, temperature preference is important because it affects a fish's diet and growth rate.

All this research on predator-prey interactions in Lake Michigan has been pursued against a backdrop of an increasing abundance of predator fish. Salmonid stocking began in earnest in 1965, and it was only a few years later that some kid caught a coho salmon off a Chicago pier and asked a local game warden, "What kind of carp is this?" A major fishery soon developed, and along with it a strong institutional momentum for increasing the stocking programs. These programs, which expanded until about 1978 and then leveled off, have been extensively coordinated and are well documented. As for the future, our projections are derived from information provided by both those who make the decisions and those who run the hatcheries.

In modeling predator-prey interactions, the mixture of predator species is also important. Lake trout, coho and chinook are the dominant components, though rainbow and brown trout are also being stocked. The proportions the species being planted is an important consideration, because we can now calculate how much demand is placed on the forage system for each unit of fishes stocked.

Here I'll compare coho, chinook and lake trout. As I've said, we can put a million fish in the lake, allow them to grow and die as we think they do, and then calculate at the end of that cohort's estimated life how much demand it placed on the forage base.

What do these comparisons tell us? Well, they say that if we stocked equal numbers of chinook, coho and lake trout, the chinook will demand twice as much from the forage base as does the same number of coho, and the lake trout in the long run will demand a bit more food than the chinook. But it should be noted that chinook feed almost entirely on alewife, whereas lake trout distribute their predation among a greater variety of forage species.

It should be pointed out that alewives were an incredible biological nuisance in the Great Lakes. In the 1960s, tons of these small ocean fish were fouling beaches and water intakes, causing tremendous economic losses and aesthetic impairment. Fish management agencies then established a biological control on this nuisance by stocking coho and chinook salmon, which were chosen because they occupied the same habitat as the alewife and preyed most effectively on it.

Our models do not allow us to predict the future, but they do tell us what we cannot do.

We were originally interested in knowing whether or not we could control the alewife population through some kind of predator stocking policy. It turned out we couldn't—because the major impact of each species differs as a function of the life history characteristics of that species. Coho salmon live in the lake only 18 months before they die, so their major impact on the forage base develops in the second summer after stocking. With chinook salmon, the peak develops some three years after stocking: the major impact of chinook stocked today will not occur until 1986. As for lake trout, their major impact on the forage base is broadly distributed some 4-6 years after they are stocked.

In other words, if we see an alewife peak now, there is no way current stocking policies for these salmon or trout can effectively follow that peak. The peak predatory demand simply occurs too many years after we have assessed prey abundance and reacted by stocking predators. Derived through computer analysis, our models do not allow us to predict the future, but they do tell us what we *cannot* do. They also can be used to tell us what we *should not* do.

But what's happening out there in "the real world"? The answer is that the alewives have been doing what virtually all populations of such fish do: they change a lot. Since the 1966-67 collapse, the alewife population in Lake Michigan has been fluctuating by a factor of two or more and in no discernable pattern. With the growth of the Lake Michi-

gan stocking program during that same period, we have been able to calculate about how much this ever-increasing population of salmonids in the lakes has been feeding on alewives. This increase has been so remarkable that, in some years, it appeared that the salmon and trout were eating every alewife in the lake.

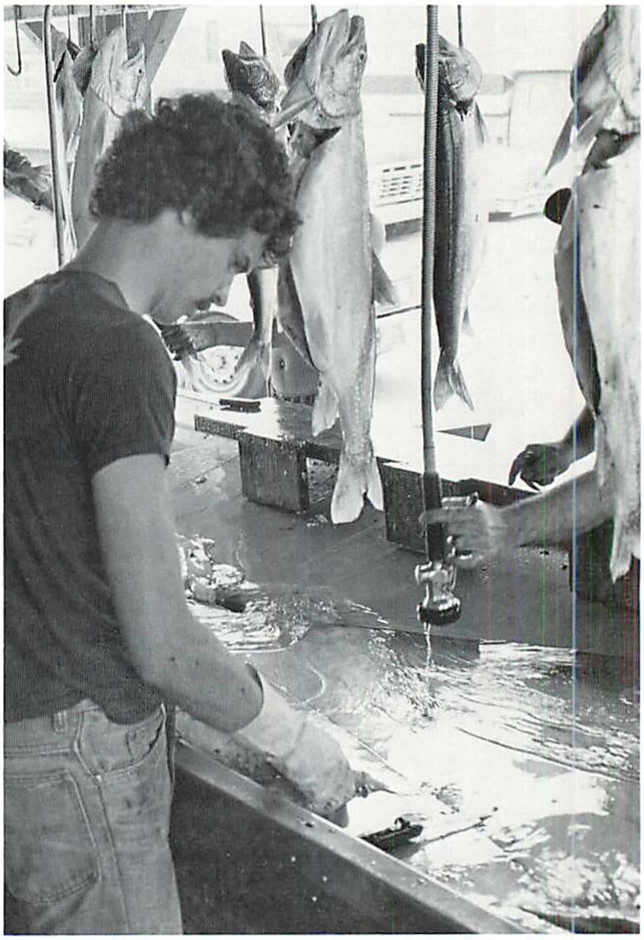
But appearances can be deceiving, because in effect we're comparing apples and oranges. These extreme appraisals were based on estimates of the total annual feeding by these stocked fishes as compared against estimates of standing crop of the available forage base in the autumn, when the U.S. Fish and Wildlife Service conducts its forage fish stocks assessment.

What we really need to know, of course, is the production rate—the elaboration of new biomass, the growth and reproductive effort that sustains this alewife biomass. We don't know that production rate. But from research on similar species, we suspect that the production/biomass ratio is about three to one for this kind of fish.

This suggests that when salmon appear to be eating all the alewives, they're probably eating about a third of the alewife population's total annual production that year. That may not sound like much, but the alewife is a clupeid fish, a herring-like fish, and if fisheries biologists from other marine environments heard about this, they would undoubtedly ask, "When is the alewife population going to crash?" That's the history of virtually every clupeid fish population in the world. When levels of exploitation approach 40-50 percent of total production, virtually every clupeid stock in the marine environment has collapsed or just disappeared. Many of the world's largest fisheries have done just that.

So when salmon and trout alone began "harvesting" close to 30 percent of the total alewife production in recent years, we became concerned about increased salmonid stocking rates, and we have urged sport and commercial fishermen to reduce their pressure for increased stocking in the lakes we've studied. We feel that increased predator pressure could contribute to a disastrous decline in the alewife populations—which is tremendously ironic, when you recall that alewives were regarded only as a nuisance 25 years ago.

Our concerns and recommendations are based on the following analysis. Salmon and trout are indeed significantly reducing the alewife population—but we may have gone too far. Continued increases in stocking—in combination with residual stocks of native lake trout and increased natural spawning of salmon—may cause the total predator population to overshoot the forage base. As I've pointed out, stocking policies are not effective in moderating short-term fluctuations in alewife populations. The system has what we call "predatory inertia," which simply means that in Lake Michigan a decision to stock predators right now won't have its major effect for two to six years. To make reliable stocking decisions right now, we have to anticipate the available forage base two to six years down the road—and we haven't mastered that technique yet. Fish management has always been handicapped by that inability.



Student Jeff Hager examines gastronomical debris of Lake Michigan salmonids.

We have been developing bioenergetics models as a way of evaluating the impact of a fish predator on its resources.

From a scientist's perspective, the course of Great Lakes history has been one of dramatic and unexpected changes. The alewife was a surprise. The local extinction of several native species was a surprise. The resurgence of native fishes today is a surprise. The success of the stocking program is a bit of a surprise, though the fact that we can't reestablish the native lake trout population in Lake Michigan is a disappointment. In fact, experienced Great Lakes fisheries biologists claim only one dynamic change was foretold: that was the sea lamprey's devastating effect in Lake Michigan—and that seemed almost inevitable, based on what had already happened in Lakes Ontario, Erie and Huron.

The lessons of history suggest that we be cautious about making predictions. What can we watch for? What can we see in the future that will guide our actions today? We know that salmon stocking programs have increased. We observe the resurgence of some native fish stocks following the marked reduction in alewife populations since 1967.

But traditional fish population monitoring can offer only after-the-fact awareness, and that is not enough. To be on top of changes as they occur, we're now looking for other kinds of evidence—short-term, real-time monitoring of *other* changes in the Great Lakes system. We can use ecological principles and evidence as a guide.

There are several things we would expect from an ecological view. One possible indicator is an increase in the abundance of large zooplankton. With piscivorous fishes preying heavily on planktivorous fishes, *their* predation on zooplankton should be reduced. As a result, you'd expect to see more and bigger zooplankton. That, of course, has some other effects, as Dave Edgington will describe.

Another possible development is the evolving impact of the two fish that were stocked to eat alewife—coho and chinook salmon. They have done that very well. But as alewives decline in number, these hungry predators will be forced to eat other things, and we are, in fact, beginning to find other fishes in their stomachs.

We'd also expect to see changes in the relationships among the competing planktivores as the alewife population, a dominant competitor, is reduced by predation. We'd expect to see a strong correlation between coho growth rate and alewife abundance. Because coho have the shortest life among Great Lakes predators, they will most closely reflect those peaks in alewife abundance.

From a scientist's perspective, the course of Great Lakes history has been one of dramatic and unexpected changes.

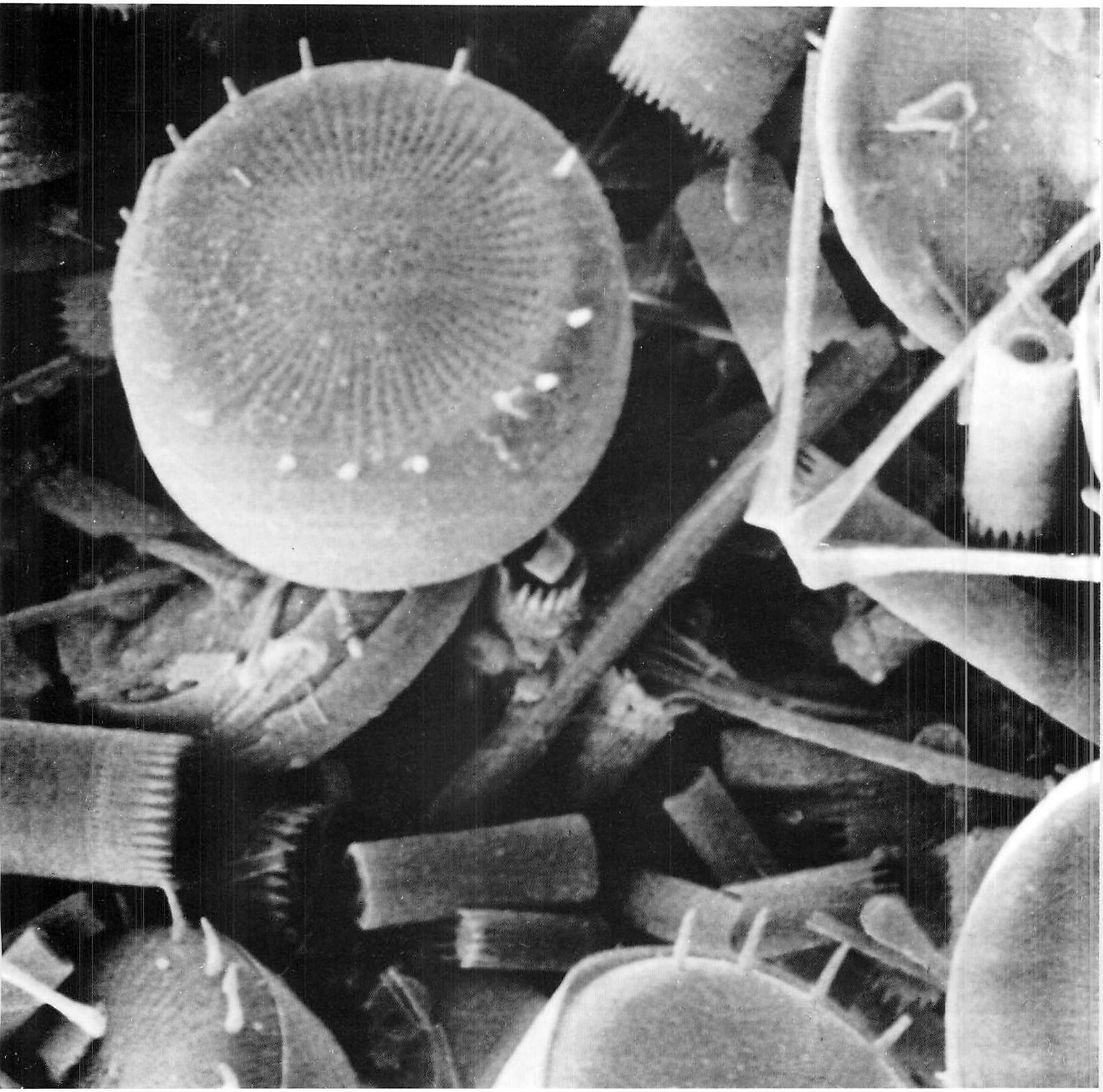
With reduced alewife populations, there should be some local increases in native fish populations formerly suppressed by the alewife, such as bloater chub, yellow perch and perhaps emerald shiner.

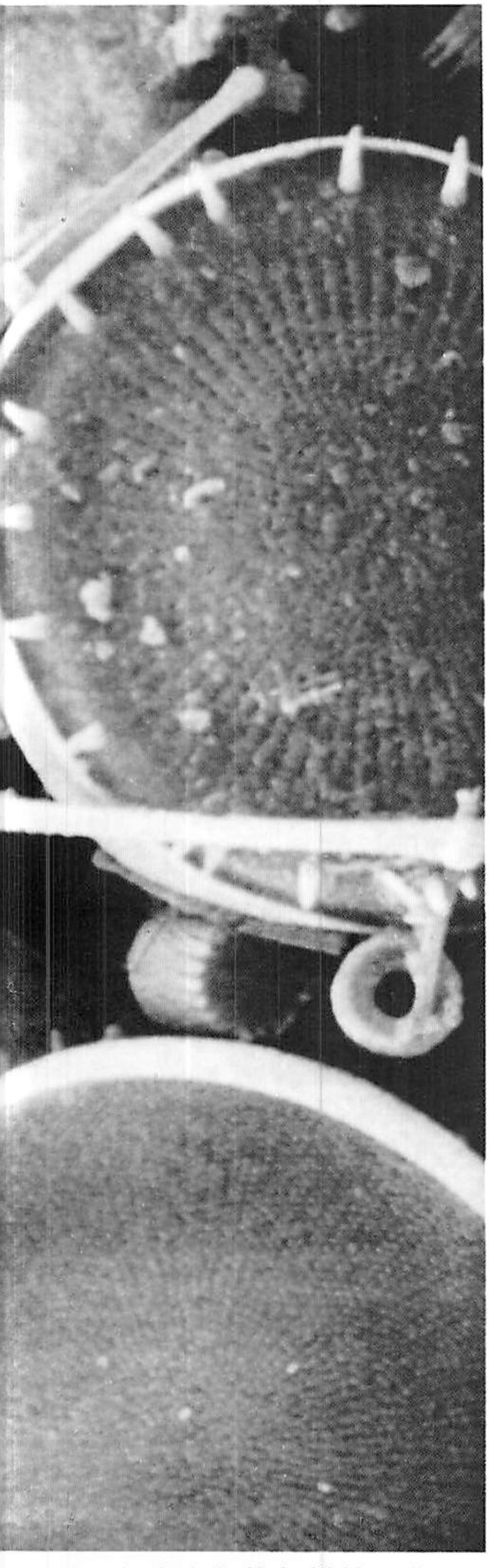
Each of those things we expect to see from an ecological view have already appeared in the lakes. There are now more of the larger zooplankton. Coho and chinook are now eating other fish besides alewives. There are ecological niche shifts occurring among competing planktivores. A strong correlation has developed between coho growth rate and the abundance of three-year-old alewives. There are, in fact, resurgences of local populations of yellow perch and several other species that we think had been suppressed due to interactions with the alewife. Fishery regulation has also helped allow that recovery.

In short, our ecological predictions seem to be borne out, and we should continue developing this perspective as it seems most instructive. Nature may bat last, but the umpires in that great game being played out in the Great Lakes fisheries are those agencies that regulate sea lamprey control, salmon and trout stocking, and the exploitation of the fisheries.

In other words, many of the interactions that cascade down from the top of this system derive from direct management decisions made by humans, whose collective wisdom derives from experience and research. That determines how the game is played and what is most likely to happen in the next inning.

. . . I believe it is important that we now take the more difficult whole-ecosystem approach . . .





Silica frustules (700 ×) of Lake Michigan diatoms.

Great Lakes Eutrophication: Fish, Not Phosphates?

David Edgington
Director, Center for Great Lakes Studies
University of Wisconsin–Milwaukee

During the last 20 years, there has been a great amount of concern regarding the accelerated eutrophication of the Great Lakes due to the increased loadings of nutrients — phosphate in particular — and of a variety of trace inorganic and organic compounds as a result of human activities.

The U.S.-Canadian International Joint Commission has repeatedly affirmed that phosphorus abatement is a needed policy to preserve the water quality of the Great Lakes, and the U.S. and Canada agreed in the early 1970s to reduce the amount of phosphorus in waste discharges to the lakes by 80 to 90 percent. For most Great Lakes states, including Wisconsin, this has meant building secondary sewage treatment plants as well as banning phosphates from detergents sold in these states.

Much of this concern is based on the work of University of Michigan Great Lakes researchers Claire Schelske and Eugene Stoermer.[6] About a decade ago, they suggested that increased loadings of phosphorus to Lake Michigan would accelerate eutrophication of the lake by causing a decline in diatoms, the lake's dominant type of algae and the cornerstone of the aquatic food web.

They reasoned that phosphorus enrichment of the lake's water would first cause the growth of large standing crops of diatoms, which require dissolved silica (soluble silicon dioxide) to form their characteristic hard outer shells, or frustules. Eventually, they said, the increased annual production of diatoms would deplete the dissolved silica in the water, ultimately causing the diatoms to decline for lack of this essential mineral.

The diatoms would then be replaced by the much less desirable green and blue-green types of algae, which would also grow to excess in the phosphorus-enriched water. The excessive growth of blue-green algae forms surface scum that decomposes with a foul odor and depletes the dissolved oxygen in the water. According to this scenario, water clarity and quality would decline, and desirable kinds of fish would be replaced by coarse fish species. This, essentially, is what eutrophication is, and it can be a natural process. The concern was that increased loadings of phosphate would greatly accelerate this process, and the consensus was that this could and should be prevented.

Initially, Schelske and Stoermer's hypothesis was supported by an apparent decrease in dissolved silica in Lake Michigan water as measured at the Chicago water intakes over 40 years. Extrapolation of this decrease indicated that the concentration of dissolved silica in the water would reach zero about 1984, which would cause major shifts in the phytoplankton community of the lake.

Recently, however, a careful reexamination of the methods used to measure dissolved silica at the Chicago Water Treatment Plant has revealed that a change in laboratories and analytical methods in 1948 resulted in significant differences in the reported concentrations of dissolved silica and other chemicals as well. This study concluded that the annual silica concentration in Lake Michigan water had *not* changed significantly over those 40 years and that the maximum spring concentration of silica has not varied significantly for the last 10 years.

Even before that study—in an attempt to find the silica supposedly being removed from the water versus the amount of silica regenerated from bottom sediments—several chemical mass balance studies examined the distribution of diatom frustules in sediment cores from major settling areas of the lake. If the Schelske and Stoermer hypothesis were correct and diatom numbers had indeed been increasing, then the largest concentrations of frustules would be found just below the water/sediment interface in the most recent, upper layers of the sediment cores.

In sum, it was discovered that less than five percent of the estimated total annual production of diatoms were incorporated into the lake's sediments, and that the frustule concentration *did* decrease markedly with depth in the cores. In fact, at the sediment depth estimated to date back 80 years, the concentration of diatoms had decreased by a factor of about 100 in every core examined. Further studies of the distribution of dissolved silica in the hypolimnion (the bottom layer of water in the lake) during late summer showed an increased concentration near the water/sediment interface—indicating there was regeneration of the lake's pool of dissolved silica from the sediments (Figure 1).

The concern was that increased loadings of phosphate would greatly accelerate this process, and the consensus was that this could and should be prevented.

But the mass balance didn't balance. The hundredfold decrease in frustule concentration in the sediments was far greater than expected, judging from the relatively small changes in the diatom standing crop size indicated by the corrected Chicago and Milwaukee water intake measurements (Figure 2). Between 1920 and 1973, the average standing crop in the southern end of the lake increased by a factor of 2.5—far less than the increase suggested by the sediment record—again indicating that considerable regeneration of dissolved silica in the water or from the sediments must be occurring.

As long as an adequate amount of silica remains in the water, according to Schelske and Stoermer's hypothesis, increasing inputs of phosphate should cause the standing crops of diatoms to increase until the surplus silica has been used up, at which point diatom production would be limited by the

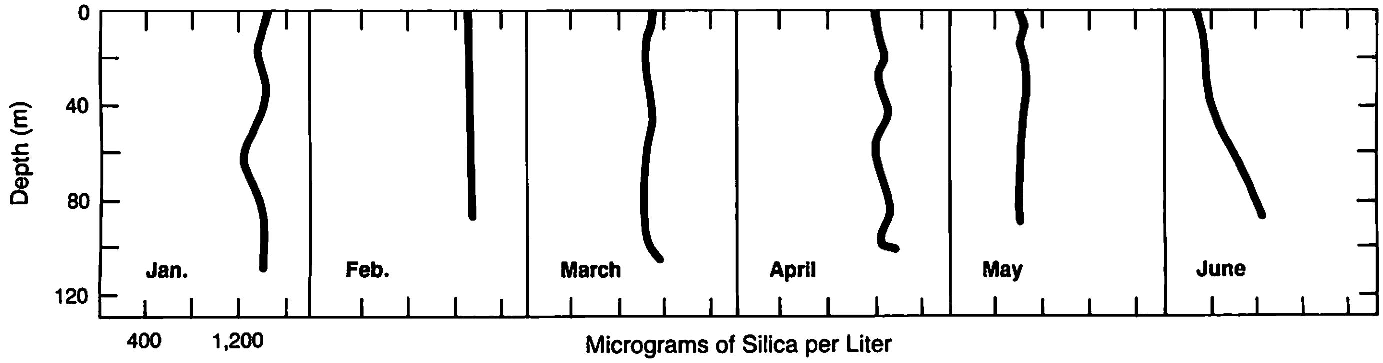


FIGURE 1: Lake Michigan Annual Silica Cycle

rate at which new silica enters the water from the atmosphere and watershed.

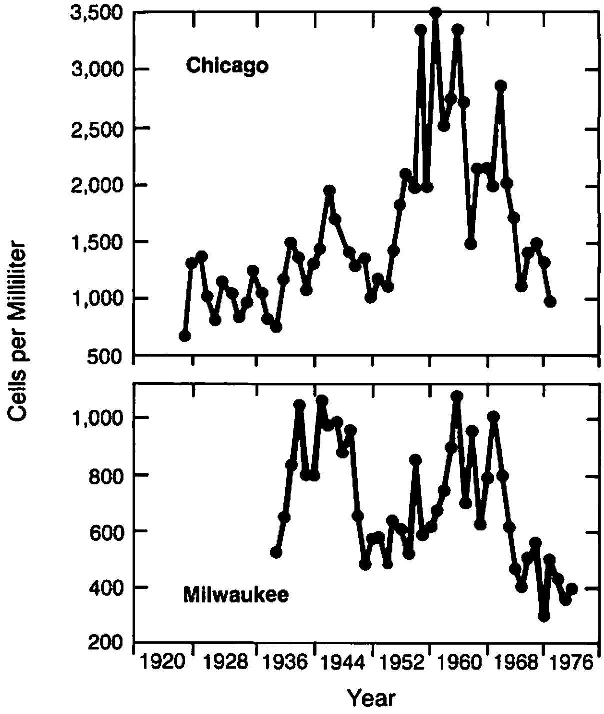
Diatom data from the Chicago and Milwaukee water intake records indicates that the standing crop was relatively constant from 1920 to 1935, and again from about 1973—just after phosphorus controls were first implemented—until the present. Between 1935 and 1975, however, two major peaks in the diatom standing crop were recorded at both Chicago and Milwaukee, about 1943 and about 1966. So, despite the mistake in the Chicago silica records and problems with the chemical mass balance, it still appeared the diatom standing crop was perhaps behaving as predicted by Schelske and Stoermer's hypothesis.

The similarities between the Chicago and Milwaukee data are striking both in terms of the timing of the peaks and the relative change between peak and baseline in standing crop, particularly for the 1966 peak. What makes this similarity particularly striking is that the Chicago samples are taken where there is little or no interference from sewage outfalls (the Chicago sewage effluents are diverted away from the lake to the Illinois River), whereas the Milwaukee intakes could be influenced by large inputs of nutrients from the Milwaukee Harbor estuary, the largest single point-source of nutrients to Lake Michigan.

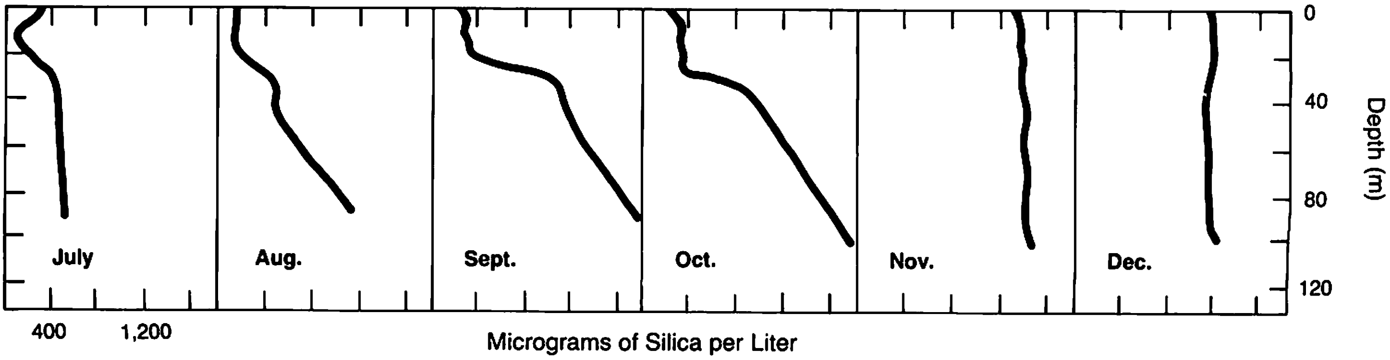
Yet—while there is no question that the input of nutrients to the lake has increased and that the size of the diatom standing crop has varied—there is no clear record of these changes in the sediments. In fact, the sediments appear to provide a poor record of ecological changes in the lake, because the more delicate diatom frustules apparently quickly dissolve back into the water. What factors besides chemical loading might have caused the changes in standing crops of diatoms that apparently have occurred?

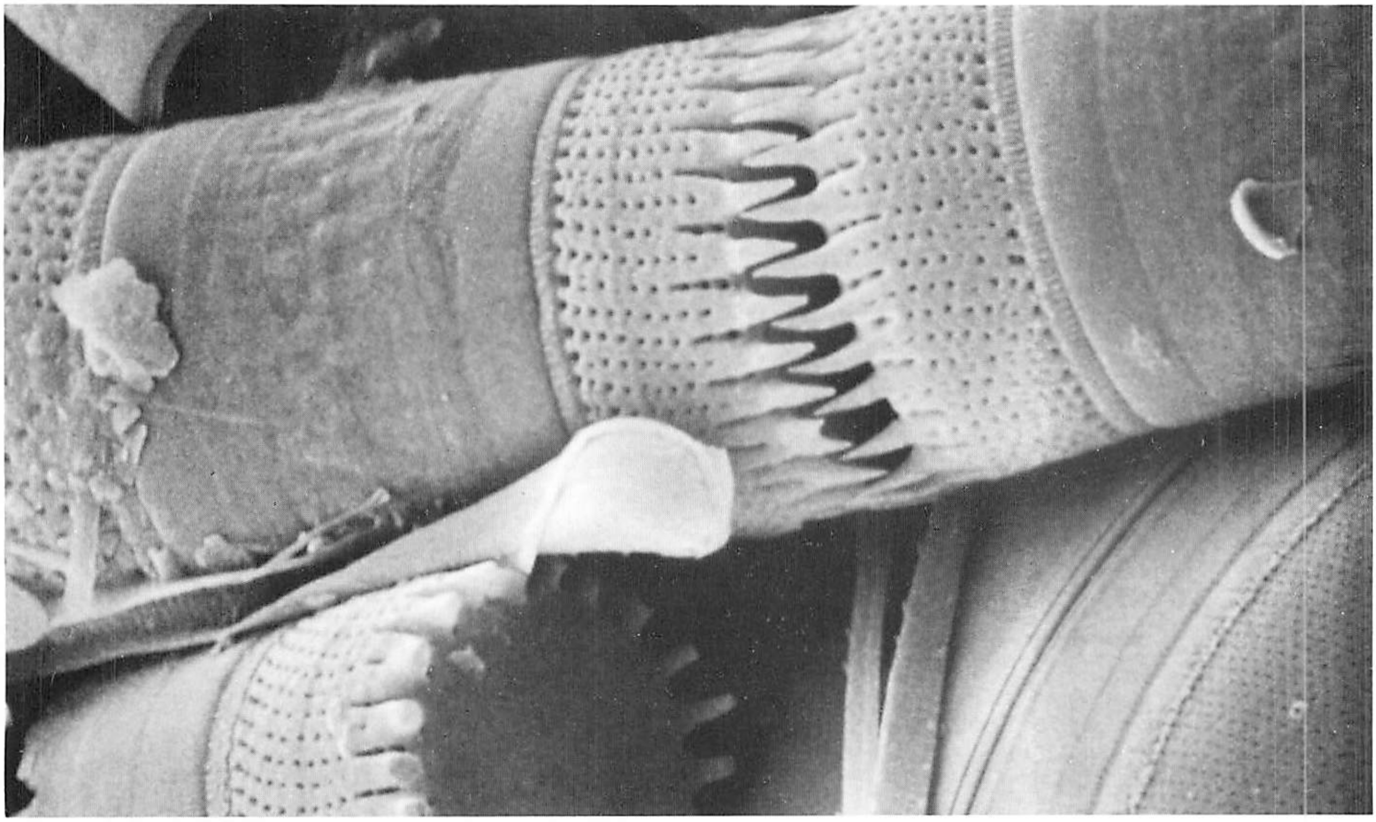
There is no reason to presume that the size of the diatom standing crop is uniquely related to nutrient inputs, since crop size is determined by the rates of predation and loss to the sink as well as its own rate of production. Lake Michigan's phytoplankton are eaten by its zooplankton, which in turn are preyed upon by forage fish like smelt and alewife.

FIGURE 2: Total Algal Counts



Since the beginning of this century, Lake Michigan and most of the other lower Great Lakes have experienced major changes in fish population and structure, and changes in major predator populations can have large effects on the lower trophic levels. In fact, the major changes in the diatom standing crop over the last 50 years can be closely matched with major changes in the Lake Michigan fishery in the same period (Figure 3).





Single diatom cells (3000 x) linked together in filamentous chain.

As James Kitchell described earlier, the fisheries of Lake Michigan and the other Great Lakes have been severely affected not only by overfishing, but also by the invasion of several exotic species—chiefly the sea lamprey, smelt and alewife.

Smelt first became established in Lake Michigan in the early 1900s and by 1936 had become abundant enough to support a successful commercial fishery. From 1936 to 1942, the lake's smelt populations (as measured by the commercial catch) increased greatly—and then crashed for no apparent reason.

The smelt boom began the same year the sea lamprey arrived in Lake Michigan and began its attack on the lake's top predator, the lake trout. The increasing numbers of smelt perhaps reflects the decreasing numbers of lake trout, which had nearly vanished from the lake by 1949—the same year the first alewives were caught in the lake. From 1950 to 1966, the alewife population shot up—hitting its ecological ceiling with a incredible die-off in the spring of 1967. In an attempt to prevent reoccurrences of that event, the states around the lake have since then stocked coho and chinook salmon and have attempted to reestablish the lake trout to prey on the alewife and control its population.

Now, alewives and young smelt are planktivorous fish, so increasing populations of these fish would therefore have put increasing pressure on the zooplankton populations. While there are very few records of changes in zooplankton populations in the lake, it is fortunate that LaRue Wells examined in detail the structure of the Lake Michigan zooplankton population in 1954, 1966 and 1968 while studying the feeding habits of the alewife.[7] The change in structure of the zooplankton population and its relation to estimated alewife biomass are shown in Figures 3 and 4.

Between 1954 and 1966, while there appears to have been no change in the *total* number of zooplankton, the proportion of *large* zooplankton like copepods and *Daphnia*—the favorite prey of planktivorous fish—decreased from about two-thirds of the total population in 1954 to only about two percent by 1966. This shift in the structure of the zooplankton community to smaller species like *Bosmina,* which alewives cannot eat effectively, resulted in a significant loss of biomass. In short, the massive die-off of alewives in 1966-67 was probably due in large part to starvation. After the die-off, the number of large zooplankton rebounded, and within two years they made up nearly half the total zooplankton population.

If it can be assumed that the rapid increase in the smelt population during 1936-42 had the same impact on the zooplankton population as the alewives did about two decades later, it is more than probable that the increased abundance of diatoms observed in the late 1930s and early 1940s and again in the late 1950s and 1960s is the result of reduced grazing by the zooplankton population, which had been decimated by growing numbers of forage fishes, whose populations were no longer controlled by the lake's top predator—the lake trout, the numbers of which had begun faltering under the sea lamprey attack as early as 1940.

These increases in the fish population, which coincide with the increases in phytoplankton recorded at Chicago and Milwaukee (see Figs. 2-4), strongly suggest that the phytoplankton communities in Lake Michigan have been strongly influenced by changes in the structure of the fish population and the effects of these changes on zooplankton populations and predation.

The major fraction of the increased biomass at the Chicago water intake is accounted for by two kinds of diatoms—*Stephanodiscus* and *Taballaria.* The increase in these two species between 1950 and 1971 has been interpreted to be an indication of eutrophication due to increased phosphate loading, and the subsequent decrease in these species has been interpreted to be a favorable response to controls on phosphate inputs.

Changes in major predator populations can have large effects on the lower trophic levels.

But the *Fragilaria* and *Synedra* species of Lake Michigan diatoms are more tolerant of nutrient enrichment than *Taballaria.* If the increases in the diatom standing crop in the 1950s and 1960s were due to nutrient enrichment and not changes in the populations of the higher trophic levels, why were *Fragilaria* and *Synedra* less abundant than *Taballaria?*

FIGURE 3: Lake Michigan Plankton Populations

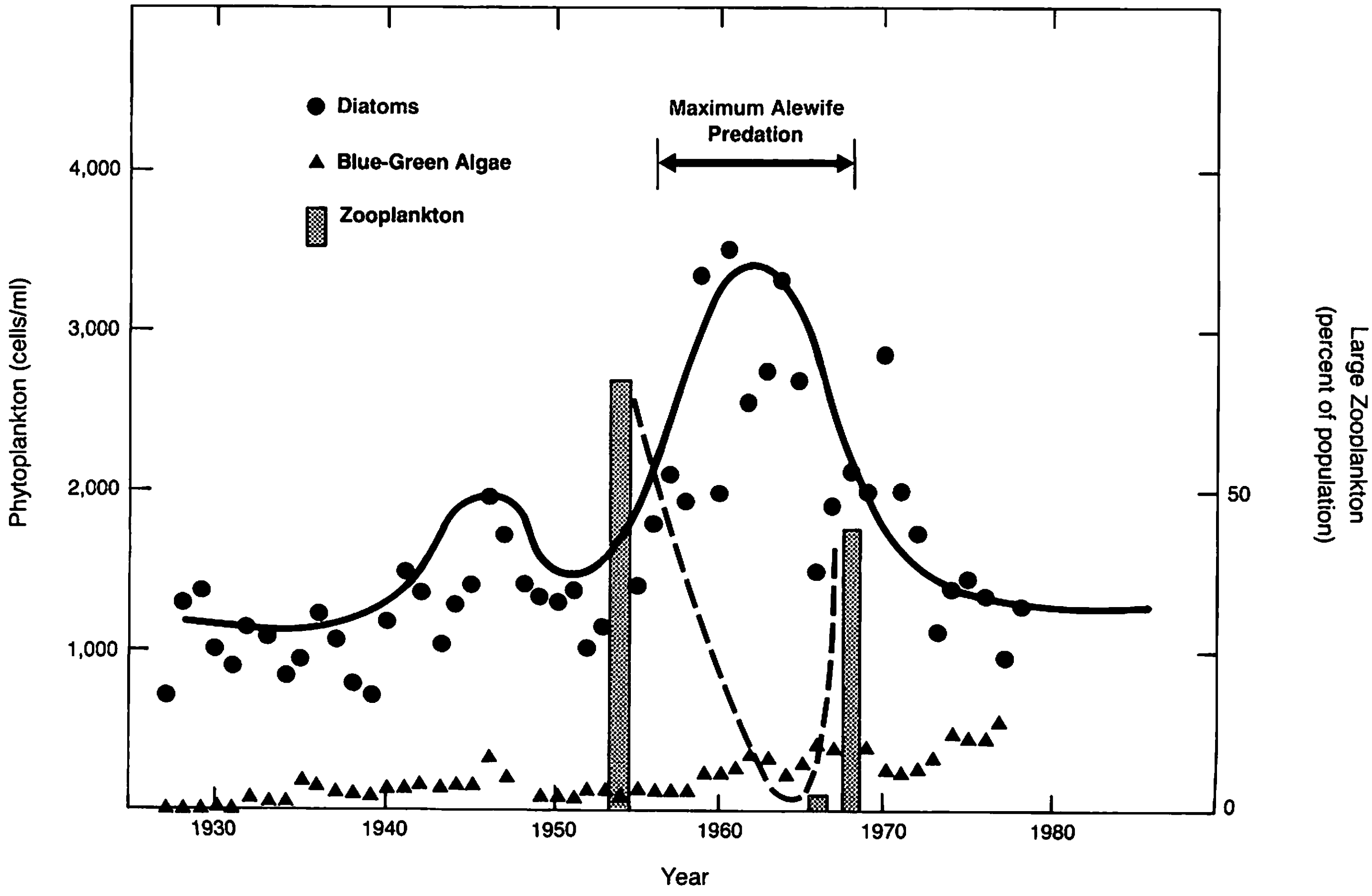
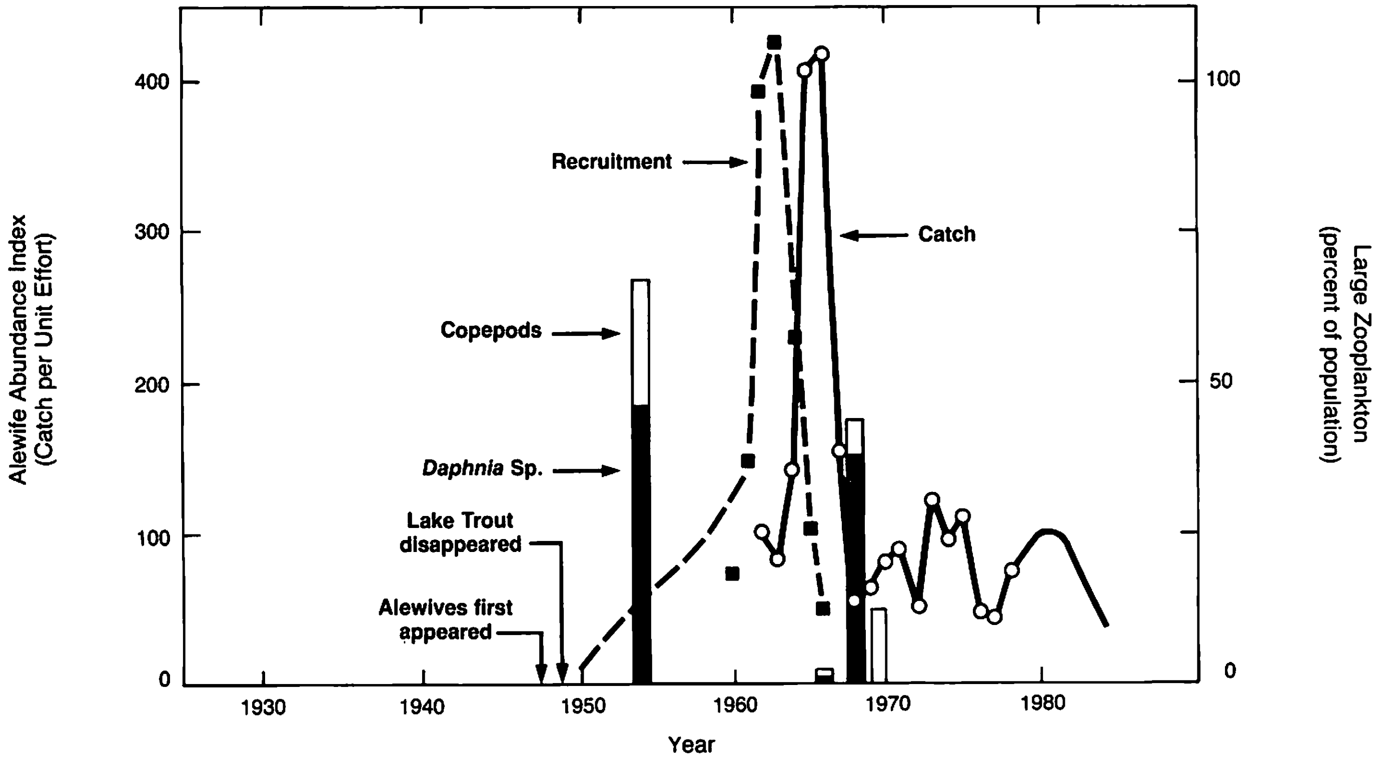
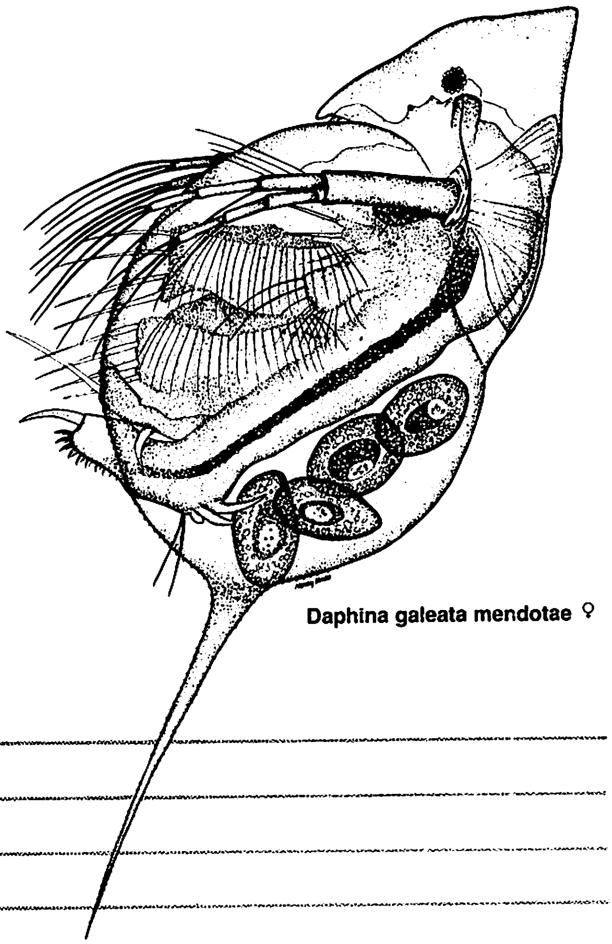


FIGURE 4: Lake Michigan Alewife & Zooplankton Populations



Again, perhaps the reason is not nutrients, but predation. It has been theorized that changes in the predator communities can influence the size-structure of phytoplankton communities. There is little direct evidence of this for Great Lakes plankton communities, but a study on the North Sea found that phytoplankton cell size and standing crop decreased as the *Calanus finmarchicus* zooplankton population and its predation increased. Conversely, it has been shown that when predation on zooplankton increases, their numbers decrease —and phytoplankton size and standing crop increase. It is perhaps significant, therefore, that the two diatoms species that increased most in abundance are those that have large cell volumes, which would be the ones preferentially cropped by large zooplankton, while those that are present as long chains, like *Fragilaria,* maintain a constant population.

If increased nutrient inputs have had little affect on the lake's diatoms, what about the green and blue-green algae? Chicago intake records also include cell counts for blue-greens. These counts, which appear to have not changed significantly between 1927 and 1960, perhaps doubled between 1960 and 1970. Overall, the standing crop concentration of blue-green algae remained about a tenth that of the diatoms. The data also show a


Daphina galeata mendotae ♀

yet-unexplained small increase in the concentration of blue-greens in the 1970s—the time when a significant effort was made to reduce phosphate inputs to the lake.

Records at the Milwaukee Linwood intake include both green and blue-green cell counts, and once again, as Figure 5 shows, the cell counts for these phytoplankton are about a tenth that for diatoms. Prior to 1952, the cell counts for green algae were significantly lower than those for blue-greens, but since 1952 the reverse has been true. Note also that—despite the installation of equipment in 1971 that greatly reduced the amount of phosphorus and other nutrients entering Milwaukee Harbor—the counts of greens and blue-greens continue to increase.

This raises yet another question about the mass balance and dynamics of phosphates in Lake Michigan. The annual cycle for silica in the water shown in Figure 1 may vary slightly, but in general the concentration decreases from about 1,500 micrograms of silica per liter in March to about 200 micrograms of silica per liter just prior to the onset of thermal stratification of the lake in early June. Since the average depth of Lake Michigan is about 100 meters, this amounts to the fixing of about 13,000 micrograms of silica per square centimeter.

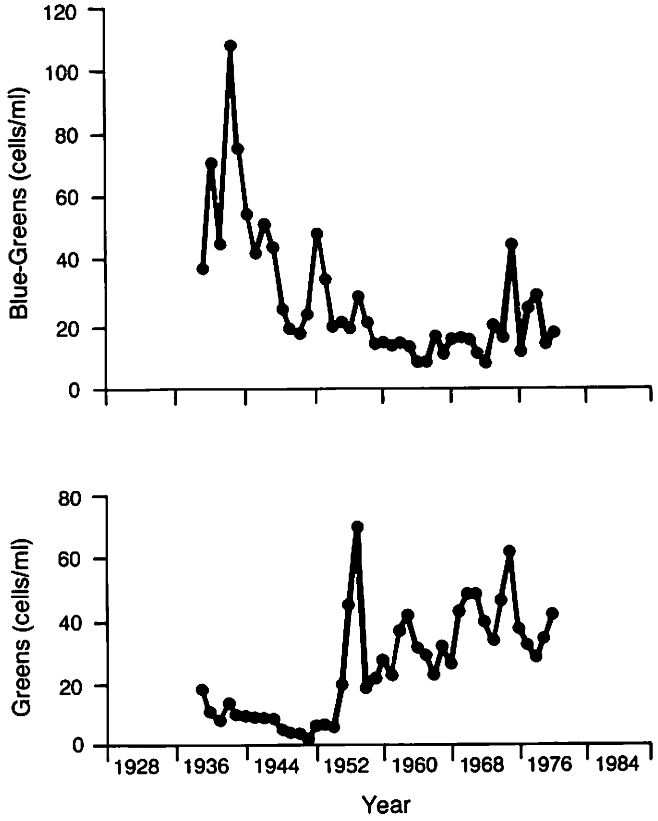
While the silica/phosphorus ratio needed by growing diatoms varies somewhat and depends on nutrient supply, a reasonable value is 100/1. The concentrations of phosphorus in the water of Lake Michigan tend to be low, averaging about 8 micrograms of phosphorus per liter, so the total phosphorus available in the water in the spring is about 80 micrograms per square centimeter. Diatom production requires about 130 micrograms of phosphorus per square centimeter—which leaves a phosphorus *deficit* of about 50 micrograms per square centimeter.

This deficit is not met through new phosphate inputs. Measurements of phosphates in the sediments and the average sedimentation rate indicate that the input of new phosphorus from all sources was less than 10 micrograms per square centimeter per year in 1971. This only amounts to about seven percent, a very small fraction, of the phosphorus required by diatoms during their spring bloom. And after stratification, the thermocline blocks circulation between the upper and lower layers of water, thus preventing a large fraction of the phosphorus released from sedimenting material or sediments from reaching the upper layer to stimulate further primary production.

As a result, phytoplankton production in the epilimnion, the surface water layer, is *phosphate-limited* rather than silica-limited. It also means that diatom production could continue, if phosphorus were available, even when the pool of available silica is less than 500 micrograms per liter. Recent research has shown that this is true.

The small changes in the standing crop of green and blue-green populations also indicate that little, if any, buildup of excess phosphorus in the epilimnion has occurred after the lake has become thermally stratified—which is not surprising, since the nutrient requirements are far greater than that supplied by new inputs over that fraction of the year.

FIGURE 5: Milwaukee Algal Cell Counts (Linwood)

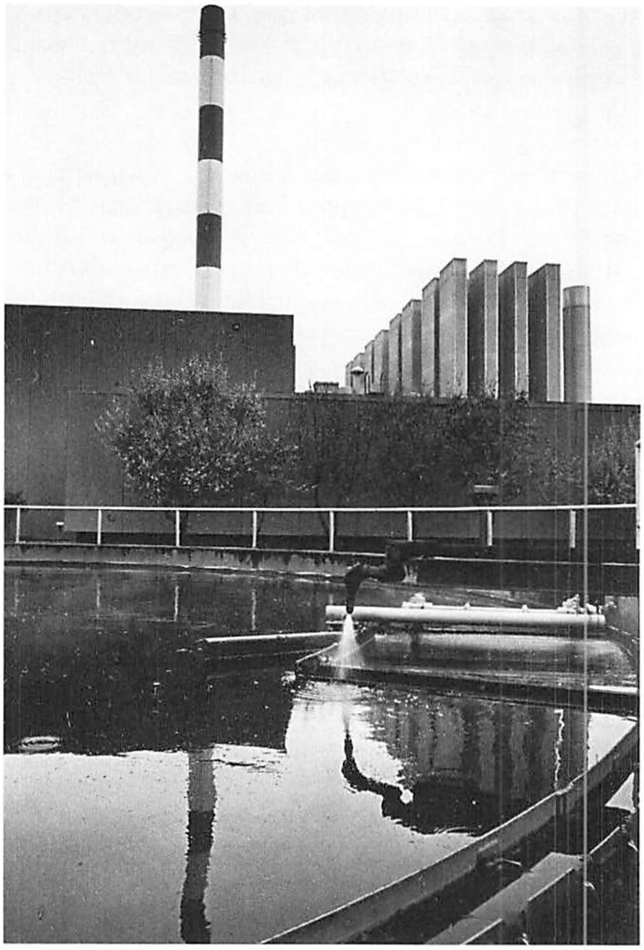


Such results should perhaps be expected, considering the quality of Lake Michigan's water. There is every reason to believe that the concentration of soluble inorganic phosphate in the lake is controlled by a geochemical process—either by the exchange of phosphate ions onto particle surfaces (ferric oxide surfaces), where the concentration might be expected to vary with the loading, or by the solubility of hydroxylapatite, where no variation in the phosphate concentration is expected as long as the water's calcium-iron concentrations and pH remain constant. Unfortunately, the soluble phosphate concentrations in Lake Michigan are almost too low to be detected with current chemical analysis techniques, so it will be difficult to get a definitive answer to this question.

So, if the model I have just proposed is correct—that is, that phytoplankton standing crop is controlled more by predator-prey relationships than by new nutrient inputs—then the nutrient demand for the spring diatom bloom *need not* have changed significantly in Lake Michigan during the last 50 years. Since more than 85 percent of the dissolved silica was fixed in the peak diatom bloom in 1975, an almost identical amount would have been fixed in 1943, or even 1843—which also must have demanded identical proportional amounts of inorganic phosphate. So the spring diatom bloom *must* be insensitive to changes in phosphate inputs, since the end of the diatom bloom appears to depend on a physical process—that is, the warming of the lake and the subsequent formation of the thermocline. Presumably, then, the magnitude of the fall diatom bloom would be controlled by the time of the breakup of the thermocline and, again, the availability of nutrients.

In conclusion, whereas it appears that changes in the water chemistry of Lake Michigan may have had some effects on the abundance and structure of its phytoplankton community, it is clear that changes in the structure of the *higher* trophic levels—in the lake's fish populations and the resulting changes in the predator-prey relationships among them—could have had an overriding influence on the structure of its phytoplankton community. In one of its more recent lake surveillance reports, the International Joint Commission's Water Quality Board admits that biotic predator-prey relationships may have had an effect on phytoplankton community similar to that of eutrophication resulting from human activities—even in Lake Erie, the most eutrophic Great Lake.

. . . increased phosphate input plays only a minor role in the eutrophication of the Great Lakes.



Green Bay Metropolitan Sewage District wastewater treatment plant.

So while it has been easy to blame nutrient inputs for changes in the ecological structure of the lower trophic levels in the lower Great Lakes, I believe it is important that we now take the more difficult whole-ecosystem approach advocated by Jack Valentyne, chief scientist at the Canadian Centre of Inland Waters, an approach also endorsed by the IJC,[8] so we are sure that *all* overriding biotic factors are considered *before* we draw any further conclusions that may significantly influence regulatory strategies and management policies and require the investment of millions of dollars to pursue in our effort to maintain or improve the water quality of the Great Lakes.

We obviously still have much to learn about the function of the total ecosystem. Water quality measurements are only a part of this understanding. We know a great deal about the response of phytoplankton to nutrient loading in laboratory or microcosm experiments in the absence of nutrient recycling from the sediments. But what would happen in the lakes if stratification did not occur and phosphorus continued to be recycled from the sediments as the ortho-phosphate in the water was used up? What is the magnitude of phosphate regeneration in the water as compared to that released from the sediments? What are the rate-determining steps for the processes of phosphorus recycling? What are the feeding habits of Great Lakes zooplankton and forage fishes? Is it valid to use phytoplankton data collected at nearshore water intakes to assess the situation for a whole lake?

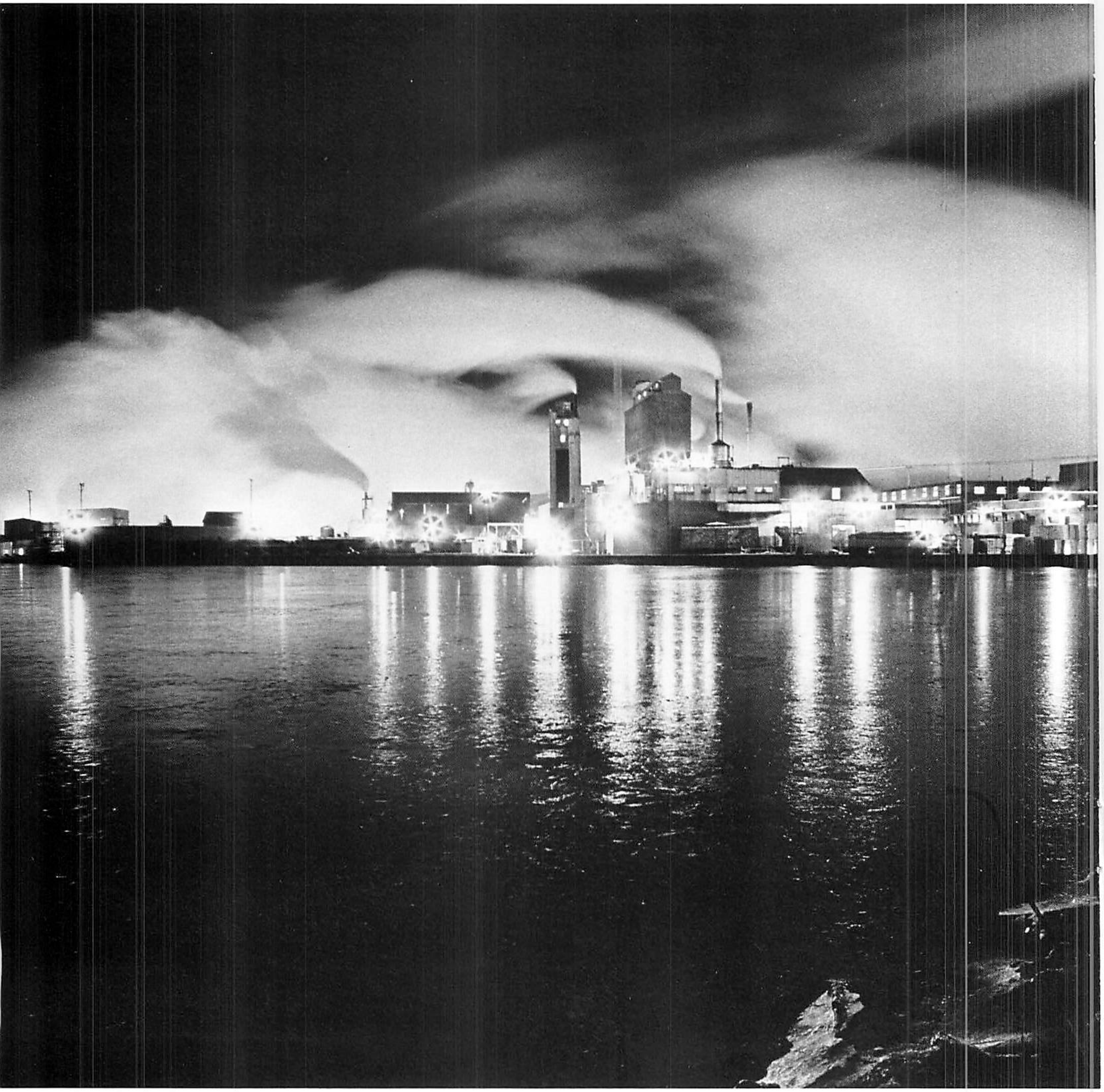
It is clear that the diverse ecosystems of the Great Lakes are extremely complex and incompletely understood. Until the interactions within and among these systems are fully understood, we must refrain from expensive managerial actions that are based on over-simplified concepts—like the concept that domestic phosphorus loading is the primary factor controlling algal species composition and abundance. Even the hypothesis that phosphate concentration is regulated by chemical and physical factors as well as biological factors must be subjected to experimental tests and quantified.

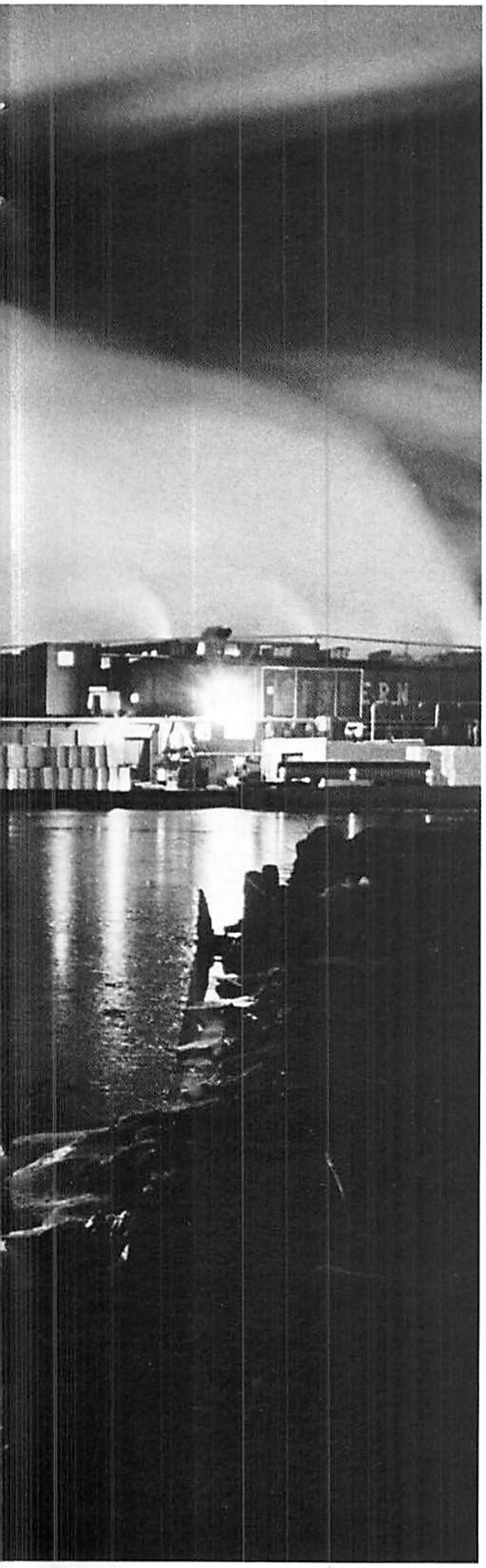
Increased inputs of phosphorus to Lake Michigan clearly have had some effect on its phytoplankton communities. But this knowledge must be tempered by the realization that, during the period of time that the lake has been intensively studied in this regard, there have been overriding changes in the lakes' predator-prey relationships.

Judging from studies of the chemical mass balances of the lake, it appears that more than 80 percent of the dissolved silica is fixed during each spring diatom bloom and that this bloom is not terminated by the depletion of silica, but more probably by the formation of the thermocline, which blocks the recycling of phosphorus from the sediments to surface waters.

Recognizing that most of the dissolved silica in the lake has always been fixed each year, and that the amount of phosphorus needed for such levels of diatom production must come from recycling and is not dependent on new inputs, we can conclude that increased phosphate input plays only a minor role in the eutrophication of the Great Lakes and that it has *not* accelerated the natural eutrophication of the lakes.

. . . the implications of higher levels of toxic metals for aquatic life in the lake have not been adequately addressed.





A Major Source of Great Lakes Pollutants: The Atmosphere

Anders W. Andren
Water Chemistry Program
University of Wisconsin–Madison

Because of all the news about acid precipitation, the public has recently become aware of the fact that the atmosphere can influence the chemical composition of lakes and streams. But scientists have for a long time been interested in atmospheric transport processes and the ability of the atmosphere to act like a big overhead conveyor belt, transporting large quantities of various gases and particles all over the world. A lot of scientific attention has been given lately to the exchange of gases and particles between the ocean and the atmosphere, especially with regard to the ocean's role as a source of aerosols and as a sink for carbon dioxide.[9]

In this part of the world, the atmosphere has been implicated as an important source of chemical contaminants in the Great Lakes. Perhaps the first estimates on the amount of metals entering Lake Michigan from the atmosphere were published in 1971 by Winchester and Nifong,[10] who theorized that the Great Lakes—especially the upper ones—were sensitive to atmospheric inputs for two reasons: (1) the watershed-to-lake surface areas ratio is small, meaning much of the water in the lakes comes directly from the air as rain or snow rather than as runoff from the watershed, where its chemical composition is modified; and (2) the airshed in the Great Lakes basin receives a tremendous quantity of emissions from industrial and municipal activities.

Subsequent studies have continued to refine and add to our understanding of pollutant and nutrient inputs to the Great Lakes. In the past three years, data from Sea Grant-funded research at the University of Wisconsin have been published in papers describing the atmospheric inputs of trace amounts of metals and organic contaminants, including polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs), to the Great Lakes [see refs. 11-14]. I will give a brief summary of our efforts to evaluate the atmospheric inputs of four metals (chromium, copper, lead and zinc), PCBs and PAHs to the Great Lakes, including a discussion of our estimation methods and the possible effects of these inputs on the water quality. Particular attention will be given to Lake Michigan, since our data base has been generated from this lake.

Before I describe the methods we use to conduct these studies, perhaps I should first delineate the various atmospheric processes responsible for delivering vapors and particles to aquatic surfaces. It was from an understanding of these mechanisms that we came to know how and what to measure.

Consider a substance, like PCBs, that may exist both as a vapor and adsorbed to aerosols. The vapor may be removed from air via dissolution into precipitation (washout), or direct transfer across the air/water interface. The part that is adsorbed to particles is removed via rainout (within clouds) or washout (below clouds), or via direct dry deposition of the particles on the surface of the lake. Theoretical relationships, mainly semiempirical ones, exist to model these processes.[9,14] But the degree of sophistication of these models must be related to the type and amount of available data.

Substances in rain are usually determined from samples collected on shore. The meteorology over the lakes is undoubtedly different from that over land, and concentration gradients are likely to occur. Our ability to collect meaningful snow samples is also limited. There are similar weaknesses in data sets for aerosols and vapors.

Dry deposition estimates have added uncertainties in that the measured air concentrations must somehow be coupled to actual deposition. The existing data sets do not usually include the necessary time and space resolutions needed to incorporate them into sophisticated models. For example, it takes 12 to 24 hours to collect enough samples to analyze for PCBs. Consequently, dry deposition estimates to the Great Lakes have been made with perhaps a few month's worth of air sample data.

Also, all estimates of atmospheric deposition should be checked with mass balance calculations. This method requires data on other sources (such as rivers, nearshore erosion, point sources), compartment concentrations of the substance of interest (in the water column, in sediments), and removal mechanisms (rivers, sedimentation, volatilization). Such data are now slowly starting to appear for selected substances, though much remains to be done.

The atmospheric loading estimates I am now about to present for the input of cadmium, chromium, copper, lead and zinc to the Great Lakes are taken from a detailed evaluation in a recently published paper by J.A. Schmidt and me.[11] The PCB and PAH loading estimates are presented only for Lake Michigan and are from three other papers based on studies in which I participated.[13,14,15]

> **. . . there may be periods during the year in which the lake may actually be a source of PCBs to the atmosphere.**

The loading values for cadmium appear to fall in a range of 5 to 10 grams per hectare per year for all lakes except Lake Michigan, whose values are mostly below 5 grams per hectare per year. This result is somewhat unexpected, since heavy industry operates in the southern basin of this lake. Our data indicate that the relative loading intensity, from highest to lowest, is Erie, Ontario, Michigan, Huron and Superior.[11]

Because few measurements exist, the loading estimates for cobalt and chromium are less certain, but the available data indicate a range of 2 to 700 grams per hectare per year. Due to the lack of measurements, a relative loading rate for the various lakes cannot be made.

As for copper, many of the early measurements of this element are suspect because the sampling device itself contaminated the aerosol collection substrate. More recent data indicate a loading rate of from 50 to 150 grams per hectare per year, the higher values appearing on Lake Erie and in the southern basin of Lake Michigan.

The loading values for nickel generally fall in the range of 10 to 50 grams per hectare per year, except for a few higher values observed over Lake Ontario and over the southern end of Lake Michigan.

The most complete data set available for all the lakes is for lead. Estimates generally range from 100 to 250 grams per hectare per year. The order of relative loading from highest to lowest appear to be Erie, Ontario, Michigan, Superior and Huron. A division of Lake Michigan into a northern and southern half shows that the southern portion compares with Lake Erie in terms of the intensity of lead inputs.

The loading pattern for zinc is similar to that for cadmium, with a range of 100 to 500 grams per hectare per year. However, many of the determinations for this element are suspect because of sampling contamination problems.

A comparison of Lake Michigan loading rates for chromium, copper, lead and zinc from the air,

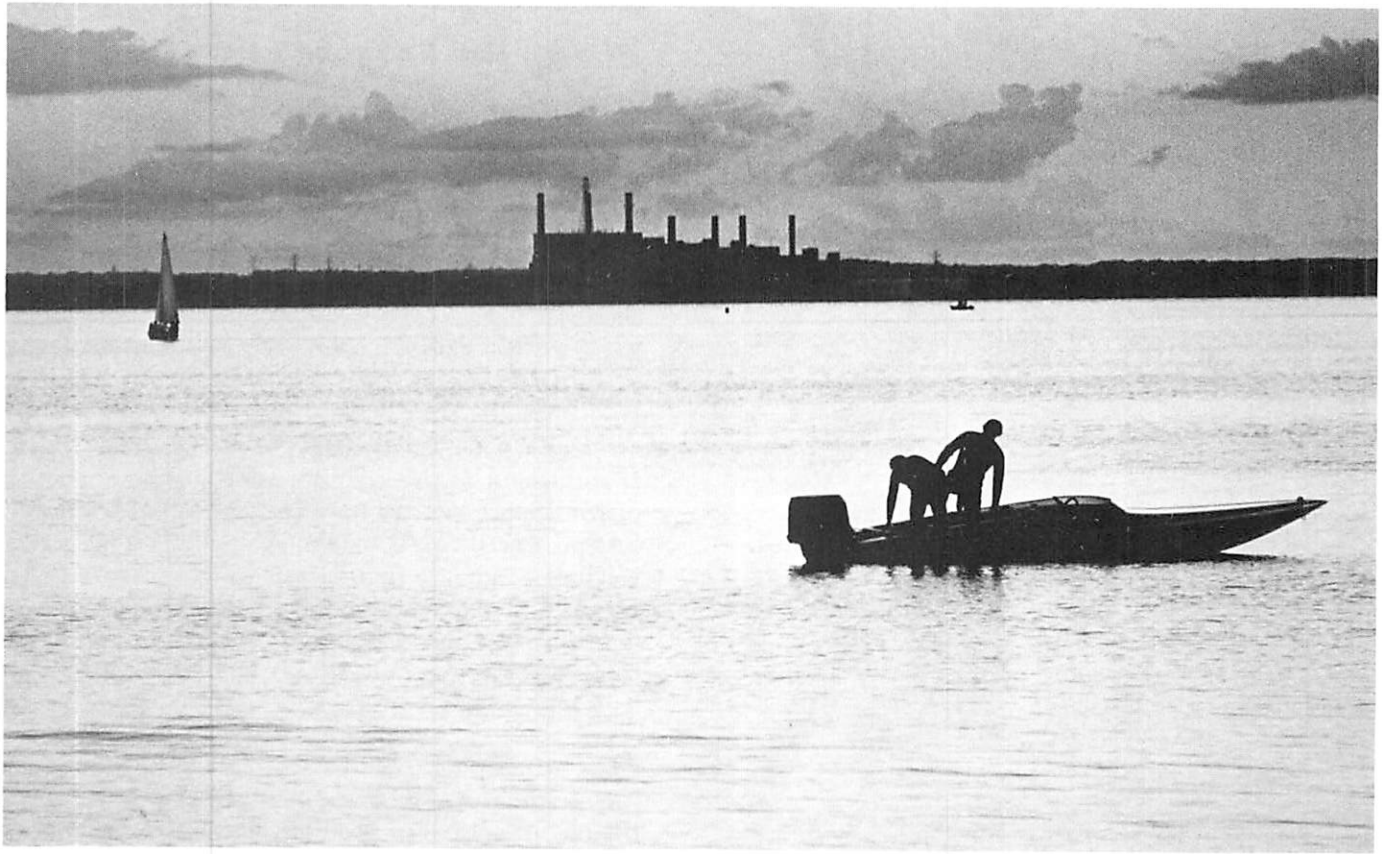


TABLE 1: Loading of Trace Metals to Lake Michigan

(in tons/yr.)[1]

Element	Air	Stream	Shoreline
Chromium	52-180	78-250	19-110
Copper	110-950	73-180	11-66
Lead	340-1,200	56-130	12-40
Zinc	740	250-350	50-440

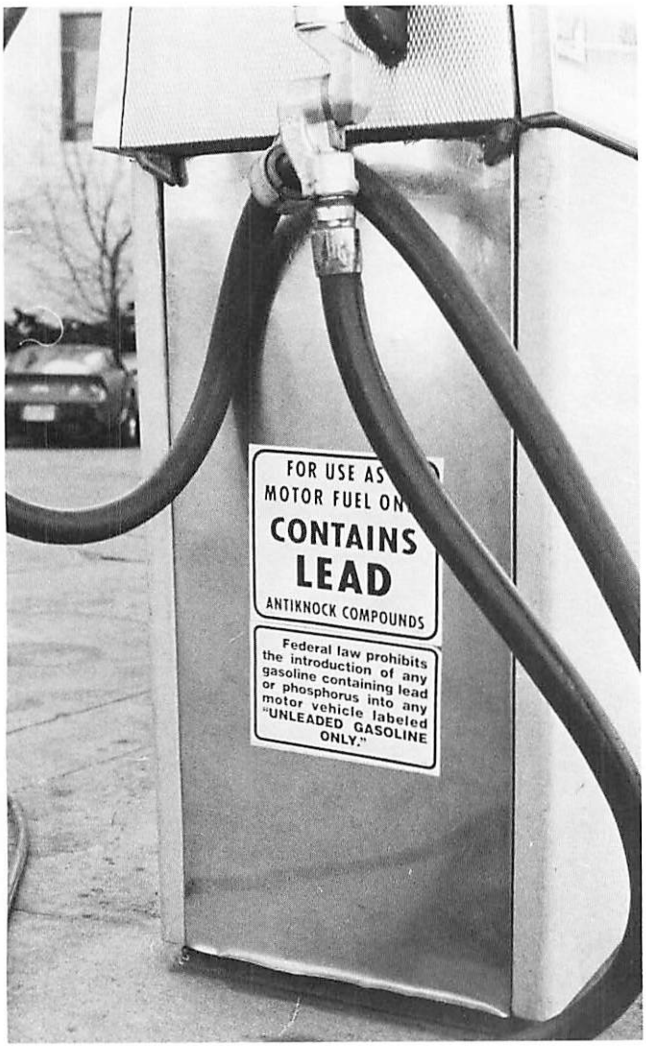
[1] Schmidt and Andren (1984).

tributary streams and shoreline erosion is presented in Table 1. These data clearly indicate that the atmospheric input for lead and zinc dominate the total annual input of trace metals to this lake.

Considerable uncertainty remains regarding the loading intensity of PCBs, chiefly because analytical difficulties still exist in the quantification of these compounds. My Sea Grant research has shown that greater than 90 percent of PCBs exist in vapor form in the atmosphere over Lake Michigan; the remaining fraction is associated with aerosols.[15] When it comes to removal of these substances, however, it appears that rain-scavenging of the *adsorbed* fraction is the most important input mechanism. Rain-scavenging of the vapor fraction and dry deposition of particles associated PCBs may not be important.

Recent data also indicate that there may be periods during the year in which the lake may actually be a source of PCBs to the atmosphere. Our annual budget calculations are confounded by this phenomenon. You should keep these uncertainties in mind, though the following estimates are certainly better than an order of magnitude. I estimate that the washout of particle-associated PCBs into Lake Michigan is presently in the range of 300 to 500 kilograms per year.[11] Washout of PCB vapor is negligible. The dry deposition of particle-associated PCBs in the lake is less than 100 kilograms per year. The net flux of vapor across the air/water interface remains unknown.

PAHs also exist in both vapor and particle-associated fractions. The degree of fractionation seems to vary considerably both for individual PAH compounds and for the time of year. The existing data sets for Lake Michigan contain only the particulate fraction for this class of compounds.



Based on earlier research, we estimate that the input of 12 different PAHs to range from 1,000 to 5,800 metric tons per year in Lake Michigan, with a wet-to-dry deposition ratio of about 9:1.[13] Further confirmation of these estimates must await additional data on the PAH vapor fraction and on bottom sedimentation rates.

TABLE 2: Mass Balance on Selected Trace Metals in Lake Michigan
(in tons/yr.) [1]

Element	Input	Output
Chromium	160-540	350-525
Copper	160-700	190-320
Lead	420-1,300	485-820
Zinc	1,000-1,500	880-1,700

[1] Schmidt and Andren (1984).

It is difficult at this time to ascertain the degree of confidence we can have in the estimates I have just presented. Mass balance calculations for Lake Michigan indicate that factors of two or three are involved. Table 2 shows the results of mass balance calculations, which agree rather well with input and output rates for chromium, copper, lead and zinc.

After attempting to add statistical confidence to these estimates, we have concluded that, even if the means existed to produce perfectly accurate loading rates, disagreement among individual estimates would still occur due to annual and long-term variations in such parameters as trace metal discharge rates, dispersion trajectories and the amounts of rain or snowfall.[11] For these reasons—and the fact that the accuracy of atmospheric load estimates is likely to remain poor for some time—any evaluation of long-term average atmospheric loading rates will remain difficult.

As for the effects of the atmospheric input of contaminants on water quality, it has been calculated that water column residence time for several metals in Lake Michigan ranges from 2 to 30 years. This indicates that the levels of many of the trace metals

TABLE 3: Mass Loading of Nonsoil Components to Lake Michigan
(in tons/yr.)[1]

Element		Tributary		Air
Chromium	(34-78)[2]	27-182	(92)	48-167
Copper	(58)	42-104	(98)	120-450
Lead	(82-90)	51-75	(100)	340-1,200
Zinc	(58-60)	145-206	(99)	730

[1] Schmidt and Andren (1984).
[2] Percentage of total mass loading due to anthropogenic sources.

in the lake may have reached a quasi-steady state, which means that the concentrations of these metals in the water column have increased as compared to pre-industrial times.

Table 3 gives an insight into the degree of contamination of Lake Michigan by chromium, copper, lead and zinc. These calculations present the mass loading of nonsoil components—that is, manmade, or anthropogenic, components—to Lake Michigan. Eighty to 90 percent of the annual input of lead is of anthropogenic origin. This would indicate an elevation of the lead level in the water column of eight to nine times that of pre-industrial times. Additional evidence of this is presented in Table 4.

TABLE 4: Comparison of Metal Fluxes from External Loading and Sedimentation Calculations [1]

Element	Loading Calculations (%)	Sediment Record (%)
Chromium	55-56	43-57
Copper	62-88	35-83
Lead	92-99	83-91
Zinc	62-88	63-87

[1] Schmidt and Andren (1984).

We used two independent computational techniques to compare anthropogenic metal fluxes to Lake Michigan. But our interpretation of these data lead to the same conclusions—specifically, that the metals in the water column of Lake Michigan may be from two to nine times higher as compared to pre-industrial times.

The trace levels of metals, PCBs and PAHs in the Great Lakes pose little danger to the people who depend on the lakes for drinking water. However, the implications of higher levels of toxic metals for aquatic life in the lake have not been adequately addressed. To date, UW Sea Grant studies and related research have indicated that chronic low-level exposure to cadmium may reduce the reproduction rate of *Daphnia,* a species of zooplankton that are an important food for Great Lakes fish.[16] The bioaccumulation of PCBs in the aquatic food web has also been shown to negatively affect the hatching of trout eggs and the survival of salmon fry.[17] But knowledge of the full implications of such effects will have to await future Sea Grant research.

REFERENCES

1. Samples, K.C., and R.C. Bishop. 1983. "Estimating the Value of Variations in Anglers' Success Rates: An Application of the Multiple-Site Travel Cost Method." Unpublished paper.
2. Kealy, M.J., and R.C. Bishop. 1983. "Theoretical and Empirical Specification Issues in Travel Cost Demand Studies." Unpublished paper.
3. U.S. Fish and Wildlife Service. 1983. *1980 National Survey of Fishing, Hunting and Wildlife-Associated Recreation: Wisconsin.* Washington, D.C.: U.S. Government Printing Office.
4. Samples, K.C., and R.C. Bishop. 1981. *The Lake Michigan Angler: A Wisconsin Profile.* University of Wisconsin Sea Grant College Program Advisory Report WIS-SG-81-423.
5. Samples, K.C., and R.C. Bishop. 1982. An economic analysis of integrated fisheries management. *Journal of Great Lakes Research* 8:593-602.
6. Schelske, C.L., and E.F. Stoermer. 1971. Eutrophication, silica depletion and predicted changes in algal quality in Lake Michigan. *Science* 173:423-24.
7. Wells, LaRue. 1970. Effects of alewife predation on zooplankton populations in Lake Michigan. *Limnol. Oceangr.* 15:556-65.
8. International Joint Commission. 1978. *The Ecosystem Approach: Scope and Implications of an Ecosystem Approach to Transboundary Problems in the Great Lakes Basin.* A special report of the Great Lakes Research Advisory Board. Winsdor, Ont.: IJC.
9. Liss, P.S., and G. Slinn. 1983. *Air-Sea Exchange of Gases and Particles.* Dordrecht, Holland: D. Reidel Pub. Co.
10. Winchester, J., and G. Nifong. 1971. *Water, Air, Soil Pollut.* 1(5).
11. Schmidt, J.A., and A.W. Andren. 1984. In: *Toxic Contaminants in the Great Lakes,* J. Nriagu and M. Simmons, eds., chapter 4. New York: John Wiley and Sons.
12. Eisenreich, S.J.; G.J. Hollod and T.C. Johnson. 1981. In: *Atmospheric Pollutants in Natural Waters,* S.J. Eisenreich, ed., chapter 21. Ann Arbor, Mich.: Ann Arbor Science Publishers.
13. Andren, A.W., and J.W. Strand. 1981. Atmospheric deposition of particulate organic carbon and polyaromatic hydrocarbons to Lake Michigan. In: *Atmospheric Pollutants in Natural Waters,* S.J. Eisenreich, ed., chapter 23. Ann Arbor, Mich.: Ann Arbor Science Publishers.
14. Andren, A.W. 1982. PCB accumulation in southern Lake Michigan sediments: Evaluation from sediment core analyses. In: *Physical Behavior of PCBs in the Great Lakes,* D. Mackay, S. Paterson, S.J. Eisenreich and M. Simmon, eds., chapter 8. Ann Arbor, Mich.: Ann Arbor Science Publishers.
15. Doskey, P.V., and A.W. Andren. 1981. Concentration of airborne PCBs over Lake Michigan. *Journal of Great Lakes Res.* 7:15-20.
16. Brooks, A.S.; P.E. Bertram and S.C. Skebba. 1980. "Population responses of *Daphnia* to long-term exposure to cadmium." Ph.D. dissertation, Center for Great Lakes Studies, University of Wisconsin–Milwaukee.
17. Guiney, P.D.; M.J. Melancon, Jr.; J.J. Lech and R.E. Peterson. 1979. Effects of egg and sperm maturation and spawning on the distribution and elimination of a polychlorinated biphenyl in rainbow trout (*Salmo gairdneri*). *Toxicology and Applied Pharmacology* 47:261-72.

BIOGRAPHICAL PROFILES

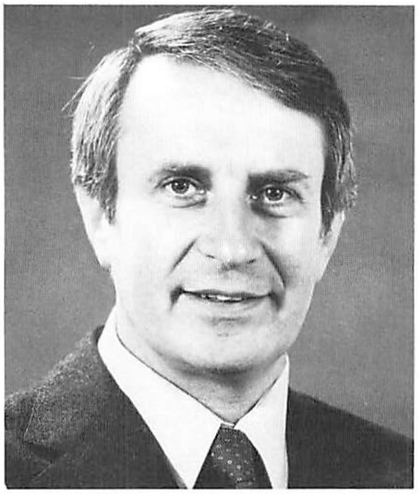
Robert A. Ragotzkie is director of the University of Wisconsin Sea Grant Institute and a professor of meteorology and environmental studies at the UW–Madison. He has recently served as chairman of the national Council of Sea Grant Directors and as a member of the Science Advisory Board of the U.S.-Canadian International Joint Commission.

Besides coordinating the research activities of the UW Sea Grant Institute, Ragotzkie's research interests include Great Lakes physical limnology and ecology, heat budgets of small lakes, Arctic and Antarctic limnology, and remote sensing of sea surfaces. He has conducted research in the Great Lakes, at Sapelo Island off Georgia,and in the Arctic and Antarctica.

An avid Great Lakes sport fisherman, Ragotzkie is a contributor to and the editor of *Man and the Marine Environment,* a book published recently by CRC Press, Boca Raton, Fla.

Anthony S. Earl was inaugurated as Wisconsin's 40th governor in January 1983, the culmination of a long career in state public service. He served in the Wisconsin State Legislature from 1969 to 1975, as Secretary of the Department of Administration in 1975, and as Secretary of the Department of Natural Resources from 1975 to 1980.

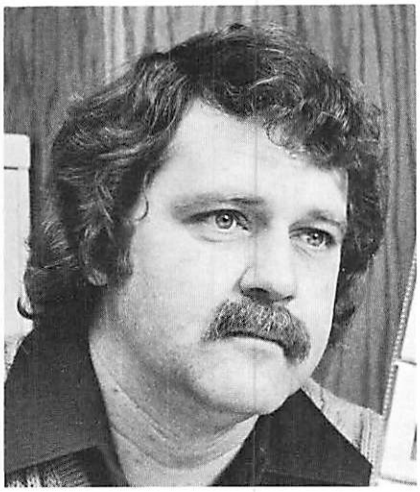
Earl's interest in the importance of the Great Lakes to the future of Wisconsin and the region stems from his tenure as DNR secretary and from his current role as chairman of the recently formed Council of Great Lakes Governors, Inc. Earl has worked closely in the past with the University of Wisconsin, and with the UW Sea Grant Institute in particular, so he has a special perspective on the role that the university community can play in formulating and enhancing state policy. He believes in a strong state-university partnership in the quest to better serve the interests of the people of Wisconsin.



Richard C. Bishop is a professor of agricultural economics at the University of Wisconsin–Madison. He also serves as vice president of the Association of Environmental Resource Economists and is a member of the Wisconsin Ad Hoc Great Lakes Fisheries Task Force.

Bishop has also worked with the Great Lakes Fisheries Commission to determine the economic values of the sport and commercial fishing industries for the entire Great Lakes region.

Besides exploring the economic implications of sport and commercial fishing, Bishop's research interests include the evaluation of environmental and natural resource assets, fisheries economics for developing countries, acid rain and the fisheries of the West Coast. He has conducted research in California, the Great Lakes and in Indonesia.



James F. Kitchell is associate director of the UW–Madison Center for Limnology and a professor of zoology. Kitchell is currently a member of the National Science Foundation's Ecosystems Studies Panel and has served on a variety of Great Lakes Fishery Commission and International Joint Commission committees.

Besides exploring Great Lakes predator-prey systems, Kitchell's research interests include aquatic ecology and ecosystem modeling, international fisheries issues and the fisheries of the West Coast. One model developed by Kitchell and his colleagues was rated as one of the top two aquatic models in the world by the U.S. Nuclear Regulatory Commission.

Kitchell has conducted research in the Great Lakes, studied the tuna fishery on the West Coast and has participated in research programs in Yugoslavia and Indonesia.

David N. Edgington is director of the University of Wisconsin–Milwaukee Center for Great Lakes Studies and a professor of geological sciences at the university's Great Lakes Research Facility.

He is currently a member of the Council of Research Directors on the International Joint Commission's Science Advisory Board and has served on the IJC's Lake Michigan Surveillance Task Force. He has also served on a task group of the National Council on Radiological Protection Committee, which examined problems related to the transport and bioaccumulation of radionuclides.

Besides coordinating the research activities of the Center for Great Lakes Studies, Edgington's research interest has been focused on sedimentation processes and their relationship with trace contaminants in Lake Michigan. He has conducted research for the U.S. Environmental Protection Agency's Ecological Science Section of the Argonne National Laboratory and has participated in research projects and scientific committees in Europe.

Anders W. Andren is associate director of the University of Wisconsin–Madison Water Resources Center and a professor of civil and environmental engineering at the university's Water Chemistry Laboratory.

Andren currently serves on a National Academy of Sciences committee, Monitoring Trends in Acid Precipitation, and formerly served on the NAS's PCBs in the Environment committee.

In addition to studying the atmosphere as a source of Great Lakes pollutants, Andren's research interests include the transfer of chemicals across air/water interfaces, the fate of hazardous substances in aqueous systems and the effect of acid precipitation on lake systems. He has conducted research in the Great Lakes, at the Environmental Science Laboratory in Oak Ridge, Tenn., and in Europe, where he studied Scandinavian acid rain research for the U.S. Environmental Protection Agency.

UW SEA GRANT PUBLICATIONS PROFILE, 1982-84

Public Information Reports

Newsyear: A Report on the Activities of the UW Sea Grant Institute, 1980-82. Communications Office staff. WIS-SG-82-139.

University of Wisconsin Sea Grant Institute Project Directory, 1983-84. Stephen Wittman. WIS-SG-83-140.

Aquaculture Research at the University of Wisconsin. Warren Downs and Peyton Smith . WIS-SG-83-142.

The Wisconsin Idea in Fish Management. Linda Weimer, Communications Office Staff. *Wisconsin Natural Resources: Special Fish Management Issue,* Vol. 7, No. 3, 1983.

Home Pickling of Fish. David Stuiber and Mary Mennes. WIS-SG-84-143.

Home Smoking of Fish. David Stuiber and Mary Mennes. WIS-SG-84-144.

The Future of Great Lakes Resources: A Report on the Activities of the UW Sea Grant College Program, 1982-84. Communications Office Staff. WIS-SG-84-145.

Ice Fishing. Warren Downs. WIS-SG-73-II5 (revised, 1982).

Getting the Most From Your Great Lakes Salmon. C.E. Johnson, D.A. Stuiber and R.C. Lindsay. WIS-SG-74-I20 (revised, 1982).

Fish of Lake Superior. Warren Downs. WIS-SG-75-I24 (revised, 1984).

Advisory Reports

Great Lakes Region Sea Grant Advisory Services Directory. Gene Woock. 1983.

The National Sea Grant Advisory Service: Serving the Nation's Marine Community. Cato Committee, Linda Weimer, ed., 1983.

Dioxin: A Cause for Concern? Thomas Stolzenburg and John Sullivan.WIS-SG-83-141.

Green Bay's Yellow Perch Fishery. Clifford Kraft. WIS-SG-82-425, (revised, 1984).

Technical Reports

Buying a Better Environment: Cost-effective Regulation Through Permit Trading. Erhard F. Joeres and Martin H. David, eds. WIS-SG-82-239.

PCB Levels in Human Fluids: Sheboygan Case Study. B. Jill Smith. WIS-SG-83-240.

Reprints

Option Value: An Exposition and Extension. Richard C. Bishop. WIS-SG-82-733.

Loss of Floy Anchor Tags from Lake Whitefish. M. Ebener and Frederick Copes. WIS-SG-82-734.

Six Thermal Habitat Shifts by Fishes at the Thermocline in Lake Michigan. Larry B. Crowder and John J. Magnuson. WIS-SG-82-735.

Excretion of Total Phosphorus, Dissolved Reactive Phosphorus, Ammonia, and Urea by Lake Michigan *Mysis relicta.* P.T. Madeira, Arthur S. Brooks and D.B. Seale. WIS-SG-82-736.

Numerical Models and Observation of Water Motion in Green Bay, Lake Michigan. N.S. Heaps, Clifford H. Mortimer and E.J. Fee. WIS-SG-82-737.

Effects of Potassium Sorbate and Other Antibotulinal Agents on Germination and Outgrowth of *Clostridium botulinum* Type E Spores in Microcultures. Robert A. Seward, Robert H. Deibel and Robert C. Lindsay. WIS-SG-82-738.

Polychlorinated Biphenyls in the Fish and Sediment of the Lower Fox River, Wisconsin. John R. Sullivan, Joseph J. Delfino, Carol R. Buelow and Thomas B. Sheffy. WIS-SG-83-739.

Foraging Behaviors and the Interaction of Alewife, *Alosa pseudoharengus,* and Bloater, *Coregonus hoyi.* Larry B. Crowder and Fred P. Binkowski. WIS-SG-83-740.

Identification of Compounds Characterizing the Aroma of Fresh Whitefish (*Coregonus clupeaformis*). David B. Josephson, Robert C. Lindsay and David A. Stuiber. WIS-SG-83-741.

Lack of Harmful Effects from Simulated Dives in Pregnant Sheep. Margie E. Bolton-Klug, Charles E. Lehner, Edward H. Lanphier and John H.G. Rankin. WIS-SG-83-742.

Cost-Effective Regulatory Options for Water Quality Limited Streams. Martin H. David and Elizabeth L. David. WIS-SG-83-743.

An Energetics Model for Lake Trout, *Salvelinus namaycush:* Application to the Lake Michigan Population. Donald J. Stewart, David Weininger, Donald V. Rottiers, Thomas A. Edsall. WIS-SG-83-744.

Harvesting Photopositive Juvenile Fish from a Pond Using a Lift Net and Light. William E. Manci, Jefrey A. Malison, Terrence B. Kayes, Thomas E. Kuczynski. WIS-SG-83-745.

Secular Variations of Surface Temperature and Precipitation Patterns Over the Great Lakes Region. W.A.R. Brinkmann. WIS-SG-83-746.

Bisulfite Suppression of Fish Aromas. D.B. Josephson, R.C. Lindsay, and D.A. Stuiber. WIS-SG-83-747.

Association Between Net Basin Supplies to Lake Superior & Supplies to the Lower Great Lakes. W.A.R. Brinkmann. WIS-SG-83-748.

Diversity: Quantification and Ecological Evaluation in Freshwater Marshes. H.J. Harris, Mark S. Milligan, Gary A. Fewless. WIS-SG-83-749.

The Effect of Food Quality on Feeding and Respiration by Daphnia and Diaptomus. Sumner Richman and Stanley I. Dodson. WIS-SG-83-750.

Landslide Hazard Potential Determination Along a Shoreline Segment. Tuncer B. Edil and Michael N. Shultz. WIS-SG-83-751.

Fish Farming in Wisconsin. Peyton Smith. *Wisconsin Trails Magazine* reprint,January-February 1983.

Review of the International Field Year for the Great Lakes. Robert A. Ragotzkie. *American Meteorological Society* reprint, 1984.

Evaluating the Constraints of Temperature, Activity and Consumption on Growth of Largemouth Bass. James A. Rice, James E. Breck, Steven M. Bartell and James F. Kitchell. WIS-SG-84-752.

Transferable Discharge Permits and Economic Efficiency: The Fox River. William O'Neil, Martin David, Christina Moore and Erhard Joeres. WIS-SG-84-753.

Predation by *Limnocalanus* as a Potentially Major Source of Winter Naupliar Mortality in Lake Michigan. Glenn J. Warren. WIS-SG-84-754.

Facing the Lake: The Coastwatchers of Racine County, Wisconsin. J. Philip Keillor and Betty Gruning. WIS-SG-84-755.

Cardiovascular Effects of Induced Decompression Sickness in Sheep Fetus. M.K. Stock, T.M. Phernetton and J.H.G. Rankin. WIS-SG-84-756.

Independent Evaluation of a Bioenergetics Model for Largemouth Bass. J.A. Rice and P.A. Cochran. WIS-SG-84-757.

Distribution and Abundance of Rainbow Smelt in Western Lake Superior as Determined from Acoustic Sampling. B.G. Heist and W.A. Swenson. WIS-SG-84-758.

UW SEA GRANT PROJECTS PROFILE, 1982–84

LIVING RESOURCES

Until recently, little was known about how lake ecosystems work. In the 1890s, University of Wisconsin scientists were pioneers in the field of limnology (the study of lakes), and university researchers are continuing this tradition today. With Sea Grant support, they are studying every aspect of how Great Lakes fish live—how they reproduce, survive and grow; what they eat; what effects competition among different kinds of fish and changes in the predator-prey balance have on the lake's fish population. Researchers are also looking at ways to better preserve and package these fish once they are harvested for human use.

Coordinators: James Kitchell, Center for Limnology, UW–Madison; Ross Horrall, Marine Studies Center, UW–Madison

Factors Influencing the Reestablishment of Self-Sustaining Stocks of Lake Trout in Lake Michigan (R/GB-7)

Ross Horrall, Marine Studies Center, UW–Madison
J. Philip Keillor, Sea Grant Institute, UW–Madison

Lake Michigan's native lake trout were virtually wiped out when the parasitic sea lamprey invaded the Great Lakes early in the 1900s. After the sea lamprey was brought under control, trout were reintroduced to Lake Michigan but failed to reproduce. To find out why, Sea Grant scientists have been studying the history and the different genetic strains of lake trout and the characteristics of trout spawning reefs in Green Bay and Lake Superior. Using this information, federal and state agencies are trying to establish a naturally reproducing trout population in the lake, which would eliminate the need for and expense of stocking the fish. The Wisconsin Coastal Management Program and Department of Natural Resources have also supported this project.

Keystone Predators in the Great Lakes (R/LR-17)

James Kitchell, Center for Limnology, UW–Madison

Kitchell is developing a computer model that describes the predator-prey interactions among fish in Lake Michigan, which will give scientists and fishery managers the capability to forecast the consequences of natural or human-induced changes in the lake's predator-prey balance. This is particularly applicable to Lake Michigan, where predation on forage fish can be manipulated through changes in trout and salmon stocking and the lamprey control program. This computer model has already been cited by the Nuclear Regulatory Commission as one of the best two aquatic computer models in the world.

Bioenergetics of the Great Lakes Bloater (Chub) (R/LR-18)

Fred Binkowski, Center for Great Lakes Studies, UW–Milwaukee

After reaching a low ebb in 1976, the bloater, or chub, has once again become a prime commercial fish and an important forage fish for salmonids in Lake Michigan. Sea Grant scientists are conducting experiments that relate the respiration and food consumption of the Great Lakes bloater to its temperature and body size. Such growth and energy-use information will provide useful insights into the distribution and ecological niche of the bloater in Lake Michigan.

Daily Growth Rates and Variable Recruitment of Larval Fishes in Lake Michigan (R/LR-22)

James Kitchell, Center for Limnology, UW–Madison
Fred Binkowski, Center for Great Lakes Studies, UW–Milwaukee

The growth, feeding habits and survival rate of young chubs, an important commercial fish, and young alewives, a key forage fish, are being studied in this project. The researchers are looking at the role that the type and amount of available food have in

UWGB scientists Paul Sager (left) and Harold J. Day (right) work on Green Bay.

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the diet of larval chubs. They are also trying to determine if the spacing of otolith rings (calcium-like deposits in a fish's internal ear) is a reliable way of establishing its age and daily growth, which would be a very valuable management tool for determining fish growth and survival rates.

Species Interactions and Early Life History Dynamics of Major Planktivores in Lake Michigan (R/LR-24)

John Magnuson, Center for Limnology, UW–Madison

Great Lakes fishery managers need to be able to predict—as far in advance as possible—what the future forage base for sport fish will be and what changes might occur in the abundance of important commercial fish. To do this, they need to know what causes strong and weak year-classes of fish. This study is examining the interactions and ecology of young forage fish (mainly chub and alewife) by comparing how these fish share or compete for food and space, and the effect predators have on forage fish populations. The investigators will then conduct experiments to reveal the critical factors behind year-class strength.

Composition and Productivity of Aquatic Macrophyte Communities in Three Lake Michigan Bays (R/LR-23)

Peter Salamun, Botany, UW–Milwaukee

North Bay, Moonlight Bay and Rowleys Bay in Door County are important fish spawning grounds and wildlife habitat that are feeling the pressures of increasing recreational use and shoreline development. In this project, botanists will identify and map the typical plant communities from the shore out into the open waters of the bays. They will also document the bays' rare and endangered plants and the effects of human activities. Planners and resource managers can use such information to make land-use plans for the future of these and similar bays on northern Lake Michigan.

Extending the Storage Life of Whitefish through Lipid Oxidation Studies (R/LR-20)

David Stuiber & Robert Lindsay, Food Science, UW–Madison

Whitefish is the most important commercial fish in the upper Great Lakes. But the fish does not keep long even when frozen, so it is available for only a short time each year. Sea Grant food scientists are studying what makes whitefish spoil so rapidly and why this occurs. By finding ways to stop or reduce spoilage and extend storage time, they hope to greatly improve the marketability of this fine-tasting fish. This would benefit commercial fishermen, retailers and consumers alike.

Safety of Methods of Modified-Atmosphere Packaging of Refrigerated Fresh Fish (R/LR-21)

Robert Lindsay, Food Science, UW–Madison
Robert Deibel, Bacteriology, UW–Madison

Modified-atmosphere packaging can keep fish fresh twice as long as present methods, but the safety of this method has not been fully explored. This research will clarify whether there is any danger of botulism in modified-atmosphere packaging of refrigerated fish. In particular, the scientists are looking at the behavior of *C. botulinum* Type E bacteria under short-term, high-temperature abuse and in long-term refrigerator storage of fish packaged this way.

The Influence of *Mysis relicta* on Fish Production in Lake Michigan (R/LR-25)

Arthur Brooks & Dianne Seale, Center for Great Lakes Studies, UW–Milwaukee

Mysis relicta are large zooplankton that appear to play a key role in Lake Michigan's web of life. This study is analyzing how important that role really is. For instance, how much do *Mysis* compete with larval fish for food? Do *Mysis* prey on larval fish, and if so, what species? To what extent do *Mysis* affect the size of food particles available for smaller zooplankton? How big of a factor are *Mysis* in the diet of the fish that prey on it? Such information will increase man's ability to predict fish growth and standing stocks through a better understanding of how the lake's food web works.

AQUACULTURE

Aquaculture in the Great Lakes region plays an important role in fisheries management, particularly in producing fish at hatcheries for stocking the area's thousands of inland lakes as well as the five Great Lakes. Aquaculture also has great commercial potential as a direct method of food production.

Given the region's cold climate, aquaculture here focuses on coolwater fish (perch and walleye) and coldwater fish (trout and whitefish). With public and private support, the UW Sea Grant Aquaculture Subprogram aims to develop and improve the technological and scientific database necessary for the propagation and culture of these fishes, with special attention to fish nutrition and diseases.

Coordinator: Clyde Amundson, Food Science, UW–Madison

Effects of Nutritional and Environmental Stress on Resistance to Disease in Fish (R/AQ-11)

Cynthia Sommer, Zoology/Microbiology, UW–Milwaukee
Terrence Kayes, Food Science, UW–Madison

Disease is one of the biggest dangers to aquacultured fish crops. To find out what reduces a fish's immunity to disease, the researchers are subjecting typical coolwater and coldwater fish (yellow perch and rainbow trout) to nutritional and environmental stresses to determine the individual and combined effects of these stresses on the fishes' resistance to a common fish pathogen, *Aeromonas*. This work could lead to increased fish production through better survival rates and a better understanding of the reasons why various attempts to immunize fish have succeeded or failed. This study is being carried out in conjunction with other Sea Grant aquaculture research around the nation.

Basic Husbandry of Great Lakes Fishes (R/AQ-8)

Clyde Amundson & Terrence Kayes, Food Science, UW–Madison

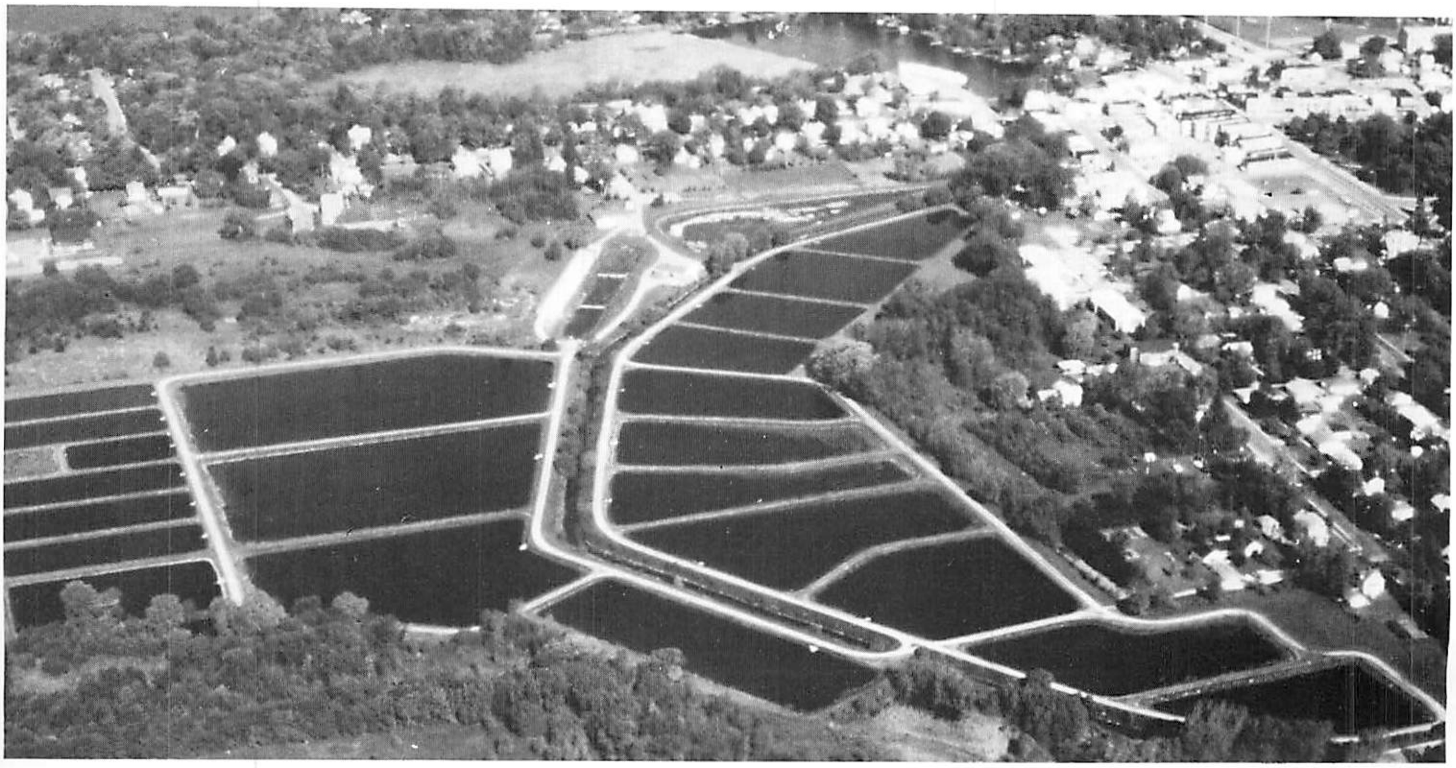
This ongoing project provides management for the UW Sea Grant Aquaculture Subprogram and the UW Aquaculture Research Laboratory, which in April 1984 was moved to new facilities at the Lake Mills State Fish Hatchery. The Aquaculture Research Laboratory provides "wet lab" space, aquaria, hatchery equipment, fish eggs, fish and feed to Sea Grant project researchers and assists them with their fish husbandry needs. Amundson and Kayes also have the task of identifying the aquaculture-related needs of Great Lakes fisheries management agencies, commercial fishermen and businesses, and they are Wisconsin's representatives to the national Sea Grant aquaculture program.

Assessment of Dietary Amino Acid Requirements of a Representative Great Lakes Fish (R/AQ-9)

Clyde Amundson & Terrence Kayes, Food Science, UW–Madison

Because marine fishmeal is so expensive, feed is one of the biggest costs of fish farming. This project is looking at how much amino acid the rainbow trout needs in its diet and to what extent high-protein feedstuffs can be used in lieu of marine fishmeal. The use of local protein sources would greatly reduce fish feed costs in the Great Lakes region, and nationally a mere five percent reduction in feed costs for rainbow trout alone would save $1.3 million to $1.7 million a year. Such knowledge could also be applied to salmon and other coldwater fishes.

Wisconsin DNR's Lake Mills Fish Hatchery is also home to the UW Aquaculture Research Laboratory.



GREEN BAY

Green Bay is one of the richest yet most polluted bays on the Great Lakes. The bay's perch and whitefish commercial fisheries have been among the most productive on Lake Michigan, but harvests have declined dramatically in the last 20 years. The International Joint Commission, the U.S.-Canadian agency that oversees the Great Lakes, has designated the bay an "area of concern" meriting top priority in water clean-up efforts.

For these reasons, UW Sea Grant has a research subprogram devoted solely to Green Bay. It is a multidisciplinary program involving ecologists, chemists, biologists and engineers. Research priorities are to restore and protect both the bay's water quality and its sport and commercial fisheries.

Coordinator: H. J. Harris, Science & Environmental Change, UW–Green Bay

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Green Bay Subprogram Coordination (R/GB-5)

H.J. Harris, Science & Environmental Change, UW–Green Bay

The thrust of this project is to exchange information and coordinate the activities of Sea Grant's Green Bay research with that of federal, state and local agencies and other groups concerned with the bay. In addition to the IJC priority designation, the bay has also been selected for one of two major whole-ecosystem rehabilitation studies funded by the Great Lakes Fishery Commission—largely because of the wealth of data already available as a result of this Sea Grant subprogram.

Vital Statistics and Population Structure of Age I, II and III Lake Whitefish in Green Bay and Northern Lake Michigan (R/GB-14)

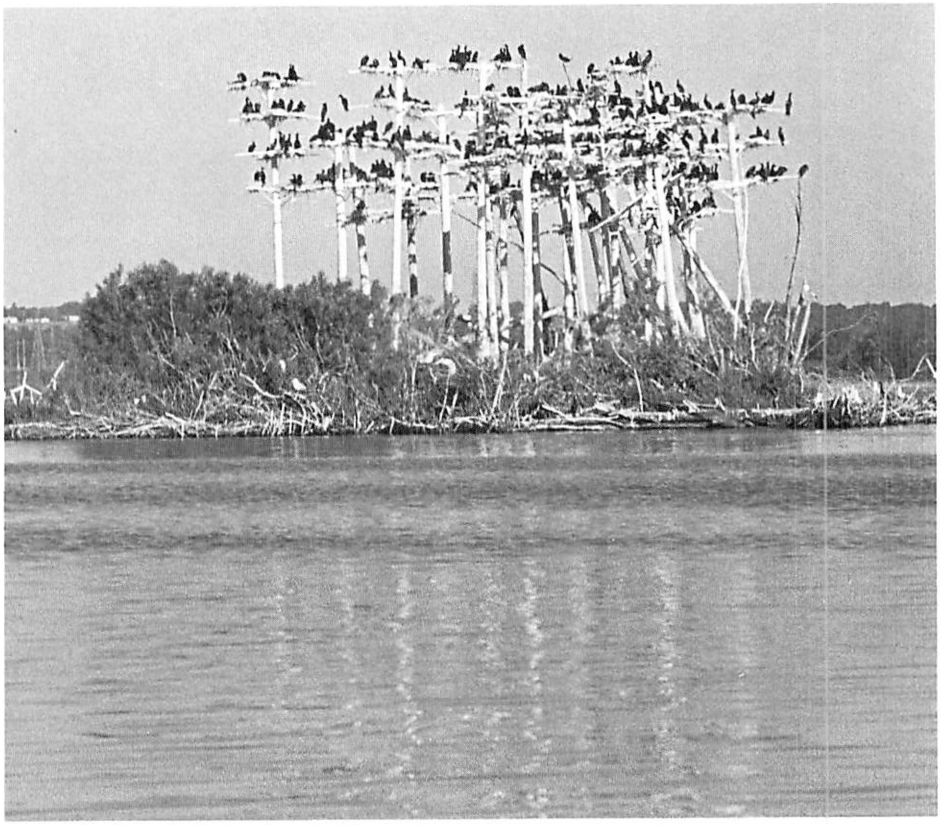
Fred Copes & Dan Coble, Wisconsin Cooperative Fishery Research Unit, UW–Stevens Point

Whitefish is one of the most valuable commercial fish in Lake Michigan. These researchers are tagging whitefish to learn about its abundance, age range and migrations in Green Bay and the northern part of the lake. Data from this study are already being used to develop a whitefish management plan for Lake Michigan. This is a cooperative study involving the Michigan Sea Grant Program, Wisconsin and Michigan Departments of Natural Resources, U.S. Fish and Wildlife Service, Wisconsin Northeast Lake Michigan Fish Council and Michigan Fish Producers Association.

The Contribution of Marshlands to the Green Bay Pelagic Food Chain (R/GB-18)

H.J. Harris, Science & Environmental Change, UW–Green Bay
Paul Sager, Biology, UW–Green Bay
Sumner Richman, Biology, Lawrence University-Appleton

To better manage Green Bay's fisheries and coastal resources, it is important to understand the contribution of the bay's west shore marshes to the nutrient base of its food chain. The investigators are studying the nature and movement of marsh nutrients and whether they are used as food by the bay's microscopic animals (zooplankton). This will indicate the amount of nutrients entering the bay from the marshes relative to industrial and municipal sources. This information will be useful in assessing the cost-effectiveness of further efforts to reduce nutrients in industrial and municipal waste discharges to make the bay less eutrophic (i.e., overrich in nutrients—a cause of algae blooms, oxygen-deficient water, fish kills and foul-tasting water).



Double-crested cormorants roosting on a Green Bay island.

The Drop Net Fishery and Its Effects on Yellow Perch Yields in Green Bay (R/GB-17)

Fred Copes & Dan Coble, Wisconsin Cooperative Fishery Research Unit, UW–Stevens Point

The Wisconsin Department of Natural Resources estimates that Green Bay's yellow perch population has an annual mortality rate of 80 to 90 percent, which means very few perch live long enough to reproduce or grow large. A possible cause is the high number of sublegal-size perch that are unavoidably killed in the course of commercial drop net operations. In cooperation with the WDNR and commercial fishermen, the researchers will find out whether the number of young perch killed is excessive and, if it is, whether drop nets can be modified to allow most sublegal perch to escape unharmed. This project may help improve fishing efficiency and result in more abundant, larger perch in the bay for sport and commercial fishermen alike.

Predator-Prey Models for Green Bay (R/GB-16)

James Kitchell & Steven Hewett, Center for Limnology, UW–Madison

The prey-to-predator transfer of biological energy up the food chain is a key factor in the balance of an aquatic ecosystem. Here, bioenergetics computer models of Lake Michigan's fish populations are being adapted to create similar models of Green Bay's fish populations. Such models could indicate, for example, if increased harvests of alewives would cause the bay's salmonid predators to go after other types of forage fish—perhaps commercially important ones. So such causes-and-effects can be demonstrated to fishermen, fisheries managers and the general public in discussions about the future of Green Bay's fisheries, the researchers also hope to adapt these models for use in portable microcomputers.

Persistence of Pollutants in the Sediments of Lake Michigan's Green Bay (R/GB-15)

David Edgington & Erik Christensen, Center for Great Lakes Studies, UW–Milwaukee

Sedimentation is a major way in which pollutants are removed from an aquatic ecosystem. This project is aimed at getting a better understanding of the behavior of sediments in Green Bay. Among other things, the investigators are examining the sources and movement of sediments in Green Bay, variations in sedimentation rates, and the extent, magnitude and frequency of sediment disturbances due to storms.

Hydrodynamic and Water Quality Modeling for Lower Green Bay (R/GB-19)

Harold Day, Science & Environmental Change, UW–Green Bay
Kwang Lee, Civil Engineering, UW–Milwaukee

The Wisconsin Department of Natural Resources is developing a wasteload allocation plan for Lower Fox River dischargers as part of its effort to improve the water quality of Lower Green Bay. With support from the WDNR and several local agencies and paper companies, these Sea Grant investigators are adapting a computer model of the dynamics and water quality of Milwaukee Harbor to Green Bay. This model will ensure that the wasteload allocation plan will be based on the best available information and that future water quality improvements will be achieved at minimum cost.

MICROCONTAMINANTS AND WATER QUALITY

Because of the hundreds of factories, thousands of farms and millions of residents in the Great Lakes region, water quality is a special concern. Trace amounts of toxic chemicals like DDT, PCBs, toxaphene and dioxin pose special problems because they are concentrated as they move up the lakes' food chain into the fish people eat.

The UW Sea Grant College Program is a national leader in research on PCBs and other contaminants. Chemists, biologists, pathologists, toxicologists and medical scientists are studying the sources, pathways and effects of contaminants in the Great Lakes and the dangers contaminants pose to the health and economic well-being of the region's people.

Coordinator: David Armstrong, Civil & Environmental Engineering/Water Chemistry, UW–Madison

Fate Assessment of Hydrophobic Organic Chemicals in Aqueous Environments (R/MW-21)

Anders Andren & David Armstrong, Civil & Environmental Engineering/Water Chemistry, UW–Madison

This project is aimed at evaluating and improving the methods now used to predict the fate of chemicals in aquatic environments like the Fox River and Green Bay. The researchers are looking at the structure of chemicals, whether they attach to other particles or vaporize, how sunlight affects them, how long it takes them to break down, and whether they break down into toxic or harmless substances. This information will then be fed into models designed to predict the potential environmental results.

Polychlorinated Dibenzodioxins (PCDDs) and Dibenzofurans (PCDFs) Persistence and Toxicity in Freshwater Fish (R/MW-27)

Richard Peterson, Pharmacy, UW–Madison
John Lech, Pharmacology & Toxicology, Medical College of Wisconsin, Milwaukee

Extremely toxic chemicals, polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) have been detected in freshwater fish. But little is known about the persistence and toxic effects of these compounds and their acutely toxic congeners like 2,3,7,8-TCDD and 2,3,7,8-TCDF. This study will determine where and how long TCDD and TCDF stay in the bodies of rainbow trout exposed to these chemicals in their food and water. It will also look at the effects on trout of acute and chronic exposures to TCDD, and compare the levels at which TCDD and TCDF become toxic to young and adult trout.

Role of Particulate Matter in Controlling Microcontaminant Behavior in Lake Michigan (R/MW-24)

David Armstrong & Anders Andren, Civil & Environmental Engineering/Water Chemistry, UW–Madison

To provide a dynamic picture of how substances behave in the lake, the researchers will collect samples of particles suspended in the lake water for analysis of their physical properties and chemistry. This information is needed by researchers trying to determine the processes that control trace elements in lakes and ultimately to assess pollution control strategies for the Great Lakes. It will also help increase our understanding of the fate of nonmetal microcontaminants in aquatic environments.

Atmospheric Concentrations and Transport of Organic Contaminants Across the Air-Water Interface in the Upper Great Lakes (R/MW-28)

Anders Andren & Theodore Green III, Civil & Environmental Engineering, UW–Madison
Edwin Lightfoot, Chemical Engineering, UW–Madison

Before remedial action can be taken, the sources and pathways of chemical contaminants in the Great Lakes must be determined. The investigators are studying the concentrations of various contaminants in the atmosphere and the rate at which these chemicals cross the air-water boundary into Lake Michigan. Among the contaminants being measured and analyzed are PCBs, PAHs and toxaphene. A computer model of air-water movement of pollutants will be developed that will help scientists determine whether a lake serves as a pollutant source or sink—and if so, how.

Status Reports on Priority Pollutants in the Great Lakes (R/MW-29)

David Armstrong, Civil & Environmental Engineering/Water Chemistry, UW–Madison

In the new Ocean-Marine Pollution Act, Congress emphasized the importance of studies on pollutants in the oceans and Great Lakes. This project's goal is a series of reports on the status of the Great Lakes regarding the 129 substances on the USEPA's Priority Pollutants List. The researchers will compile information on the main sources of these substances, their presence in the Great Lakes basin, their health effects and environmental fate, and evaluate the reliability of existing data. These reports will be particularly valuable to legislators, industrial chemists and fish biologists in identifying and controlling priority pollutants in the Great Lakes. The first such report—*Dioxin: A Cause for Concern?*—has already been published.

Detection of Mutagenic and Carcinogenic Effects of Environmental Pollutants in Aquatic Ecosystems (R/MW-30)

Ruth Phillips, Zoology/Center for Great Lakes Studies, UW–Milwaukee

This project will adapt the sister chromatid exchange (SCE) technique to the aquatic environment for detecting substances that cause mutations or cancer in trout eggs. Once proven, this technique could be used to determine or assess how fish and other aquatic organisms are affected by exposure to toxic substances in their environment. Such a technique would be a powerful monitoring and surveillance tool for determining the presence of and future outlook for toxic substances in the Great Lakes and other aquatic environments.

POLICY STUDIES

Natural resource problems require more than technical information—they require social, economic and political answers as well. The UW Sea Grant Policy Studies Subprogram analyzes Great Lakes and marine resource problems and recommends the best ways of solving them. Projects have included studies of Great Lakes shipping and transportation systems, the international Law of the Sea Treaty, the possibility of using marketable permits to control pollution at less cost, the Milwaukee vs. Illinois Lake Michigan pollution case, the economics behind coastal wetlands conversion and protection, the feasibility of underwater parks in the Great Lakes, and the unique Afro-American culture of the Sea Islands, S.C.

Coordinator: Richard Bishop, Agricultural Economics/Center for Resources Policy Studies & Programs, UW–Madison

Management of Great Lakes Water (R/PS-30)

Erhard Joeres & Kenneth Potter, Civil & Environmental Engineering, UW–Madison
Martin David, Department of Economics, UW–Madison

In this project, environmental engineers and resource economists are analyzing the costs and impacts of navigation, hydropower, shoreline protection and the diversion of water from the basin to other watersheds (as at Chicago). They are also developing computer models to determine the best water diversion plans possible under a variety of water use and pricing scenarios. This research will help Great Lakes states, the Province of Ontario and the International Joint Commission better manage Great Lakes water.

Great Lakes Transportation in the 1980s (R/PS-31)

Eric Schenker, School of Business Administration, UW–Milwaukee
Harold Mayer, Geography, UW–Milwaukee
Ronald Heilmann, Business/Management Research Center, UW–Milwaukee

This study will evaluate the role of the Great Lakes as a transportation system and analyze the critical factors affecting the lakes' maritime trade. The researchers then plan to develop and present policy recommendations regarding shipping activity in the Great Lakes-St. Lawrence system. These recommendations will deal particularly with issues of port and regional economic development and its relevance to national transportation policies. This project will update and expand past Sea Grant work on this topic by these investigators.

ADVISORY SERVICES

Through personal contacts, public meetings and media communications, the Advisory Services branch of the UW Sea Grant Institute provides the information and service link between the few who study marine and Great Lakes resources and the many who use, manage and depend on these resources.

Headquartered at UW–Madison, the Advisory Services program includes four field offices, with agents at Superior, Sister Bay, Green Bay and Milwaukee. The program also employs specialists in food science, recreation, business and coastal engineering. The Communications Office in Madison produces publications, the *Earthwatch* public service radio program, TV spots and films.

Coordinator: Allen Miller, Sea Grant Advisory Services, UW-Madison

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Advisory Services Coordination and Specialist Activities (AS/A-1)

Allen Miller, Sea Grant Advisory Services UW-Madison

Advisory Services activities involve the application of Sea Grant research through information and technical assistance to the public, government agencies on all levels and various industry groups. Areas of special emphasis include toxic substances, fisheries, marine minerals, coastal engineering, aquaculture, recreation and resource economics. This assistance is provided through conferences and outreach efforts—particularly through multistate and/or multiagency meetings on topics related to Sea Grant research activities. One of the most notable such meetings is the annual Underwater Mining Institute, now in its 14th year, cosponsored by the Texas Sea Grant College Program.

Advisory Services Field Agent Network (AS/A-14)

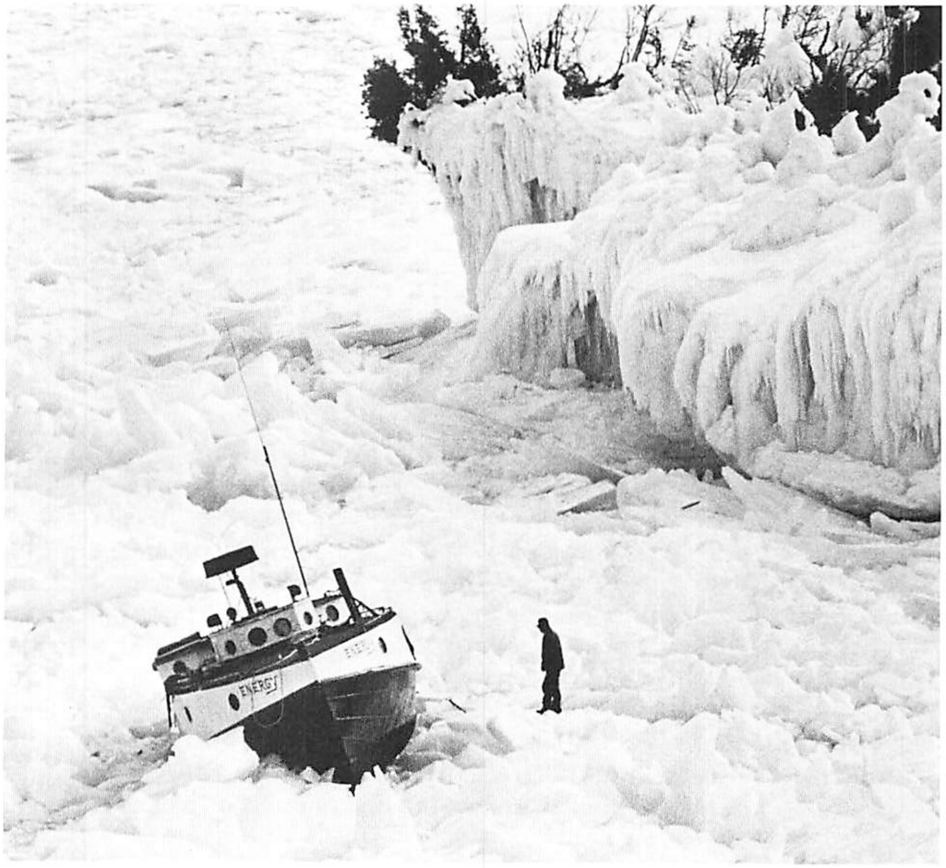
Allen Miller, Sea Grant Advisory Services, UW–Madison

UW Sea Grant's four field agents at Superior, Green Bay, Sister Bay and Milwaukee provide information about the Sea Grant program and carry out a variety of education and information projects, ranging from meetings on lake contaminants to short courses on lake biology for commercial fishermen. Specialists in Great Lakes-related subjects, the field agents offer technical advice and services to a wide variety of local audiences.

Earthwatch Public Service Radio Program (AS/A-3)

Peyton Smith, Sea Grant Institute, UW–Madison

Earthwatch is a daily two-minute environmental radio program produced in cooperation with the UW–Madison Institute for Environmental Studies. Carried by about 100 stations throughout Wisconsin and in other Midwest states, *Earthwatch* informs the public about issues related to the Great Lakes and the activities of the UW Sea Grant Institute in particular, and marine resources and the environment in general.



Lake Superior commercial fisherman's boat in ice jam off Devil's Island.

Sea Grant Communications (AS/A-2)

Peyton Smith, Sea Grant Institute, UW–Madison

Sea Grant and Great Lakes information is disseminated in many ways—through published reports, science journal articles, news articles, radio programs and special exhibits. Publications range from "The ABCs of PCBs" to *Methods for Analysis of Organic Compounds in the Great Lakes.* The Communications Office fields inquiries from the public and manages news media relations for Sea Grant scientists and staff. It also produces the institute's newsletter, program reports and project funding proposals to the National Sea Grant College Program Office.

Lake Ice and Marina Design Advisory Services (AS/A-20)

C. Allen Wortley, Engineering, UW Extension–Madison

Over the years, winter ice causes millions of dollars in damages to navigation and harbor facilities on the Great Lakes. This project will result in three advisory reports that provide practical information on ice conditions and ways to reduce ice damage—"Design Manual for Northern Harbors and Structures," "Technical Report on Ice Navigation" and "Compendium of Winter *Conditions in Great* Lakes' Harbors." These reports will be used as part of the investigator's ongoing technical assistance to designers, builders and operators of harbor facilities.

NEW APPLICATIONS

This subprogram includes projects that build on existing data or previous Sea Grant projects and applies them to new or different aspects of a Great Lakes or marine resource problem. A geological study of subterranean water movement is the latest project in this category. Past projects have looked at how climate variations affect Great Lakes water levels, the value of different kinds of shoreline vegetation in controlling erosion and the factors behind coastal bluff collapse.

Coordination: UW Sea Grant Institute

Geophysical Assessment of the Hydraulic Connection between Lake Michigan and the Groundwater Aquifers on Its Western Boundary (R/MN-1)

Mary Anderson, Geology & Geophysics, UW–Madison
Robert Taylor & Douglas Cherkauer, Geological Sciences, UW–Milwaukee

Information from this study will enable scientists for the first time to assess how much Wisconsin groundwater flows into Lake Michigan—or how much can be induced to flow from the lake into areas of declining groundwater supplies. This information will be valuable in determining where contamination of the lake via groundwater might be possible as a result of surface waste disposal (e.g., landfills and sewage sludge) and in assessing the environmental impact of power plant and other construction sites.

DIVING PHYSIOLOGY

An estimated 2.5 million Americans scuba dive for fun, and an increasing number of people dive for pay at offshore drilling sites and other marine operations. By studying the way the human body functions under water, UW Sea Grant scientists have become national leaders in assembling the fundamental medical knowledge needed to help make scuba diving a safer activity.

In the course of this work, researchers have discovered that immersion exercise may be therapeutic for victims of respiratory diseases. Researchers have also broken new ground in assessing the risks of diving during pregnancy and a rare phenomenon called "the chokes," a severe decompression sickness caused by a rapid change from high to low pressure environments.

Coordinator: Edward Lanphier, Biotron/Preventive Medicine, UW–Madison

Animal Fetal Responses to Decompression (R/DP-1)

J.H.G. Rankin, Physiology & Gynecology-Obstetrics, UW–Madison
Edward Lanphier, Biotron/Preventive Medicine, UW–Madison

This project will determine whether standard decompression tables, designed for men, are suitable for use by women of child-bearing age. The scientists are assessing the resistance of sheep fetuses to decompression sickness and developing safety recommendations for women who dive during pregnancy. The study involves experiments on the effects of standard decompression and no-decompression dives on sheep at various stages of gestation.

Physiology of Diving (R/NA-11)

Edward Lanphier, Biotron/Preventive Medicine, UW–Madison
Edwin Lightfoot, Chemical Engineering, UW–Madison
William Reddan & Steven Sauter, Preventive Medicine, UW–Madison
James Will, Veterinary Science, UW–Madison
Michael Wilson & Stefan Winkler, Radiology, UW–Madison

This project continues four years of work on the medical and physiological aspects of deep-sea diving and underwater performance. Researchers are using the hyperbaric chamber, immersion tanks and other facilities at the UW–Madison Biotron to examine the phenomenon of carbon dioxide retention, the effects of water temperatures and underwater exertion on heart and lung function, immersion diuresis, possible therapeutic effects of immersion exercise on heart and lung patients, and decompression sickness. From these interrelated studies, the researchers are developing recommendations for improved diver safety and efficiency.

EDUCATION AND ADMINISTRATION

UW Sea Grant began in 1968 and just four years later was the fifth full-fledged Sea Grant College Program in the nation and the first in the Great Lakes region. In the intervening 16 years, it has continued to grow and now has an annual budget of $2.9 million. This subprogram provides for the overall management and development of the UW Sea Grant College Program, including education projects, program planning, project evaluation, proposal development, research coordination, program reporting and other administrative functions.

Coordinator: Robert Ragotzkie, Sea Grant Institute, UW–Madison

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Ship Time in Support of Sea Grant Research Projects (SGA-3)

Robert Ragotzkie & J. Philip Keillor, Sea Grant Institute, UW–Madison

Ship time is provided for projects that require field work on Lakes Michigan and Superior, including fisheries, geological and toxic substances projects. Two small research vessels are operated by the university, the *R/V Aquarius* and *R/V Neeskay,* based at Sturgeon Bay and Milwaukee, respectively.

A Guide to the Natural History of the Lake Michigan Shoreline (AS/A-21)

Jean Lang, University-Industry Research Program, UW–Madison

An educational booklet that describes the general ecology and geology of Wisconsin's Lake Michigan shoreline will result from this project. The booklet emphasizes the complex links between the physical and biological nature of the lakeshore and man's influences upon it.

Special Education Programs (E/E-1)

Coordinator: Robert Ragotzkie, Sea Grant Institute, UW–Madison

The Sea Grant Institute sponsors several educational activities, including assistantships for students working on Sea Grant research, the creation of new Great Lakes and oceanography courses on University of Wisconsin campuses, and special film/lecture series around the state. During the 1982-83 fiscal years, this project provided graduate student support in these areas:

- Research on the vertical motion of near-shore ice associated with waves (Theodore Green III, Civil & Environmental Engineering, UW–Madison).
- A study of an economic simulation and evaluation of open-pond rearing of perch (John Norback, Business/Food Science, UW–Madison).
- Research on engineering problems relevant to Sea Grant interests (Ali Seireg, Mechanical Engineering, UW–Madison).
- Travel support was provided for students making research cruises.
- A research assistantship was provided for a student studying contaminants in southern Lake Michigan sediments.

Great Lakes Public Education (AS/A-22)

H. Richard Hiner & Robert Lovely, WHA Television, UW Extension-Madison

In this project, two Extension educational communications specialists produced a half-hour film documentary about the Great Lakes as a limited but renewable resource. Illustrating the progress that has been made in restoring the Great Lakes fisheries and water quality, the film will be offered to more than 280 public television stations nationwide and made available to film libraries and educational institutions. The Joyce Foundation, Wisconsin Educational Communications Board and WHA-TV are cosponsoring this project.

PROGRAM DEVELOPMENT

Although housed under the administration of the UW Sea Grant Institute, the Program Development project (SGA-1) can be likened to a research subprogram. Funds from Program Development are used to initiate projects proposed in the middle of a grant period and/or to augment existing projects or program areas. This flexibility allows the UW Sea Grant program to take advantage of special opportunities and to respond quickly to needs in high priority areas, such as toxic substances research.

Coordinator: Robert Ragotzkie, Sea Grant Institute, UW-Madison

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An Investigation of the Culture Techniques and Early Life History of the Lake Sturgeon (R/LR-26)

Fred Binkowski, Center for Great Lakes Studies, UW-Milwaukee

A once-numerous native fish prized for its meat and caviar, the lake sturgeon is rarely found today, but demand for the fish remains strong. With the support of Sea Farms, Inc., of Norway and Wisconsin Electric Power Co., a UW-Milwaukee biologist is working with the WDNR to develop ways to grow the sturgeon in indoor tanks, ponds and floating cages in Lake Michigan. If successful, this project will not only provide a means of meeting the commercial demand for sturgeon, but will also create a reliable supply of sturgeon for restocking Wisconsin's lakes and rivers as well as preserving an important native fish.

The Role of Microcontaminants in the Reproductive Failure of Forster's Terns on Green Bay (R/GB-21)

H. J. Harris, Science & Environmental Change, UW-Green Bay

Forster's terns, an endangered species in Wisconsin, has a low rate of reproduction on lower Green Bay. The researcher is attempting to determine if this is due to the presence of PCBs, dioxin or other chemical contaminants in the bay. This will help determine if the contamination is sufficient to warrant costly monitoring and research of the problem as well as providing useful information about an endangered species.

Assessment of the Feasibility of Combined Pond and Cage Culture of Yellow Perch (R/AQ-12)

Clyde Amundson & Terrence Kayes, Food Science, UW-Madsion

Wisconsin has nearly 400,000 hectares of natural lakes and over 10,000 farm ponds, most of which are not being used to any great extent for fish production. By hatching perch eggs in open pond water and later growing the fish to market size in submerged cages, the researchers say it is theoretically possible to produce as much as 6,000 pounds of perch per hectare per year. This theory will be tested in a pilot project involving two ponds on a farm near Oconto. The UW University-Industry Research Program and two agribusinessmen are also providing support for this project.

Economic Analysis for Management of the Green Bay Yellow Perch Fisheries and Other Great Lakes Fisheries of Wisconsin (R/PS-32)

Richard Bishop, Agricultural Economics, UW-Madison

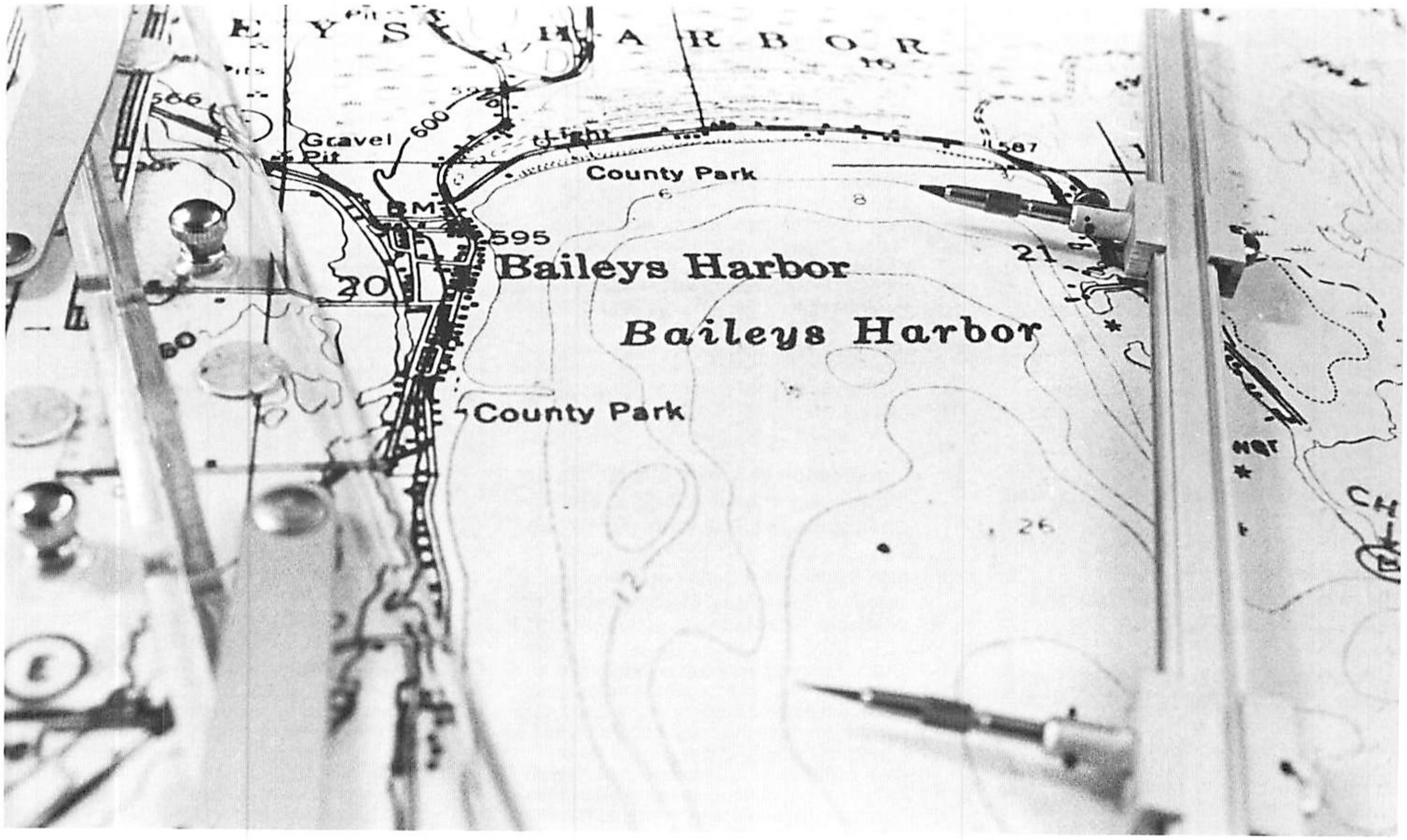
In 1983, the Wisconsin Department of Natural Resources imposed a quota on Green Bay commercial perch harvests of 200,000 pounds per year. This project is undertaking an economic analysis of alternative commercial fishing policies for yellow perch in Green Bay in an investment framework—the first practical application of investment theory to fisheries management problems. As a result, the state DNR and fishing industry will have for the first time a full economic analysis based on investment theory to guide them in managing the Green Bay's yellow perch fishery. The project has already provided timely data on Great Lakes fishing to public agencies and interest groups, including the Wisconsin Great Lakes Fisheries Task Force.

Ecological Research and the Management of the Great Lakes Fisheries from about 1920 to about 1950 (SGA-1a)

Frank Egerton, Social Sciences, UW-Parkside

The history of the Great Lakes fishery is largely a history of disasters both natural and man-made. This study is looking at the fishery at the time when science was first brought to bear on the fishery's problems. It will describe and evaluate the attempts made by scientists and managers at various levels of government to understand and control a complex natural resource. The insights gained from this study should be useful to government administrators and fishery managers as well as scientists and environmental science historians.

A 180-pound lake sturgeon big enough to ride—speared in Lake Winnebago in 1953.



RECENTLY COMPLETED PROJECTS

Often it takes several years before investments in research, advisory services and education begin to pay dividends. The research and development of alternative water pollution control strategies, new fish products, computer models for fishery management, erosion control methods, aquaculture technology and educational programs can begin to benefit society only after the Sea Grant project is completed. The findings of some of these recently completed research projects are already being used, while the importance of some others will be realized by the public in the years ahead.

Competition for Resources among Planktivorous Fishes in Lake Michigan (R/LR-15)

John Magnuson, Center for Limnology, UW–Madison

Fish stocking levels and harvest quotas must be based, in part, on knowledge about the plankton-eating fish populations that in turn are eaten by salmon, trout and other predatory fish. Magnuson and his associates examined how planktivorous fish compete for the lake habitat from season to season and how this affects the distribution of the fish that prey on them. They learned that the alien alewives came to dominate Lake Michigan in the 1960s because they can filter-feed on very small zooplankton—which gave them a competitive advantage over native fish like cisco and bloater chub. It was also shown that competition between two species of planktivorous fishes in Lake Michigan will cause one to move out of its preferred water temperature—confirming that competition regulates this fish community.

Alternative Management Strategies for Minimizing Polychlorinated Biphenyls in Lake Michigan Fishes (R/LR-14)

James Kitchell, Zoology/Center for Limnology, UW–Madison

Building on past Sea Grant work, the researchers completed a bioenergetics model for the alewife, a major source of PCBs in the lake's salmonid predators, to examine the potential effectiveness of management strategies for minimizing the levels of PCBs in Lake Michigan fish. This model, coupled with the models of the diet and growth rates of other fish, has enabled Kitchell to forecast a decline in the PCB levels in large sport fish in the years ahead. These models have also enabled him to warn WDNR managers that stocking too many of the cheaper but longer-lived Chinook salmon could lead to a collapse in the lake's alewife population, which would cause predator fish to turn to commercially valuable forage fish species.

Characterizing the Green Bay Pelagic Food Chain and the Relationship between Phytoplankton and Fish Production (R/GB-13)

Sumner Richman, Biology, Lawrence University-Appleton
Paul Sager, Biology, UW–Green Bay

This study analyzed the sizes, standing stock and productivity of Green Bay phytoplankton as part of an effort to assess the feasibility of using such data to predict the standing stock and productivity of Green Bay's fisheries. This relationship has been shown to be applicable to saltwater environments but had never been tested in freshwater lakes. Data was collected on the seasonal and geographical distribution and species composition of Green Bay's algae and zooplankton populations, and primary productivity measurements were made to characterize the bay's various water masses. Commercial fish harvest records are now being examined to determine the relationship between fish productivity and phytoplankton productivity in Green Bay.

Economics of Rehabilitating the Lake Michigan Fishery: A Case Study (R/LR-16)

Richard Bishop, Agricultural Economics, UW–Madison

The present sport and commercial fisheries of Lake Michigan exist only as a result of the millions of dollars spent to stock the lake with salmonids and to control the sea lamprey. Is it worth it? In cooperation with Michigan State University Sea Grant researchers, Bishop assessed the benefits and the costs of lamprey control and salmonid stocking programs for all of Lake Michigan. Such information is of vital interest to fishermen and fishery managers, who must justify continued public funding of these programs. Based on their analyses, the economists report that these programs more than pay for themselves, returning several times their cost in direct and indirect economic benefits.

Significance of *in situ* Nutrient Regeneration in Lake Michigan's Nutrient Budget (R/LR-19)

Arthur Brooks & Charles Remsen, Center for Great Lakes Studies, UW–Milwaukee

This project extended other studies on the significance of *in situ* regeneration of the nutrient budget of Lake Michigan. The goal was to determine to what extent this input meets the nutrient requirements of primary and secondary biological production. It was discovered that about 10 percent of the nutrient requirements of algae is regenerated by the feeding activity of *Mysis relicta,* and about 10 percent more is provided in the zooplankter's excretions. This work provided essential fundamental information on an important but neglected link in the lake's food web.

Transferable Discharge Permits: Implementation Studies (R/PS-28)

Martin David, Economics, UW–Madison
Erhard Joeres, Civil & Environmental Engineering, UW–Madison

Based on previous Sea Grant research, this study simulated the effects of a transferable discharge permit (TDP) system, where industries have the opportunity to purchase and sell waste discharge permits. The researchers assessed the effects of a TDP system on water quality, the likelihood of violations of water quality standards and the river's ability to withstand short-term pollution shocks. They concluded that TDP markets were feasible and could reduce waste processing costs by 20 to 30 percent and not reduce water quality. A comprehensive report was made to the Wisconsin Department of Natural Resources, which with legislative sanction has now established TDPs as a new regulatory option. With UW Sea Grant support, a national conference on TDPs was convened in June 1982; the proceedings of that conference are now available in a 296-page book, *Buying a Better Environment: Cost-Effective Regulation through Permit Trading.*

Sources of Polychlorinated Biphenyls to Lake Michigan (R/MW-23)

David Armstrong, Civil & Environmental Engineering/Water Chemistry, UW–Madison

PCBs in the sediment of different parts of Lake Michigan were analyzed to find out if local inputs (dumps, runoff, etc.) or atmospheric deposits are the major source of PCBs in the lake. The concentrations and types of PCBs were found to be fairly uniform throughout the lake, confirming that the atmosphere is the major source of this contaminant. This information will be useful in determining how much and how soon Lake Michigan will recover from PCB contamination.

Modification of Xenobiotic Metabolizing Activity in Lake Michigan Fish by Environmental Pollutants (R/MW-26)

Mark Melancon & John Lech, Pharmacology & Toxicology, Medical College of Wisconsin–Milwaukee

The mixed-function oxidase (MFO) system in the liver and other organs is an enzyme system that helps detoxify and expell foreign substances from the body. Laboratory tests have shown that PCBs and other toxic chemicals trigger an increase in MFO activity in fish. In experiments using Milwaukee Harbor water and uncontaminated hatchery fish, these researchers found that fish exposed to the harbor water went through a 12-fold increase in mono-oxygenase activity, which returned to normal levels when the fish were returned to clean water. This proves that pollutants *do* affect fish and that the resulting increase in enzyme activity could serve as a sensitive indicator of water pollution.

Transport of Microcontaminants into Lake Superior by Suspended Solids (R/MW-25)

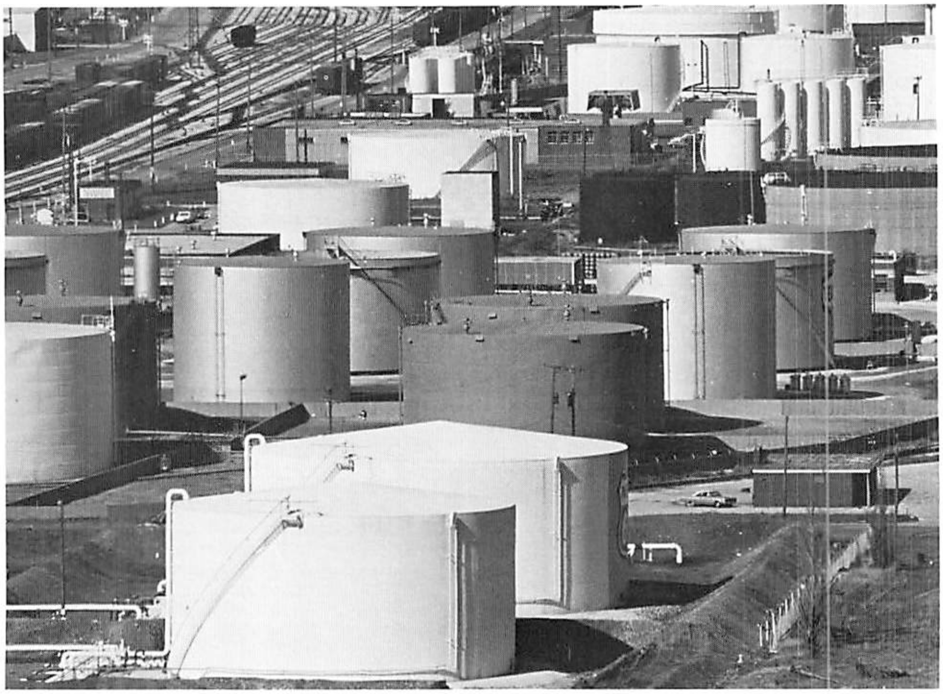
Donald Bahnick, Nasim Ahmad & Thomas Markee, Center for Lake Superior Environmental Studies, UW–Superior

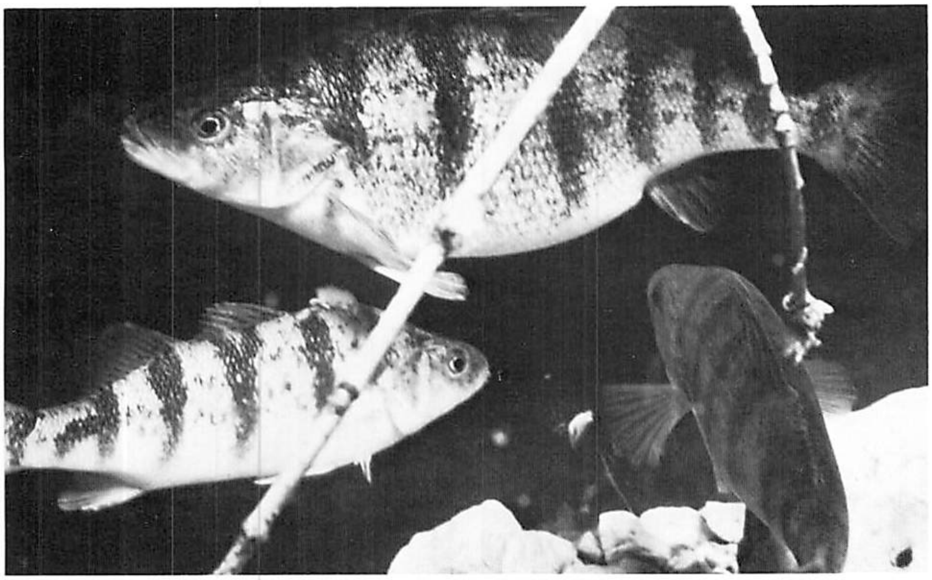
This study looked at the kinds and amounts of microcontaminants that suspended solids may be carrying into Lake Superior. The release of these microcontaminants to the lake's water and fish was also studied. The results of this study will help determine how likely the lake's fish and other aquatic animals are to be contaminated from this source. Among other uses, this information will help assess the effects of dredging operations along Lake Superior's southwest shore.

Assessment of Selected Organic Pollutants in the Lower Fox River and Green Bay (R/MW-20)

Joseph Delfino & John Sullivan, State Laboratory of Hygiene/Civil & Environmental Engineering, UW–Madison

Through literature reviews and an analysis of the chemicals used and discharged by municipalities and industries in the Lower Fox River basin, these Sea Grant researchers identified more than 500 chemical compounds likely to be found in the Lower Fox-Lower Green Bay aquatic environment. This information was compiled in a 180-page report, *A Select Inventory of Chemicals Used in the Lower Fox River, Wisconsin,* which is now being used by industries and regulatory agencies in Wisconsin and around the nation as a source and as a model to assess the magnitude of organic pollutant problems based on industrial chemical usage.





Yellow perch used in UW Sea Grant aquaculture experiments.

Control of Sexual Differentiation in Yellow Perch, a Representative Coolwater Fish (R/AQ-10)

Clyde Amundson & Terrence Kayes, Food Science, UW–Madison

As with most coolwater fish, the female yellow perch grows faster and bigger than the male. This project tested the possibilities of using sex hormones and related growth-promoting chemicals to control sexual differentiation in fish so more females than males are produced. This information may help greatly improve the efficiency of coolwater fish aquaculture in terms of the pounds of fish produced per unit.

Biological Production in Green Bay Coastal Marshes (R/GB-6)

H.J. Harris, Science & Environmental Change, UW–Green Bay
Wendel Johnson, Biology, UW–Marinette

This project's systematic sampling of the biota of three wetlands—Peters Marsh, Sensiba Wildlife Area and Peshtigo Marsh—has provided a better understanding of these sensitive coastal environments. The data collected on these wetlands' plants, animals and birds is also revealing the effects of natural changes in water levels as well as human perturbations like diking and dredge disposal.

Physical-Chemical Characteristics and Dynamics of Green Bay (R/GB-12)

James Wiersma, Science & Environmental Change, UW–Green Bay

This project provided baseline data against which the effects of future activities on the bay can be assessed. It was shown that the patterns of currents and wind conditions are very important to the quality of the bay's bottom waters. Also, deep water circulation turned out to be more than was previously supposed, and it was learned that the bay's water quality in any given year is directly tied to the weather pattern. This information can be used to test predictive mathematical models of eutrophication and water-mass movement.

Economic Incentives and Barriers to Coastal Wetlands Protection (R/PS-29)

Richard Barrows, Agricultural Economics, UW–Madison

Farmers are often the major opponents of legislative and regulatory efforts to preserve Wisconsin's wetlands—and with good reason. This study showed that a farmer can make a lot more money if he expands his acreage by draining a wetland than if he rents additional dry land. The study included development and application of a conceptual mathematical model of these economic incentives for typical Wisconsin farms. This knowledge will be essential to lawmakers in developing a system to reverse the economic incentives to drain wetlands, perhaps through partial or full compensation to wetland owners.

Development of Underwater Devices (R/OE-8)

Ali Seireg, Mechanical Engineering, UW–Madison

In this project, engineering researchers have designed safer and more efficient equipment to assist underwater divers in the strenuous and often disorienting realm beneath the waves. Their achievements have included development of techniques for improving the design of standard snorkels, air regulators that allow easier breathing and the one-time reuse of exhaled gases, and the design of lighter, stronger scuba tanks.

Development of Remote Sensing Course with Emphasis on the Coastal Resources of Green Bay (E/E-8)

Thomas McIntosh, Science & Environmental Change, UW–Green Bay

This project helped incorporate quantitative techniques of remote sensing by LANDSAT satellite into the instructional, outreach and research programs at UW–Green Bay. This will enhance local use of LANDSAT and related databases to assess temporal changes in land use and quality in the Green Bay watershed, and provide formal academic instruction, short courses or seminars to individuals and agencies interested in remote sensing techniques.

PCB Levels in Human Fluids: Sheboygan Case Study (R/MW-18)

Vernon Dodson & Jill Smith, Preventive Medicine, UW–Madison

Conducted in cooperation with the Sheboygan Public Health Department, this three-year study examined the health of infants exposed to PCBs while in the womb and later in their mothers' breast milk. The data indicate that exposure to high levels of PCBs in the womb resulted in an increased number of infectious illnesses in the first four months of life, though infant development and growth was normal. It appears also that the benefits of breast-feeding outweigh the risks of PCBs in the milk at the levels studied. This study was done in direct response to requests by Wisconsin's Department of Health and Social Services, and Department of Natural Resources, and resulted in a published report, *PCB Levels in Human Fluids: Sheboygan Case Study.*

Trophic Status of Lower Green Bay (R/GB-20)

Paul Sager, Biology, UW–Green Bay

This three-month project was initiated to resolve uncertainty about the water quality status of lower Green Bay by measuring the levels of chlorophyll *a* and two key nutrients (phosphorus and nitrogen), estimating the daily amount of these nutrients entering the bay from the Fox River, and comparing this data to 1969 data to assess recent changes in nutrient/algae conditions in the bay.

The Response of the Hepatic Monooxygenase System of Lake Trout Embryos to PCBs (R/MW-31)

John Lech, Pharmacology & Toxicology, Medical College of Wisconsin-Milwaukee

It has been speculated that one of the reasons stocked lake trout have failed to reproduce naturally in Lake Michigan is that contaminants like PCBs may reach toxic levels in the fish embryos. As a measure of the level of this toxicity, this study examined how much PCB exposure triggered the liver enzyme defenses of trout embryos.

PROJECT STANDING TABLE

N = New Project
C = Continuing Project
F = Completed Project
T = Terminated Project

Living Resources		**1982–83**	**1983–84**
R/GB-7	Factors Influencing the Reestablishment of Self-Sustaining Stocks of Lake Trout in Lake Michigan	C	C
R/LR-17	Keystone Predators in the Great Lakes	C	F
R/LR-18	Bioenergetics of the Great Lakes Bloater (Chub)	C	F
R/LR-22	Daily Growth Rates and Variable Recruitment of Larval Fishes in Lake Michigan	N	C
R/LR-24	Species Interactions and Early Life History Dynamics of Major Planktivores in Lake Michigan	N	T
R/LR-25	The Influence of *Mysis relicta* on Fish Production in Lake Michigan	N	F
R/LR-23	Composition and Productivity of Aquatic Macrophyte Communities in Three Lake Michigan Bays	C	F
R/LR-20	Extending the Storage Life of Whitefish through Lipid Oxidation Studies	C	F
R/LR-21	Safety of Methods of Modified-Atmosphere Packaging of Refrigerated Fresh Fish	F	–
Aquaculture			
R/AQ-8	Basic Husbandry of Great Lakes Fishes	C	C
R/AQ-10	Control of Sexual Differentiation in Yellow Perch, a Representative Coolwater Fish	F	–
R/AQ-9	Assessment of Dietary Amino Acid Requirements of a Representative Great Lakes Fish	C	F
R/AQ-11	Effects of Nutritional and Environmental Stress on Resistance to Disease in Fish	C	C

		1982–83	1983–84
Green Bay			
R/GB-5	Green Bay Subprogram Coordination	C	C
R/GB-14	Vital Statistics and Population Structure of Age I, II and III Lake Whitefish in Green Bay and Northern Lake Michigan	C	F
R/GB-17	The Drop Net Fishery and Its Effects on Yellow Perch Yields in Green Bay	N	F
R/GB-18	The Contribution of Marshlands to the Green Bay Pelagic Food Chain	N	C
R/GB-16	Predator-Prey Models for Green Bay	N	F
R/GB-15	Persistence of Pollutants in the Sediments of Lake Michigan's Green Bay	C	F
R/GB-19	Hydrodynamic and Water Quality Modeling for Lower Green Bay	N	F
Microcontaminants and Water Quality			
R/MW-21	Fate Assessment of Hydrophobic Organic Chemicals in Aqueous Environments	C	C
R/MW-24	Role of Particulate Matter in Controlling Microcontaminant Behavior in Lake Michigan	C	F
R/MW-25	Transport of Microcontaminants into Lake Superior by Suspended Solids	F	-
R/MW-28	Atmospheric Concentrations and Transport of Organic Contaminants across the Air/Water Interface in the Upper Great Lakes	N	C
R/MW-29	Status Reports on Priority Pollutants in the Great Lakes	N	F
R/MW-27	Polychlorinated Dibenzodioxins (PCDDs) and Dibenzofurans (PCDFs) Persistence and Toxicity in Freshwater Fish	C	C
R/MW-30	Detection of Mutagenic and Carcinogenic Effects of Environmental Pollutants in Aquatic Ecosystems	N	F
Policy Studies			
R/PS-30	Management of Great Lakes Water	N	C
R/PS-31	Great Lakes Transportation in the 1980s	N	F
Diving Physiology			
R/NA-11	Physiology of Diving	N	C
R/DP-1	Animal Fetal Response to Decompression	C	F
New Applications			
R/MN-1	Geophysical Assessment of the Hydraulic Connection between Lake Michigan and the Groundwater Aquifers on its Western Boundary	C	F
Advisory Services			
AS/A-1	Advisory Services Coordination and Specialist Activities	C	C
AS/A-14	Advisory Services Field Agents Network	C	C
AS/A-2	Sea Grant Communications	C	C
AS/A-3	Earthwatch Public Service Radio Program	C	C
AS/A-20	Lake Ice and Marina Design Advisory Services	C	C
Education			
E/E-1	Special Education Programs	C	C
Program Administration			
SGA-1	Program Development	C	C
SGA-3	Ship Time in Support of Sea Grant Research Projects	C	C
SGA-2	Program Management	C	C

BUDGETS BY ACTIVITIES

	1982–83		1983–84	
	NOAA	**UW**	**NOAA**	**UW**
Marine Resources Development				
Aquaculture	$ 226,340	$ 67,997	$ 222,835	$ 46,490
Living Resources	82,817	40,413	88,891	43,572
Socio-Economic and Legal Studies				
Socio-Political Studies	38,517	20,555	44,332	22,358
Marine Technology Research and Development				
Ocean Engineering	17,235	9,780	23,430	5,325
Resources Recovery and Utilization	222,374	81,626	225,688	81,830
Transportation Systems	25,152	14,217	39,183	20,270
Marine Environmental Research				
Coastal Management Research	71,784	14,846	72,283	18,626
Ecosystems Research	169,181	76,337	200,956	92,287
Pollution Studies	237,465	174,610	245,305	139,133
Environmental Models	91,000	43,911	96,615	48,812
Marine Education and Training				
Education	25,733	26,642	30,001	25,823
Advisory Services				
Extension Programs	194,506	76,489	203,828	81,937
Other Advisory Services	289,527	112,264	242,911	123,044
Program Management and Development				
Program Administration	155,132	213,303	141,722	222,053
Program Development	53,237	27,010	22,020	28,440
TOTAL	**$1,900,000**	**$1,000,000**	**$1,900,000**	**$1,000,000**

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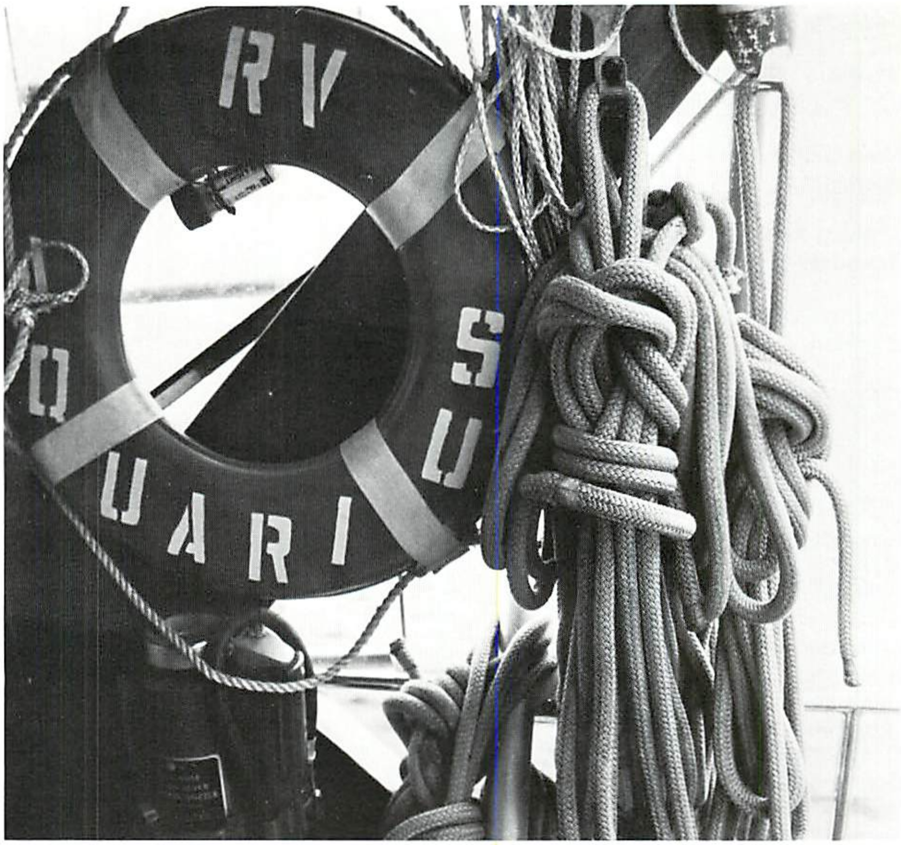

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Gone fishin'.

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