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Commemorating 50 Years of Great Lakes Research at the University of Michigan: A Tribute to David C. Chandler

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This special section includes papers commemorating 50 years of Great Lakes research at the University of Michigan that are dedicated to David C. Chandler who guided the development of Great Lakes research. Nine papers were authored or coauthored by: Chandler's students at the University of Michigan (Beeton, Richman, Robertson, and Schelske), students who obtained their degrees under faculty affiliated with various Great Lakes programs (Kerfoot, Fahnenstiel, and Francis), and former or current research scientists and staff in the Great Lakes programs (Evans, Jude, Schneider, and Stoermer). In addition, a version of another paper originally intended for this special section is dedicated to Dr. Chandler (Schelske in press). Each of these contributions is placed in the historical setting that follows and is also summarized in the Appendix to this introductory paper.

David Chandler came to Ann Arbor in 1952 to implement the University of Michigan's program in Great Lake research mandated by the Board of Regents in 1945 for the ". . . encouragement and integration of studies of the physical, chemical, biological, and other aspects of the Great Lakes and related areas" (Beeton and Schneider 1998, Beeton and Chandler 1966). This mandate by the University of Michigan recognized the strong institutional tradition of environmental research extending more than 100 years and was a challenge accepted willingly by Chandler who had spent a number of years at the Franz Stone Laboratory, Put-in-Bay, working on western Lake Erie. Chandler brought a broad and dedicated vision for Great Lakes programs to Michigan which is documented in Beeton and Schneider (1998). Some of his visions and contributions will be reviewed here in an attempt to illustrate his invaluable role in promoting Great Lakes research at the University of Michigan, in the Great Lakes region, and in the world-wide community, and in guiding the University of Michigan's academic program to prominence as a leading institution dedicated to research on large lakes. Chandler's efforts will be discussed under four broad categories: disseminating and communicating information, building a Great Lakes research program, directing graduate students, and Chandler's legacy. The interplay among these activities is important as we review his influence using the perspective of 50 years of history.

DISSEMINATING AND COMMUNICATING INFORMATION

The importance of scientific publications and dissemination of scientific studies by University of Michigan scientists was a high priority for the fledgling Great Lakes Institute under David C.

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Chandler's direction. The University published and distributed the Proceedings of the Great Lakes Conferences before and during the early years of the International Association for Great Lakes Research (IAGLR) (Beeton and Schneider 1998). Activities related to publications and public relations led to the early appointment of Mr. R. Stephen Schneider who has served in several related capacities since 1967. These activities and other efforts in publication were conducted with the highest professional standards as the result of demanding editorial standards established by Margaret N. Everett who provided administrative services to the Great Lakes Institute (GLI) and the Great Lakes Research Division (GLRD) and also edited the Proceedings of IAGLR for many years. Special reports, publications, and contributions were established as three different publication series (Beeton and Schneider 1998). Special reports were prepared mainly for sponsoring agencies highlighting major findings and providing sources of data. The publication series included some Proceedings of the International Association for Great Lakes Research (IAGLR) and research publications in the style of monographs. Contributions to the open, refereed literature, now numbering more than 600, were emphasized as the primary means to enhance the Great Lakes program.

One of Chandler's first activities as the Director of GLI was to organize the first international conference on Great Lakes research which was convened at the University of Michigan Biological Station in 1953 (McNaught 1993). These conferences continued and were so successful that IAGLR, a formal society to sponsor such activities, was established in 1967. Chandler drafted the bylaws and was elected the first President during the 10th Conference held in Toronto that year. This society, first through its annual Proceedings and then in 1975 through its Journal of Great Lakes Research (JGLR), became recognized internationally for activities promoting Great Lakes research in the broadest context. IAGLR recognized the important roles David C. Chandler and Margaret N. Everett played in the early development and continued prosperity of the society by establishing the Chandler-Meisner and Anderson-Everett awards: Chandler-Meisner for the best paper published each year in JGLR and Anderson-Everett for service to the society (McNaught 1993). These awards recognize the early efforts by founding members to make IAGLR an international society with an international viewpoint because Chandler and Everett represented the United States and Meisner and Anderson represented Canada. IAGLR recognized Chandler again in 1997 by honoring him with a life membership in the society. Undoubtedly IAGLR would not have developed without Chandler's guidance and the University of Michigan's financial and administrative support. Therefore, the importance of Chandler's contributions in promoting Great Lakes research regionally and internationally cannot be overestimated.

BUILDING A GREAT LAKES PROGRAM

Chandler's intent to carry out the broad mission for Great Lakes research mandated by the Board of Regents was evident immediately in one of his conditions for appointment in 1952. This condition was that Chandler would bring three faculty members with him from Cornell University: Professor John C. Ayers and two Assistant Professors, George H. Lauff and Charles F. Powers. These faculty members were appointed with general funds in the Department of Zoology. Ayers and Chandler, the senior members of the group, worked together until Chandler's retirement in 1972 and were instrumental in establishing many of the early endeavors of GLI and GLRD (see Beeton and Schneider 1998). Powers who had been a student of Ayers worked on Great Lakes research in GLI and GLRD (Beeton and Schneider 1998). George Lauff who had been Chandler's student at Cornell split his activities between research and teaching and worked closely with Chandler in developing the graduate program in limnology. Chandler recognized that systems as large as the Great Lakes must be studied at the mesoscale. The decision to hire two oceanographers so an oceanographic perspective could be included in the study of these large lakes was an early example of his broad vision for Great Lakes research. Classic studies on currents and water masses in Lake Michigan and Lake Huron resulted from the application of these early oceanographic approaches (Ayers *et al.* 1956, Ayers *et al.* 1958). A modern approach using satellite, remote sensing to study currents in the Great Lakes is presented in this special section (Budd *et al.* 1998).

Chandler's broad interests and vision were apparent with the multidisciplinary research program that developed in the first decade of his tenure at the University of Michigan (see Beeton and Schneider 1998). It culminated in the Coherent Areas Study (Ayers and Chandler 1967). This unique program encompassing multidisciplinary research was sup-

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ported by a four-year grant from the U.S. Public Health Service. The comprehensive nature of the research program in GLRD was evident by important areas of research that were underway or were being proposed. These include mechanisms of nutrient enrichment, nutrient budgets and cycling, energy budgets and trophic dynamics, environmental requirements of biota, use of remote sensing techniques from airplanes and satellites, observation and sampling from research submarines, impact of land drainage on lake processes, atmospheric/water exchange of chemical substances, and impact of socio-economic factors in the drainage basin. Curtailment of the Coherent Areas Study prematurely by changes in federal funding severely impacted the research program. By this time, administrative reorganization established GLRD as a part of the post-Sputnik, Institute of Science and Technology (see Beeton and Schneider 1998).

The GLRD program was revitalized in the late 1960s by new sources of federal funding. First, Chandler obtained a contract for ecological studies related to nutrient enrichment in Lake Michigan from the U.S. Atomic Energy Commission. This agency solicited research on Lake Michigan in anticipation of environmental concerns related to future siting of nuclear power plants on the lake. One of the first findings from this contract related to nutrient enrichment and silica depletion in Lake Michigan (Schelske and Stoermer 1971). By the early 1970s, funding from various forerunners of the present Environmental Protection Agency was obtained to support additional research. Second, the opportunity to undertake new studies on the near shore environment began with industrial funding from the American Electric Power Service Corporation for environmental studies on the Donald C. Cook Nuclear Power Plant in the 1970s (Beeton and Schneider 1998). The expanded program led to new research activities including studies on fishes directed by David Jude and studies on zooplankton directed by Marlene Evans. The work of Jude and Evans is presented in this special section (Jude *et al.* 1998, Evans *et al.* 1998)

Federal funding for academic research on the Great Lakes was reduced drastically when research priorities were redirected in the late 1970s. One of the main reasons for redirection of federal funding was the perception that nutrient enrichment problems were solved and that eutrophication no longer was an issue. This perception resulted in part from the success of the International Water Quality Agreement signed in 1972 by the United States and Canada that recognized historic phosphorus enrichment as the major water quality problem and established goals for reductions in phosphorus loading to the Great Lakes. The membership of IAGLR also reflected eroding federal support for studies related to nutrient enrichment beginning in the late 1970s (McNaught 1993). This trend, surprising in itself, was not anticipated because understanding nutrient dynamics is fundamental to many basic and applied studies in aquatic ecology and because major emphasis was placed on aquatic toxicology. Potentially harmful effects from inputs of chlorinated hydrocarbons and heavy metals into the lakes and accumulation of toxic concentrations of these compounds in the food chain led to increased funding. Papers on chlorinated hydrocarbons in zebra mussels (Robertson and Lauenstein 1998) and mercury in the biota of Old Woman Creek (Francis *et al.* 1998) in this special section reflect that shift in emphasis.

Research by Chandler and his students and research scientists at the University of Michigan was important in decisions on the need to control phosphorus loading to improve water quality in the Great Lakes. Chandler conducted a four-year study of factors limiting phytoplankton abundance in western Lake Erie, finding that limnological and meteorological factors and interannual variability were important in the production of plankton (Chandler and Weeks 1945). Beeton (1965) clearly documented that the Great Lakes had been affected by anthropogenic factors, including nutrient enrichment. Historical chemical data, compiled primarily from data collected from sampling municipal water intakes, and other data showed the lower Great Lakes (Lake Erie and Lake Ontario) were affected more than the upper Great Lakes and that Lake Superior remained relatively pristine. Subsequent paleolimnological studies, however, revealed that effects of nutrient enrichment could be found in all the Great Lakes, including pristine Lake Superior (Stoermer *et al.* 1985). The importance to the scientific community and general public of anthropogenic changes was apparent by publication of a paper on the aging Great Lakes (accelerated eutrophication) in Scientific American (Powers and Robertson 1966). It was shown by Beeton and Edmondson (1972) that eutrophication of the Great Lakes spread from nearshore areas and harbors and later became evident in the entire lake, an important finding that negated arguments that this type of pollution was restricted to small parts of these large lakes. Silica depletion, a rapid, ecosystem response to low-level phosphorus enrichment, was another consequence of anthropogenic factors starting as early as the mid 1800s (Schelske *et al.* 1983). Contemporaneous biological changes on similar time scales in these large lakes are supported by research on diatom microfossils summarized in this special section (Stoermer 1998), as well as by biogeochemical studies (Schelske in press). In this special section, Fahnenstiel *et al.* (1998) examine the present similarity in food-web structure of all the Great Lakes, a recent change that can be attributed to phosphorus load reductions and the filtering activities of non-indigenous mussels. Also, in this special section De Stasio and Richman (1998) examine the distribution of phytoplankton across nutrient gradients in Green Bay, a highly enriched bay, prior to the establishment of zebra mussel populations.

The need to address practical and applied problems has arisen in many ways during the history of Great Lakes research (Beeton and Schneider 1998, Stoermer 1998). David Chandler did not discourage such work, as long as it provided an opportunity to expand the research program and, more important, to publish results in scientific journals. In this respect Dr. Chandler was a strong proponent of Great Lakes research both within and outside the Great Lakes basin. Two of Chandler's activities at the national level provide examples of his many contributions in promoting Great Lakes research. The first was his strong support for federal legislation that led to the establishment of the Sea Grant Program. His efforts were instrumental in the recognition that the Great Lakes were a fourth coast, which was commonly accepted in formulating the legislation. Later, such recognition was important when the University-National Oceanographic Laboratory System (UNOLS) was established. Because the Great Lakes were legislated as part of the national oceanographic effort, Chandler was able to argue that the Great Lakes should be represented in UNOLS and that R/V Inland Seas be designated as a UNOLS vessel. In fact, the University of Michigan is still the only fresh-water institution in UNOLS and currently operates the R/V Laurentian as a research vessel in the UNOLS fleet. The availability of a UNOLS research vessel combined with grant funds from the National Science Foundation allows investigators from the scientific community to conduct research on the Great Lakes.

DIRECTING GRADUATE STUDENTS

Chandler's direction of graduate students and graduate teaching at the University of Michigan reflected his early experiences at other universities. As a faculty member at Ohio State University, Chandler worked at the Stone Laboratory at Put-in-Bay. From this island laboratory and field station in western Lake Erie, he conducted year-around research on plankton and directed the research of graduate students (Beeton and Chandler 1966). Although this was a successful program, the logistics and disadvantages of a permanent off-campus activity were apparent and not forgotten. Chandler resisted attempts to establish a permanent field station while at the University of Michigan. He instead taught limnology at the University of Michigan Biological Station during the summer and utilized facilities at the station for some summer research activities on the Great Lakes during the early development of the research program (Beeton and Schneider 1998). He strongly believed, however, that the most important facility for Great Lakes research was a research vessel that provided a stable, mobile platform and could move from site to site as necessary. Graduate students at the University of

Michigan were not pressured in any way to undertake research on the Great Lakes. Chandler's students were encouraged to address problems using state-of-the-art experimental approaches. Although applied research was not viewed favorably in academia, basic research on small lakes or in laboratory studies was emphasized because it provided the opportunity to study a variety of challenging problems in limnology. Either applied or basic studies on the Great Lakes were difficult to pursue because of logistics, particularly the lack of suitable research platforms and limited sources of funding.

Three of Chandler's students, Alfred M. Beeton, G. Richard Marzolf, and Andrew Robertson, addressed Great Lakes or marine problems for their doctoral dissertation (see Table 1, Beeton and Schneider 1998). Beeton and Marzolf worked on the dominant macro-invertebrates in the Great Lakes, *Mysis relicta* and *Pontoporeia (= Diaporeia) affinis*. Robertson measured herbivore standing crop in oceanic systems using the continuous plankton recorder and then later used this technique in the Great Lakes. Beeton was active in Great Lakes work throughout his career, first with the U. S. Fish and Wildlife Service in Ann Arbor and then at the Center for Great Lakes Studies, University of Wisconsin-Milwaukee. In 1976, he returned to Ann Arbor where he was Director, Great Lakes and Marine Waters Center, University of Michigan, and later Director, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration (NOAA). Andrew Robertson was a staff member of GLRD and of different components of NOAA's Great Lakes programs. Claire L. Schelske studied the biogeochemistry of iron in a marl lake, but returned to Michigan to work on the Great Lakes. Schelske held several positions, including Acting Director, during 20 years in GLRD. Chandler's students who did not work on the Great Lakes studied energetics (energy transformation), lake metabolism using radioactive tracers, cycling of zinc, effects of ionizing radiation on *Daphnia pulex*, and the life history and food relations of *Epischura lacustris* (see Table 1, Beeton and Schneider 1998). These students and those who pursued Great Lakes careers appreciated Chandler's wisdom in giving students freedom to pursue individual interests during their graduate studies.

CHANDLER'S LEGACY

This tribute is intended to recognize David C. Chandler's many and varied contributions in promoting and developing Great Lakes research at the University of Michigan and in the Great Lakes community and international community beyond North America. His first effort to provide institutional support for Great Lakes research was apparent in bringing three associates from Cornell with him when he came to the University of Michigan in 1952 (see Beeton and Schneider 1998). Later, as Director of GLI and GLRD, he recruited broadly trained research faculty and postdoctoral students to develop a comprehensive research program. In this special section, there is a paper by the only member of the research faculty recruited by Chandler (Stoermer 1998) remaining at the University of Michigan. The continued success of the Great Lakes program at the University of Michigan after Chandler's retirement in 1972 was due to his foresight in establishing an institutional framework and his success in providing continuing federal support for the purchase and operation of modern research platforms. His invaluable role in organizing and promoting Great Lakes research through IAGLR has been recognized (McNaught 1993). Chandler's legacy to Great Lakes research through his students and faculty from GLI and GLRD at the University of Michigan is apparent from the papers dedicated to him in this special section. One way to highlight his influence is to note that three of these contributions (Budd, Fahnenstiel, and Francis) represent the third generation; these legacies are especially important to recognize here because they reflect his legacy and his continued influence on Great Lakes research. A truly historical record of accomplishments obviously would be much longer and more extensive.

During his 20 years at the University of Michigan, David C. Chandler displayed many admirable characteristics. He was highly principled, evenhanded, and collegial in his professional associations as an administrator, scientist, and teacher. He was very modest about his accomplishments and willingly shared or relinquished the limelight in his professional career. Here we simply want to acknowledge and thank David C. Chandler for all of his efforts in promoting and guiding Great Lakes research and for his influence in shaping the professional development of his associates and students.

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APPENDIX
Summary of Contributed Papers

Few people are better qualified than Al Beeton and Steve Schneider to write a historical perspective on a century of research at the University of Michigan. Beeton and Schneider (1998) trace the foundation and background for 50 years of Great Lakes research that are commemorated in this special section. Jacob Reighard began studies of the Great Lakes ecology in the late 19th century with investigations related to fishery problems. Many important aspects of fisheries research on the Great Lakes can be traced to Reighard. A formal program in limnology began with Paul S. Welch who first taught limnology in 1923 at the University of Michigan Biological Station. Welch later wrote a textbook for limnology and directed many graduate students including David Chandler. Beeton and

Schneider's paper, which is cited frequently above, outlines important events that led to the Chandler years beginning in 1952 and to the development of Great Lakes research on its 50th anniversary.

Eugene Stoermer, the only member of the present University of Michigan faculty who was appointed under Dr. Chandler's direction, provides some interesting insights based on his studies of diatoms over the past 30 years (Stoermer 1998). Stoermer's paper reviews previous studies and includes sections on exploration, experiment, synthesis, and future considerations based to a large extent on work in his laboratory. He shows that long-term records of biotic populations, particularly microfossil populations in sediments, have proven to be very important in understanding ecosystem change and its causes. Unfortunately, basic data in systematics and physiology are presently insufficient to most effectively utilize this approach. One of his conclusions is that paleolimnological studies of diatoms are a powerful alternative to large-scale sampling campaigns and provide the best current hope for tracking biotic changes in the Great Lakes. This conclusion may be controversial, but only if the reader interprets it as meaning that one approach could be substituted for the other.

Studies of plankton were an important part of the research program during the Chandler era and they are included in this special section. Fahnenstiel *et al.* (1998) provide a unique data set from all five Laurentian Great Lakes to examine the present overall similarities in food-web structure across the lakes. Structure was determined from data on producers (autotrophs), decomposers (bacteria), micrograzers (protozoans and rotifers), and mesograzers (crustaceans). These groups comprised 40%, 30%, 11%, and 19% of total planktonic carbon, respectively, during the spring and 32%, 15%, 9%, and 43%, respectively, during the summer. Structure within seasons was similar among lakes. Spring TP, also, was similar at all stations (except in Lake Superior which was not sampled and in western Lake Erie), ranging only from 3 to 7 µg/L and summer TP for all lakes only ranged from 4 to 10 µg/L. The similarity was attributed to phosphorus load reductions and the impact of non-indigenous zebra mussels in the lower lakes which have reduced TP dramatically.

The question of whether invasion of exotic zebra mussels and nutrient reduction programs affected food-web structure was raised by Fahnenstiel *et al.* (1998). This question can not be addressed because data comparable to those collected from 1993 to 1995 are not available in the literature for the lower lakes during the early 1970s when TP concentrations were several fold greater or before the invasion of zebra mussels in the 1990s. De Stasio and Richman (1998) document spatial and seasonal patterns of change in phytoplankton composition, size structure, and standing stock along a trophic gradient in Green Bay before the invasion of zebra mussels. Analyses demonstrate that the hypereutrophic, lower bay and the meso-oligotrophic, upper bay regions undergo seasonal changes comparable to lakes with different trophic status. These data will be valuable to test hypotheses about effects of nutrient reduction and invasion of zebra mussels beginning in 1992.

Evans *et al.* (1998) characterized particles microscopically and then estimated dry weight and settling velocities for different categories of particles produced by plankton. Flux was dominated by autochthonous biological particles classified as fecal matter, fecal pellets, organic aggregates, phytoplankton, and zooplankton exoskeletons. Mean settling rates for the most abundant particles were 5.6 m/d for fecal pellets, 3.2 m/d for fecal matter, and only 1.5 m/d for organic aggregates. Large fecal pellets with a rapid settling rate (mean 19.8 m/d) were rare. Particle flux varied seasonally, being highest in spring and autumn during periods of isothermal mixing. This study points out that changes in zooplankton community structure affect not only grazing pressure on the phytoplankton assemblage but also the pathways of sedimenting autochthonous particles. Organic matter is retained and recycled more efficiently in a water column dominated by cladocerans and copepods which produce fecal matter or organic aggregates than in one dominated by calanoid copepods which produce well-defined and relatively larger fecal pellets.

Effects of anthropogenic stresses were an important component of the program developed during the Chandler era. Jude *et al.* (1998) studied the distribution and abundance of larval lake herring and lake whitefish in the St. Marys River in relation to effects of winter navigation. The river, based on larval fish densities, is an important spawning and nursery area for these species, but whether the river nursery is important to recruitment for either river or Great Lakes populations is an unanswered question. The potential impact of winter navigation on spawning was examined in terms of the life history of species that inhabit and reproduce in the river. Both lake herring and lake whitefish spawn during November to early December. Because lake herring eggs begin hatching within several days of ice break-up, breaking ice prematurely for winter navigation could cause early hatching when critical food supplies may not be available. Lower incident solar radiation during periods of early hatching also may limit the daily duration of visual feeding. This paper points out that basic data on fish spawning, larval fish development, and early development are essential for evaluation of potential effects of winter navigation.

Mercury was measured in various compartments of the food web of Old Woman Creek, a tributary on Lake Erie, to determine the most important pathways for mercury to enter fish species (Francis *et al.* 1998). Although mercury was not detectable in water samples (< 20 ng/L), analysis of other samples provided evidence of biomagnification of mercury in the food web. Concentrations of mercury in sediments, zooplankton, and fish were < 0.05 μg total Hg/g wet weight whereas concentrations in fish tissue ranged from 0.001 to 0.636 μg total Hg/g wet weight. Mercury content was positively correlated with length and weight in channel catfish *Ictalurus punctatus* and common carp *Cyprinus carpio*. Channel catfish accumulated higher levels of mercury than common carp, an indication that a pelagic pathway was more effective in delivery of mercury to fish than a benthic pathway.

Measuring chemical contaminants bioaccumulated in the tissues of specific organisms is a valuable tool for comparing levels of contamination in space and time. Robertson and Lauenstein (1998) analyzed dreissenid mussels for 16 chlorinated organic compounds, mostly pesticides. Concentrations of chlorinated organic compounds among 21 sites apparently varied in relation to localized sources of these compounds and were not related to lipid levels in the mussels. Total DDTs which include metabolites of DDT were detected at all sites at mean and median concentrations greater than any of the organic contaminants analyzed. Levels were greatest in southern Lake Michigan where total DDT was > 160 ng/g at 5 stations and 274 ng/g in Milwaukee Harbor, the highest level. Comparing concentrations of chlorinated organic compounds in Great Lakes dreissenids with those in marine mussels and oysters showed that levels were generally similar for most compounds, but hexachlorbenzene and mirex were higher in Great Lakes dreissenids and lindane was greater in marine molluscs.

Finally, the paper on large-scale water circulation in Saginaw Bay by Budd *et al.* (1998) complements this special section because two of the early papers in the Chandler years were on currents and water masses in Lake Michigan and Lake Huron (Ayers *et al.* 1956, 1958). Thermal structure in these early papers was based on data recorded on smoked glass slides obtained from bathythermograph casts made during synoptic cruises on chartered, commercial fishing tugs. Budd *et al.* (1998) identified circulation patterns using satellite-derived lake-surface temperature maps. This type of synoptic reconnaissance verified previously known seasonal events, such as the spring thermal bar, but also provided better spatial and temporal resolution than is possible with other techniques. This study documents frequent wind-induced circulation reversals that result in complex patterns of surface water transport. Such data are important in understanding how physical factors affect biological and chemical transport in a dynamic area such as Saginaw Bay.