tem. N.Y. Federal Aid Project F-17-R-
). N.Y. State Dep. Environ. Conser.
logical Field Station.) 12 p.
inshore fishes in Oneida Lake, 1916 ...
3-81.
od of the yellow perch, Perca flavescens,
wing mayfly, Hexagenia limbata. Ohio
persal of four deepwater fishes on the
n eastern Ontario and western Quebec.
5:553.
967. Dissolved oxygen criteria for the
E. L. Cooper (ed.). A symposium on
aquatic life. Am. Fish. Soc. Spec.
ortalities due to an internal seiche ...
h. Res. Board Can., 27:1165-1168.
minant year classes in a yellow perch
. 100:739-749.
of smallmouth bass in Oneida Lake
):132-154.
N.Y. Federal Aid Project F-17-R-...
N.Y. State Dep. Environ. Conserv.
ical Field Station.)
w perch abundance, walleye preda-
in Oneida Lake, New York. Trans.
of the cisco (Coregonus artedii) in
ams, 4:177-228.
ida Lake with emphasis on factors
Dep. Inter. Geol. Surv., N.Y. Dep.
nce of the mayfly (Hexagenia lim-
ake. N.Y. Fish Game J., 13:168.
ects of sewage pollution on the fish
Trans. Am. Fish. Soc., 82:156-165.
body form relative to feeding ecol.
Lake Opinicon, Ontario. J. Fish
3. Some phases of the life history
5.
cession in oligotrophic fish com-
ns. J. Fish. Res. Board Can., 29:
Ohio State Univ. Press, Colum-
. Parasites of Oneida Lake fishes.
survey of the worm parasites.
n of fish in southeastern Lake
Bull., 67:1-15.

ACCEPTED 22 JANUARY 1976

ECKBIAD

The Morphometry, Benthos and Sedimentation Rates of a Floodplain Lake in Pool 9 of the Upper Mississippi River

JAMES W. ECKBLAD, NANCY L. PETERSON and KENNETH OSTLIE
Department of Biology, Luther College, Decorah, Iowa 52101

and

ANNE TEMTE

Department of Biology, Utah State University, Logan 84322

ABSTRACT: Big Lake is a shallow (mean depth = 0.89 m in 1973) 56-ha backwater lake on the floodplain of the Mississippi River in NE Iowa. During the summers of 1973 and 1974 *Sphaerium* and *Hexagenia* made up 81% of the benthic macroinvertebrate abundance and 92% of the benthic biomass; both taxa had greatly reduced abundance and biomass within stands of emergent *Sagittaria* along the lake margin. During July 1974 the *Sagittaria* net productivity was about 19 g/m^2/day. Between 1896 and 1973 about 76 cm of sediment had accumulated in Big Lake, and the recent sedimentation rate (1964-1974) was about 1.7 cm/year. The calculated annual reduction in lake volume of about 17,400 m^3/year suggests that the physical and biological components of this productive aquatic habitat will be greatly modified during the next few decades.

INTRODUCTION

Since the 1930s the flow of the Upper Mississippi River has been constrained through a series of locks and dams. Pools of varying lengths were created behind these structures, and the riverine ecosystems were considerably altered. Numerous studies have been conducted on the biota and ecology of these pools (*e.g.,* Carlson, 1968; Fremling, 1964; Carlander, 1954; van der Shalie and van der Shalie, 1950).

In the spring of 1937 the U. S. Army Corps of Engineers completed lock and dam number 9 on the Mississippi River 1042 km (647.9 miles) above the mouth of the Ohio River. The pool created behind this lock and dam extends for 50.4 km to lock and dam number 8 which is just S of Genoa, Wisconsin. At normal pool elevation (189 m above mean sea level), there are approximately 11,730 ha of water and 9310 ha of above-water lands in what is known as Pool 9. Most of the open-water area is located S of the town of Lansing, Iowa, and the area to the N consists of the main navigation channel, backwater lakes, ponds and running sloughs. From 1953-1964 the mean annual commercial fish harvest for Pool 9 was 605 metric tons. Although this 50.4 km reach constitutes less than 3.8% of the Upper Mississippi River, its commercial fish harvest accounted for 12.9% of the total (Upper Mississippi River Conservation Committee, 1967).

The largest backwater lake of Pool 9 is Big Lake, located ca. 2.4 km N of Lansing, Iowa. Big Lake was a 144-ha floodplain lake shown on the 1896 Mississippi River Commission survey maps, so its existence is documented for at least 41 years prior to the impoundment of water behind lock and dam number 9. Following impoundment, the surface area of Big Lake increased by about 78%. The studies reported here were conducted during 1973 and 1974 to obtain data on the lake's morphometry, benthic macroinvertebrates, macrophyte production and rates of sedimentation.

METHODS

Lake morphometry and water chemistry.—A sonar unit was used to read depths along 20 transects across Big Lake during the summer of 1973 while Pool 9 was at normal elevation. The southern end of Big Lake is ca. 3.2 km upstream from the control point for this pool, and the estimated gradient for this section is 0.08 m per km. A bathymetric map with 0.3-m (1 ft) contour intervals was constructed from the sounding data, and morphometric parameters were estimated graphically using a planimeter (Lind, 1974). The exchange of water through Big Lake was estimated during the same period by measuring the cross-sectional area of sloughs entering and leaving the lake in conjunction with mean current velocity as determined with a Gurley pigmy current meter. Various chemical parameters of Big Lake were also recorded using standard methods (American Public Health Association, 1971

Benthic macroinvertebrates.—During the summer of 1973, bottom samples were taken with a 232-cm² Ekman grab. Three replicate samples were taken from seven sites scattered throughout Big Lake on three dates (22 June, 16 July, 30 July). Samples were first sieved through a U.S. Sieve No. 30 screened wash bucket, benthic organisms were sorted, and their numbers and dry weights were recorded. The data were used to calculate mean diversity indexes (Shannon and Weaver, 1963) using both numbers and dry weights.

During the summer of 1974, bottom samples were taken with a 529-cm² Ponar grab to compare the benthic fauna in emergent *Sagittaria* stands with the benthic fauna in the open-water regions. The weight of the Ponar grab (27 kg) and the tapered jaw with an attached underlip enabled sampling within stands of emergent vegetation. Ponar grab samples were taken from sites within emergent *Sagittaria* on the eastern side of Big Lake, and from sites located in open water ca. 150 m lakeward from the sites within emergent vegetation.

Aquatic macrophyte production.—Midsummer is usually when emergent macrophyte production is most evident in the Mississippi River valley, and our production estimates were confined to the midsummer of 1974. A harvest and reharvest procedure was used to estimate net primary production for stands of *Sagittaria* (mostly *S. cuneata*) along the eastern and southern shores of Big Lake. Six randomly selected 0.25-m² quadrats were sampled from each of the stands on 3 July, 18 July and 1 August 1974. Plants were harvested and separated into aboveground (emergent and submergent) and below-ground portions. Dry weights were determined for both portions of the harvested plants. During mid-August 1974 a combination

of ground and aerial survey was used to estimate
emergent *Sagittaria* in Big Lake.

Rates of sedimentation.—The bathymetric
developed in 1973 was compared with the depth r
six transects shown on the 1896 Mississippi River
Water level values given for the sounding date
enabled the calculation of bottom elevations. F
the 1973 data these elevations were changed acc
adjusted mean sea level.

During 1974 a series of 12 composite core sar
three locations along each of four transects acros
corresponded to the approximate locations of fo
used in the 1896 survey. Core samples were divid
ments and analyzed for Cesium-137 content. This
described by Ritchie *et al.* (1973) and uses t
Cesium-137 as a tracer for dating sedimenta
fallout records show a fallout peak in 1963. Once
Cesium-137 is strongly adsorbed on the finer partic
natural processes is limited (Davis, 1963). Cesium-
the surface 5 cm of the soil profile. The surface
able to erosion and contributes most of the to
Empirical evidence suggests that most of the C
particles settle out in somewhat less than a year.
identify the 1964 sediment layer by the peak conce
Ritchie *et al.*, 1973).

RESULTS

Lake morphometry and water chemistry.—Big
shallow basin with a maximum depth (at normal
Fig. 1). The area circumscribed by a plot of
hypsographic curve) equals the volume of the
lake this is just over 2.27 million m³ (Table 1).
m and mean slope of only 0.47% further chara
nature of this backwater lake. The exchange of wa
normal pool level averaged 58 m³ per sec; this give
of water in the lake of about 10.9 hr.

The water chemistry of Big Lake during the s
typical of backwater lakes along the Upper Missis
The lake is exposed to considerable wind action
evidence of thermal stratification or oxygen deple
waters. During a 24-hr study (29 June 1974) the
ranged from 5.30 mg/liter at 5:00 AM to 7.0

Benthic macroinvertebrates.—Fingernail clams
transversum plus some *S. striatum*) and naiads of *H*
numerically dominant taxa. The two species of ma
limbata (about 64% of the numbers in 1973) and
1973 summer, *Hexagenia* abundance averaged

at least 41 years prior to the impoundment of water
am number 9. Following impoundment, the surface
ncreased by about 78%. The studies reported here
uring 1973 and 1974 to obtain data on the lake's
thic macroinvertebrates, macrophyte production
entation.

METHODS

etry and water chemistry.—A sonar unit was used
g 20 transects across Big Lake during the summer of
was at normal elevation. The southern end of Big
upstream from the control point for this pool, and
ent for this section is 0.08 m per km. A bathymetric
1 ft) contour intervals was constructed from the
morphometric parameters were estimated graphi-
eter (Lind, 1974). The exchange of water through
ited during the same period by measuring the cross-
ughs entering and leaving the lake in conjunction
velocity as determined with a Gurley pigmy current
mical parameters of Big Lake were also recorded
ods (American Public Health Association, 1971
vertebrates.—During the summer of 1973, bottom
with a 232-cm^2 Ekman grab. Three replicate
from seven sites scattered throughout Big Lake on
e, 16 July, 30 July). Samples were first sieved
No. 30 screened wash bucket, benthic organisms
ir numbers and dry weights were recorded. The
calculate mean diversity indexes (Shannon and
both numbers and dry weights.
ner of 1974, bottom samples were taken with a
to compare the benthic fauna in emergent *Sagit-*
benthic fauna in the open-water regions. The
grab (27 kg) and the tapered jaw with an at-
led sampling within stands of emergent vegeta-
ples were taken from sites within emergent *Sagit-*
side of Big Lake, and from sites located in open
vard from the sites within emergent vegetation.
yte production.—Midsummer is usually when
production is most evident in the Mississippi
production estimates were confined to the mid-
harvest and reharvest procedure was used to esti-
roduction for stands of *Sagittaria* (mostly *S.*
eastern and southern shores of Big Lake. Six
5-m^2 quadrats were sampled from each of the
July and 1 August 1974. Plants were harvested
boveground (emergent and submergent) and
. Dry weights were determined for both por-
plants. During mid-August 1974 a combination

of ground and aerial survey was used to estimate the area covered by emergent *Sagittaria* in Big Lake.

Rates of sedimentation.—The bathymetric map of Big Lake developed in 1973 was compared with the depth readings taken along six transects shown on the 1896 Mississippi River Commission maps. Water level values given for the sounding date (6 October 1896) enabled the calculation of bottom elevations. For comparison with the 1973 data these elevations were changed according to the 1912 adjusted mean sea level.

During 1974 a series of 12 composite core samples were taken at three locations along each of four transects across Big Lake. These corresponded to the approximate locations of four of the transects used in the 1896 survey. Core samples were divided into 10-cm segments and analyzed for Cesium-137 content. This technique has been described by Ritchie *et al.* (1973) and uses the bomb-produced Cesium-137 as a tracer for dating sedimentation rates. Yearly fallout records show a fallout peak in 1963. Once in contact with soil, Cesium-137 is strongly adsorbed on the finer particles and removal by natural processes is limited (Davis, 1963). Cesium-137 is concentrated in the surface 5 cm of the soil profile. The surface soil is most susceptible to erosion and contributes most of the total sediment load. Empirical evidence suggests that most of the Cesium-137 carrying particles settle out in somewhat less than a year. Therefore, one can identify the 1964 sediment layer by the peak concentration of Cesium-137 (Ritchie *et al.*, 1973).

RESULTS

Lake morphometry and water chemistry.—Big Lake is a relatively shallow basin with a maximum depth (at normal pool level) of only 2 m (Fig. 1). The area circumscribed by a plot of area against depth (hypsographic curve) equals the volume of the basin, and for Big Lake this is just over 2.27 million m^3 (Table 1). The mean depth of 0.89 m and mean slope of only 0.47% further characterize the shallow nature of this backwater lake. The exchange of water in Big Lake at normal pool level averaged 58 m^3 per sec; this gives an average turnover of water in the lake of about 10.9 hr.

The water chemistry of Big Lake during the summer was rather typical of backwater lakes along the Upper Mississippi River (Table 2). The lake is exposed to considerable wind action, and there was no evidence of thermal stratification or oxygen depletion in the bottom waters. During a 24-hr study (29 June 1974) the oxygen concentrations ranged from 5.30 mg/liter at 5:00 AM to 7.05 mg/liter at 4:00 PM.

Benthic macroinvertebrates.—Fingernail clams (mostly *Sphaerium transversum* plus some *S. striatum*) and naiads of *Hexagenia* were the numerically dominant taxa. The two species of mayfly noted were *H. bilineata* (about 64% of the numbers in 1973) and *H. limbata.* During the 1973 summer, *Hexagenia* abundance averaged 730 per m^2, and

Sphaerium abundance averaged 1507 per m^2. Chironomidae and Oligochaeta were also common and their numbers averaged 147 per m^2, and 133 per m^2, respectively. *Sphaerium* and *Hexagenia* also dominated the biomass of benthic fauna, with a mean standing biomass of about 21 g per m^2 for *Sphaerium* (including weight of shell) and a mean standing biomass of about 6 g per m^2 for *Hexagenia*. The total

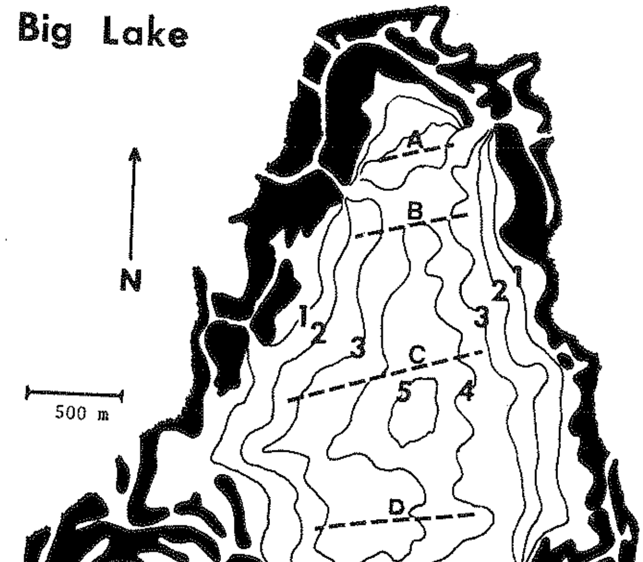


Fig. 1.—Bathymetric map of Big Lake in 1973 showing 1 ft (0.3 m) depth contour intervals at normal pool level. An earthen dam constructed in the 1920s, and now about 0.3 m below the surface, is shown extending across a portion of the lake at its southern end. Also shown are the five transects (A-F) used for getting sediment samples in 1973 and 1974; these correspond to transects across Big Lake in 1896

abundance of benthic macroinvertebrates a per m^2, and the mean standing biomass was 2 sity indices calculated from the 1973 data s exceptions) the mean diversity of numbers exc based upon dry weights (Fig. 2). Accordi benthic communities were somewhat less dive dominated by a few taxa.

The 1974 samples showed some consistent benthic fauna within emergent *Sagittaria* and tions of Big Lake. *Asellus* and Oligochaeta we emergent vegetation sites, and open-water site numbers of *Hexagenia* and *Sphaerium* (Table were generally not independent of sample parametric Wilcoxon Rank Sum test (Wilco was used to compare taxa in open water wit emergent vegetation. *Hexagenia* and *Sphaer* cantly greater ($p < 0.01$) in the open water, vegetation was significantly greater ($p < 0.$ and *Physa integra* ($p < 0.05$). The estimated densities were 3275 organisms per m^2 in the organisms per m^2 in the emergent vegetation (not strictly benthic but were taken with the g ferences in benthos dry weights showed trends s

TABLE 1.—Morphometric parameters

Surface area	
Volume	
Mean depth	
Shoreline length	
Shoreline development	
Maximum depth	
Maximum length	
Volume development	
Slope of basin	
Mean slope of basin	

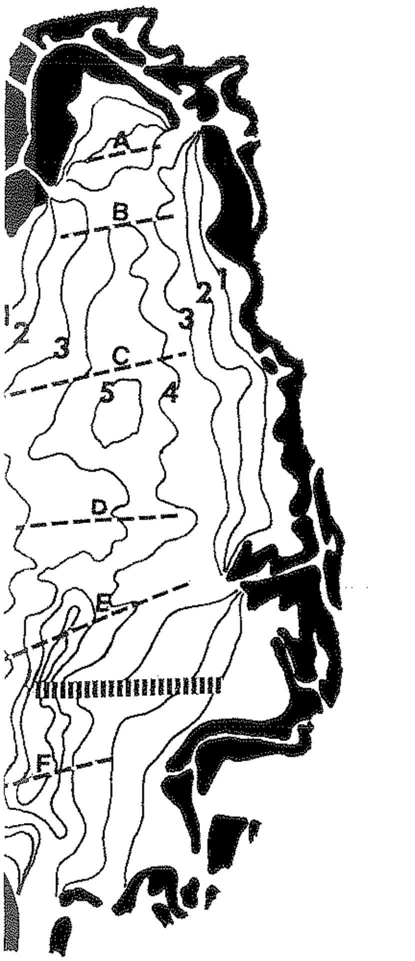
[1] All values are for normal pool level of 189 m

TABLE 2.—Chemical parameters of

	Rang
Temperature (C)	23.6 -
pH	8.2 -
Dissolved oxygen (mg/liter)	4.2 -
Total alkalinity (mg/liter)	130 -
Turbidity (JTU)	16 -
Orthophosphate (mg/liter)	0.43 -
NO_3-NO_2-N (mg/liter)	0.002 -
Total solids (mg/liter)	236 -
Volatile solids (mg/liter)	86 - 2

[1] Data based upon periodic samples taken from Ju 1974

ged 1507 per m^2. Chironomidae and
n and their numbers averaged 147 per
ively. *Sphaerium* and *Hexagenia* also
hic fauna, with a mean standing biomass
erium (including weight of shell) and
t 6 g per m^2 for *Hexagenia*. The total



ake in 1973 showing 1 ft (0.3 m) depth
l. An earthen dam constructed in the
he surface, is shown extending across a
Also shown are the five transects (A-F)
1973 and 1974; these correspond to

abundance of benthic macroinvertebrates averaged 2756 organisms per m^2, and the mean standing biomass was 29.8 g per m^2. The diversity indices calculated from the 1973 data showed that (with three exceptions) the mean diversity of numbers exceeded the mean diversity based upon dry weights (Fig. 2). According to these indices, the benthic communities were somewhat less diverse by weights and more dominated by a few taxa.

The 1974 samples showed some consistent differences between the benthic fauna within emergent *Sagittaria* and in the open-water portions of Big Lake. *Asellus* and Oligochaeta were more numerous in the emergent vegetation sites, and open-water sites had consistently larger numbers of *Hexagenia* and *Sphaerium* (Table 3). Sampling variances were generally not independent of sample means, and the nonparametric Wilcoxon Rank Sum test (Wilcoxon and Wilcox, 1964) was used to compare taxa in open water with the taxa from within emergent vegetation. *Hexagenia* and *Sphaerium* density was significantly greater ($p < 0.01$) in the open water, and density in emergent vegetation was significantly greater ($p < 0.01$) for *Hyalella azteca* and *Physa integra* ($p < 0.05$). The estimated total benthic-population densities were 3275 organisms per m^2 in the open water, and 2963 organisms per m^2 in the emergent vegetation (some of these taxa were not strictly benthic but were taken with the grab samples). The differences in benthos dry weights showed trends similar to their numbers.

TABLE 1.—Morphometric parameters of Big Lake[1]

Surface area	2,557,537 m^2
Volume	2,273,615 m^3
Mean depth	0.89 m
Shoreline length	11,399 m
Shoreline development	2.01
Maximum depth	1.98 m
Maximum length	3374 m
Volume development	1.35
Slope of basin	0.34% to 1.10%
Mean slope of basin	0.47%

[1] All values are for normal pool level of 189 m (620 ft) above mean sea level

TABLE 2.—Chemical parameters of Big Lake[1]

	Range	Mean
Temperature (C)	23.6 - 26.2	25.1
*p*H	8.2 - 8.8	8.5
Dissolved oxygen (mg/liter)	4.2 - 9.0	7.6
Total alkalinity (mg/liter)	130 - 150	138.3
Turbidity (JTU)	16 - 44	29.6
Orthophosphate (mg/liter)	0.43 - 0.65	0.55
NO_3–NO_2–N (mg/liter)	0.002 - 0.30	0.08
Total solids (mg/liter)	236 - 312	270.7
Volatile solids (mg/liter)	86 - 208	147.3

[1] Data based upon periodic samples taken from June to August during 1973 and 1974

Mean weights per individual tended to be somewhat lower in the emergent *Sagittaria* for many of the taxa. Mean standing biomass for the open water was 34.6 g per m², while from the emergent *Sagittaria* it was only 7.5 g per m² (Table 3).

Aquatic macrophyte production.—Net primary productivity for *Sagittaria* along the eastern and southern margins of Big Lake from 3 July to 1 August was 14.9 g/m²/day for the aboveground (emergent and submergent) portion, and 4.4 g/m²/day in the below-ground portion (Table 4). During this period there was almost a fivefold increase in the mean dry weight of the emergent portion of these plants (47.7 g/m² to 226.0 g/m²), and this was reflected in a dramatic change in appearance of the *Sagittaria* stands. During this period the below-ground tubers produced by *Sagittaria* the previous season were decreasing in weight, while the rest of the below-ground portions (rhizomes, roots, new tubers) were gaining weight. Apparently most of the active new tuber growth took place after the 1 August sampling date.

The emergent stands of *Sagittaria* did not usually extend more than 74 m out from the shore of Big Lake, and water depth at this distance was usually less than 0.3 m. The total area covered by emergent *Sagittaria* in mid-August 1974 was about 41 ha, 16% of the surface area of Big Lake.

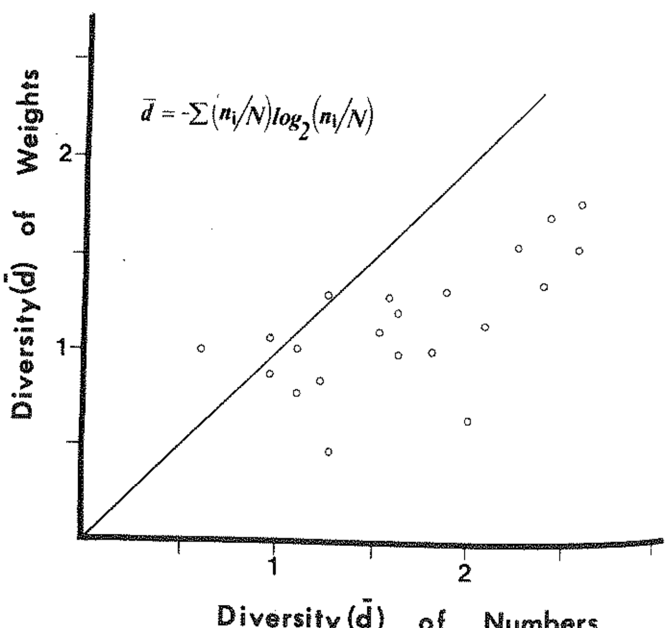


Fig. 2.—Comparison of macroinvertebrate diversity index using dry weights and using numbers. The 45° diagonal line shows expected values if the two indices were equivalent for the seven sites on the three sampling dates

Rates of sedimentation.—The comparison of [...] with 1973 data along the six transects (Fig. 1) [...] sediment accumulation of 30-122 cm. During t[...] from 1896 to 1973, there was an average rise in [...] due to sedimentation, of 76 cm in Big Lake (Table [...] of sediment accumulated at a uniform rate over [...] interval, the mean rate of sedimentation would b[...] If the time period used in figuring sedimentation r[...] since impoundment (1937), then the mean rate [...] this 36-year period would be 2.11 cm per year.

The 1974 analysis for recent sediment using [...] that a mean of 16.94 cm of sediment had accum[...] during the 10-year period from 1964-1974 (Ta[...] recent sedimentation rate of 1.69 cm per year us[...] dating technique was only 19% below the rate o[...]

TABLE 3.—Numbers and dry weights of macroinverte[...] within emergent *Sagittaria* sp. and an open-water sit[...]

	Numbe[...]
	Sagittaria
***Sphaerium* sp.	83.3 ± 14.62
***Hexagenia* sp.	115.4 ± 36.15
Chironomus sp.	439.1 ± 36.63
Palpomyia sp.	35.3 ± 11.56
Misc. Diptera	237.2 ± 64.67
Branchiura sowerbyi	19.2 ± 19.23
Misc. Oligochaeta	115.4 ± 41.84
Asellus sp.	96.2 ± 37.16
Helobdella sp.	60.9 ± 15.24
***Hyalella azteca*	1173.0 ± 362.25
**Physa integra*	137.8 ± 53.57
Gyraulus parvus	32.1 ± 14.62
Campeloma sp.	0 ± 0

[1] Means were based upon 6 Ponar grab samples alon[...] Lake on 9 July 1974. Significant differences were teste[...] Rank Sum statistic, and levels of significance (for both n[...] are indicated to left of taxa; * = P < 0.05, ** = P < 0.[...]

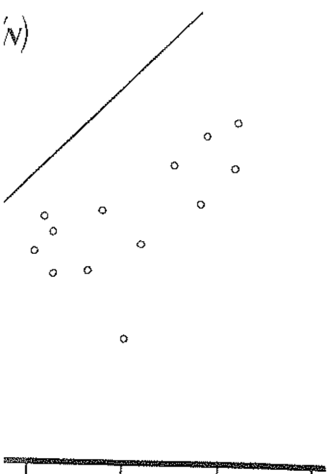
TABLE 3.—(continued)

	Mg/[...]
	Sagittaria
***Sphaerium* sp.	799.7 ± 276.24
***Hexagenia* sp.	857.3 ± 396.37
Chironomus sp.	1233.9 ± 99.96
Palpomyia sp.	28.2 ± 9.49
Misc. Diptera	68.0 ± 16.71
Branchiura sowerbyi	27.2 ± 27.24
Misc. Oligochaeta	51.0 ± 15.90
Asellus sp.	55.8 ± 21.62
Helobdella sp.	58.7 ± 21.81
***Hyalella azteca*	440.7 ± 127.91
**Physa integra*	1052.5 ± 532.08
Gyraulus parvus	113.1 ± 54.77
Campeloma sp.	2458.2 ± 2458.23

nded to be somewhat lower in the he taxa. Mean standing biomass for , while from the emergent *Sagittaria*).

ion.—Net primary productivity for outhern margins of Big Lake from 3 day for the aboveground (emergent 1.4 g/m²/day in the below-ground period there was almost a fivefold of the emergent portion of these and this was reflected in a dramatic *taria* stands. During this period the *Sagittaria* the previous season were rest of the below-ground portions gaining weight. Apparently most of place after the 1 August sampling

ia did not usually extend more than ke, and water depth at this distance e total area covered by emergent s about 41 ha, 16% of the surface



rate diversity index using dry weights ine shows expected values if the two on the three sampling dates

Rates of sedimentation.—The comparison of 1896 depth readings with 1973 data along the six transects (Fig. 1) showed a range in sediment accumulation of 30-122 cm. During the 77-year interval, from 1896 to 1973, there was an average rise in the floodplain floor, due to sedimentation, of 76 cm in Big Lake (Table 5). If this quantity of sediment accumulated at a uniform rate over the entire 77-year interval, the mean rate of sedimentation would be 0.99 cm per year. If the time period used in figuring sedimentation rates was the interval since impoundment (1937), then the mean rate of sedimentation for this 36-year period would be 2.11 cm per year.

The 1974 analysis for recent sediment using Cesium-137 showed that a mean of 16.94 cm of sediment had accumulated in Big Lake during the 10-year period from 1964-1974 (Table 5). The mean recent sedimentation rate of 1.69 cm per year using the Cesium-137 dating technique was only 19% below the rate of 2.11 per year cal-

TABLE 3.—Numbers and dry weights of macroinvertebrates from a site within emergent *Sagittaria* sp. and an open-water site (means ± SE)[1]

	Numbers/m²	
	Sagittaria	Open water
***Sphaerium* sp.	83.3 ± 14.62	1419.8 ± 235.38
***Hexagenia* sp.	115.4 ± 36.15	602.5 ± 75.41
Chironomus sp.	439.1 ± 36.63	314.1 ± 55.44
Palpomyia sp.	35.3 ± 11.56	48.1 ± 19.07
Misc. Diptera	237.2 ± 64.67	282.0 ± 40.84
Branchiura sowerbyi	19.2 ± 19.23	115.4 ± 96.53
Misc. Oligochaeta	115.4 ± 41.84	185.9 ± 63.71
Asellus sp.	96.2 ± 37.16	57.7 ± 22.21
Helobdella sp.	60.9 ± 15.24	214.7 ± 89.57
***Hyalella azteca*	1173.0 ± 362.25	9.6 ± 6.57
**Physa integra*	137.8 ± 53.57	0 ± 0
Gyraulus parvus	32.1 ± 14.62	0 ± 0
Campeloma sp.	0 ± 0	3.2 ± 3.21

[1] Means were based upon 6 Ponar grab samples along eastern edge of Big Lake on 9 July 1974. Significant differences were tested using the Wilcoxon Rank Sum statistic, and levels of significance (for both numbers and weights) are indicated to left of taxa; * = $P < 0.05$, ** = $P < 0.01$

TABLE 3.—(continued)

	Mg/m²	
	Sagittaria	Open water
***Sphaerium* sp.	799.7 ± 276.24	17,665.6 ± 2231.16
***Hexagenia* sp.	857.3 ± 396.37	10,737.9 ± 2106.23
Chironomus sp.	1233.9 ± 99.96	923.7 ± 293.76
Palpomyia sp.	28.2 ± 9.49	41.3 ± 17.37
Misc. Diptera	68.0 ± 16.71	103.2 ± 35.44
Branchiura sowerbyi	27.2 ± 27.24	248.7 ± 218.66
Misc. Oligochaeta	51.0 ± 15.90	253.5 ± 89.92
Asellus sp.	55.8 ± 21.62	59.3 ± 37.12
Helobdella sp.	58.7 ± 21.81	167.3 ± 55.03
***Hyalella azteca*	440.7 ± 127.91	4.2 ± 3.16
**Physa integra*	1052.5 ± 532.08	0 ± 0
Gyraulus parvus	113.1 ± 54.77	0 ± 0
Campeloma sp.	2458.2 ± 2458.23	0 ± 0

culated from the 1896 soundings assuming most deposition since 1937.

Discussion

Big Lake is one of many relatively shallow backwater lakes found in the valley of the Upper Mississippi River where it borders southeastern Minnesota, northeastern Iowa and western Wisconsin. There are about 20 backwater lakes with a surface area of at least 100 ha in the 332 km section of the Mississippi River between Wabasha, Minnesota, and Bellview, Iowa. Their biotic and abiotic characteristics depend upon the interaction of factors including sediment accumulation, water level fluctuations, allochthonous and autochthonous nutrient inputs, and the exchange of water from sloughs running into and out of each lake.

Sedimentation in the Upper Mississippi River backwater lakes is rapidly reducing their storage capacities. If the 0.76 m of sediment

TABLE 4.—Production of *Sagittaria* stands of Big Lake (1974)

	3 July	18 July	1 August
Mean standing biomass (g/m²)[1]	528.4 ± 70.86	825.8 ± 106.16	1088.0 ± 141.9
Aboveground (%)	52.0	54.4	64.9
Below-ground (%)	48.0	45.6	35.1
Mean net production (g/m²/day)		19.83	18.73

[1] Mean of six samples ± standard error

TABLE 5.—Sediments accumulated between 1896 and 1973, and recent sedimentation rate in Big Lake

Transect	Number of comparison points along transect	Sediment accumulated (m) between 1896 and 1973 (mean ± SE)
A	3	0.91 ± 0.000
B	2	0.91 ± 0.000
C	4	0.76 ± 0.015
D	2	1.07 ± 0.015
E	6	0.56 ± 0.094
F	3	0.71 ± 0.010
Totals	20	0.76 ± 0.056

TABLE 5.—(continued)

Transect	Number of samples along transect	Depth (cm) of peak Cesium-137 concentration (mean ± SE)
A		
B	3	13.54 ± 1.694
C	3	27.10 ± 6.774
D	3	11.86 ± 1.694
E	3	15.24 ± 0.000
F		
Totals	12	16.94 ± 2.367

accumulated sometime since 1896 in Big Lake i hypsographic curve, it is possible to calculate h sediment influenced some of the lake's morph Near the entrance of several sloughs into Big Lal course to medium sand, but for most of the lake t size consists of very fine sand to clay. If this se since impoundment, the present lake volume of ju ar is only about 55% of what it was after impoun mean depth would have been 1.62 m in 1937 stantial change in surface area) rather than the of 0.89 m. The calculated annual reduction in lak would be about 53,400 m³ per year. At this rate span" of Big Lake is about 43 years. If instead, t ment accumulated from 1964 to 1974 is added t curve, the recent mean annual reduction in lake v at about 37,400 m³ per year. If this rate conti life span" of Big Lake is about 61 years. These "li based upon simple linear extrapolation of sedimer provide very precise estimates, but they do ap intervals involved.

The July net productivity rate of over 19 g/m of Big Lake is one of the higher known short-tern (Odum, 1971). If at least 25% of the annual net either before or after the study period, then these were at least as productive as the 600 g/m²/year rep *lancifolia* in Mississippi Gulf Coast estuaries (De this productivity rate the *Sagittaria* stands of Big an autochthonous input of ca. 246 metric tons ann

The further development of *Sagittaria* around Lake appears to be limited through the interaction water depth. The river valley tends to channel and any northern or southern component. Big Lake ha exposure, and the emergent *Sagittaria* have usually lakeward if the depth exceeded 0.3 m at normal projected decreased depth accompanying sediment the continued expansion of the *Sagittaria* stands; would also be expected for the floating *Nelumbo lu odorata* which are also common in Big Lake.

Few studies demonstrate just how important th waters are to the riverine system (Schramm and benthos of Big Lake corresponded closely to the *Hex* dominated community reported elsewhere for the above dam 19 at Keokuk, Iowa (Carlson, 1968) summer population densities of Big Lake were usual than those reported for other habitats (Britt, 195 Paloumpis and Starrett, 1960; Craven and Brown, known importance of these nymphs in the diet o fishes (Hoopes, 1960), the high numbers may be a

}6 soundings assuming most deposition since 1937

Discussion

of many relatively shallow backwater lakes found Upper Mississippi River where it borders south northeastern Iowa and western Wisconsin. There ter lakes with a surface area of at least 100 ha of the Mississippi River between Wabasha, Min . Iowa. Their biotic and abiotic characteristics eraction of factors including sediment accumula ctuations, allochthonous and autochthonous n exchange of water from sloughs running into and

the Upper Mississippi River backwater lakes r storage capacities. If the 0.76 m of sedimen

uction of *Sagittaria* stands of Big Lake (1974)

3 July	18 July	1 August
528.4 ± 70.86	825.8 ± 106.16	1088.0 ± 141.9
52.0	54.4	64.9
48.0	45.6	35.1
19.83	18.73	

s ± standard error

; accumulated between 1896 and 1973, and recent edimentation rate in Big Lake

Number of comparison points along transect	Sediment accumulated (m) between 1896 and 1973 (mean ± SE)
3	0.91 ± 0.000
2	0.91 ± 0.000
4	0.76 ± 0.015
2	1.07 ± 0.015
6	0.56 ± 0.094
3	0.71 ± 0.010
20	0.76 ± 0.056

Table 5.—(continued)

Number of samples along transect	Depth (cm) of peak Cesium-137 concentration (mean ± SE)
3	13.54 ± 1.694
3	27.10 ± 6.774
3	11.86 ± 1.694
3	15.24 ± 0.000
12	16.94 ± 2.367

accumulated sometime since 1896 in Big Lake is added to its 1973 hypsographic curve, it is possible to calculate how this quantity of sediment influenced some of the lake's morphometric parameters. Near the entrance of several sloughs into Big Lake the sediments are coarse to medium sand, but for most of the lake the sediment particle size consists of very fine sand to clay. If this sediment accumulated since impoundment, the present lake volume of just over 2.27 million m³ is only about 55% of what it was after impoundment in 1937. The mean depth would have been 1.62 m in 1937 (assuming no substantial change in surface area) rather than the present mean depth of 0.89 m. The calculated annual reduction in lake volume since 1937 would be about 53,400 m³ per year. At this rate the projected "life span" of Big Lake is about 43 years. If instead, the 16.9 cm of sediment accumulated from 1964 to 1974 is added to the hypsographic curve, the recent mean annual reduction in lake volume is calculated at about 37,400 m³ per year. If this rate continues, the projected "life span" of Big Lake is about 61 years. These "life span" projections based upon simple linear extrapolation of sedimentation rates do not provide very precise estimates, but they do approximate the time intervals involved.

The July net productivity rate of over 19 g/m²/day for *Sagittaria* in Big Lake is one of the higher known short-term productivity rates (Odum, 1971). If at least 25% of the annual net production occurred either before or after the study period, then these stands in Big Lake were at least as productive as the 600 g/m²/year reported for *Sagittaria lancifolia* in Mississippi Gulf Coast estuaries (De la Cruz, 1974). At this productivity rate the *Sagittaria* stands of Big Lake would provide an autochthonous input of ca. 246 metric tons annually.

The further development of *Sagittaria* around the margins of Big Lake appears to be limited through the interaction of wave action and water depth. The river valley tends to channel and amplify winds with any northern or southern component. Big Lake has considerable wind exposure, and the emergent *Sagittaria* have usually not spread further lakeward if the depth exceeded 0.3 m at normal pool level. With a projected decreased depth accompanying sedimentation, there should be continued expansion of the *Sagittaria* stands; a similar expansion would also be expected for the floating *Nelumbo lutea* and *Nymphaea odorata* which are also common in Big Lake.

Few studies demonstrate just how important the benthos of backwaters are to the riverine system (Schramm and Lewis, 1974). The benthos of Big Lake corresponded closely to the *Hexagenia-Sphaerium*-dominated community reported elsewhere for the Mississippi River above dam 19 at Keokuk, Iowa (Carlson, 1968). The *Hexagenia* summer population densities of Big Lake were usually as high or higher than those reported for other habitats (Britt, 1955; Sublette, 1957; Paloumpis and Starrett, 1960; Craven and Brown, 1969). Given the known importance of these nymphs in the diet of Mississippi River fishes (Hoopes, 1960), the high numbers may be an important factor contributing to the relatively abundant fish populations (as indicated by commercial catch statistics) of Pool 9. The abundant *Sphaerium* populations of Big Lake also provide a valuable food supply for fish and for numerous species of migratory waterfowl.

In terms of benthic community structure, numerical abundance may not be as meaningful as biomass. Odum (1971) has suggested that the pyramid of numbers is not as fundamental to community structure as a pyramid of biomass, since the geometric fact is that a great many small units are required to equal the mass of one large unit. The diversity index calculated for the macroinvertebrates of Big Lake using numbers, and then biomass, shows the relationship between the two ways of describing community structure. When diversity is redefined in biomass units as suggested by Wilhm (1968), *Asellus* weighing 0.6 mg does not have the same influence on the index as *Physa integra* weighing 7.6 mg. For the benthic macroinvertebrates of Big Lake the lower biomass diversity index appeared to better reflect the dominance of a few taxa within the community.

The differences observed between benthic communities within stands of *Sagittaria* and open water is suggestive of the changes which are likely with further sedimentation and reduction in water depth. As *Sagittaria* continues to encroach on the open-water portion of Big Lake, the present dominance of *Sphaerium* and *Hexagenia* will likely shift to a dominance of Chironomidae, Oligochaeta and Gastropoda. These changes in benthic populations, along with further reduction in water volume, will no doubt influence the organisms at higher trophic levels.

Acknowledgments.—This research was supported by the National Science Foundation (GY-10703 and GY-11302). We would like to thank Jerry Ropp, Donna Poesch, Greg Hanson and Karen Horn for assistance in the collection of data. Jon Verdon collected the sediment samples, and Drs. J. Roger McHenry and Jerry C. Ritchie of the USDA Sedimentation Laboratory at Oxford, Miss., determined Cesium-137 levels within the sediment samples. Drs. McHenry and Ritchie have also made helpful comments on this manuscript.

LITERATURE CITED

AMERICAN PUBLIC HEALTH ASSOCIATION. 1971. Standard methods for the examination of water and wastewater. 13th ed. Am. Public Health Assoc., New York. 874 p.

BRITT, N. W. 1955. *Hexagenia* (Ephemeroptera) population recovery in western Lake Erie following the 1953 catastrophe. *Ecology*, **36**:520-522.

CARLANDER, H. B. 1954. A history of fish and fishing in the Upper Mississippi. Upper Mississippi River Conservation Committee, Iowa Conservation Commission, Des Moines. 96 p.

CARLSON, C. A. 1968. Sunmmer bottom fauna of the Mississippi River, above dam 19, Keokuk, Iowa. *Ecology*, **19**:162-169.

CRAVEN, R. E. AND B. E. BROWN. 1969. Ecology of *Hexagenia* naiads (Insecta: Ephemeridae) in Oklahoma reservoir. *Am. Midl. Nat.*, **82**:346-358.

DAVIS, J. J. 1963. Cesium and its relation to potassium in ecology, p. 539-564. *In:* V. Schultz and A. W. Klements, Jr. (eds.). Radioecology. Reinhold, New York. 746 p.

DE LA CRUZ, A. A. 1974. Primary production of Mi (abstract). *Bull. Ecol. Soc. Am.*, **55**:28.

FREMLING, C. E. 1964. Mayfly distribution indicates Upper Mississippi River. *Science*, **146**:1164-11

HOOPES, D. T. 1960. Utilization of mayflies and caddis River fishes. *Trans. Am. Fish. Soc.*, **89**:32-34.

LIND, O. T. 1974. Handbook of common methods in l Co., St. Louis. 154 p.

ODUM, E. P. 1971. Fundamentals of ecology. W. B. phia. 574 p.

PALOUMPIS, A. A. AND W. C. STARRETT. 1960. An eco organisms in three Illinois River flood plain lake 406-435.

RITCHIE, J. C., J. R. MCHENRY AND A. C. GILL. 1973. sediments. *Limnol. Oceanogr.*, **18**:254-263.

SCHRAMM, H. L., JR. AND W. M. LEWIS. 1974. Study water chutes to a riverine fishery. Army Engin ment Station report AD-786544. National Tech vice, Springfield, Va. 144 p.

SHANNON, C. E. AND W. WEAVER. 1963. The mathe munication. Univ. of Illinois Press, Urbana. 11

SUBLETTE, J. E. 1957. The ecology of the macroscopic Texaoma (Denison Reservoir). Oklahoma and T **57**:371-402.

SWANSON, G. A. 1967. Factors influencing the distribu *Hexagenia* nymphs (Ephemeroptera) in a Mi *Ecology*, **48**:216-225.

UPPER MISSISSIPPI RIVER CONSERVATION COMMITTEE. of fishery information on the Upper Mississip Committee. Iowa Conservation Commission, De

VAN DER SHALIE, H. AND A. VAN DER SHALIE. 1950. Th sippi River. *Am. Midl. Nat.*, **44**:448-466.

WILCOXON, F. AND R. A. WILCOX. 1964. Some rapid procedures. Lederle Laboratories, Pearl River, N.

WILHM, J. L. 1968. Use of biomass units in Shannon's 153-156.

SUBMITTED 20 OCTOBER 1975 ACCEPT

y abundant fish populations (as indicated
cs) of Pool 9. The abundant *Sphaerium*
o provide a valuable food supply for fish
migratory waterfowl.
nmunity structure, numerical abundance
s biomass. Odum (1971) has suggested
ns is not as fundamental to community
omass, since the geometric fact is that a
quired to equal the mass of one large unit
d for the macroinvertebrates of Big Lake
mass, shows the relationship between the
munity structure. When diversity is re
suggested by Wilhm (1968), *Asellus*
ave the same influence on the index as
ng. For the benthic macroinvertebrates
diversity index appeared to better reflect
within the community.
between benthic communities within
water is suggestive of the changes which
entation and reduction in water depth.
croach on the open-water portion of Big
of *Sphaerium* and *Hexagenia* will likely
onomidae, Oligochaeta and Gastropoda
ulations, along with further reduction in
nfluence the organisms at higher trophic

rch was supported by the National Science
1302). We would like to thank Jerry Roppe
Karen Horn for assistance in the collection
e sediment samples, and Drs. J. Roger Mc
USDA Sedimentation Laboratory at Oxford
els within the sediment samples. Drs. Mc
helpful comments on this manuscript.

RATURE CITED

CIATION. 1971. Standard methods for the
wastewater. 13th ed. Am. Public Health

phemeroptera) population recovery in west
1953 catastrophe. *Ecology*, **36**:520-522.
of fish and fishing in the Upper Mississippi
onservation Committee, Iowa Conservation
6 p.
ottom fauna of the Mississippi River, above
logy, **19**:162-169.
969. Ecology of *Hexagenia* naiads (Insecta-
reservoir. *Am. Midl. Nat.*, **82**:346-358.
elation to potassium in ecology, p. 539-566.
Klements, Jr. (eds.). Radioecology. Rein-

DE LA CRUZ, A. A. 1974. Primary production of Mississippi coastal marshes (abstract). *Bull. Ecol. Soc. Am.*, **55**:28.

FREMLING, C. E. 1964. Mayfly distribution indicates water quality on the Upper Mississippi River. *Science*, **146**:1164-1166.

HOOPES, D. T. 1960. Utilization of mayflies and caddisflies by some Mississippi River fishes. *Trans. Am. Fish. Soc.*, **89**:32-34.

LIND, O. T. 1974. Handbook of common methods in limnology. C. V. Mosby Co., St. Louis. 154 p.

ODUM, E. P. 1971. Fundamentals of ecology. W. B. Saunders Co., Philadelphia. 574 p.

PALOUMPIS, A. A. AND W. C. STARRETT. 1960. An ecological study of benthic organisms in three Illinois River flood plain lakes. *Am. Midl. Nat.*, **64**: 406-435.

RITCHIE, J. C., J. R. MCHENRY AND A. C. GILL. 1973. Dating recent reservoir sediments. *Limnol. Oceanogr.*, **18**:254-263.

SCHRAMM, H. L., JR. AND W. M. LEWIS. 1974. Study of importance of backwater chutes to a riverine fishery. Army Engineer Waterways Experiment Station report AD-786544. National Technical Information Service, Springfield, Va. 144 p.

SHANNON, C. E. AND W. WEAVER. 1963. The mathematical theory of communication. Univ. of Illinois Press, Urbana. 117 p.

SUBLETTE, J. E. 1957. The ecology of the macroscopic bottom fauna in Lake Texaoma (Denison Reservoir). Oklahoma and Texas. *Am. Midl. Nat.*, **57**:371-402.

SWANSON, G. A. 1967. Factors influencing the distribution and abundance of *Hexagenia* nymphs (Ephemeroptera) in a Missouri River reservoir. *Ecology*, **48**:216-225.

UPPER MISSISSIPPI RIVER CONSERVATION COMMITTEE. 1967. A compendium of fishery information on the Upper Mississippi River Conservation Committee. Iowa Conservation Commission, Des Moines. 225 p.

VAN DER SHALIE, H. AND A. VAN DER SHALIE. 1950. The mussels of the Mississippi River. *Am. Midl. Nat.*, **44**:448-466.

WILCOXON, F. AND R. A. WILCOX. 1964. Some rapid approximate statistical procedures. Lederle Laboratories, Pearl River, N.Y. 60 p.

WILHM, J. L. 1968. Use of biomass units in Shannon's formula. *Ecology*, **49**: 153-156.

SUBMITTED 20 OCTOBER 1975 ACCEPTED 23 DECEMBER 1975