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Decline in zoobenthos densities in the profundal sediments of Lake Mendota (Wisconsin, USA)

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Abstract

High densities of zoobenthos inhabited Lake Mendota's profundal zone in the early 1900s through the mid-1940s. *Chaoborus punctipennis* was the most abundant organism during the winter, along with moderate densities of *Chironomus* spp., *Pisidium* sp., oligochaetes, and *Procladius* sp. By the early 1950s, *Chaoborus punctipennis* densities had declined to 10% of former levels, while *Chironomus* increased significantly. However, by the mid-1960s, *Chaoborus*, *Chironomus*, and *Pisidium* densities had decreased to very low population levels. By 1987–89, *Pisidium* was no longer found. Zoobenthos that had not decreased from earlier surveys were oligochaetes and *Procladius*, although further sampling of oligochaetes is needed to confirm current densities. These organisms are the most tolerant of severe anoxia.

Four possible reasons for this decline were evaluated: (a) decline in food availability, (b) increase in fish predation, (c) use of toxic insecticides in the drainage basin, and (d) changes in the profundal sediment environment. Based on literature information and long-term data for Lake Mendota, a change in the profundal sediment environment is the most likely explanation for the decline in the less-tolerant zoobenthos species. Although the duration and extent of anoxia in the hypolimnion have not changed since the early 1900s, hypolimnetic ammonia and hydrogen sulfide concentrations apparently have increased as Mendota became more eutrophic after the mid-1940s. However, further study is needed to determine if these higher concentrations or other factors were responsible for the dramatic decline in lake Mendota's profundal zoobenthos.

Introduction

The profundal zoobenthos (macroinvertebrates) have been used to determine the trophic condition of many northern temperate-latitude lakes (Jónasson, 1969; Brinkhurst, 1974; Wiederholm, 1980). Moderately deep eutrophic lakes with anoxic hypolimnia have fairly simple profundal zoobenthos communities represented by large densities of only a few species adapted to low oxygen tensions. *Chironomus plumosus* L., *C. anthracinus* Zett. (in Europe), *Procladius* spp., *Chaoborus* spp., a few oligochaete species, and the fingernail clam *Pisidium* spp. are often the dominant zoobenthos. In some lakes with prolonged anoxia, oligochaetes as well as *Procladius* can be the only organisms present (Wiederholm, 1980; Bazzanti & Seminara, 1987; Kajak, 1988).

Changes in zoobenthos densities in lakes have been related to organic pollution, principally from sewage discharges (Brinkhurst, 1974; Wiederholm, 1978; Pearson *et al.*, 1986; Bazzanti & Seminara, 1987) and to density changes in bottom-feeding fish (Kajak, 1988). However, these changes were noted over relatively short periods. Only a few lakes have been studied over many decades, during which time long-term changes in profundal zoobenthos populations have been documented.

Lake Esrom (Denmark) is probably the best known example, with extensive sampling begun by Berg (1938) and continued in later years by Jónasson (Jónasson, 1977; Jónasson, 1984). Within a 20-year period, densities of *Chironomus anthracinus* remained relatively stable, but densities of *Pisidium* sp. declined by 85% concomitant with a 400% increase in oligochaete densities. These changes were linked to an increase in the duration of summer anoxia in the hypolimnion due to increased pollution.

Lake Mendota is another lake where a long-term zoobenthos record is available because it was the site of extensive physical, chemical, and biological studies conducted during the early 1900s (reviewed by Frey, 1963). The zoobenthos of 0–7 m and >8 m water depths were detailed by Muttkowski (1918) and Juday (1921), respectively. Since that time, additional surveys (published and unpublished) have been conducted on Lake Mendota's profundal zoobenthos, but these data have never been synthesized. To document current population densities and determine if any major changes have occurred over time, a survey was conducted by the Wisconsin Department of Natural Resources, Bureau of Research (Wis. DNR) in January–February of 1987–89. This paper incorporates past and present zoobenthic density information and relates changes in the zoobenthos to lake factors.

Lake description

Lake Mendota is a calcareous, eutrophic lake located near Madison, in southern Wisconsin (USA). It has a surface area of 3 985 ha and maximum and mean depths of 25.3 m and 12.7 m, respectively. The lake thermally stratifies from about mid-May to mid-October. Hypolimnetic water temperatures generally are between 10 and 13 °C, and surface temperatures reach 25–26 °C, although higher temperatures have occurred in both strata in some years. Based on the lake's thermal stratification, the profundal zone is defined as >10 m, which represents about 63% of the lake surface area (Fig. 1). In this paper, I also refer to a deep-hole region, defined as >20 m, which represents 21% of the lake area.

The entire hypolimnion generally becomes anoxic during early July; this has occurred since the early 1900s when dissolved oxygen (DO) data were first collected by Birge & Juday (1911) (Fig. 2). During the winter, approximately the bottom 5 m of lake water becomes anoxic by March, one month before ice-out, based on early and recent data (Birge & Juday, 1911; Wis. DNR unpubl. data). Although variable from year to year, summer DO depletion rates for the hypolimnion also were determined by Stewart (1976) and Brock (1985) to not have changed between early and more recent years.

Methods

Data on profundal and sublittoral zoobenthos were collected from past surveys/studies conducted during the winter. Zoobenthos were also sampled during the summer, but because insects emerge during this period, these density data were not used for long-term comparisons. Thus problems were avoided in determining accurate densities for chironomids that could have passed through the coarse-mesh sieves when the organisms were small (Jónasson, 1955) and for early-instar *Chaoborus* that are only planktonic (Juday, 1921). For the profundal zone, January–February data were available for 1917–18 (Juday, 1921), 1943–44 (Hasler, 1945), 1951 (Mackenthun & Cooley, 1952), 1965 (J. A. Šapkarev, University of Skopje, Yugoslavia, unpubl. data collected while visiting Madison), and 1987–89 (Wis. DNR). For the sublittoral zone, comparable winter data were available only from 3 of these 5 surveys (in 1951, 1965, and 1987–89). A detailed study of the deep-water *Chironomus* spp. was also conducted by Dugdale (1955) in 1954. Because densities of other organisms were not recorded

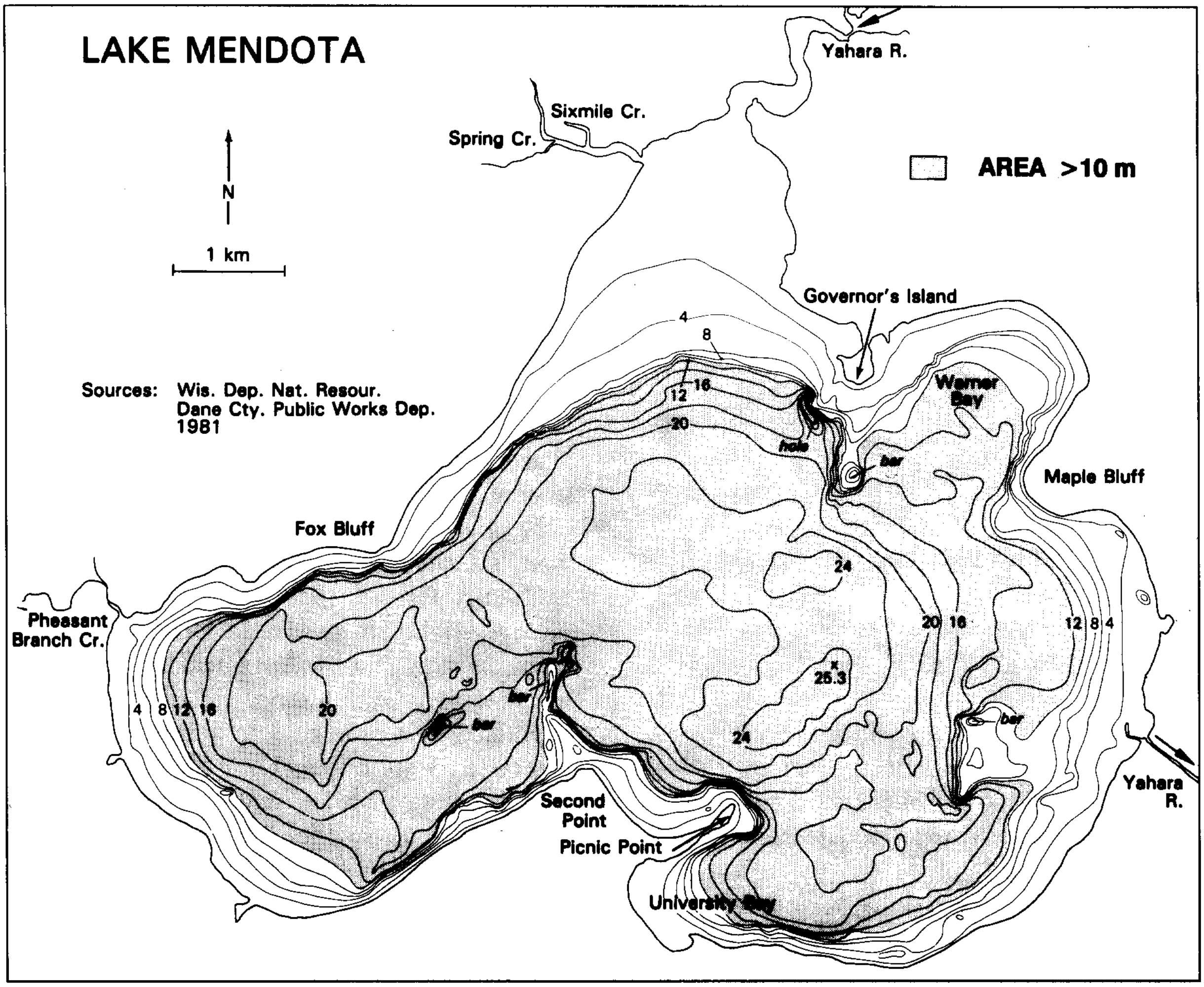

Fig. 1. Lake Mendota hydrographic map with depth contours in 2 m intervals and the profundal zone (area > 10 m) shaded.

and *Chironomus* densities were not greatly different than the 1951 survey data, Dugdale's 1954 data were not incorporated in the long-term analysis presented here.

In all studies, profundal sediments were sampled with Ekman dredges. A larger dredge (473 cm^2) was used by Juday (1921), while smaller dredges (232 cm^2) were used in later studies. Sieve mesh sizes used to screen the zoobenthos samples were not always reported, but mesh sizes of 500–600 μm were commonly used (Welch, 1948; Jónasson, 1955; APHA, 1971). Juday (1921) used a gauze net of unreported mesh size.

The Wisconsin DNR sampled Lake Mendota during the 3 winters of 1987–89. Five Ekman dredge (232 cm^2) samples were collected at each station located at depth contour intervals of 6, 9, 12, 15, 18, 21, and 24 m on a transect from the deepest location (25.3 m) northeast toward Warner Bay. Additional stations were also located in University Bay and in the west end of the lake at 18–20 m for comparison to similar depths along the main transect.

Individual dredge samples were sieved through a 300 μm screen by washing them with a gentle stream of water. The organisms (and debris) collected on the screen were transferred to a jar and preserved with 95% ethanol for later enumeration. The chironomids were identified only to genus, which corresponded to most earlier

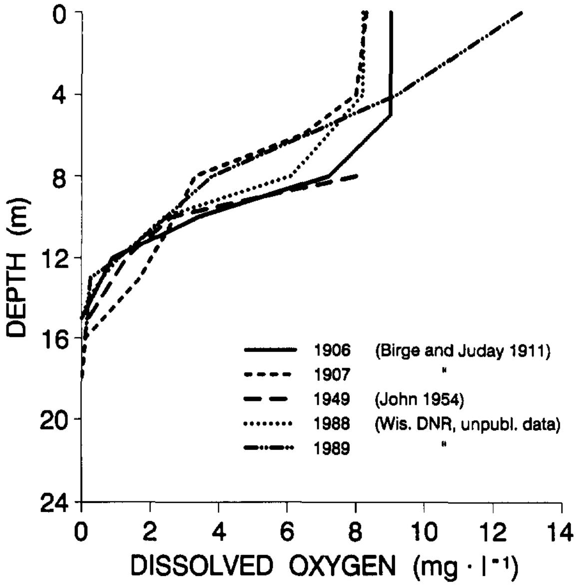

Fig. 2. Dissolved oxygen vertical profiles in Lake Mendota during 17–23 July 1906–07, 1949, and 1988–89.

surveys. *Chaoborus* was identified to species. Oligochaete densities were not reported for 1987–89, because the sieving procedure and alcohol did not adequately preserve these fragile organisms for accurate enumeration.

Because sampling depths were not uniform between surveys, an average density for each species in the deep-hole region (> 20 m water depths) and a weighted mean density for the entire profundal zone (depths > 10 m), which included the deep-hole region, were calculated. These calculations were based on average densities of samples collected in each of 3 depth regions (10.0–14.9 m, 15.0–19.9 m, and ≥20.0 m) weighted by the regions' respective areas. Average densities were also computed for 6.0–9.0 m to represent the distribution of selected species in the sublittoral zone.

The long-term trends in zoobenthos densities were only considered to be significant if density differences between surveys for both the deep-hole region and the entire profundal zone were at least one order of magnitude. Smaller density changes were noted but not considered important due to potential interpretation problems caused by differences or uncertainties in past sampling methods or sieving techniques, the lack of multi-year sampling for many surveys, and the inherent year-to-year variability in zoobenthos populations. Because the sieve used in the 1987–89 Wisconsin DNR survey was probably of equal or finer mesh compared to earlier surveys, large density declines in the 1987–89 data were most likely real.

Results

Species

The zoobenthos found in Lake Mendota's profundal sediments in the different studies were: (a) *Chaoborus punctipennis* Say; (b) *Chironomus* spp. (*C. plumosus* L. was identified by Mackenthun & Cooley, 1952 and by Dugdale, 1955; *C. staegeri* Lundb. was also identified by Dugdale, *op. cit.* and by Augenfeld, 1960); (c) oligochaetes (*Limnodrilus* spp. and *Tubifex* spp. were identified in a ratio of 4 to 1 by Juday, 1921); (d) *Pisidium* sp. (*P. idahoense* Roper was identified by Juday, *op. cit.* and by Mackenthun & Cooley, *op. cit.*); and (e) *Procladius* sp. (*P. choreus* Meigen was identified by Juday, *op. cit.*).

Profundal density changes

Winter zoobenthos densities changed dramatically during the 1900s (Fig. 3). *Chaoborus punctipennis*, the organism with the highest recorded densities, decreased from 20000–25000 ind m^{-2} in the deep-hole region in 1917–18 and 1943–44 to 2400 ind m^{-2} in 1951. Similar declines also occurred in weighted mean densities of *Chaoborus* for the entire profundal zone, which had densities about one-half of those in the deep-hole region. In 1965 and 1987–89, deep-hole and profundal zone densities of *Chaoborus* were <60 ind m^{-2}.

Chironomus spp. densities in the profundal zone and deep-hole region were 400–1200 ind m^{-2} in 1917–18 and 1943–44 and then increased to 3800–5300 ind m^{-2} for both regions in 1951. Weighted mean profundal zone densities recorded by Dugdale (1955) in the winter of 1954 were 2100 ind m^{-2}, although deep-hole densities were only about 500 ind m^{-2}. Mean profundal

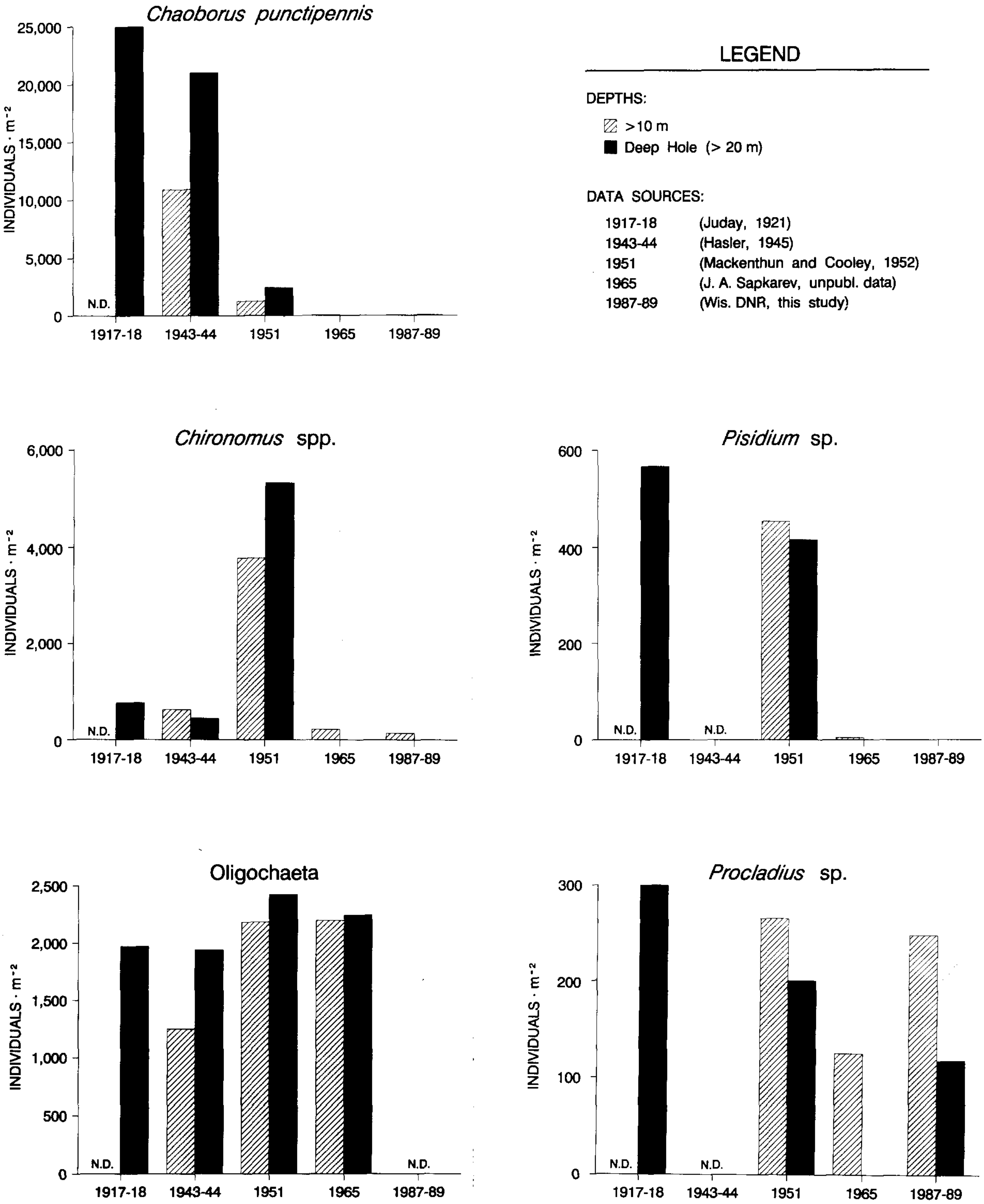

Fig. 3. Winter zoobenthos densities for the profundal zone (> 10 m) and deep-hole region (> 20 m) in Lake Mendota.

zone densities of *Chironomus* were 210 ind m $^{-2}$ and 130 ind m^{-2} in 1965 and 1987–89, respectively. No *Chironomus* were found in the deep-hole region in 1965, and only 2 ind m^{-2} were found in 1987–89.

Pisidium sp. exhibited relatively stable densities of 400–600 ind m^{-2} in the profundal zone and deep-hole region for surveys conducted through 1951, including data collected in the summer of 1944 (Sawyer *et al.*, 1945). In 1965, no *Pisidium* were recorded in the deep-hole region and only 4 ind m^{-2} were found in the entire profundal zone. In 1987–89, *Pisidium* were not found in the profundal zone of Lake Mendota.

Oligochaetes did not exhibit a major density change in the surveys conducted through 1965. Densities for the entire profundal zone including the deep-hole region averaged around 2000 ind m^{-2}. Oligochaetes were found during the 1987–89 survey, but accurate enumerations were not possible due to poor preservation of these fragile organisms. Densities determined on 2 unsieved samples taken in May 1991 were 4700 ind m^{-2}, but further testing is needed for verification.

The only other profundal zoobenthos organism that did not exhibit any major density decline from earlier surveys to 1987–89 was *Procladius* sp. Weighted mean profundal zone densities were 270 ind m^{-2}, 130 ind m^{-2}, and 250 ind m^{-2} in the 1951, 1965, and 1987–89 surveys, respectively. In the deep-hole region, densities decreased from surveys in 1917–18 to 1951 to 1965 (when no *Procladius* was recorded), but increased again in 1987–89. Because these density differences were not that great except for the 1965 deep-hole data, long-term trends are less certain.

Sublittoral densities

Chironomids (*Chironomus* and *Procladius*) recorded in samples collected in 6 to 9 m depths in the sublittoral zone did not exhibit any major population declines between surveys conducted in 1951, 1965, and 1987–89 (Fig. 4), given the normal annual variability in these emerging insects. Comparable data were not reported for earlier surveys. If anything, densities of *Procladius* may have increased during these years. Because *Chaoborus*, *Pisidium*, and oligochaetes were much less dense in sublittoral sediments than in profundal sediments, based on Juday's (1921) detailed sampling, these organisms were not used in comparing trends in this region.

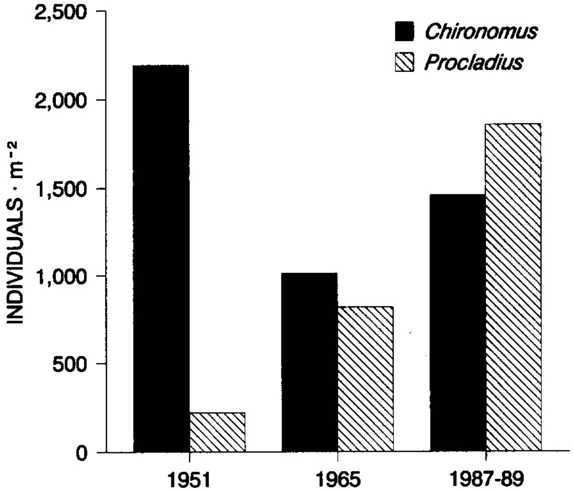

Fig. 4. Winter zoobenthos densities for the sublittoral zone (6–9 m) in Lake Mendota.

Discussion

Lake Mendota's profundal zone (> 10 m), representing 63% of the lake surface area, historically had high densities of zoobenthos. In 1917–18, total zoobenthos densities in the deep-hole region (water depths > 20 m) during the winter months were 25000 ind m^{-2} or greater. Weighted mean densities throughout the entire profundal zone were about one-half of deep-water densities but still high. *Chaoborus punctipennis* was the most abundant species. *Chironomus* spp. (including *C. plumosus*), *Pisidium* sp., oligochaetes, and *Procladius* sp. were also dense in the profundal sediments. The *Chaoborus* and chironomid midge larvae were an important food source for yellow perch (*Perca flavescens* Mitchill), one of the most important and abundant fish species in Lake Mendota (Pearse & Achtenberg, 1920). These midges composed 25–60% of the perch diet by volume during the open water period.

Between the mid-1940s and 1951, the profundal zoobenthos began to change. Densities of *Chaoborus* had declined to about 10% of earlier densities, while *Chironomus* had increased by as much as 700% to densities 2–3 times higher than those for *Chaoborus*. Densities of other zoobenthic organisms were still similar to those in earlier years. *Chironomus* densities remained high in 1954.

By 1965, the zoobenthos severely declined, resulting in the almost total elimination of *Chaoborus* and *Pisidium* throughout the entire profundal zone and of *Chironomus* and *Procladius* in the deep-hole region. *Chironomus* populations in the whole profundal zone were also greatly diminished. However, profundal oligochaete densities were stable from earlier years through 1965, the last year when detailed data were available.

In 1987–89, zoobenthos densities generally were similar to 1965 densities. *Chaoborus* and *Chironomus* populations were low, while *Pisidium* was not found throughout the entire profundal zone. However, in 1987–89 *Procladius* had increased to densities similar to those in 1951.

Reasons for decline

Four possible reasons for the decline in Lake Mendota's profundal zoobenthos can be suggested: (a) decline in food availability; (b) increase in fish predation; (c) use of toxic insecticides in the drainage basin; and (d) changes in the profundal sediment environment. Each is discussed separately.

Food availability should not have caused the decline. *Chaoborus* larvae feed almost exclusively on smaller zooplankton, which have not changed significantly during the 1900s (Brock, 1985; Lathrop & Carpenter, 1992b). Phytoplankton, including diatom populations, have exhibited similar species composition and presence of blooms throughout the 1900s (Lathrop & Carpenter, 1992b). These algae, after sinking to lake sediments, would have been a major food source for *Chironomus*, *Pisidium*, and oligochaetes.

An increase in predation by bottom-feeding fish may have occurred in Lake Mendota, because carp (*Cyprinius carpio* L.) and freshwater drum (*Aplodinotus grunniens* Rafinesque) populations increased during the mid-1900s (Lathrop *et al.*, Wis. DNR, unpubl. rep.). Neither carp nor drum were native to Lake Mendota and its Yahara River system prior to the late 1800s and 1920s, respectively. However, fish predation should not have caused the massive density declines of some profundal zoobenthos, leaving *Procladius* and sublittoral populations of *Chironomus* and *Procladius* unaffected. Kajak (1988) reviewed case studies where benthivorous fish predation decreased zoobenthos densities in all water depths. Larger organisms and the more mobile invertebrate predators such as *Procladius* were preferentially selected as prey over smaller non-predatory organisms.

Toxic insecticides that may have entered Lake Mendota from runoff were another possible cause of the zoobenthos decline. Aldrin, dieldrin, and heptachlor for agricultural crops (mostly corn), and DDT for mosquito and elm disease control had their heaviest use during the 1950s–60s (Dr. W. Gojmerac, Univ. Wisconsin-Extension, pers. comm.). However, insecticide concentrations determined by the Wisconsin State Lab of Hygiene on sediments sectioned from a deep-hole core revealed that aldrin, dieldrin, and heptachlor and its epoxide were all $<0.01\ \mu g\ g^{-1}$ dry wt for sediments deposited since the 1920s. The DDD + DDE derivatives of DDT (DDT was not found) had the highest concentration of $0.25\ \mu g\ g^{-1}$ in sediments deposited in the early 1940s to early 1950s (Lathrop, 1992c). Sediments deposited since about 1970 had lower DDD + DDE concentrations (0.03–$0.06\ \mu g\ g^{-1}$).

Low level concentrations of DDD + DDE found in lake sediments bioaccumulate in chironomids and oligochaetes and are not acutely toxic to these organisms (Johnson *et al.*, 1971; Oliver, 1984). Large doses of DDD that were used to kill *Chaoborus* larvae in Clear Lake, California in 1949, 1954, and 1957 did not prevent their return in large densities in ensuing years (Rudd & Herman, 1972; Brown, 1978). Bottom mud residues of DDD + DDE built up in Clear lake to $0.8\ \mu g\ g^{-1}$, a level much higher than concentrations found in Lake Mendota's deep-hole sediments, particularly since the 1950s. It would seem unlikely that similar massive doses of any organochlorine insecticide could have entered Lake Mendota during runoff because its large size and volume would have diluted any insecticide inputs. The fact that sublittoral densities of chironomids in Mendota remained high since the early 1950s also suggests that insecticides were not present in toxic levels.

One factor that may have contributed to the zoobenthos decline in the profundal zone is a change in the sediment environment. Many authors have stressed that as the duration of anoxia in the hypolimnion increases, only the most tolerant zoobenthos such as the oligochaetes and *Procladius* can survive (Carr & Hiltunen, 1965; Brinkhurst, 1974; Wiederholm, 1980; Bazzanti & Seminara, 1987). Jónasson (1984), in his 20-year study of Lake Esrom, which experienced an increasing summer period of hypolimnetic anoxia, reported a 400% increase in oligochaete densities to about 20000 ind m^{-2} and a 85% decrease in *Pisidium* spp. to about 690 ind m^{-2}. This density of *Pisidium* spp. was similar to that found in Lake Mendota in early years before 1965. While the extent and duration of anoxia in Lake Mendota have not changed since the early 1900s (Stewart, 1976; Brock, 1985), other signs of eutrophication in Lake Mendota have occurred that may have adversely affected the profundal sediment environment for zoobenthos survival.

Lake Mendota probably became more eutrophic after the mid-1940s because of higher nutrient loadings from sewage effluents from upstream communities and an increased use of agricultural fertilizers (Lathrop, 1992b). As a result of these higher loadings, hypolimnetic ammonium concentrations (measured in early September at a depth of 20 m) increased from about 0.6–0.7 mg N l^{-1} in 1925–32, to about 1.6–2.2 mg l^{-1} in the 1970s and 1980s. Free ammonia concentrations, which are toxic to aquatic life, would have also increased as a result.

Data on Lake Mendota's hypolimnetic hydrogen sulfide concentrations are not extensive, but they appear to have also increased. Concentrations at 20 m were measured in mid-September at 0.7 mg S l^{-1} in 1908, 2.1 mg l^{-1} in 1967, and 3.0 mg l^{-1} in 1979 (Lathrop, 1992a). These higher sulfide concentrations in the anoxic hypolimnion may have resulted from corresponding increases in average sulfate concentrations in surface waters – from about 8–12 mg SO_4^{-2} l^{-1} in the late 1940s (Lee, 1962) to about 22 mg l^{-1} since the mid-1960s (Lathrop, 1992a).

Both the ammonia and hydrogen sulfide concentrations at 20 m would have been even higher in waters nearer to the bottom and in the bottom sediments. Whether these higher concentrations were toxic to profundal zoobenthos such as *Chaoborus*, *Chironomus*, and *Pisidium* is not known. Further research can determine if the chemical environment of the profundal sediments could have caused the zoobenthos decline or if other factors may have been important.

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