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A Century of Great Lakes Research at the University of Michigan

Alfred M. Beeton[1*] and R. Stephen Schneider[2]

[1]*U. S. Department of Commerce*
National Oceanic and Atmospheric Administration
Office of the Chief Scientist
14th and Constitution Avenue, N.W.
Washington, D.C. 20230

[2]*University of Michigan*
Center for Great Lakes and Aquatic Sciences
501 East University
Ann Arbor, Michigan 48109-1090

ABSTRACT. *The University of Michigan has had a long and productive history of promoting, enhancing, and facilitating research on the Laurentian Great Lakes. This interest in Great Lakes research was evident before the turn of the century under the leadership of Prof. Jacob E. Reighard. Early research was primarily concerned with fish and fisheries. The emphasis on fisheries started to shift to basic limnological research after the 1920s when Prof. Paul S. Welch started a limnology course and wrote his book* Limnology. *His student, Prof. David C. Chandler, returned to the University in 1953 to chair the Council of the Great Lakes Research Institute, and subsequently became the Director of the Great Lakes Research Division in 1960. The emphasis was and has been on basic and applied research involving a broad spectrum of disciplines. The published contributions include biology, chemistry, geology, meteorology, paleolimnology, physical limnology, pollution, radiolimnology, and integrated studies. Among the University's many contributions to furthering Great Lakes research was the origination of the Conferences on Great Lakes Research, started in 1953. Publications of the* Proceedings *of these conferences provided a valuable reference to research in the 1950s and 1960s. These conferences led to the formation of the International Association for Great Lakes Research and subsequently the* Journal of Great Lakes Research. *The University acquired several research vessels. The earliest large vessel acquired was the* Inland Seas *(1960) which was replaced by the* Laurentian *in 1974. A research submersible was brought into Lake Michigan for evaluation by the Great Lakes Research Division in 1966. At about this time Michigan Sea Grant Program was started in 1969 and the Coastal Zone Laboratory in the 1970s. More recently the Cooperative Institute for Limnology and Ecosystem Research was created in 1989 as a partnership among the University, Michigan State University, and the Great Lakes Environmental Research Laboratory of the National Oceanic and Atmospheric Administration. Much of the Great Lakes research activity at the University was realigned into several colleges and schools in the late 1980s. Great Lakes research at the University has passed through a number of reorganizations, and now exists as the Aquatic Research Programs of the University of Michigan Biological Station.*

INDEX WORDS: *Great Lakes, University of Michigan, history, Great Lakes Research Division, Michigan Sea Grant, CILER, limnology, Chandler, Welch, Reighard, Conferences on Great Lakes Research.*

INTRODUCTION

The University of Michigan has a long and prominent history of research on the Laurentian Great Lakes. Its inland location at Ann Arbor, far from Great Lakes water, would seem to be a deterrent to such interests, even though the State of Michigan has over 3,200 miles of shoreline bordering on Lakes Michigan, Superior, Huron, and Erie. The true motivation for its involvement has not been geographical, but rather the interests, activities, and foresight of prominent faculty such as Jacob E. Reighard, Paul S. Welch, Carl L. Hubbs, and David C. Chandler. These are but a few of the

*Corresponding author. E-mail: alfred.beeton@mci2000.com

many faculty who have both guided and advanced the University's interest in Great Lakes matters, and nurtured students who would do the same, both at the University and throughout the Great Lakes area. It is impossible in a short article to describe the important contributions made by the many hundreds of scientists who have researched and taught at the University over the years. This paper only touches on some high points of the progression of Great Lakes activities at the University, and apologies are offered to those many contributors who, of necessity, have been neglected.

The goal of this paper is to present an understanding of how research on the Great Lakes became important to the faculty, staff, and students of the University of Michigan and in turn how this research became important in the region to state and federal agencies, the research community, the public, and industry.

EARLY DIRECTIONS

Jacob Reighard (1861–1942) (Fig. 1) probably had the greatest early influence on research on the Great Lakes. He received his MA at the University of Michigan in 1878 and his Ph.D. at Harvard in 1884, where he had been a student of Alexander Agassiz. He returned to the University of Michigan in 1886, and served as the Director of the Museum of Zoology from 1895 to 1913. His explorations of Michigan's fishes eventually focused on diversity of inland fish behaviors; Great Lakes fish identities had been mostly worked out by Louis Agassiz.

In the late nineteenth century, Lake St. Clair suffered a drastic decrease in its population of whitefish, which greatly concerned the Michigan Fish Commission, the state institution then responsible for such matters. Reighard's particular interest in fish behavior and habitat selection prompted him to work closely with the Michigan Fish Commission to organize a study of Lake St. Clair in 1893. In this study (Reighard 1894) he emphasized the need "to study carefully and in the broadest possible way the life of the lake." His linking of a broad understanding of the ecosystem with practical management problems is well summarized in his presentation to a meeting of the American Fisheries Society (Reighard 1899): "Is it not better . . . to take up the study of the biology of the lakes from the point of view of pure science for the purpose of finding out as far as possible of the facts and making clear as many as possible of the principles? Then when, in the future, any fisheries problems arise, the facts

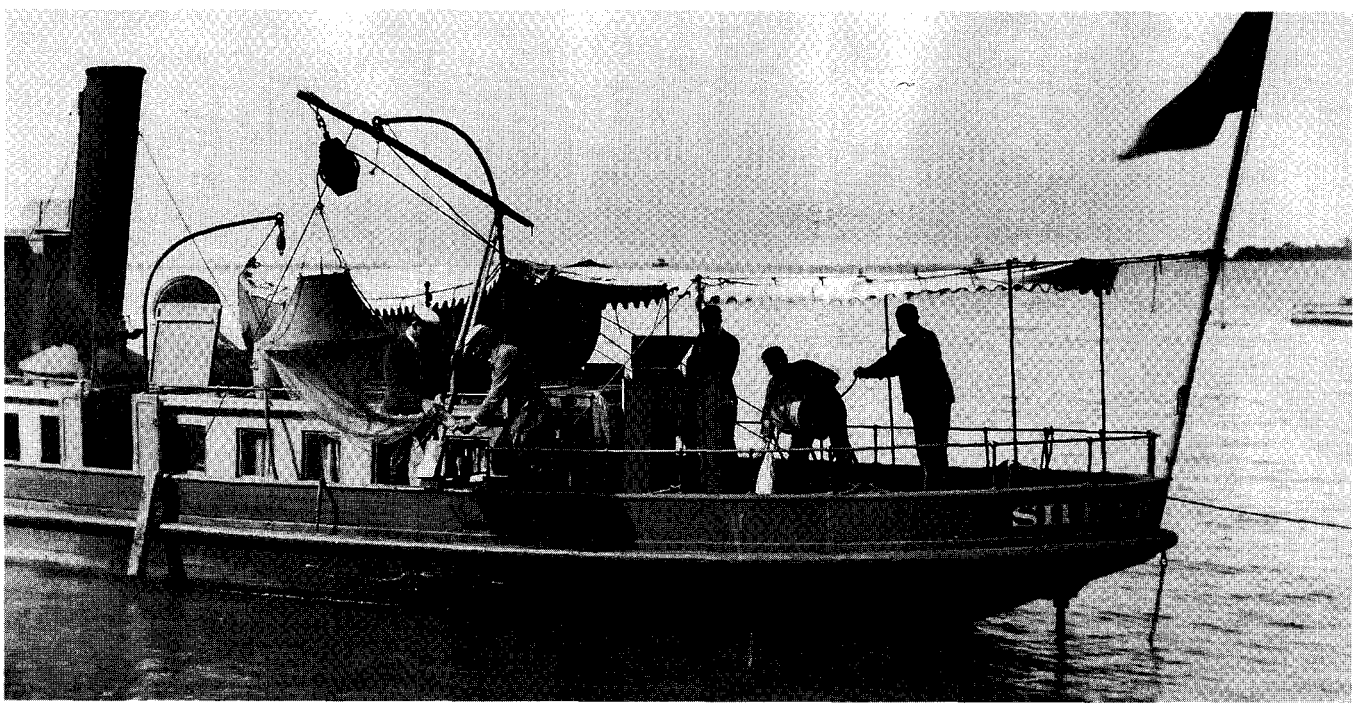

FIG. 1. Jacob Reighard examines a phytoplankton net aboard the **Shearwater** *in 1901. Photo courtesy of Bentley Historical Library, University of Michigan.*

and principles for their solution will have been already determined in large part." In 1900, Jacob Reighard led an effort to have the Board of Regents establish a biological station to promote the study of plants and animals in their natural habitat. In 1909 the station was established at Douglas Lake, near Petoskey, Michigan, with Reighard as its first director. This station was to significantly impact later Great Lakes research at the University.

Reighard's Lake St. Clair study became a model for lake and stream surveys emphasizing the measurement of environmental factors affecting fish and associated biota (Chandler 1963). A closely similar study was undertaken on Lake Michigan in the vicinity of Charlevoix in 1894 (Ward 1896). These were truly collaborative studies, a type of effort the University would continue to pursue in the future, and they brought together many of the aquatic biologists prominent at the turn of the century, such as Reighard, H. B. Ward, Frank Smith, Charles Kofoid, E. A. Birge, C. Dwight Marsh, and H. S. Jennings. David C. Chandler (1963) stated, "These studies represented the first serious investigation of the Great Lakes and established a philosophy and design of lake survey that was to be followed in the state for the next several decades."

Reighard helped organize the Great Lakes Laboratory of the U. S. Bureau of Commercial Fisheries (initially under John Van Oosten), which in 1927 was housed in the University of Michigan Museum. Reighard also conceived of the Institute of Fisheries Research (IFR), established later as a branch of the Michigan Department of Conservation (initially under Carl Hubbs and John R. Greeley). IFR was also housed in the University of Michigan Museum. Starting in 1950, these two agencies were housed in a building near the Museum that had been converted to a laboratory. To promote interaction between these agencies and the University, Reighard helped organize the University's Research Club and the Michigan Academy of Science, Arts, and Letters. Over the years, the University has continued the policy of attracting Great Lakes organizations to Ann Arbor by offering them space in which to get started. The agency appreciation of the advantages of this were recognized early on. Elmer Higgins, in his Bureau of Fisheries report on "Progress in biological Inquiries 1927" (Higgins 1928) said "The advantages of maintaining headquarters for field workers in universities, where laboratory facilities are excellent and access may be had to great libraries, are obvious, and the cooperation of such institutions is appreciated greatly." The Great Lakes Commission, created in 1955 and housed then in the University's Institute of Science and Technology, still maintains its offices on the University campus. The U.S. Bureau of Commercial Fisheries (now the Great Lakes Science Center) built its laboratory on the University's North Campus in 1965, on land sold to the Bureau by the University for $1. The presence of these various agencies in Ann Arbor attracted other Great Lakes organizations to the area, including the Great Lakes Foundation, the Great Lakes Basin Commission, the Great Lakes Fishery Commission, and the NOAA Great Lakes Environmental Research Laboratory.

THE NEXT GENERATION

Jacob Reighard's students included some of the great biologists of the early 20th century: J. B. Johnston, Raymond Pearl, A. G. Ruthven, Max Peet, J. Speed Rogers, Peter Okkelberg, C. P. Hickman, Frank Blanchard, and Walter Koelz. The most notable of Koelz's several Great Lakes publications is "Coregonid fishes of the Great Lakes" (1929). Over 340 pages long, it includes fold-out bathymetric maps of each of the Great Lakes and an immense quantity of statistics on coregonid fishes from many of the major Great Lakes landings. Systematics, morphological variation, ecology, food, spawning habitats, and evolutionary hypotheses are included in this work, which is still among the standard references on these fishes. Other students of Reighard were to play important roles in the Great Lakes research community. John Van Oosten became the first director of the U. S. Bureau of Fisheries laboratory on the Great Lakes in 1927, and served it until 1950. This laboratory (now the Great Lakes Science Center of the U. S. Geological Survey) has had a distinguished record and has been sited on the University's campus since its formation. Another student of Reighard with Great Lakes interests was Thomas H. Langlois, who directed the Great Lakes program at the Franz Theodore Stone Laboratory of Ohio State University at Put-in-Bay, Lake Erie, from 1938 to 1955. On this lab's staff was David C. Chandler.

The next generation of University of Michigan fish biologists was brought together by Carl L. Hubbs of the Museum of Zoology. Hubbs' students and associates studied fishes of the Great Lakes and tributary waters. This group included C. Willard Greene who studied Wisconsin fishes (including Lakes Superior and Michigan) and Milton Trautman, who studied Ohio fishes (including Lake

Erie). Among Hubbs' students who contributed to Great Lakes studies were Gerald Cooper (Michigan Department of Natural Resources), Fenton Carbine (Institute for Fisheries Research and Regional Director of the U.S. Bureau of Commercial Fisheries), Karl Lagler (School of Natural Resources and Great Lakes Research Division), who with Hubbs wrote many editions of *Fishes of the Great Lakes Region* (Hubbs and Lagler 1947), Reeve Bailey (Museum of Zoology), Jan Metzlaar (who died at age 29, swept overboard while working on the Great Lakes), Edwin and Charles Creaser, Ruben Eschmeyer, Walter Crowe (Michigan Department of Natural Resources), and Henry van der Schalie (molluscs). J. B. Burch, van der Schalie's student, continues the study of Great Lakes molluscs in the University Museum. The next generation of Great Lakes fish students, under Bailey and Lagler, included Gerald Smith of the Museum of Zoology and Stanford Smith of the School of Natural Resources and the U.S. Bureau of Commercial Fisheries.

Research in the Great Lakes at the University was a natural consequence of early interest in natural history and ecology which led to development of limnology as a discipline. Paul S. Welch (Fig. 2) offered the first limnology course at the University of Michigan Biological Station in 1923, and five years later he offered it on campus in Ann Arbor. His book, *Limnology*, was the first comprehensive text on the subject published in the United States (Welch 1935). Paul Welch's interest in Great Lakes science was transmitted to two of his students: James W. Moffett was to become director of the Great Lakes Fishery Laboratory of the U.S. Bureau of Commercial Fisheries (formerly the U.S. Bureau of Fisheries), and David C. Chandler (Fig. 3) was to become the director of the University's Great Lakes Research Division and guide many more students (Table 1) into the mysteries and delights of aquatic sciences, including the Great Lakes. Added to the students in Table 1, although he was not one of Dr. Chandler's Michigan doctoral students, should be George H. Lauff. George Lauff was Dr. Chandler's student at Cornell University. and came to the University of Michigan with him. The influence of Paul S. Welch is also evident in the research and publications of his student Frank E. Eggleton. Eggleton conducted the first truly quantitative study of the benthos of the Great Lakes in cooperation with the U.S. Bureau of Fisheries (Eggleton 1936). Welch's influence is evident in Eggleton's publication on the importance of the benthos to lake productivity (Eggleton 1939) in which he presents his ideas, which essentially represent an ecosystem approach, although he refers to the "microcosmic economy" of a lake. Eggleton recognizes that Welch (1935) had stated that biological productivity was "the central influence" of limnology.

FIG. 2. Paul S. Welch. Photo courtesy of Bentley Historical Library, University of Michigan.

The year 1953 saw the arrival on the Ann Arbor campus of David C. Chandler, a Professor of Zoology brought from Cornell University, who would go on to become Senior Scientist of the Great Lakes Research Institute, Chairman of the Council of the Great Lakes Research Institute, and first Director of the Great Lakes Research Division. David Chandler, like Paul Welch, was interested in pursuing basic science. But the vicissitudes of funding and the necessity of being able to answer environmental questions of applied science to resolve state problems would bring change to that.

FIG. 3. David C. Chandler, Director of the Great Lakes Research Division, examines the camera on the research submersible **Star II.** *Photo by R. Stephen Schneider.*

TABLE 1. David C. Chandler's Michigan doctoral students' dissertations were indicative of his wide-ranging interests, as well as theirs.

STUDENT	YEAR	DISSERTATION TITLE
Sumner Richman	1957	The transformation of energy by *Daphnia pulex*
Francesco B. Trama	1957	The transformation of energy by an aquatic herbivore *Stenonema pulchellum* (Ephemeroptera)
Alfred M. Beeton	1958	The vertical migration of *Mysis relicta* in Lakes Huron and Michigan
George W. Saunders	1958	The application of radioactive tracers to the study of lake metabolism
Claire L. Schelske	1960	The availability of iron as a factor limiting primary production in a marl lake
Roger Werner Bachmann	1961	An experimental study of the freshwater zinc cycle
Clyde Hedman Eriksen	1961	Respiration and substrate as factors influencing the distribution of the burrowing mayflies *Ephemera simulans* and *Hexagenia limbata*
Jack Stanton Marshall	1961	The effects of continuous gamma radiation on the intrinsic rate of natural increase of *Daphnia pulex*
Robert A. Main	1961	The life history and food relations of *Epischura lacustris* Forbes (Copepoda:Calanoida)
George Richard Marzolf	1962	Substrate relations of the burrowing amphipod *Pontoporeia affinis* Lindstrom
Andrew Robertson	1964	A method for studying herbivore standing crop with the continuous plankton recorder

ORGANIZATIONAL SUPPORT FOR RESEARCH

Great Lakes Research Institute

In May of 1945, the Regents of the University of Michigan established the Great Lakes Research Institute for the "encouragement and integration of studies of the physical, chemical, biological, and other aspects of the Great Lakes and related areas." Thus form had been added to the considerable substance developed since the 19th century. The GLRI was guided by a Council, composed of members with academic interests ranging from astronomy to zoology. The Council considered GLRI a research organization in the broadest sense. It was first dedicated to the implementation of the University's relevant teaching and research programs. It emphasized the development of basic information, on topics such as water circulation and water quality, which was needed to assist in the management of the Great Lakes. Economic realities limited the Institute's activities to the summer, with a small staff, using chartered vessels.

Great Lakes Research Division

By 1960, the Institute had become too diverse in its interests to be administered by a traditional department. After consideration of many alternatives, GLRI was reorganized as the Great Lakes Research Division (GLRD) of the Institute of Science and Technology (IST). This decision was undoubtedly influenced by the long-standing interest in the Great Lakes of James T. Wilson (Geology), who was then Associate Director of IST. This association with IST provided GLRD with strengthened financial support and expanded laboratory, administration, and equipment facilities. GLRD's years under Dave Chandler, from its creation in 1960 until Chandler's retirement in 1972, were to prove among the most productive and innovative in the University's history. GLRD was directed by Claire L. Schelske from 1973 to 1976, a period of program and personnel expansion.

Great Lakes and Marine Waters Center

In 1976 an umbrella organization, the Great Lakes and Marine Waters Center (GLMWC) was created to include Michigan Sea Grant, the Coastal Zone Laboratory, GLRD, and other related units. This organization was directed by Alfred M. Beeton, who had come from the Center for Great Lakes Studies, University of Wisconsin-Milwaukee. The combination of the various programs added a substantial element of applied and socially oriented research to an organization previously committed to the physical and biological sciences. GLMWC was dealt a blow by the dismemberment of its parent organization, IST, in 1986. Alfred Beeton then left to become Director of NOAA's Great Lakes Environmental Research Laboratory, and the Directorship descended upon Robert G. Wetzel (1986–1987), and then on Interim Directors Eugene F. Stoermer (1987–1988), and David K. Rea (1988–1989). The period 1986 to 1989 saw the realignment of GLMWC's programs into different university schools. Program losses were paralleled by personnel losses.

Center for Great Lakes and Aquatic Sciences

In 1989 the Great Lakes Research Division was renamed the Center for Great Lakes and Aquatic Sciences (CGLAS), and Theodore C. Moore was hired as the Director. Although by this time the Center's assets had been seriously reduced, it maintained operations of the R/V *Laurentian* and some components of its previous laboratory base, and its scientists expanded their affiliations with other schools and units as well as their public outreach and education efforts.

As of 1 July 1998, CGLAS joined with the University of Michigan Biological Station and Russell A. Moll assumed responsibility for aquatic programs of the Station, including the operation of the R/V *Laurentian*.

Coastal Zone Laboratory

In 1973 the University of Michigan Coastal Zone Laboratory was contracted by the State's Department of Natural Resources to participate in a program to take "action to avert catastrophic consequences" of shoreland erosion. The program placed a special emphasis on helping shoreline land owners make effective decisions regarding the protection of their property from erosion. Fifteen demonstration sites were selected throughout the state by Ernest F. Brater, who had been studying Great Lakes shore processes for many years, and Coastal Zone Lab Director John M. Armstrong. Each demonstration project represented a different approach to low cost, effective shore erosion control on a different shore type, situated in Lakes Michigan, Superior, and Huron. After completion of construction, the effectiveness of the various

structures was monitored through various storm events. The results of the tests were published and distributed to concerned citizens through workshops and distribution of printed materials.

Michigan Sea Grant

In 1966, Congress instituted a new federal approach to marine research and outreach with the creation of the Sea Grant Program in the National Science Foundation. Later it became part of the National Oceanic and Atmospheric Administration (NOAA), Department of Commerce. Recognizing that the nation's water resources are as important to it as its agricultural resources, Sea Grant was established to parallel the long-established and successful Land Grant Program. The Michigan Sea Grant Program was established at the University of Michigan in 1969 with a three part program of research, education, and advisory services. Over the years it has initiated many innovative and beneficial projects. Among the most famous is the discovery of techniques to revive cold water drowning victims. In 1975 a university medical doctor resuscitated a teenager who had been under water for nearly 40 minutes following a car accident. The doctor wondered if this was a fluke, or an indication of a natural recuperative process that could be tapped routinely to revive people who were assumed to be drowned. Michigan Sea Grant funded his investigations, which led to development of cold water near-drowning resuscitation techniques that are used world-wide today to save lives. This project epitomized the Sea Grant concept: funding for important research followed by a vigorous education effort to get the information into the hands of those who can use it. Today, conservative estimates indicate that over 1,500 lives have been saved in the U.S. alone by this project (NOAA Sea Grant 1998). Michigan Sea Grant College Program, today a cooperative program with Michigan State University, supports Great Lakes research at a number of Michigan universities.

CILER—Strengthening Cooperation

In 1989 a Memorandum of Understanding between the University of Michigan, Michigan State University, and the Environmental Research Laboratories (ERL) of the National Oceanic and Atmospheric Administration (NOAA) established the Cooperative Institute for Limnology and Ecosystems Research (CILER). The Institute is based at the University of Michigan, and undertakes cooperative oceanic and atmospheric research involving university researchers throughout the Great Lakes basin and researchers at NOAA's Great Lakes Environmental Research Laboratory in Ann Arbor. Currently CILER has more than 70 Fellows from 15 Great Lakes universities who represent almost every phase of limnological and atmospheric research. According to CILER Director Guy Meadows, "collaboration between the universities and NOAA provides an interdisciplinary approach and a pooling of resources required to address the complex environmental problems facing the Great Lakes and coastal oceans. This cooperative approach will help develop better scientific understanding and help improve prediction."

THE CONFERENCES ON GREAT LAKES RESEARCH AND IAGLR

In 1953 the Great Lakes Research Institute hosted the first Conference on Great Lakes Research, held at the University of Michigan Biological Station at Douglas Lake. Clearly, the Council recognized the need for broad-scale interdisciplinary exchange of information. The first Conference on Great Lakes Research focused on the upper Great Lakes, and was attended by some 35 scientists from the various university, federal, and state organizations who were actively involved in Great Lakes research. Attendees presented progress reports on their work in the disciplines of hydrology, meteorology, geology, limnology, and fisheries. This conference was the precursor of what has now become the annual Conference on Great Lakes Research, hosted by the International Association for Great Lakes Research, and attended by up to 700 people each year.

David Chandler, in the spirit of the First and Second Conferences, recognized the need to undertake basin-wide research and involve government agencies as well as academia in Canada and the United States. Consequently, he worked closely with G. B. Langford, Great Lakes Institute, University of Toronto, to have the Fifth Conference on Great Lakes Research held at the University of Toronto. This conference was the first occasion on which one of the series was not held at the University of Michigan. Chandler believed in closer ties with Canadian and U.S. agencies and helped establish the Great Lakes Study Group which included Canadian and U.S. agencies as well as the two universities. This Study Group encouraged the

establishment of the Great Lakes Regional Data Center at the U.S. Lake Survey, Army Corps of Engineers. The Study Group also established an International Committee on Scheduling of Ships and Facilities in 1968, chaired by J. P. Bruce, Canada Centre for Inland Waters, and R. J. Walton of the U.S. Lake Survey. The idea was to exchange information and coordinate field programs involving ships, aircraft, and other observation platforms, an idea that was revisited recently by the Great Lakes research community when it held the Great Lakes Research Vessel Coordination Workshops in March 1997 and 1998.

In February 1966 David Chandler prepared a draft of bylaws for an "International Association for Great Lakes Research" (McNaught 1993). Formal responses to this initial draft were prepared by Study Group members Alfred Beeton, Marvin Fast, and William Nichols. In the fall of 1966 the bylaws were adopted and a Board of Directors chosen. In January of 1967 the Board, composed mostly of Study Group members, met for the first time. At the 10th Conference on Great Lakes Research, in April of 1967 in Toronto, David Chandler was chosen President of IAGLR (McNaught 1993).

GREAT LAKES PUBLICATIONS — REFLECTING TRENDS IN RESEARCH

At the conclusion of the first Great Lakes Conference in 1953 it was determined that "a committee of four will prepare a final report which will be duplicated and distributed by mail." That humble beginning was to develop into the *Proceedings* of the annual Conference on Great Lakes Research, production of which was overseen by Margaret N. Everett, Administrative Assistant to David Chandler, and underwritten by the Great Lakes Research Institute and later by the Great Lakes Research Division. The *Proceedings* would eventually grow, under the direction of the International Association for Great Lakes Research, into the *Journal of Great Lakes Research*, an internationally respected peer-reviewed journal.

Many of the accomplishments and contributions to Great Lakes research made by the University of Michigan faculty, staff, and students can be found in their input to the Publication Series, Special Report Series, and Contributions Series (papers published in various journals) of the Great Lakes Research Institute and its three successors, the Great Lakes Research Division, the Great Lakes and Marine Waters Center, and the Center for Great Lakes and Aquatic Sciences. Publications authored by faculty and students from departments in several colleges and schools are not included in the above three series.

The Publication Series commenced in 1956 with a paper on "Currents and water masses of Lake Huron" (Ayers *et al.* 1956) and ended in 1986 with the major report "Southeastern nearshore Lake Michigan: impact of the Donald C. Cook Nuclear Plant" (Rossmann 1986a). Of the 22 publications in this series, six were the *Proceedings* of the third through eighth Conferences on Great Lakes Research.

The Special Report Series commenced in 1953 with a summary of the first Great Lakes research conference, entitled The Great Lakes and the University of Michigan. This series ended in 1988 with the publication of Special Report 124 "Drift of zooplankton, benthos, and larval fish and distribution of macrophytes and larval fish in the St. Marys River, Michigan, during winter and summer, 1985" (Jude *et al.* 1988). Fourteen of the reports were general summaries, *Proceedings* of the first and second conferences on Great Lakes research, or dealt with no Great Lakes research.

The University faculty, staff, and students published over 600 papers in journals from 1958 through 1997. The first contribution number was assigned to a paper on artificially created marshes (Cook and Powers 1958). Most of the contributed papers dealt with research on the Great Lakes, but 124 dealt with research on other ecosystems.

Publications in the Contributions and the two publication series as well as publications from other faculty and students fall into nine research areas, i.e., biology, chemistry, geology, integrated studies, meteorology, paleolimnology, physical limnology, pollution, and radiolimnology. Much of the research has been biological, and biology can be subdivided into algology, zooplankton, benthos, fish, and non-indigenous or exotic species.

Physical Processes

Major contributions were made by University of Michigan scientists toward our understanding of the currents and water masses of the Great Lakes. Prior to the 1950s, few studies had dealt with physical processes other than water levels and the effects of tides and seiches on water levels and thermal structure and cycles (Beeton and Chandler 1963). The need to understand physical processes was recognized by the Council of the Great Lakes Research

Institute. Prof. David C. Chandler stated at the Third Conference on Great Lakes Research that there was "general recognition that the Great Lakes are essentially small oceans and require oceanographic equipment and methods for their proper study." (Chandler 1960, p. 2). Several oceanographers, including William S. von Arx, Clarence M. Cross, and Alfred C. Redfield, were invited to participate on a panel "Survey of the present and recommendations for the future" (In *Proc. Third Conf. Great Lakes Res.*, pp. 151–160, 1960).

Physical studies were the main emphasis of the Great Lakes Research Institute in the 1950s. All the publications from those years dealt with currents and water masses and methods and techniques for studying the physical processes. Most of the research was under the leadership of John C. Ayers. He applied methods developed for the oceans such as the dynamic height method for determination of currents (Ayers 1956), although in later years the method had limited use due to recognition of large internal waves in the lakes. The application of the synoptic survey approach to determine currents and water masses of an entire lake was successfully used to study Lake Huron (Ayers *et al.* 1956) and Lake Michigan (Ayers *et al.* 1958). The Lake Michigan study documented for the first time the extent of a major upwelling on the east shore of the lake. Research on physical limnology was enhanced when Vincent E. Noble joined the Great Lakes Research Institute/Great Lakes Research Division and undertook studies of the thermal structure of Lake Michigan (Noble 1965) and horizontal diffusion (Noble 1961). At about the same time Frank E. Bellaire began to publish on his research in wind driven currents in the lakes (Bellaire 1963). Physical limnology research continued to be a dominant activity throughout the 1960s and 16 papers were published comprising 23 percent of all publications from the Great Lakes Research Division. By 1970 the interest in physical limnology had declined and only seven papers were published, mostly by J. C. K. Huang, who published on thermal currents (Huang 1971a) and eddy diffusivity in Lake Michigan (Huang 1971b). Few publications on physical limnology occurred after the 1970s.

Meteorology

Meteorological research became a major interest and was almost as important as physical limnology in the 1960s. The initial studies were primarily concerned with atmospheric diffusion and largely dealt with practical problems of point sources, e.g., the research of Brock and Hewson (1963). Another interest was in developing improved techniques for measuring atmospheric diffusion (Bierly and Gill 1963), and wind and temperature profiles over water (Portman 1960). Subsequent research dealt with aerosols and their effect on water quality as a result of the recognition that atmospheric transport was important for carrying pollution to the lakes (Loucks and Winchester 1970, Winchester and Nifong 1971). No major atmospheric studies were carried out after the 1970s.

Geology

Jack L. Hough was largely responsible for the emphasis on geological research in the early 1960s (Hough 1962, 1966), primarily dealing with further elucidation of glacial history of the Great Lakes. William Farrand (1969) published on the Quaternary history of Lake Superior. Subsequent studies were concerned with the sedimentary environment and involved a number of researchers, e.g., the research by Callender (1969) and Rea *et al.* (1980). The discovery of manganese nodules in Lake Michigan in the 1960s (Rossmann and Callender 1968) led to speculation that potential existed for mining the nodules (Callender 1970). Sediments were still of importance in the 1970s but interest had shifted to coastal erosion (Seibel and Maresca 1975) and recession (Gray and Wilkinson 1979). Geological studies turned to the nature of the sedimentary environment in the 1980s and dealt with petroleum hydrocarbons (Meyers *et al.* 1980), hydrophobic organic materials (Meyers and Kawka 1982), and heavy metals in pore water (McKee *et al.* 1989).

Chemistry

Chemistry was of obvious importance in some of the geological research (Rossmann and Callender 1969) and those efforts concerned with aerosols (Loucks and Winchester 1970) in the 1960s and 1970s. A number of studies can be categorized as chemistry *per se*. Publication of chemistry papers never exceeded 7.5 percent of the total papers in 1960 to 1990. James R. Kramer undertook studies which were truly chemical, e.g., his publications on chemistry of Lakes Erie and Ontario (Kramer 1967) and subsurface brines and mineral equilibria (Kramer 1969). John W. Winchester followed with research on chemical equilibria of iodine (Winches-

ter 1970). Trace elements continued to be of interest and research was undertaken on the sources of trace metals (Robbins *et al.* 1972). Ronald Rossmann continued inorganic chemistry research on particulate matter and trace elements in the 1980s (Rossmann 1986b, Rossmann and Barres 1988). Several studies were undertaken on silica, largely because of its importance as a nutrient for diatoms and its importance in eutrophication (Conley *et al.* 1986; Conley 1988; Schelske and Stoermer 1971, 1972). G. J. Keeler undertook extensive research on photoproduction, atmospheric deposition, and uptake by plants of mercury in the 1990s.

Radiolimnology

In 1970 GLRD began collaborating with the Radiological and Environmental Research Division of Argonne National Laboratory (RER-ANL) in using natural and fallout radionuclides to characterize physical and biogeochemical processes in the Great Lakes. That collaboration, particularly between John Robbins at GLRD and David Edgington at RER-ANL, continued into the late 1970s and resulted in major contributions to the growing field of radiolimnology. Among the most significant contributions was the development of the lead-210 method for dating recent sediments following a suggestion made by Goldberg (1963) almost a decade earlier. Sediments of Lake Michigan were among the first to be dated (Robbins and Edgington 1972, 1975) by what would become one of the most widely used methods in paleolimnology. The technique was applied to interpret manganese profiles in Lake Michigan sediments (Robbins and Callender 1975) and the study became a textbook example of modeling diagenesis of redox-sensitive elements (Berner 1980). Lead-210 dated sediments from Michigan were shown to hold time-records of loading of such contaminants as lead (Edgington and Robbins 1976a) and the long-lived radionuclides, cesium-137 and plutonium 239/240, originating from atmospheric testing of nuclear weapons (Edgington and Robbins 1975, 1976b). Lead-210 dating was used to verify the ragweed (Ambrosia) pollen horizon chronologies in sediments from Lakes Erie and Ontario (Robbins *et al.* 1978).

Another important outcome of the radiolimnological research at GLRD was the recognition and quantitative treatment of surface sediment mixing processes in the Great Lakes. Radionuclide profiles were used to determine depths and eventually rates of sediment mixing (Edgington and Robbins 1975, 1976b) most likely caused by the action of benthic organisms (Robbins *et al.* 1977, Krezoski *et al.* 1978). Initially the mixed layer thickness was recognized as limiting the time resolution with which historical records could be reconstructed from sediment cores (Edgington and Robbins 1976a, b; Robbins 1982). But during the 1980s, it was also recognized that the time of residence of particles in the sediment mixed-layer ultimately controlled the persistence of nutrients and contaminants in water (Robbins 1982). Thus the mixed-layer became a major component in whole-lake mass balance models while notions of surface mixing were translated into the first quantitative, species-specific sediment transport models (Fisher *et al.* 1980) incorporating particle-selective effects (Robbins 1986). A spin-off from field studies of benthos altered radionuclide profiles was the development at GLRD of the first gamma-scan system in collaboration with David White in the School of Natural Resources at the University of Michigan. This device used sediments labelled with gamma-emitting nuclides to quantitatively track their redistribution in microcosms inoculated with various infaunal macrobenthic species (Robbins *et al.* 1979). The scanner was used to determine sediment mixing rates by organisms (Krezoski and Robbins 1985), the influence of organism mixing on solute transport (Krezoski *et al.* 1984), and the effects of varying dissolved oxygen levels (Robbins *et al.* 1984) and temperature (White *et al.* 1987).

Biology

Research on the biology of the Great Lakes, especially Lake Michigan, became dominant in the 1970s and has continued its dominance into the 1990s. In the 1960s, publications on biology (20%) were almost as numerous as research publications in physical limnology (23%) and meteorology (21%). Research on algae and benthos formed the major interests in the 1960s. Fishery research became increasingly important in the 1980s and into the 1990s. The invasion of the zebra mussel, *Dreissena polymorpha*, in the late 1980s led to increased attention to research on non-indigenous species in the 1990s.

Algology

The future of algology research was determined when Eugene F. Stoermer joined the Great Lakes Research Division in 1965. A few studies were

published by researchers other than Stoermer, but publications by Stoermer were dominant. His contributions were in diatom taxonomy, ecology, and distribution, and in paleolimnology. He also participated in a number of integrated studies. The nature of his studies was evident in his publication in the 1960s "Plankton diatom assemblages in Lake Michigan" (Stoermer and Yang 1969). In the 1970s algology studies contributed to research on eutrophication (Stoermer *et al.* 1978). During the 1970s algology research dominated the biology and accounted for 20 percent of the publications. By the late 1970s the diatom flora was fairly well known (Stoermer and Kreis 1978). A number of students studied with Stoermer, e.g., Russell Kreis, Gary Fahnenstiel, and Edward Theriot. Stoermer and Theriot published several papers on taxonomy of diatoms in the 1980s, e.g., Theriot and Stoermer (1982). During this period Auer and Canale (1982) undertook extensive research on *Cladophora*. Research was also underway on filamentous algae (Graham 1982). The relative importance of algology research on the Great Lakes declined in the 1980s and into the 1990s as fishery research gained greater prominence, and Stoermer had extended his studies to other ecosystems.

Zooplankton

Zooplankton research did not gain the importance of phytoplankton research in the 1960s; only about two percent of the publications were concerned with zooplankton. Nevertheless, some important contributions were made by Andrew Robertson (e.g., Robertson 1966). Much basic research was needed in these early years and Sharon Czaika and Andrew Robertson (1968) made a valuable contribution in their publication "Identification of the copepodids of the Great Lakes species of *Diaptomus* (Calanoida, Copepoda)."

By the 1970s, zooplankton research had grown in importance and made up eight percent of the total publications. Research results were beginning to deal more with ecology (Kerfoot 1974) and behavior of zooplankton (Saunders 1969) than with occurrence and distribution. Prof. Chandler had long recognized the importance of opossum shrimp, *Mysis relicta*, to the ecology of the Great Lakes and he encouraged his student, Alfred M. Beeton, to undertake studies of its life history and vertical migration (Beeton 1960) in the 1950s. The results of these studies were added to and enhanced by students of Beeton in the 1970s and 1980s (Morgan and Beeton 1978, Grossnickle and Beeton 1979, and Beeton and Bowers 1982). Marlene Evans joined the Great Lakes Research Division in the 1970s and many of the zooplankton studies in the late 1970s and subsequent years were due to her work, especially those studies concerned with entrainment and effects of discharge from the Donald C. Cook Nuclear Plant on the southeastern shore of Lake Michigan (Evans 1975, 1981). During the 1970s and into the 1980s it appeared that some significant changes may have been occurring in the zooplankton as a consequence of eutrophication and invasions of non-indigenous species (Evans and Jude 1986).

Zooplankton publications made up 11 and 10 percent of the total publications in the 1980s and 1990s. The publication "Historic changes in Lake Michigan zooplankton community structure: the 1960s revisited" (Evans 1992) pulls together much of the zooplankton research.

Benthos

Research on the benthos was second only to studies of algae in the 1960s, comprising six percent of the total publications. E. B. Henson pulled together much of the knowledge on the Great Lakes benthic community in the publication co-authored with C. C. Davis (Davis and Henson 1966). Subsequently, Andrew Robertson undertook research on zooplankton and benthic communities (Robertson and Alley 1966). Research begun in the 1960s continued in the 1970s with the studies on *Pontoporeia* by Henson (1970). Major sampling of the benthos of Saginaw Bay was conducted in 1956. The research was completed in the 1960s (Schneider *et al.* 1969). Benthos research was enhanced by concern over the possible impact of nuclear power plants and resulted in a number of publications in the 1970s and 1980s (Mozely and Winnell 1975, Zdeba and White 1985). Benthic research in the late 1970s and 1980s became more oriented to study of effects of biota on their environment (Krezoski *et al.* 1978, White *et al.* 1987), their ecology (Winnell and White 1984), and importance of benthos as indicators of ecosystem conditions (Winnell and White 1985). Little benthic research continued into the 1990s.

Sampling the benthos of the Great Lakes, especially at greater depths, presented a challenge which was not readily dealt with by benthic grabs available in the 1950s and 1960s. The Ekman grab did not sample well in deep water and on hard substrate, whereas the Peterson grab disturbed the finer

sediments when it was lowered to the bottom. The orange-peel grab was used successfully in hard and soft sediments, but it was difficult to develop quantitative data using this grab. Marine biologists developed the spring-loaded Smith-McIntyre sampler in the 1950s (McIntyre 1954) which became widely used in the oceans by the 1960s. A. M. Beeton borrowed a Smith-McIntyre sampler from the Narragansett Laboratory, U.S. Bureau of Commercial Fisheries, in 1962. A study of the relative sampling efficiencies of the Peterson, orange-peel, and Smith-McIntyre samplers was undertaken in Lake Michigan in 1962. The Smith-McIntyre clearly outperformed the Peterson and orange-peel grabs (Beeton *et al.* 1965).

The original Smith-McIntyre proved to be too large and cumbersome to be easily used on Great Lakes research vessels. Consequently, several Smith-McIntyre samplers were manufactured in three-quarter size of the original for the Great Lakes Fishery Laboratory of the U.S. Bureau of Commercial Fisheries and the Great Lakes Research Division of the University of Michigan. The Great Lakes Research Division scientists, especially Charles Powers and Andrew Robertson, concluded that the springs and heavy frame of the Smith-McIntyre could be eliminated and the grab unit with the screen top retained for use in the Great Lakes. Thus the PONAR grab was developed. It is named after Charles F. Powers, Robert A. Ogle, Jr., Vincent E. Noble, John C. Ayers, and Andrew Robertson. The design of the sampler was given to the Wildlife Supply Company (WILDCO) for commercial development. The PONAR was first sold in 1966 and subsequently evolved into a world class bottom sampler as evidenced by its world-wide sales and citations in scientific literature. PONAR is the registered trademark issued to WILDCO in 1974 (William H. Phillips, WILDCO, personal communication).

Fisheries

Fisheries research was the focal point of most early University interests in the Great Lakes, although it did not become important in the Great Lakes Research Division until the 1970s and 1980s, when it formed a major part of the studies on the Donald C. Cook Nuclear Plant (Jude *et al.* 1975, 1982). The nature of and future direction of fish research was almost entirely due to David Jude, who joined the Division in the 1970s to undertake studies concerned with the nuclear plant. An important contribution arising from these studies was the development of criteria for identifying larval fishes (Dorr *et al.* 1976, Auer 1982). The collection of larval fish specimens for study continues to be maintained by David Jude.

By the 1980s, studies of fish were as important as algology, and fishery research dominated biological studies by the 1990s. James Diana joined the Division and the U of M School of Natural Resources in the 1980s. His research dealt with energy dynamics of fish and related topics (Flath and Diana 1985, Diana and Salz 1990). Jude's research extended beyond the the power plant studies and now deals with non-indigenous species (Jude *et al.* 1992) and other fish population studies (Jude 1992).

Exotic Species

Non-indigenous species have long been a concern in the Great Lakes with introductions of nonnative species such as carp and the invasion of the sea lamprey. The invasion and establishment of the zebra mussel, *Dreissena polymorpha*, the spiny water flea, *Bythotrephes cederstroemi*, and the round and tubenose gobies, *Neogobius melanostomus* and *Proterorhinus marmoratus*, in the Great Lakes in the 1980s and 1990s resulted in a new direction for research at the University of Michigan (Evans 1988, Lehman 1991). The zebra mussel was first found in Lake St. Clair but soon spread to Lake Erie where it was first found in 1988. Ruth Holland had been studying diatom populations in Hatchery Bay, western Lake Erie since 1983. She discovered diatom numbers declined 86 percent after zebra mussels became established (Holland 1993). Furthermore, the impact of the mussel affected water clarity and concentrations of major nutrients (Holland *et al.* 1995). In the early 1990s two species of Gobiidae were discovered for the first time in Lake St. Clair (Jude *et al.* 1992). The potential effects of gobies and other new species on the Great Lakes habitat prompted Jude to continue his studies of them (Jude and DeBoe 1996).

Paleolimnology

Paleolimnology became an important area of research in the 1960s because of Margaret Davis. Her research made important contributions to phytogeography and palynology (Davis 1965), although little of this research was specific to the Great Lakes (Davis *et al.* 1971). Because of her research, seven percent of all publications of the Division in

the 1960s were in paleolimnology. In the 1980s, Stoermer and Schelske and their associates turned their attention to siliceous microfossils in sediments and to biogeochemistry of silica (Stoermer *et al.* 1985, 1987; Schelske *et al.* 1983). This kind of research continued into the 1990s, and accounted for 12 percent of total Division publications. The nature and results of this research are largely summarized in Stoermer *et al.* (1993), Stoermer (1998), and Schelske (in press).

Pollution Studies

Studies of pollution of the Great Lakes became of major concern along with the growth of the national environmental movement in the 1980s. This topic was of minor importance in the 1960s (3 percent) and 1970s (5 percent). None of the publications in the 1950s dealt with pollution *per se*.

The early (1960s) publications on pollution dealt with the effect of pollutants on waterfowl, plants, and invertebrates in the Detroit River (Hunt 1961, 1962), although research was started on pollutant pathways and chemical aspects (Winchester 1969). Interest turned to the atmospheric transport of pollutants in the 1970s. John W. Winchester was a leader in these studies (Winchester and Nifong 1971).

By the 1980s concern over pollution and eutrophication greatly increased and publications dealing with pollution made up 14 percent of all the Division publications. The increased emphasis on pollutants largely resulted from the concern over persistent toxic substances and their biomagnification in the food web. Polychlorinated biphenyl and hydrocarbon contamination in fish and in sediments resulted in a number of publications (Simmons *et al.* 1980, Meyers *et al.* 1980, Rice *et al.* 1982). By the late 1980s research was underway on the toxicokinetics of a variety of toxic substances (Evans and Landrum 1989). The pollutant research included a number of studies on effects of contaminants on organisms (Sicko-Goad *et al.* 1989a, b, c, d), groups of organisms (Moll and Mansfield 1991), populations (Andresen and Sicko-Goad 1993), and food webs (Evans *et al.* 1991). Pollution research had become a major concern in the Division by the 1990s. Twenty percent of all publications dealt with pollutants.

Integrated Studies

Researchers have long recognized the need for and the importance of integrated studies, dating back to the pioneering work of Jacob Reighard. This can be seen in the report by Ayers and Chandler (1967) on the environment and eutrophication of Lake Michigan and in the development of a modified C^{14} technique for estimating the primary productivity of the Great Lakes (Saunders *et al.* 1962).

The integrated studies only accounted for three percent of all the publications in the 1960s, but by the 1970s these kinds of studies made up 14 percent of the publications. Much of the Michigan Sea Grant funding was for research on Grand Traverse Bay, Lake Michigan (Vogel *et al.* 1976). During the 1970s the influence of Claire Schelske and Eugene Stoermer in their collaborative research began to be seen (Schelske and Stoermer 1971). Much of their research dealt with nutrients and phytoplankton dynamics (Schelske *et al.* 1971) and the relationship of these dynamic processes to eutrophication of the Great Lakes (Schelske and Stoermer 1972). An important contribution which facilitated these studies, as well as research by other scientists in the region, was the publication of a compendium of field and laboratory procedures for studies of the Great Lakes (Davis and Simmons 1979). The environmental impact studies for the Donald C. Cook Nuclear Plant represent major integrated applied research which greatly influenced the kinds of research done by GLRD in the 1970s and early 1980s.

Eutrophication of the Great Lakes became a major concern and a unifying concept for focusing research on the lakes, especially at the Great Lakes Research Division, in the 1960s and 1970s. Evidence that changes were occurring in Lake Erie, Lake Ontario, Green Bay of Lake Michigan, and Saginaw Bay of Lake Huron became apparent in the 1920s and 1930s. Nevertheless, the overall importance of these changes was not recognized and any changes were generally considered consequences of specific human activity, e.g., overfishing and pollution. Other changes were observed but no coherent hypotheses were proposed until A. M. Beeton presented his report on "Environmental Changes in Lake Erie" to the Lake Erie Fish Management Committee at Niagara Falls on 11 May 1960 (Beeton 1961). What Beeton provided was a unifying hypothesis for the ongoing changes in the Great Lakes. He recognized that most of the changes in Lake Erie and the other Great Lakes, except Lake Superior, were indices of eutrophication used by limnologists for studying nutrient enrichment in small lakes, e.g., increases in nutrients, dissolved oxygen depletion, increases in phytoplankton, demise of coregonid fishes (Beeton

1965). A subsequent paper provided evidence that eutrophication of large ecosystems, e.g., Lake Erie, appears first in the coastal zone and spreads lakeward (Beeton and Edmondson 1972).

Schelske and Stoermer (1971) recognized that the major nutrient for diatoms, i.e., silica, had been ignored in studies of eutrophication. Diatoms are the dominant algae in the Great Lakes phytoplankton. Changes in the diatom community and increases in their abundance resulted in silica depletion (Schelske and Stoermer 1972). This diatom-silica relationship and trend proved to be good indices of early effects of nutrient loading on the Great Lakes and the sensitivity of these systems to phosphorus enrichment. Biogeochemical silica depletion, a rapid, ecosystem response to low-level phosphorus enrichment, was first reported (Schelske and Stoermer 1971) and later documented in Lake Michigan (Schelske 1985, 1988) and the lower Great Lakes (Schelske *et al.* 1986b). Silica depletion developed in Lake Michigan from 1955 to 1970 and in the lower lakes in the late 1800s when phosphorus loading increased as a result of early European settlement (Schelske *et al.* 1983; Schelske and Hodell 1991, 1995). Silica depletion occurred in Lake Erie and Lake Ontario in the late 1800s as a result of early European settlement and forest clearance (Schelske *et al.* 1983), a response that occurred in Lake Michigan in the 1950s and 1960s (Schelske 1988). Studies of microfossil diatoms also support the conclusion that the biological communities in the lower lakes were modified severely by early changes in the watershed as the result of European settlement in the 19th century (Stoermer 1998). The wide-spread occurrence of silica depletion as a consequence of eutrophication has been documented on a global scale spanning many freshwater, estuarine, and marine environments (Conley *et al.* 1993)

The research on eutrophication, especially the early work on documenting changes in Lake Erie, was important for sensitizing people to problems of environmental degradation in general. The popular press grabbed the concept of eutrophication and widely publicized the "dying and dead Lake Erie," at the time when the environmental movement was gaining momentum. Consequently, eutrophication of Lake Erie became a "cause celebre" and provided additional momentum to the environmental movement nationally, but especially in the Great Lakes region, and led to the U.S. and Canada referencing the International Joint Commission to make recommendations on phosphorus loading reductions which eventually reversed eutrophication.

Research which documented eutrophication was trend analysis dependent and such research was successful only because of studies made by earlier researchers. The research by David C. Chandler (1942, 1944) provided detailed information on the plankton and water chemistry of western Lake Erie and therefore a baseline for documenting eutrophication. Chandler's studies are among the few which extended over several years and provided knowledge on seasonal dynamics.

Integrated studies continued their importance into the 1980s when they comprised 15 percent of Division publications. Division scientists undertook studies to establish the state of the lakes, e.g., the Lake Huron intensive survey in 1980 (Moll *et al.* 1985). During this period John T. Lehman increased his research on the Great Lakes, especially in the area of phosphorus dynamics (Lehman and Sandgren 1982) and microscale patchiness of nutrients in plankton communities (Lehman and Scavia 1982). Schelske continued his research on silica and its importance to eutrophication (Schelske 1985, Schelske *et al.* 1986a).

The integrative research undertaken in the 1990s dealt more with physical and chemical processes affecting nutrient uptake (Schelske and Sicko-Goad 1990) and nutrient availability and cycling (Moll *et al.* 1993). Overall these kinds of studies declined in relative importance compared with research on fish, pollution, and paleolimnology. Claire Schelske is no longer at the University of Michigan, however he has continued to pursue collaborative studies with colleagues in the Great Lakes region as demonstrated by his papers on historic phosphorus loadings, silica depletion, and stable isotopes based on analyses of cores from the Great Lakes (Schelske and Hodell 1991, 1995; Schelske in press).

The Great Lakes Research Division was contracted by the Indiana & Michigan Electric Company to conduct an environmental impact study of the Donald C. Cook Nuclear Plant as a consequence of concern over siting such plants on the Great Lakes and federal regulations. The impact study focused on major biological components of the ecosystem and shoreline erosion, as well as some physical and chemical studies. Sporadic surveys of phytoplankton and some benthos and zooplankton began in 1966. Beginning in 1972 and continuing into 1982, sampling frequency and intensity increased and equal effort was given to studies of phytoplankton, zooplankton, and benthos. Fishery studies began in 1972, and subsequently made up

50% of the effort between 1973 and 1982. Chemical studies of water and sediment began in 1973. All field studies ceased in 1982.

The project was conducted under the direction of John C. Ayers from its inception in 1966 until his retirement in 1983. From 1983 until its completion in 1986, the project was directed by Ronald Rossmann. During the project duration, notable contributions to its management were made by Erwin Seibel. Studies were conducted by over 70 technical staff and students under the direction of more than 20 principal investigators. Results of the project were reported to the sponsor in 59 Great Lakes Research Division Special Reports. Final results of the study are summarized in a publication of the Great Lakes Research Division titled "Southeastern Nearshore Lake Michigan: Impact of the Donald C. Cook Nuclear Plant" (Rossmann 1986a).

PLATFORMS

At an early stage the Institute recognized the need for platforms from which scientists could sample the Great Lakes environment. Early efforts made do with rented vessels, often fishing tugs, but problems of coordinating scientific needs with commercial needs led the University of Michigan to become the first university in the Great Lakes to purchase and operate its own research vessels. In 1957 the Institute obtained the 35-foot *Naiad* from the University's Biological Station. It had been built in 1951 and was used by GLRD scientists for such tasks as studying sediment geology in the Straits of Mackinac, current patterns in Little Traverse Bay, air movement patterns over Lake Michigan, and biological sampling. The *Naiad* was returned to the Biological Station in 1967, by which time the GLRD was operating three other larger research vessels. In 1961, the University purchased the 114 foot *Inland Seas* (Fig. 4), a wooden hulled vessel which had been built for the military in World War II and then served the National Park Service for many years as the *Ranger II*, a ferry between Houghton and Isle Royale. The *Inland Seas* was home ported at Grand Haven, on Lake Michigan, and was to serve GLRD in all the Great Lakes for 12 years, when increasing hull deterioration brought about her sale in 1973. The 50-foot Chris Craft yacht *Highland Lassie II* was acquired by GLRD in 1963, a gift of Chicago industrialist Bruce L. Simpson. It was converted to support divers in their underwater investigations of the lakes, as well as other types of research, but proved an unsatisfactory platform and was sold in 1967. The 50-foot, steel-hulled *Mysis* was built for the University by the Sturgeon Bay Shipbuilding and Drydock Company in 1963, and was an appropriate complement to the larger *Inland Seas*. The *Mysis*, with its smaller crew, shallower draft, and lower operating costs, filled a niche for short-term or smaller scale research efforts. The *Mysis* was to perform well for GLRD for over 25 years, sampling all aspects of all five Great Lakes for two generations of scientists. The National Science Foundation, which payed for the construction of the *Mysis*, transferred ownership of the ship to Northeastern Univerity in Nahant, Massachussetts in 1989, when dwindling research dollars made her unneeded at GLRD.

In 1974 the Research Vessel *Laurentian* was purchased by the University, and still serves its research needs (Fig. 5). The *Laurentian* is an 80-foot steel hulled vessel, and the only Great Lakes research vessel that is a member of the University-National Oceanographic Laboratory System (UNOLS), a consortium of 57 academic institutions with significant marine science programs that operate or use the U.S. academic research fleet. Though only 80 feet long, the *Laurentian* proved its seaworthiness in 1984 by crossing the Atlantic to support a University research project in the Gambia River, in West Africa. The *Laurentian* has served extensively in all five Great Lakes, carrying equipment to sample air, sediments, biota, and chemistry of the water. She has also served over the last 10 years to introduce over 8,000 Michigan grade and high school students and their teachers to the intricacies of Great Lakes science, in a program designed to heighten public awareness of the need for stewardship of the Great Lakes.

Ships of Opportunity

Financial support for research vessel operation has been an ongoing problem in Great Lakes research over the years. In an attempt to determine the feasibility of decreasing sampling platform costs by placing scientific laboratory "pods" aboard the deck of a commercial ship and conducting experiments without interfering with the ship's regular operations, the University participated in an Office of Naval Research experiment dubbed "Research Ships of Opportunity" (RSO) in 1966. Project Neptune-Limnos of the RSO saw the U of M load a 20-foot-long self-contained laboratory aboard the SS *Exilona* in Detroit, along with GLRD

FIG. 4. The Research Vessel **Inland Seas,** *in 1970. Photo by R. Stephen Schneider.*

Project Manager Dr. Andrew Robertson and Grant Barkley, a student from Western Michigan University. The ship sailed through the Great Lakes, out the St. Lawrence Seaway, and across the Atlantic to Europe, with Robertson and Barkley sampling all the way. If nothing else, the ability of cooperating scientists to successfully "hire a taxicab instead of buying a Cadillac" was proven.

Looking Beneath the Surface

In 1966, the Great Lakes Research Division decided to evaluate a new type of sampling platform, a submersible which would allow the scientist to view the underwater environment directly. Arrangements were made with General Dynamics Corporation to bring the research submersible *Star II* into Lake Michigan and have scientists in different disciplines evaluate its data gathering potential. After adding flotation pods (Fig. 6) to compensate for the bouyancy difference between fresh water and the *Star II*'s usual salt water surroundings, *Star II* spent a week diving in Lake Michigan carrying various GLRD scientists and other interested parties. Despite the fascination of seeing first hand the wonders of Lake Michigan's depths, scientists reluctantly concluded that "The submersible is not considered practical in its present form for search and survey operations in water of poor quality" (Somers *et al.* 1968). Scuba diving proved to be more useful for geological research (Somers 1967). It was during this period that the Lakelab underwater habitat was constructed and then evaluated (Somers 1973).

Twenty eight years later, in 1994, the University

FIG. 5. The Research Vessel* Laurentian *has operated in all the Laurentian Great Lakes, and even traveled across the Atlantic to do a stint on the Gambia River, in West Africa. Photo by R. Stephen Schneider.

again sought a "first-hand look" at underwater conditions when it acquired the *M-ROVER*, a Remote Operated Vehicle that can carry its high resolution, low light color video camera to any depth in the Great Lakes. *M-ROVER* also carries a color, scanning, imaging sonar which gives the operator sophisticated acoustical coverage to parallel the visual coverage. Its three-function articulated arm allows *M-ROVER* to retrieve items from the lakebed as well as cut line and lightweight cable and other work tasks. The operator controls the ROV by watching a video screen that has a "heads up" display overlaid on it that tells depth, altitude, compass bearing, temperature, time, date, and pan and tilt of the video camera. The *M-ROVER* is used for teaching and service functions, as well as research.

CONCLUSIONS

The University of Michigan faculty, staff, and students have benefited from a Great Lakes research emphasis at the University, as has the regional research community in the United States and Canada, and various government agencies, commissions, industry, and citizens. Much of what has been accomplished would not have been as successful without the encouragement and participation of many non-university associates. In the latter regard, emphasis has changed from informal cooperation and collaboration to more formal partnerships, grants, and contracts, e.g., the Cooperative Institute for Limnology and Ecosystems Research and the Michigan Sea Grant College Program.

Research on the Great Lakes continues at the University but with greater involvement by faculty

FIG. 6. The research submersible* Star II, *in Lake Michigan in 1966. Designed for use in salt water,* Star II *needed flotation pods added to compensate for the lower bouyancy of fresh water. The pods were retained when* Star II *was returned to salt water as it was discovered during her Great Lakes stint that they added significantly to her anti-rolling capability. Photo by R. Stephen Schneider.

and students at the departmental level and through cooperative agreements with federal and state agencies. Facilities such as the R/V *Laurentian* will continue to be operated in support of the University-wide community. Other facilities, such as a proposed lake-side laboratory, will also be made available University-wide. Partnerships with federal and state agencies are becoming increasingly important, especially to meet the needs of these agencies and commissions, e.g., International Joint Commision, Great Lakes Commission, and Great Lakes Fishery Commisson.

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