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EFFECTS OF WINTERKILL AND CHEMICAL ERADICATION OF FISH ON A LAKE ECOSYSTEM[1/]

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Effects of Winterkill and Chemical Eradication of Fish On a Lake Ecosystem

by

Farrell Bandow

Page	Section	Paragraph	Line	Correction
3	Study Lake	3	3	spelling - resistant
5	Methods	4	1	should read...late May
6	Methods	5	11	spelling - colorimetric
6	Methods	5	13	spelling - cadmium
9	Methods	16	1	spelling - Chironomidae
16	Findings	14	6	should read...Anabaena are not apparent
18	Findings	16	12	should read...which were well below
32	Rotenone Treatment	4	9	spelling - resistant
33	Rotenone Treatment	7	1	spelling - benthic
36	Discussion	4	9	delete - Shapiro
40	Literature Cited		7	spelling - Wononskopomuc
40	Acknowledgements	1	6	spelling - analysis
40	Acknowledgements	1	7	spelling - manuscript

EFFECTS OF WINTERKILL AND CHEMICAL ERADICATION OF FISH ON A LAKE ECOSYSTEM

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ABSTRACT

Chemical, physical, and biological characteristics of a shallow lake dominated by black bullheads were to be compared before and after reclamation with rotenone. The pretreatment phase was shortened to one summer by a winterkill in 1975 that nearly eliminated the bullhead population. The surviving bullhead population was treated with rotenone in the fall of 1975. In the three summers following the winterkill there was a substantial decline in chlorophyll *a* concentrations and a more moderate decline in primary production. Secchi disc visibility correspondingly increased and submerged macrophytes which initially were nearly absent at depths over 5 feet proliferated to occupy nearly the entire lake bottom. During the final summer the chlorophyll concentration reached a relatively low peak in early July and then declined despite relatively high nutrient concentrations. The postwinterkill years were characterized by increased numbers of large filter feeding zooplankters presumably as a result of reduced bullhead predation. The postwinterkill decline in chlorophyll is largely attributed to the increase in the large filter feeding zooplankters.

The plankton Crustacea were substantially reduced by the rotenone treatment. The calanoid copepods, which were the most abundant zooplankter at the time of treatment, never regained their former abundance during the following two summers. Instead, *Daphnia* became the most abundant zooplankter in the community. The chemical treatment may also have caused a change in the species composition of rotifers and a temporary reduction in some of the major benthic invertebrates.

INTRODUCTION

Frequently noted changes in warmwater lakes following eradication or reduction of bottom feeding fish have been a marked decline in algal abundance and increases in light penetration and abundance of submerged macrophytes. Although most cases concern carp (Cyprinus carpio) as a major contributor to water quality deterioration, similar changes following bullhead (Ictalurus sp.) removal have been noted in Minnesota.1/

It was once widely accepted that the mechanism by which bottom feeding fish caused deterioration of water quality was by physically disturbing bottom sediments thus uprooting benthic vegetation and increasing turbidity and nutrient availability to phytoplankton. Recent findings, however, indicate digestive activity of carp to be far more important than physical activity in recycling nutrients from the sediments (Lamarra 1975). Observations by Shapiro et al. (1975) and Shapiro (1978) show that planktivorus fish also cause high phytoplankton densities in many lakes by restricting the abundance of grazing zooplankters.

This investigation was originally designed to document chemical, physical, and biological changes occurring in a shallow lake dominated by black bullheads (Ictalurus melas) following reclamation with rotenone. The lake was to be sampled, beginning in 1974, for two summers prior to reclamation of the fishery followed by two years of duplicate sampling. However, a severe winterkill early in 1975 substantially reduced the fish population before the second summer of scheduled pretreatment sampling. Surviving bullheads were repop-

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1/ Unpublished data, Minnesota Department of Natural Resources ulating the lake so the rotenone treatment was made as scheduled in September 1975 but it failed to eliminate all of the bullheads. Bullhead populations during the years 1975 through 1977 were similar and in sharp contrast to the prewinterkill population of 1974. Therefore, for most comparisons made in this report, 1974 is considered the pretreatment phase and the latter three years the posttreatment segment.

STUDY LAKE

Carls (McMahon) Lake is located in Scott County amidst fertile agricultural country in southeastern Minnesota. It occupies an ice block basin deposited in glacial till (Anonymous 1968). The watershed is mostly cropland interspersed with some pasture and a small amount of woodland. A substantial area of marsh adjoins the north and south sides of the lake and a moderate sized dairy herd utilizes parts of the south and east shores. There is no permanent surface inlet or outlet.

Carls Lake has a surface area of approximately 110 acres and a usual maximum depth near 14 ft. but because of severe dry weather it declined to about 10 ft. before the conclusion of this investigation (Figure 1). A persistent thermocline does not occur but temporary thermal stratification during hot, calm periods was occasionally noted. Summer measurements of total alkalinity at the lake surface ranged from 66 to 86 mg/l and pH values were commonly above 9.

Carls Lake is typical of many shallow lakes in southern Minnesota in that it is characterized by summer algal blooms and periodic winterkills that create an imbalanced fishery dominated by the resistant black bullhead. The lake, originally classified as a bass-panfish lake, was a popular fishing lake in the 1950's but the latest lake survey, conducted

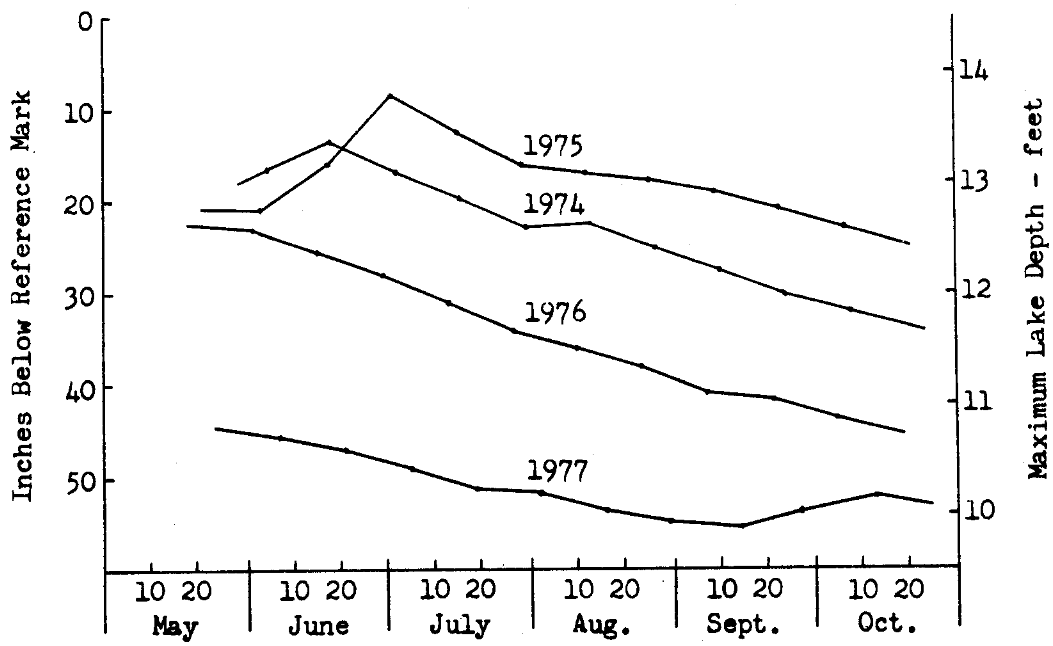

Figure 1.- Carls Lake surface levels.

in 1971, showed it to be heavily dominated by small black bullheads.[2/]

METHODS

Sampling schedules and procedures established in 1974 were duplicated as closely as circumstances permitted in 1975, 1976, and 1977.

Fishery

Assessment of the Carls Lake fishery was conducted in July and September with experimental gill nets, trap nets, bag seine, and minnow traps. Gill nets were nylon, 250 ft. long with five 50 ft. sections of mesh graded from 0.75 to 2 in. square measure. Trap nets were 0.75 in. square measure mesh with leads extending approximately 50 ft. The bag seine had 0.25 in. square measure mesh and was 50 ft. long. Minnow traps were 12 in. diameter by 30 in. long and constructed of 0.25 in. hardware cloth.

Gill net and trap net sets ranged from 19 to 24 hr. in duration and minnow trap sets were of approximately 48 hr. duration. Shoreline seine hauls were 250 ft. in length. Individual total lengths and weights were recorded to the nearest 0.1 in. and 0.01 lb., respectively, on samples of each species captured by gill net and trap net. Fish captured by minnow trap and seine were enumerated by species.

Chemical and Physical Parameters and Plankton

Biweekly sampling was conducted 12 times a season beginning in late May but in 1974 only 11 complete series of samples beginning the first week of

2/ Minnesota Department of Natural Resources, Section of Fisheries, lake survey reports, Carls (McMahon) Lake, 1958 and 1971.

June were obtained. Although most graphs presented show 12 samples, all comparisons made in the way of seasonal averages take into account only the 11 samples beginning in June.

Water chemistry sampling was conducted at 1 m intervals to 3 m at one site over the deepest part of the lake (2.5-3 m in 1977 as lake depth permitted). Chlorophyll a was measured by the procedure of Strickland and Parsons (1968) where algae were collected on glass fiber filters after which the filters were homogenized and the chlorophyll extracted with acetone followed by spectrophotometric measurement of the extract. Depth profiles were combined in determining mean chlorophyll values. Phosphorus and nitrogen analyses were made according to U.S. Environmental Protection Agency (1974). Phosphorus measurements were by the stannous chloride-ammonium molybdate method on unfiltered samples. Total phosphorus was measured by colorimetric determination of persulfate digested samples and orthophosphate by direct colorimetry. Nitrate nitrogen analyses were colorimetric measurements following cadmium-copper reduction of filtered samples. Ammonia nitrogen was determined from unfiltered samples with an ammonia gas selective electrode.

Primary production measurements generally followed Megard (1970). Samples collected with a Van Dorn horizontal sampler at 0.5 m depth intervals were incubated in pairs of transparent and opaque B.O.D. bottles for 6 hours at the depth from which they were collected beginning 3 hr. before midday. The gross photosynthesis at each sample depth was determined after incubation as the difference between the dissolved oxygen concentration in the transparent and opaque bottle with the maximum photosynthetic rate (pmax; g $O_2/m^3/6$ hr.) occurring at the depth where light intensity was optimal. The maximum specific photosynthetic rate (Pmax; mg O_2/ mg chl./6 hr.) is the ratio pmax: chlorophyll a. The integral photosynthetic rate (Σp; g $O_2/m^2/6$ hr.) was computed as the area enclosed by the depth-gross photosynthesis curve.

Dissolved oxygen measurements were by the azide modification of the Winkler method. A magnetic stirrer was used for titrations which were recorded to the nearest 0.01 ml with a microburet. Water temperatures and secchi disc transparencies were measured at the beginning and end of the incubation period and are expressed as mean values.

Plankton samples were collected at the same site at the surface and 3 m(2.5-3 m in 1977 as lake depth permitted) and consisted of 21-32 liters concentrated to about 300 ml with a no. 25 plankton net and preserved with 5 percent formalin.

Phytoplankton was counted in a Sedgwick-Rafter cell under magnification of 100X with a compound microscope equipped with a Whipple micrometer. The more abundant algae were counted in 10 fields and the less abundant types in two strips the length of the cell. They were counted as cells, filaments, colonies, clusters, or fragments.

After settling periods of several weeks samples were decanted to 70 ml with a syringe for zooplankton analyses. Crustaceans were counted in the Sedgwick-Rafter cell under magification of 20X. Length measurements with a linear micrometer were made on up to 20 individuals of each taxa in each of two size groups above and below 1 mm. Daphnia were measured to the base of the caudal spine and copepods to the end of the caudal rami. Rotifers were counted in two strips as described for phytoplankton.

Plankton values for the two sample depths were combined and are expressed as mean number of organisms per liter.

Submerged Macrophytes

Sampling was conducted each year in June and September. The technique employed, with some modification, was after Jessen and Lound (1962). Transects were established across the lake at 250 ft. intervals and sampling stations were spaced at 250 ft. intervals along the transects with the first station on a transect established at the 3 ft. contour on alternating sides of the lake. At each station the bottom was dredged four times with a rake at 90 degree intervals and vegetation types were assigned density ratings from 0 to 5. Ratings of 0 to 4 equated the frequency with which they were recovered and 0.25 was added to each recovery if the teeth of the rake were full. In computing mean values only stations having a particular vegetation type recorded were considered.

Data were grouped for depth intervals of less than 5 ft., 5-10 ft., and over 10 ft. Because of substantial lake depth variation, effort was made during some early surveys to duplicate approximate sample depths more than locations by sometimes altering distances on and between transects. However, by September 1976 the surface elevation had dropped so severely that this procedure was no longer possible for depths greater than 10 ft. accounting for an abrupt decline at that time in the number of stations over 10 ft. and a corresponding rise in the number within the 5-10 ft. interval.

Species classification was according to Carlson and Moyle (1968).

Bottom Fauna

Bottom fauna were sampled in spring, midsummer, and fall. Six sampling sites were establised where a north-south transect intersected the 4, 8, and 12 ft. contours. Dense vegetation at the 4 ft. contour necessitated altering some sample depths to 3-4 ft. in 1976 and 2-3 ft. in 1977. Because of reduced lake depth the deeper samples were 10-11 ft. in the fall of 1976 and 9.5-10.5 ft. in 1977.

Samples, usually consisting of three to five grabs with a 6 $in.^2$ Eckman dredge, were washed and collected in a U.S. standard no. 30 sieve, preserved in 70 percent ethanol, and later hand picked with the aid of sugar solution. Three replicates, spaced at approximately 25 ft., were collected at each sampling site for standard error determination and data from all sites were combined in determining mean number of organisms per square meter. Mean diversity indices were computed according to the formula derived from information theory as given by Wilhm and Dorris (1968):

$$d = -\sum (n_i/n)\log_2(n_i/n)$$

where n_i = the number of individuals in the ith taxon and n= the total number of individuals.

Classification of Chironomidae was according to Hilsenhoff (1975).

FINDINGS

Fishery

Species present in the catches during the 4 year period were black bullhead (*Ictalurus melas*), bluegill (*Lepomis macrochirus*), brown trout (*Salmo trutta*), channel catfish (*Ictalurus punctatus*), fathead minnow (*Pimephales promelas*), golden shiner (*Notemigonus crysoleucas*), green sunfish (*Lepomis cyanellus*), largemouth bass (*Micropterus salmoides*), northern pike (*Esox lucius*), and walleye (*Stizostedion vitreum vitreum*) (Tables 1-3).

The Carls Lake fishery was dominated by a large population of slow growing black bullheads in prewinterkill 1974. Bullheads in the July 1974

Table 1.- Gill net and trap net catches in Carls Lake; mean number/mean weight (lb.) per lift

	No. Sets	Black Bullhead	Bluegill	Brown Trout	Channel Catfish	Largemouth Bass YY	Largemouth Bass 1+	N. Pike	Walleye
<u>1974</u>									
Gill Net									
July 9-11	3	239.0	-	-	-	-	-	3.7	-
		23.90	-	-	-	-	-	7.08	-
Oct. 1-3	3	308.3	-	-	-	-	-	2.7	-
		36.51	-	-	-	-	-	2.80	-
Trap Net									
July 9-11	6	94.7	20.7	-	-	-	-	1.0	-
		9.47	14.00	-	-	-	-	0.60	-
<u>1975</u> (postwinterkill)									
Gill Net									
July 10-17	6	0.2	-	-	-	-	-	22.8*	-
		0.09	-	-	-	-	-	4.17	-
Trap Net									
July 10-17	6	5.2	-	-	-	-	-	5.3	-
		1.68	-	-	-	-	-	0.97	-
<u>1976</u> (postrotenone)									
Gill Net									
July 8	2	-	-	77.0	-	-	1.5	-	11.5
		-	-	73.00	-	-	0.86	-	3.11
Sept. 28	2	2.5	-	-	14.0	14.5	2.0	-	17.5
		2.01	-	-	5.84	1.85	2.40	-	10.65
Trap Net									
July 8-9	6	2.2	-	7.5	-	-	1.5	-	1.5
		1.06	-	6.92	-	-	0.95	-	0.44
Sept. 28-29	6	-	-	-	-	8.0	0.8	-	-
		-	-	-	-	0.66	1.08	-	-
<u>1977</u>									
Gill Net									
July 12	2	7.5	9.0	-	-	-	58.5	4.0	27.5
		2.80	2.25	-	-	-	18.70	12.70	21.76
Oct. 4	2	32.0	-	-	6.0	-	5.0	1.5	7.5
		18.65	-	-	10.10	-	1.85	0.71	6.31
Trap Net									
July 12-13	5	0.4	6.4	-	-	-	7.4	0.4	0.8
		0.07	1.61	-	-	-	2.47	1.76	0.64
Oct. 4-5	6	2.8	4.0	-	-	-	0.8	-	-
		1.59	1.96	-	-	-	0.31	-	-

* Total catch included one adult - 2.95 lb.

Table 2.- Shoreline seine catches in Carls Lake

	Black Bullhead	Bluegill	Fathead Minnow	Green Sunfish	Largemouth Bass	Northern Pike
1974						
July 11						
North Haul	2,277	5**	8	2**	-	-
South Haul	1,845	-	-	3**	-	3*
Oct. 3						
North Haul	5	-	12,400	-	-	-
South Haul	-	-	314	-	-	-
1975 (postwinterkill)						
July 16						
North Haul	138*	-	1,551	-	-	2*
Sept. 15						
North Haul	20*	-	2,615	-	-	3*
South Haul	14*	-	64	-	-	6*
1976 (postrotenone)						
Aug. 6						
North Haul	-	-	-	-	7*	-
South Haul	33*	-	9	-	-	-
Sept. 29						
North Haul	1*	-	-	-	4*	-
South Haul	-	-	-	-	7*	-
1977						
July 13						
North Haul	-	-	12	-	12*	-
Oct. 5						
North Haul	-	-	-	-	-	-

* Young of the year
** Yearling

Table 3.- Minnow trap catches in Carls Lake

	No. Traps	Black Bullhead*	Fathead Minnow	Green Sunfish**	Largemouth Bass*	Northern Pike*
1974						
July 9-10	8	-	-	14	-	-
Oct. 1-2	8	-	101	-	-	-
1975 (postwinterkill)						
July 10-11	8	8	2	-	-	-
1976 (postrotenone)						
July 8-9	8	-	-	-	66	-
Sept. 28-29	8	10	1	-	-	-
1977						
July 12-13	6	-	-	-	19	1
Oct. 4-5	8	-	-	-	-	-

* Young of the year
** Yearling

catches were in the 4.5-7.5 in. range and numbered 10 per lb. No evidence of bullhead reproduction was noted in 1974 either through capture or observations of nests or schooled fingerlings.

The bluegill was the major panfish inhabiting the lake. Individuals in the trap net catch ranged in length from 8 to 9 in. Analysis of scales from 15 yielded a strong mode at age 4 with the youngest being aged as 3 yr. old. This imbalance in age structure and the sparcity of juvenile bluegills in the seine and minnow trap catches indicate low reproductive success of bluegills in previous years.

The northern pike was the only predator species present in the catch and the fathead minnow was the dominant forage species. Not tabulated for July 1974 were one golden shiner in each of the total trap net and gill net catches and one green sunfish in the total trap net catch.

Catches of bullhead during the three summers following the winterkill were greatly reduced and in sharp contrast to the 1974 catches. In July 1975 bullheads that survived the winterkill numbered 3.1 per lb. and were repopulating the lake. The only other species noted to have survived the winterkill was the fathead minnow. All but one of the northern pike present in the July 1975 catches were offspring from broodstock placed in a controlled spawning marsh adjacent to the lake that spring. Their growth was rapid and they entered the gill net catch in July averaging 8.6 inches in length. The single adult was presumably one of the broodstock that escaped efforts at recapture when the marsh was drained.

In September 1975 elimination of the bullheads was attempted with rotenone followed that same year by stockings of 1,650 largemouth bass fingerlings, 1,950 walleye fingerlings, 2,200 channel catfish fingerlings, and 4,000 catchable size brown trout. The brown trout provided appreciable winter angling but, as expected, perished a week after the July 1976 netting series.

Largemouth bass broodstock were added in the spring of 1976 and produced a good year class. Walleye fry stockings in the spring of 1976 and 1977 failed. Six thousand northern pike fingerlings along with the broodstock from the spawning marsh and 26,000 bluegills averaging 18 per lb. were added in the spring of 1977. The bluegills grew rapidly and by October ranged from 1.4 to 3.0 per lb. and averaged 2.0 per lb.

The rotenone failed to eliminate all of the bullheads but recovery of the population appeared to be slowed, probably by the presence of bass and other predators.

Chemical and Physical Parameters and Plankton

Notable changes occurred in the chlorophyll *a* concentrations in the years following the winterkill (Figure 2). Seasonal mean chlorophyll concentrations in 1975, 1976, and 1977 relative to 1974 were 39, 44, and 19 percent, respectively. The declining chlorophyll concentrations were accompanied by increasing secchi disc transparencies.

Trends in the integral photosynthetic rate (Σp) reflected the trends in chlorophyll but differences in Σp between pre and postwinterkill years were more moderate. Seasonal mean Σp values in the postwinterkill years relative to 1974 were 70, 69, and 56 percent, respectively. The nonlinearity between the two parameters was, in part, due to shading activity of algae concentrated near the lake surface imposing upper limits on photosynthesis on an areal basis. In 1974, on the average, 81 percent of the photosynthesis occurred in the first meter of the water column compared to 58, 61, and 49 percent in 1975, 1976, and 1977, respectively. Since the chlorophyll was fairly evenly distributed in the water column, at least at the time of sampling, there was a large amount of chlorophyll relatively inactive in 1974 when integral photosynthetic rates perhaps approached a theoretical maximum.

Postwinterkill declines in photosynthesis on a volumetric basis (maximun photosynthetic rate - pmax) more closely reflected trends in chlorophyll concentrations. The seasonal means of pmax in the latter years relative to 1974 were 47, 56, and 36 percent respectively. These declines, however, were still more moderate than the chlorophyll declines and suggest further explanation to the moderate response of Σp to the chlorophyll reductions. The seasonal mean values of the maximum specific photosynthetic rates (Pmax) were 68, 79, 77, and 140 mg O_2/mg chl/6 hr. for 1974 through 1977, respectively. As an indicator of the physiological state of the algae, Pmax is largely dependent upon nutrient concentrations and the increases in the postwinterkill period may have been responses to increased nutrient release by grazing zooplankton and thus partly compensated for the chlorophyll redutions.[3/]

Notable changes in the zooplankton community occurred following the winterkill (Figure 3). The 1974 prewinterkill community consisted generally of a mixture of cyclopoid and calanoid copepods, *Bosmina*, and small *Daphnia*. In 1975 Cyclopoida peaked in May and *Daphnia* had a moderate peak in June but both faded while Calanoida remained abundant most of the summer. The last two summers were mostly dominated by *Daphnia* with a brief pulse of *Ceriodaphnia* in 1976 and two moderate peaks of Calanoida in 1977. Also noteworthy was the presence of larger Daphnia during the years 1975 through 1977, particularly

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3/ J. Shapiro, personal communication, 1979

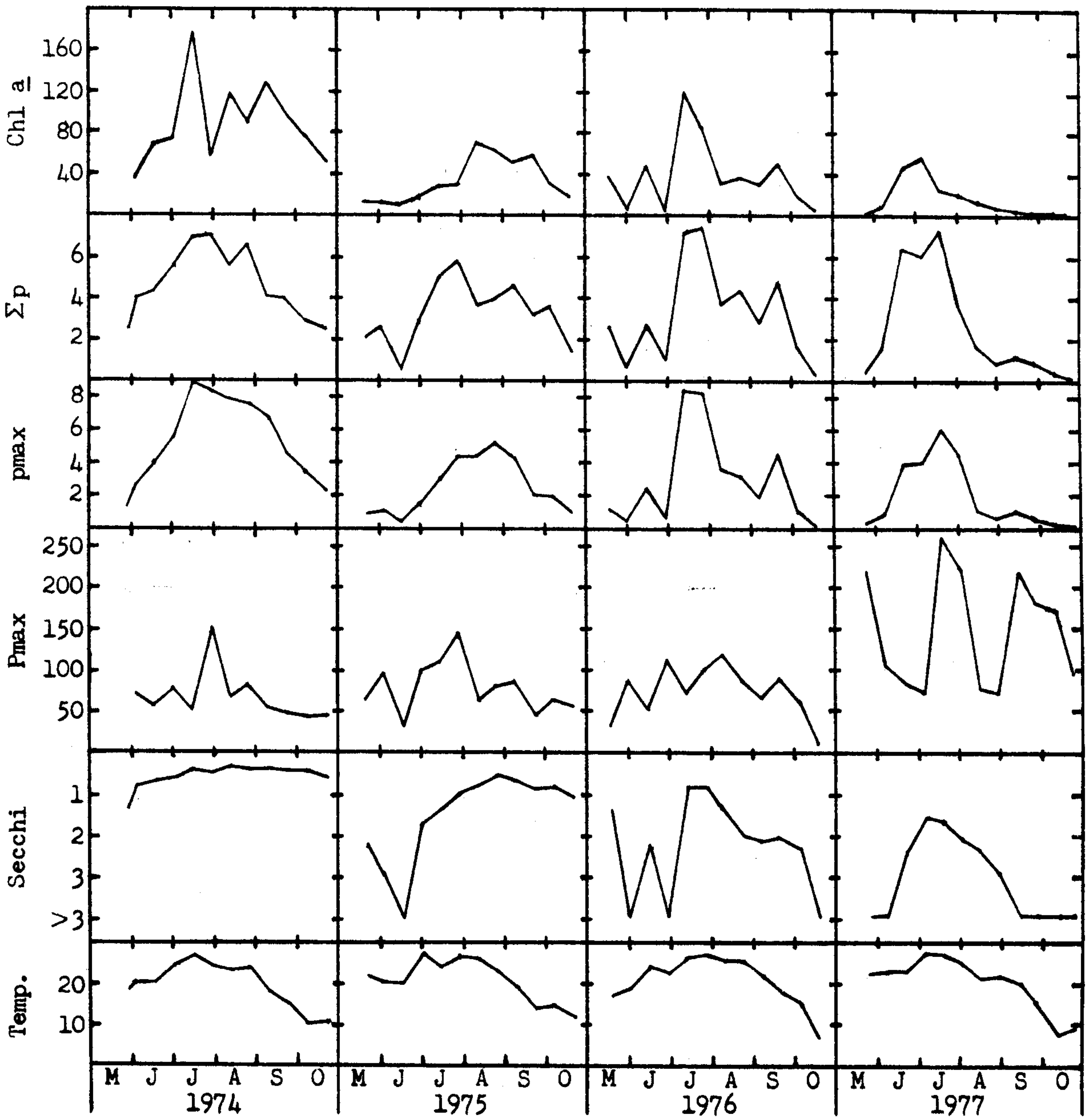


Figure 2.- Carls Lake. Mean chlorophyll a concentrations - mg/m^3. Integral photosynthetic rates (Σp) - g O_2/m^2/6 hr. Maximum photosynthetic rates (pmax) - g O_2/m^3/6 hr. Maximum specific photosynthetic rates (Pmax) - mg O_2/mg chl/6 hr. Mean secchi disc transparencies - m. Mean surface temperatures - °C.

at times of high densities. The latter three years then, relative to 1974, were characterized by increased numbers of relatively large sized filter feeding zooplankters presumably as a result of reduced predation after the severe reduction of the bullhead population. Although the black bullhead is generally considered a bottom feeder it is also planktivorous, at times exclusively (Olson and Koopman 1976) and no doubt the dense population of small bullheads inhabiting Carls Lake prior to the winterkill could have had a substantial influence on the structure of the zooplankton community. Selection of the largest zooplankters as food has been reported for some perciform and salmonid species (Gerking 1962; Hall 1964; Galbraith 1967) and alewives (Hutchinson 1971) and there is ample evidence that zooplanktivores can exert substantial control over the species and size composition of zooplankton communities (Hutchinson 1971; Warshaw 1972; Walters and Vincent 1973; reviews by Shapiro et al 1975 and Shapiro 1978).

Daphnia peaks in 1977 were lower than in 1976 possibly because of the introduction of the planktivorous bluegill at a rate of more than 200 per acre in the spring of 1977. Perhaps the rotenone treatment in September 1975 which decimated the, then dominant, calanoid copepods was instrumental in the change in species composition after 1975 (discussed further in a subsequent section concerning the rotenone treatment).

There is also abundant evidence that large filter feeding zooplankters have substantial influence on phytoplankton density (reviews by Shapiro et al. 1975 and Shapiro 1978). In Carls Lake it appears there was a generally inverse relationship between numbers of filter feeders (*Daphnia* and calanoid copepods) and *Aphanizomenon* density but such relationships with *Microcystis* and *Anabaena* are apparent (Figure 3). Sorokin (1968) indicated that

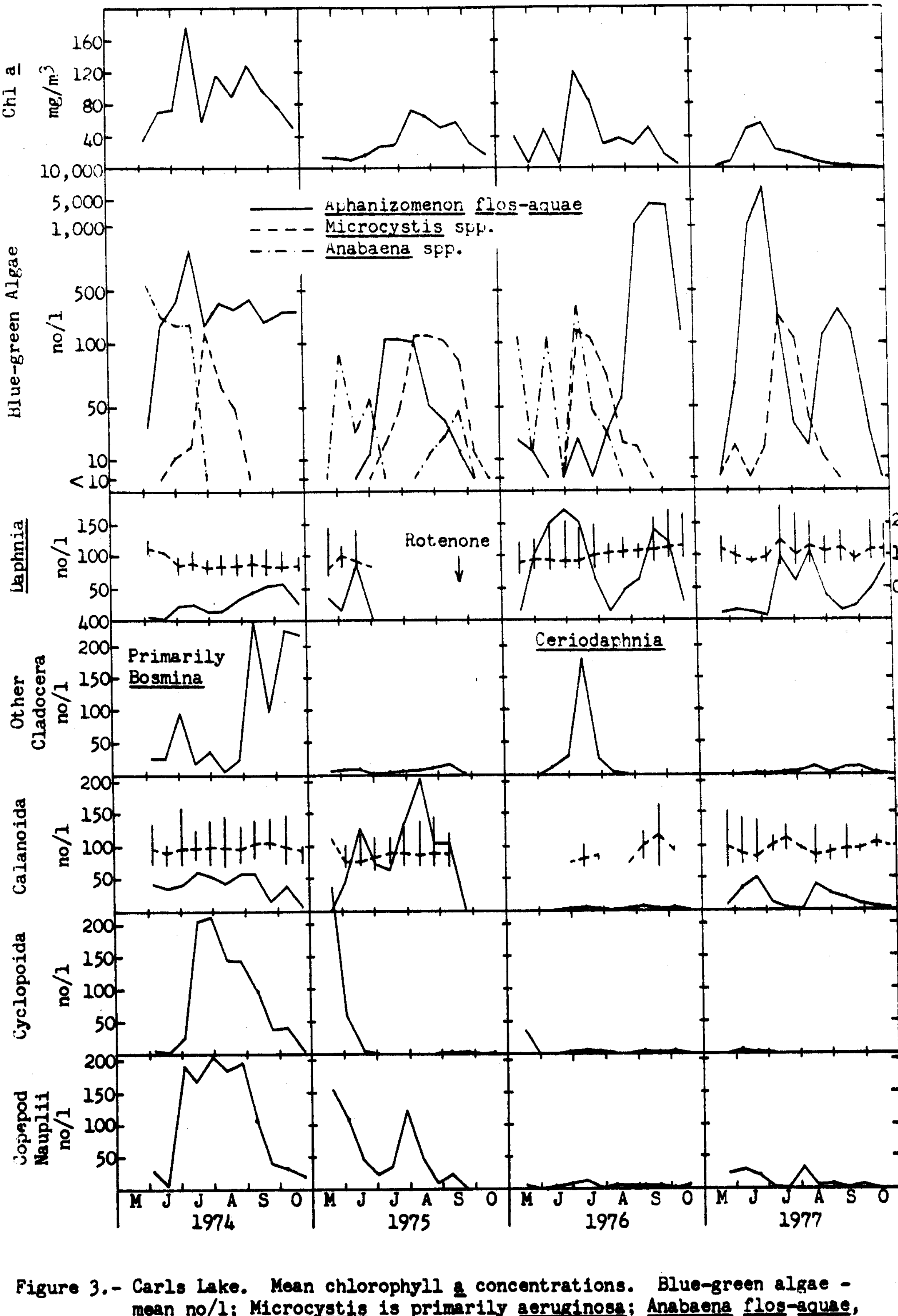


Figure 3.- Carls Lake. Mean chlorophyll a concentrations. Blue-green algae - mean no/l; Microcystis is primarily aeruginosa; Anabaena flos-aquae, spiroides, circinalis, and affinis. Plankton Crustacea - solid line mean no/l, broken line mean length, and vertical line length range.

some blue-green algae, including *Aphanizomenon flos-aquae*, can be excellent food for zooplankton while *Microcystis* and some species of Anabaena are little utilized.

Recognizing that wide variation in dimensions of algal units makes counts an unreliable indicator of algal biomass and with the deficiencies in chlorophyll analysis as a measure of phytoplankton density, a close linearity between algae counts and chlorophyll concentrations was not expected. However, the wide divergences between chlorophyll and *Aphanizomenon* values noted in September 1976 and July 1977 relative to other times were much greater than was expected (Figure 3).

Although blue-greens strongly dominated the phytoplankton in all years of the investigation an evident trend following the winterkill was a continuing decline in numbers of the relatively large centric diatoms, non-flagellated green algae, and the flagellates *Mallomonas* and *Cryptomonas* (Table 4). Small green flagellates were not included in the analysis. Most organisms that were relatively abundant in 1974 showed continuing declines and were very scarce in, or absent from, the 1977 samples. The still relatively large 1975 seasonal means of *Melosira* and *Cryptomonas* were perhaps an indirect result of the rotenone treatment which nearly eliminated the grazing zooplankton. Through the first nine samples of 1975 they, respectively, had mean densities of 1,260 and 295 per liter which was well below their respective means for the entire summer, then both showed strong increases following the treatment. Conversely, *Dictyosphaerium* showed an abrupt decline following the rotenone treatment but had similarly declined in 1974. The relatively high mean density of *Oocystis* in 1975 was largely the result of one sample on June 3 when grazer density was low. Following the winterkill conspicuous increases in abun-

Table 4.- Mean number of phytoplankters per liter in Carls Lake exclusive of blue-green algae and small green flagellates

	1974	1975	1976	1977
BACILLARIOPHYCEAE	22,143	7,394*	1,213	2,509
Centrales				
Cyclotella	-	- *	-	327
Melosira	7,263	6,917	177	114
Stephanodiscus	14,638	66	36	14
Pennales	242	411	1,000	2,054
CHLOROPHYCEAE	26,005	7,593	3,826	2,301
Actinastrum hantzschii	534	5	7	-
Ankistrodesmus falcatus	3,144	265	24	7
Closteriopsis longissima	-	28	-	-
Closterium sp.	-	-	-	36
Coelastrum microporum	29	128	-	-
Cosmarium sp.	-	-	9	14
Crucigenia rectangularis	-	5	7	7
Dictyosphaerium sp.	15,259	4,491	461	-
Dispora crucigenoides	7	-	-	-
Eudorina sp.	7	5	228	-
Oocystis spp.	904	2,280	793	153
Pediastrum boryanum	427	52	222	14
P. duplex	107	19	-	-
P. simplex	143	14	-	-
Phacotus sp.	741	-	88	36
Pleodorina californica	-	-	1,024	-
Scenedesmus acutiformis	14	-	-	-
S. quadricauda	36	33	-	29
S. spp.	21	19	71	7
Schroederia sp.	93	5	799	1,998
Selenastrum gracile	57	61	-	-
S. sp.	-	33	-	-
Sorastrum americanum	-	-	7	-
Sphaerocystis schroeteri	142	-	12	-
Staurastrum paradoxum	4,034	127	43	-
Tetraedron constrictum	21	-	-	-
T. hastatum	29	9	-	-
T. limneticum	242	14	-	-
T. regulare	14	-	-	-
Volvox sp.	-	-	31	-
CHRYSOPHYCEAE	1,503	321	-	-
Mallomonas alpina	1,389	321	-	-
M. pseudocoronata	114	-	-	-

* excludes a large number of tiny *Cyclotella*

(continued)

Table 4 (continued)

	1974	1975	1976	1977
CRYPTOPHYCEAE				
Cryptomonas sp.	1,494	846	194	171
DINOPHYCEAE	327	56	67	-
Ceratium hirundinella	320	47	67	-
Peridinium sp.	7	9	-	-
EUGLENOPHYCEAE				
Phacus sp.	-	-	-	1,617

dance were seen only in *Phacus* and relatively small *Schroederia* and pennate diatoms.

Early season total phosphorus concentrations in the postwinterkill period were similar to 1974 concentrations but in July 1976 and 1977 phosphorus concentrations unexpectedly soared (Figure 4). These high concentrations, as well as high ammonia concentrations, were associated with low oxygen concentrations near the lake bottom during periods of temporary thermal stratification. The release of phosphorus from lake sediments during anoxic periods at the sediment-water interface is a well known phenomenon. Relatively low chlorophyll concentrations accompanied the high phosphorus concentrations which were largely orthophosphate. In 1976 nitrates were low and perhaps limited algal growth but in 1977 nitrate concentrations were relatively high in July but chlorophyll concentrations continued to decline. Shapiro et al. (1975) noted low algal densities despite high nutrient concentrations in controlled plastic bag experiments when fish were absent and the zooplankters were allowed to graze actively.

Submerged Macrophytes

The major rooted species found in Carls Lake during the surveys (Figure 5) included bushy pondweed (Najas flexilis), Canada waterweed (Elodea canadensis), coontail (Ceratophyllum demersum), curled pondweed (Potamogeton crispus), and narrowleaf pondweed (P. strictifolius). Species occurring sporadically and never at more than 3 percent of the stations and not included in Figure 5 were flatstem pondweed (P. zosteriformis), Fries pondweed (P. friesii), sago pondweed (P. pectinatus), and wild celery (Vallisneria americana).

In 1974 when Carls Lake was densely populated with bullheads it was nearly barren of benthic vegetation at depths greater than 5 ft. During the three years following the winterkill there was a continuous invasion of Canada waterweed and curled pondweed into deeper water and by 1977 most of the lake bottom had moderate to dense stands of these species. This expansion at depths over 5 ft. was consistent with the steady improvement in secchi disc visibility previously noted in Figure 2. These species also showed general increases at depths less than 5 ft. after 1974 but much of those increases was at the expense of coontail in a shallow bay which accounted for more than a third of the stations under 5 ft. and where, in 1974, coontail was dense and Canada waterweed and curled pondweed were sparse. Also, values for some stations under 5 ft. were sometimes misleading in that they reflected lake depth fluctuations more than changes in vegetation density because of a fallibility in the sampling procedure. For example, in 1977 much of the lake was barren near shore and curled pondweed became increasingly dense as the depth approached 5 ft. The lake depth declined about 9 in. between the June and September surveys bringing the denser vegetation previously near

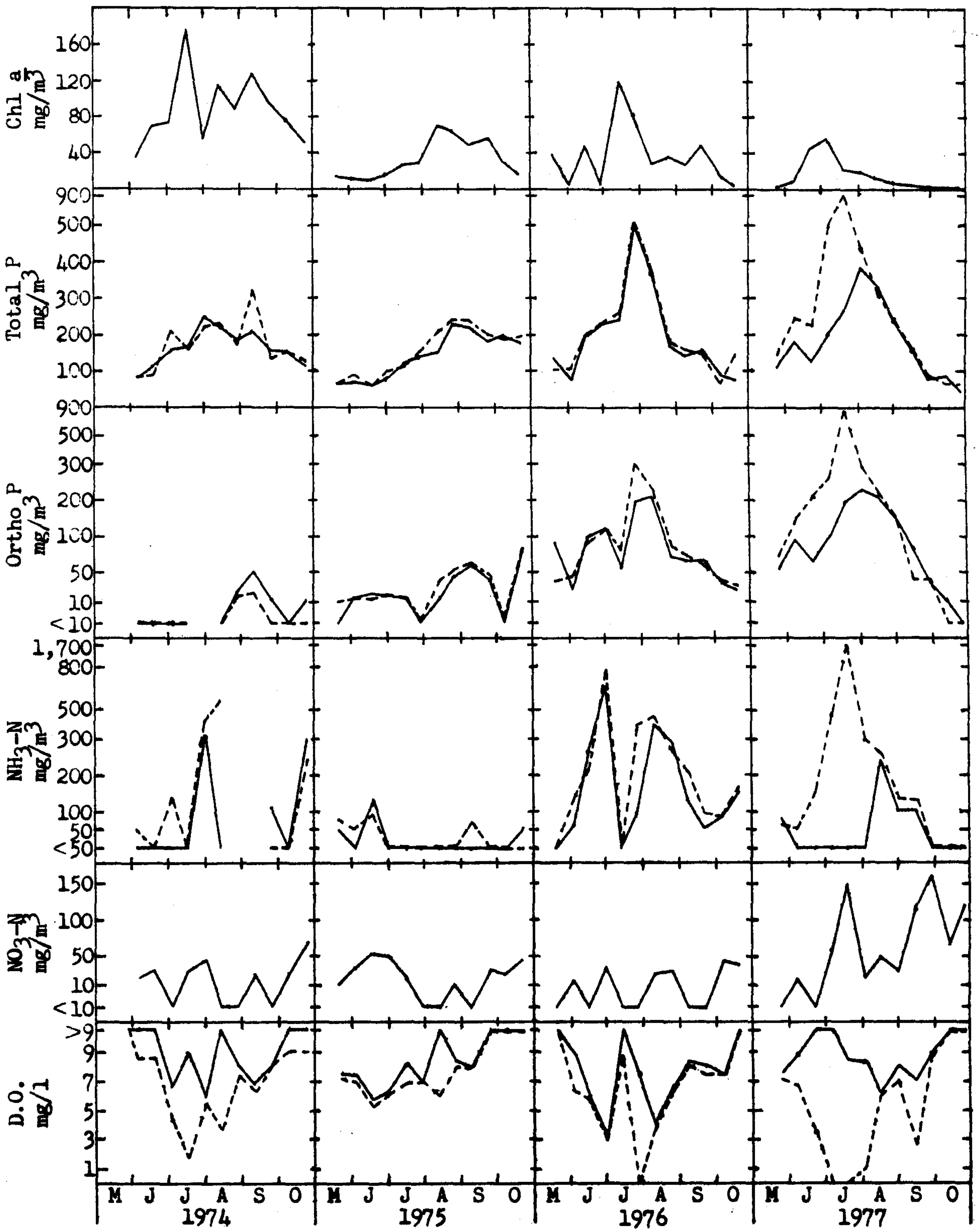


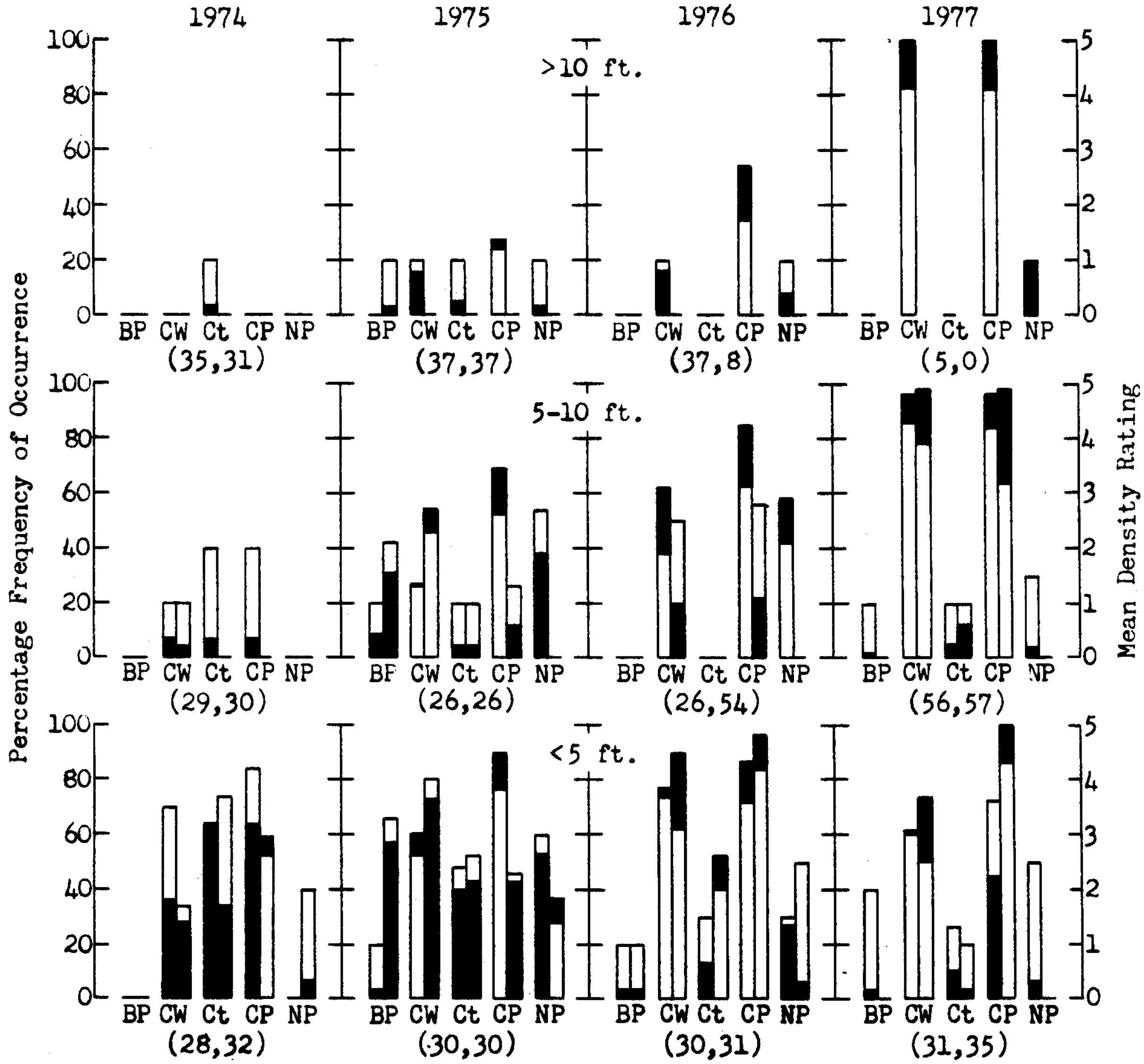
Figure 4.- Carls Lake. Mean chlorophyll a concentrations. Total phosphorus, orthophosphate, ammonia nitrogen, nitrate nitrogen, and dissolved oxygen concentrations - solid line surface and broken line 3 meters.

the 4 ft. contour to the 3 ft. contour where the first sampling station on each transect was established and thus giving an unrealistic impression of a large increase in curled pondweed between July and September.

Bushy pondweed and narrowleaf pondweed became moderately abundant in 1975 but the former greatly declined by the next year while the latter faded in 1977. Chara sp. (not included in Figure 5) was not found in 1974 surveys but became fairly common in 1975 and then declined in subsequent years. In 1975 it occurred at 13 and 33 percent of the stations under 5 ft. in June and September, respectively, and at 8 and 4 percent of the 5-10 ft. stations. However, it was sparse with mean density ratings never above 1.5.

Bottom Fauna

Carls Lake was undergoing continuing change in chemical, physical, and biological conditions throughout the study period which may have influenced results of the bottom sampling directly and by affecting sampling procedure. Together the unstable fishery and the rotenone treatment probably had the largest impact on bottom fauna composition and abundance and because of the possible impact of rotenone a more extensive examination of trends is presented in the following section. In general, however, from 1974 to 1977 there was a change in species composition as shown by increase in the number of taxa found and the mean diversity index (Table 5). There was an increase in the total number of organisms present as judged by spring collections but no significant difference as judged by fall samples because of the large standard error in the fall of 1977 which was due to a large standard error in numbers of the abundant Paratanytarsus collected at shallow stations where lake bottom types were transitional (Table 6). The summer counts are not very reliable because of the instability of most insect populations during



Percentage Frequency of Occurrence

Mean Density Rating

September

June

() Number of Stations - June, September

BP Bushy Pondweed
CW Canada Waterweed
Ct Coontail
CP Curled Pondweed
NP Narrowleaf Pondweed

Figure 5.- Abundance of the major submerged macrophytes in Carls Lake.

warm weather.

Table 5. Carls Lake bottom fauna; number of taxa (s), mean total number of organisms per square meter (N), and mean diversity ($\bar{d}$); standard error (n=3) of N in parentheses

	1974			1975			1976			1977		
	Apr. 24	July 31	Nov. 6	May 6*	July 30	Oct. 8**	May 4	Aug. 3	Oct. 13	May 10	July 26	Oct. 18
s	17	13	17	20	29	17	19	23	21	26	29	28
N	1,636 (77)	1,594 (23)	4,527 (208)	3,282 (110)	2,250 (100)	1,487 (164)	1,056 (18)	4,201 (40)	4,702 (144)	5,148 (338)	2,141 (167)	5,824 (593)
$\bar{d}$	1.62	2.15	1.90	2.04	3.35	2.78	2.81	2.04	2.91	3.03	3.43	3.31

* Following winterkill
** 16 days after Chem-fish treatment

ROTENONE TREATMENT

Treatment

On September 22, 1975 the 2.5 percent rotenone formulation Chem-fish[4/] was applied at the surface of Carls Lake by helicopter at the rate of 3 mg/l (0.075 mg/l rotenone). The next day many dead northern pike fingerlings, fathead minnows, and bullhead fingerlings were found but only a few adult bullheads had succumbed. Many bullheads were seen swimming in distress but apparently recovering. All northern pike and fathead minnows confined in live boxes on the lake bottom were dead but the bullheads were alive. Water samples collected on September 23 at three locations for rotenone analysis (after Post 1955) had concentrations ranging between

4/ Mention of brand names does not constitute product endorsement by the Minnesota Department of Natural Resources

0.03 and 0.04 mg/l. At the lake surface the water temperature was 13.5 C, the total alkalinity 77 mg/l, and the pH 8.9.

On September 25 the confined bullheads were still alive so on September 26 the lake was retreated at the same rate with the 2.5 percent rotenone formulation Pro-noxfish.[5/] Although the population was further reduced the bullhead kill was still incomplete (Tables 1-3). The second treatment yielded no additional observations of surfaced northern pike or fathead minnows but some fathead minnows were taken in the seine and minnow traps the following summer. Water samples collected on September 29 had rotenone concentrations ranging from 0.01 to 0.04 mg/l and by October 7 concentrations were less than 0.01 mg/l.

Impact on Zooplankton

The rotenone nearly obliterated the plankton Crustacea and there was no sign of recovery by October 21, 29 days after the Chem-fish treatment and the last sampling date in 1975 (Figure 3). On the three sampling dates following the treatment (covering the period September 23-October 21) plankton Crustacea numbers were 0 to 1.4 percent of those recorded on September 9, 13 days before treatment. On September 9 the crustacean community was dominated by calanoid copepods followed, in order of decreasing abundance, by copepod nauplii, *Diaphanosoma*, *Bosmina*, and cyclopoid copepods. *Daphnia* which was present in moderate numbers earlier in the summer had been absent from samples for some time. On September 23, the day after the Chem-fish treatment, *Ceriodaphnia* (not present in September 9 collections) and Cyclopoida were the only crustaceans present in samples but were sparse. No crustaceans

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5/ Mention of brand names does not constitute product endorsement by the Minnesota Department of Natural Resources

Table 6.- Mean number of benthic macroinvertebrates per square meter in Carls Lake; standard error (n=3) in parentheses

	1974			1975			1976			1977		
	Apr. 24	July 31	Nov. 6	May 6*	July 30	Oct. 8**	May 4	Aug. 3	Oct. 13	May 10	July 26	Oct. 18
Coleoptera												
Dytiscidae										0.8 (0.8)	0.8 (0.8)	1.6 (1.6)
Laccophilus	-	-	-	-	0.5 (0.5)	-	-	-	-			
Gyrinidae												
Dineutus	-	-	-	-	0.5 (0.5)	-	-	-	-	-	-	-
Haliplidae										2.4 (0)	1.6 (1.6)	
Haliplus	-	-	-	-	-	-	-	-	-			48 (8)
Hydrophilidae												3.2 (2.1)
Berosus	-	-	0.5 (0.5)	-	-	-	-	-	-	-	-	
Collembola	-	-	-	-	-	-	-	0.8 (0.8)	-	-	-	-
Diptera												
Ceratopogonidae	96 (32)	91 (17)	206 (5)	356 (33)	33 (10)	64 (8)	98 (16)	328 (40)	378 (40)	828 (56)	224 (23)	210 (26)
Chaoboridae												
Chaoborus	-	-	-	-	40 (2)	208 (12)	87 (3)	556 (80)	1,014 (90)	187 (5)	-	2.3 (1.4)
Chironomidae												
Chironominae												
Chironomini												
Chironomus	65 (6)	216 (27)	794 (75)	346 (40)	700 (85)	194 (16)	33 (4)	2,573 (36)	350 (29)	69 (15)	275 (130)	819 (86)

(continued)

* Following winterkill
** 16 days after Chem-fish treatment

Table 6 (continued)

	1974			1975			1976			1977		
	Apr. 24	July 31	Nov. 6	May 6*	July 30	Oct. 8**	May 4	Aug. 3	Oct. 13	May 10	July 26	Oct. 18
<u>Cryptochironomus</u>	86 (9)	59 (13)	151 (6)	118 (8)	50 (20)	12 (3)	-	3.2 (3.2)	59 (5)	97 (4)	6.4 (2.1)	388 (14)
<u>Cryptocladopelma</u>	1.9 (1.9)	19 (5)	-	11 (7)	0.5 (0.5)	-	-	2.4 (1.4)	0.8 (0.8)	7.2 (2.4)	2.4 (1.4)	-
<u>Einfeldia</u>	-	0.8 (0.8)	-	0.8 (0.8)	1.9 (1.3)	-	-	-	-	-	0.8 (0.8)	-
<u>Endochironomus</u>	0.5 (0.5)	-	-	1.4 (0.8)	117 (24)	-	0.8 (0.8)	-	6.4 (2.9)	-	1.6 (0.8)	119 (37)
<u>Glyptctendipes</u>	17 (3)	12 (5)	2.4 (2.4)	5.7 (1.7)	74 (28)	36 (23)	307 (39)	111 (30)	-	1.6 (1.6)	134 (101)	257 (79)
<u>Lauterborniella</u>	-	-	-	-	-	0.5 (0.5)	-	-	-	-	-	-
<u>Parachironomus</u>	-	5.3 (2.4)	-	149 (34)	13 (5)	-	1.6 (0.8)	-	-	-	0.8 (0.8)	-
<u>Polypedilum</u>	16 (14)	318 (71)	232 (56)	33 (2)	10 (4)	-	-	8.8 (3.5)	-	84 (23)	22 (7)	14 (4)
Tanytarsini		2.9 (1.4)										
<u>Paratanytarsus</u>	-		-	-	20 (10)	-	23 (2)	14 (6)	-	670 (376)	4.0 (2.1)	686 (470)
<u>Tanytarsus</u>	-		-	0.5 (0.5)	2.4 (2.4)	-	-	4.0 (4.0)	53 (5)	854 (113)	-	59 (13)

(continued)

Table 6 (continued)

	1974			1975			1976			1977		
	Apr. 24	July 31	Nov. 6	May 6*	July 30	Oct. 8**	May 4	Aug. 3	Oct. 13	May 10	July 26	Oct. 18
Orthocladinae												
Brillia	-	-	-	-	-	-	0.8 (0.8)	-	-	-	-	-
Corynoneura	-	-	-	-	-	-	-	-	-	-	-	1.6 (0.8)
Cricotopus	-	-	-	34 (3)	1.0 (1.0)	-	0.8 (0.8)	-	-	-	-	-
Heterotrissocladius	-	-	-	-	-	-	0.8 (0.8)	-	-	0.8 (0.8)	-	-
Parametriocnemus	-	-	-	-	-	-	-	-	-	-	-	129 (37)
Trissocladius	-	-	-	0.5 (0.5)	-	-	-	-	-	-	-	-
Tanypodinae												
Coeltanypus	-	-	-	-	-	-	-	-	17 (7)	21 (3)	1.6 (1.6)	16 (6)
Procladius	1,191 (90)	810 (53)	2,795 (205)	1,990 (93)	355 (54)	165 (10)	285 (23)	299 (22)	594 (39)	1,358 (50)	146 (15)	329 (8)
Unidentified	-	-	-	-	11 (3)	-	-	1.6 (0.8)	-	-	18 (7)	29 (2)
Tabanidae	-	-	-	-	-	-	1.6 (0.8)	-	-	-	-	-

(continued)

Table 6 (continued)

	1974			1975			1976			1977		
	Apr. 24	July 31	Nov. 6	May 6*	July 30	Oct. 8**	May 4	Aug. 3	Oct. 13	May 10	July 26	Oct. 18
Ephemeroptera												
Caenis	5.7 (1.9)	-	48 (24)	11 (2)	56 (5)	17 (4)	1.6 (0.8)	10 (5)	97 (14)	72 (16)	181 (32)	245 (39)
Callibaetis	-	-	0.5 (0.5)	-	5.3 (1.3)	-	-	4.6 (1.2)	85 (19)	1.6 (1.6)	37 (10)	37 (12)
Unidentified	-	-	-	-	-	-	-	-	-	1.6 (1.6)	-	-
Hemiptera												
Corixidae	1.2 (0.9)	-	12 (7)	-	8.6 (1.7)	1.6 (0.8)	-	-	0.8 (0.8)	-	0.8 (0.8)	18 (7)
Notonectidae	-	-	-	-	-	-	-	0.8 (0.8)	-	-	-	-
Lepidoptera	-	-	0.5 (0.5)	-	6.7 (2.5)	2.4 (1.4)	1.6 (0.8)	0.8 (0.8)	0.8 (0.8)	0.8 (0.8)	20 (3)	10 (4)
Trichoptera												
Leptocerus	8.6 (4.0)	-	-	-	-	-	-	-	-	-	-	-
Oecetis	6.5 (1.8)	7.0 (2.2)	23 (7)	2.9 (0.8)	22 (6)	2.9 (1.8)	-	1.6 (0.8)	1.6 (0.8)	-	4.8 (3.7)	289 (4)
Zygoptera												
Enallagma	1.4 (0.4)	-	-	0.5 (0.5)	25 (4)	34 (4)	23 (1)	46 (12)	17 (5)	6.4 (4.2)	45 (15)	31 (3)
Amphipoda												
Hyalella azteca	109 (21)	1.0 (0.5)	104 (20)	29 (4)	271 (34)	4.8 (1.4)	12 (4)	85 (9)	1,183 (43)	575 (248)	559 (20)	1,947 (210)

(continued)

Table 6 (continued)

	1974			1975			1976			1977		
	Apr. 24	July 31	Nov. 6	May 6*	July 30	Oct. 8**	May 4	Aug. 3	Oct. 13	May 10	July 26	Oct. 18
Hirudinea	1.4 (0.8)		1.0 (1.0)									
<u>Erpobdella</u> <u>punctata</u>		-		1.4 (0.8)	232 (5)	176 (11)	59 (3)	56 (5)	20 (2)	56 (14)	128 (19)	34 (5)
<u>Helobdella</u> <u>fusca</u>		-		-	-	-	-	-	-	0.8 (0.8)	0.8 (0.8)	-
<u>H.</u> <u>stagnalis</u>		-		0.8 (0.8)	86 (14)	23 (9)	4.8 (2.8)	18 (4)	10 (4)	4.0 (2.1)	151 (26)	10 (5)
<u>Placobdella</u> <u>rugosa</u>		-		-	27 (2)	-	-	3.2 (1.6)	-	-	14 (2)	-
Hydracarina	0.5 (0.5)	-	2.9 (2.2)	-	6.2 (1.3)	0.5 (0.5)	-	-	18 (3)	4.0 (2.1)	4.8 (3.7)	6.4 (1.6)
Oligochaeta	28 (3)	52 (8)	152 (21)	190 (39)	74 (10)	545 (176)	116 (8)	73 (11)	791 (55)	243 (59)	155 (26)	85 (17)
Pelecypoda	-	-	2.4 (1.2)	-	-	-	-	-	5.6 (4.4)	1.6 (1.6)	0.8 (0.8)	-

were found on October 7 and on October 21 only a few cyclopoids were found.

Calanoid copepods were sparse throughout the 1976 season and in 1977 attained peaks near their prewinterkill peak densities of 1974 but never retained their prerotenone abundance. Instead, cladocerans (primarily Daphnia) came to dominate the community in 1976. Anderson (1970) found it took 1 to 3 years for plankton Crustacea species to retain prerotenone abundance in two alpine lakes and suggested rotenone to be more devastating to species not having reached their annual reproductive peak. The upsurge of Daphnia early in 1976 was perhaps possible because of an abundance of resistent ephippial eggs formed before the population collapse in June 1975, long before the rotenone treatment.

Given the low abundance or absence of rotifers in late season samples in all four years, the highly cyclic nature of rotifer populations, and the long sampling interval which did not adequately detect population pulses, the data are inconclusive on the immediate effect of the rotenone on rotifer abundance. Keratella, the only rotifer found in the two samples previous to the first rotenone treatment, was present the day after treatment but it is not known if the specimens were alive at the time of collection (Table 7). Keratella has been reported to be generally unaffected by rotenone (Anderson 1970; Neves 1975).

On an extended time basis it does not appear that the rotenone had a detrimental impact on rotifers as a whole. There was a strong pulse of an unidentified rotifer on October 21 (29 days after the first treatment) and Keratella was abundant the following spring. However, Conochilus, which had strong pulses in the prerotenone period of 1974 and 1975, was scarce in 1976 and, as all rotifers were, in 1977 samples. Instead Keratella, Trichocerca, and an unidentified rotifer dominated the 1976 collections. The shift in species composition was perhaps related to the treatment although Neves (1975) reported Conochilus to be little affected by rotenone. The low rotifer abundance noted in 1977 is an enigma but accompanies low abundance of large flagellates, green algae, and centric diatoms as previously shown in Table 4.

Impact on Bottom Fauna

Although the rotenone did not eliminate any bethic inverebrate that was reasonably common in samples before the treatment it appears that it might have caused a temporary reduction in some species and in the total number of macroinvertebrates inhabiting Carls Lake. By far the lowest mean total number of organisms in fall samples was collected in 1975 two weeks after the treatment and the following spring the lowest total for spring collections occurred (Table 5). In 1975, after the winterkill, there was an increase in the number of taxa present in the spring and summer collections followed by a reduction after the rotenone treatment.

Many of the more common organisms exhibited their lowest fall and spring densities in 1975 and 1976, respectively, but the sharp contrast between the 1974 and 1975 fall totals was due mainly to a large reduction in Procladius (Table 6). Conversely, a few taxa showed increases from fall 1974 to fall 1975 but the impact of the rotenone on many organisms could have been obscured because of the winterkill as some were perhaps more strongly on the increase, as a result of the bullhead reduction, than the 1975 fall samples indicated. Comparison of summer densities would seem to support this possibility but the uncertainty in comparing summer standing crops of unstable insect populations is large.

Table 7. - Mean number of rotifers per liter in Carls Lake; letters beneath values indicate taxa present in order of decreasing abundance; taxa in alphabetical order are: Brachionus, Conochilus, Filinia, Keratella, Lepadella, Monostyla, Polyarthra, Synchaeta, Trichocerca, and unidentified

1974		6/5	6/18	7/2	7/16	7/30	8/13	8/27	9/10	9/24	10/8	10/24
		626 C U K	799 F C K	829 K C,F U	157 K F	32 C	-	2,927 C	266 C	47 U C	16 U	31 K
1975	5/21	6/3	6/17	7/1	7/15	7/29	8/12	8/26	9/9	1/ 9/23	2/ 10/7	10/21
	3,546 C* K U	804 C K P U	117 P K U	94 C	-	63 C F K	3,501 C* F K	11 K	84 K	126 K U	-	2,259 U* B
1976	5/18	6/1	6/15	6/29	7/13	7/27	8/10	8/24	9/7	9/21	10/5	10/19
	4,849 K* M C,U	2,143 K* L,M	304 T M K,U	189 U P,S K M	1,289 T* P U	2,607 U* T L	1,174 T* U P	16 M	16 U	-	-	-
1977	5/24	6/7	6/21	7/5	7/19	8/2	8/16	8/30	9/14	9/27	10/13	10/25
	-	-	32 C	32 C	16 U	-	-	16 M	16 S	16 U	47 U	-

* Heavily dominant
1/ Chem-fish treatment September 22
2/ Pro-noxfish treatment September 26

Following the 1976 spring sampling there was a rapid recovery in the total number of organisms collected which was due more to increases in a variety of taxa than to a resurgence of Procladius accounting for the increases in the mean diversity index over 1974.

Most investigators have reported the effect of rotenone, if any, on most benthic inverebrates to be generally mild and short term (eg. Leonard 1939; Smith 1940; Brown and Ball 1943; Cushing and Olive 1957; Houf and Campbell 1977).

DISCUSSION

The changes in water quality noted in Carls Lake after the winterkill were probably largely a result of the changes that occurred in the zooplankton community structure because of the reduction in the number of opportunistic feeding black bullheads. This, however, is not to suggest that nutrient recycling by bottom feeding fish cannot be an important factor affecting water quality in many lakes, particularly deeper ones. Alternate mechanisms existed in shallow Carls Lake for making sediment nutrients available to phytoplankton that would be less prominent in deeper lakes.

During periods of temporary thermal stratification and oxygen depletion near the sediment surface of Carls Lake, considerable amounts of orthophosphate and ammonia were released from the sediments and subsequently dispersed in the water column when wind disrupted the thermal barrier. In deep lakes much of the dissolved nutrients released from sediments are confined to the tropholytic zone by a persistent thermocline.

Perhaps a trade-off occurred if a reduction in nutrient recycling by bottom feeding fish was negated by the nutrient pumping activity of benthic macrophytes. Elodea has been found capable of recycling substantial amounts of phosphorus from lake sediments (Shapiro, 1977) and macrophytes (including *Elodea canadensis*), which initially were nearly absent at depths greater than 5 ft. in Carls Lake, expanded to occupy virtually the entire lake bottom following the bullhead reduction as a result of increased water transparency. In deeper lakes the proliferation of macrophytes should be less extensive.

Past experience with lake reclamation in Minnesota led to the anticipation of a more rapid and dramatic response to the bullhead reduction than was observed in Carls Lake. The growth form of the *Aphanizomenon* possibly moderated the influence grazing zooplankters had on algal densities if clumped filaments are resistant to grazing. In 1974 the *Aphanizomenon* was not observed in the characteristic clumps, however, during the post-winterkill period it was always clumped at times of high density. Thus it may have avoided some grazing pressure. Similar cases where *Aphanizomenon* clumping has been related to high *Daphnia* abundance are reviewed by Shapiro Shapiro (1979).

The postwinterkill improvement in Carls Lake water quality implied by chlorophyll concentrations and secchi disc transparencies was likely, on occasion, not apparent to the casual observer. The clumping of *Aphanizomenon* filaments was undoubtly responsible for an inexplicable portion of the improvement in secchi disc visibility because the clumped filaments of the post-winterkill period were less restrictive to light than the solitary filaments in 1974 which imparted a dense hue to the water. Also, the previously discussed paradox of the relatively large discrepancies between chlorophyll concentrations and *Aphanizomenon* counts in September 1976 and July 1977 are noteworthy but remained unresolved.

The significance of the severe decline in depth of Carls Lake during the final two years (Figure 1) to the findings of the study is not altogether clear but was probably not large. Although Rawson (1955), in comparing several lakes, showed mean depth and productivity to be generally negatively correlated, the cause of the depth decline of Carls Lake may have been partly self compensating. A decline in lake volume would lead to increased nutrient concentrations in the water column if the influx of nutrients from internal and external sources did not decline. However, the cause of the reduced lake volume was a severe lack of precipitation which brought about reduced lake levels regionally and an accompanying consequence of the drought should be a reduction in the influx of nutrients from the fertile agricultural watershed through surface runoff and groundwater flow. However, input from internal sources in 1976 and 1977 when precipitation was greater apparently did not influence chlorophyll concentrations.

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