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Effect of Winterkill on the Water Quality of Prairie Lakes

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EFFECT OF WINTERKILL ON THE WATER QUALITY OF PRAIRIE LAKES [1]

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ABSTRACT

The water quality of two prairie lakes was evaluated from the following measurements taken weekly to biweekly during the open water season for six years in Lake Hendricks, S. D. and three years in Oak Lake, S. D.: 1. water transparency, 2. nutrient levels, 3. algal densities, and 4. zooplankton densities. Two of the years sampled in each lake followed partial winterkill of fish. Data were separated into spring, early summer, and late summer seasons and tested for significant differences between years by Duncan multiple range test.

Lake Hendricks showed significantly improved water quality in terms of lower algal densities and higher water transparency in 1978, following the most severe winterkill. Ammonia-nitrogen and phosphate-phosphorus levels were significantly elevated in 1978, and zooplankton densities were significantly increased in the early summer season. The same significant changes were not noted after years of less extensive winterkill (Lake Hendricks 1975, Oak Lake 1978 and 1979).

Impact of fish population density on nutrient levels and plankton densities was further investigated through *in situ* container experiments with and without varying densities of fish, tested for significance by Duncan multiple range test and linear correlation analysis. Both tests showed significantly lower algal populations and higher zooplankton populations in containers without fish (Duncan) or with lower fish biomass (correlation), the same results as observed after severe winterkill. Nutrient levels in containers showed opposite trends from nutrient levels in the lake after severe winterkill, however, with significantly lower nutrient levels in containers without fish. Presence of dead and decomposing fish in the lake, but not in the containers without living fish, is assumed to be the reason for the discrepancy.

Since nutrient levels were unusually high after winterkill, the reason for decreased algal bloom density and improved water transparency was probably due to increased zooplankton grazing. Other measures which increase the zooplankton effectiveness, such as management for larger numbers of piscivorous fishes which prey upon zooplanktivorous fishes might also be expected to improve water quality.

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INTRODUCTION

The chain of prairie lakes in the eastern Dakotas is, for its populace, the principal source of water-based recreation and fisheries. However, deterioration of water quality has been rapid in recent years because of extensive nutrient enrichment. In the shallower lakes, limitation of incoming nutrients to improve water quality is not feasible because of the storehouse of nutrients already present in lake sediments (Harrison *et al.,* 1972; Barica, 1974; Haertel, 1976). However, changes in fish population structure have resulted in substantial water quality improvement elsewhere through the elimination of species such as carp which act as nutrient pumps (Shapiro, *et al.,* 1977; Lamarra, 1975) and through the impact of decreased fish predation on zooplankton (Hrbacek, *et al.* 1961; Gammon and Hasler, 1965; Schmitz and Hetfield, 1965; Hurlburt, *et al.,* 1972; Zaret and Paine, 1973). Many previous studies suggested that zooplankton improve water quality by filtering particulate matter and nuisance algae (Nauwerck, 1963; Gliwicz, 1969; Haney, 1973; Applegate, *et. al.,* 1973; Moriarity, *et al.,* 1973; Porter, 1977; Haertel, 1979; Edmondson and Litt, 1982). Consequently, factors which would be expected to lower fish predation on zooplankton (such as fish winterkill) can be expected to improve water quality.

A unique opportunity existed to test the effect of changes in fish populations on water quality in eastern South Dakota lakes because of the unusually extensive fish winterkill during late winter 1978. Since two of the lakes had been sampled by the senior author prior to winterkill (Haertel, 1972, 1976, 1977), a backlog of data existed with which to compare the water quality after the extensive winterkill.

In addition to comparing the water quality before and after winterkill, the effect of fish density on water quality was tested directly by *in situ* container experiments. Replicated containers with and without fish were incubated in both winterkill lakes studied and in another nearby lake which did not experience winterkill. The same water chemistry, algal and zooplankton variables were measured in both the lake water and container experiments.

The two winterkilled lakes are located in northeast Brookings County. Lake Hendricks has an area of 630 ha and a maximum depth of 2.4 m. Data are available for Lake Hendricks for six open water seasons, 1970-1979. Lake Hendricks also showed evidence of partial winterkill in 1975 (Robert Hanten, personal communication). Oak Lake has an area of 193 ha and a maximum depth of 2 m. Data are available for Oak Lake for three open water seasons, 1970-1979. Oak Lake also winterkilled in 1979. Both lakes are sufficiently shallow for wave action to mix nutrients from the sediments into the water column on windy days (Haertel, 1976), and both support massive bluegreen algal blooms. The blooms are dominated by *Aphanizomenon holsatica* and *Anacystis incerta* in Lake Hendricks and by *A. incerta, Agmenellum thermale,* and other bluegreen algal species in Oak Lake.

The objectives of the study were:

1. To determine if water transparency, water chemistry parameters, algal abundance, and zooplankton abundance were significantly different in lake water in the years following winterkill compared to years following no winterkill;

2. To directly test in replicated small volume containers the effect of the presence or absence of fish on water chemistry parameters, algal abundance, and zooplankton abundance.

METHODS

Sampling of Water Quality and Plankton

Sampling and analysis of water quality and plankton was conducted weekly in 1970-1972 and bi-weekly in 1975 and 1978-1979, during the open water season. Samples were taken at 2 stations and 2 depths (just below the surface and just above the bottom) in 1970-72, at 1 station and 2 depths in 1975, and at 1-2 stations and 1 depth (just below the surface) in 1978-79. Single samples were taken in 1970-72, duplicates in 1975, and duplicates - quadruplicates in 1978-79.

Samples for water chemistry, chlorophyll *a* analysis, and algal cell counts were taken out of the same Van Dorn Bottle cast. The chemical parameters measured included nitrate (NO_3-N, dulcine-sulfanilic), ammonia (NH_3-N, direct Nesslerization), organic-nitrogen (Kjeldahl), orthophosphate (PO_4-P, stannous chloride), total phosphate (PO_4-P, persulfate digestion) and silicate (heteropoly blue, American Public Health Association, 1971). Chlorophyll *a* was measured using the Strickland-Parsons (1968) method. Samples for cell counts were taken and preserved in Lugol's solution. Preserved cell count samples were concentrated in a plankton centrifuge and counted on an inverted stage microscope. Fields were randomly counted until 100 of the most numerous species were recorded (Lund *et al.*, 1958).

Zooplankton were sampled with a Clarke-Bumpus sampler with a #12 mesh net. Duplicate oblique tows were made at one station in each lake on all dates. Zooplankton were counted using the method described in Haertel and Osterberg (1967).

Temperature was determined at all locations by use of a bucket thermometer, and water transparency was measured with a Secchi disc.

Shoreline seining for fish was done on each sampling date in 1978 using a 15.2-m beach seine (mesh diameter 1.77 cm), estimating the linear distance seined.

Samples taken from late April to mid-June were designated "spring," mid-June to mid-July were designated "early summer" and mid-July to early September were designated "late summer."

With the data separated by season, differences between years were determined by using least squares analysis of variance and Duncan's new multiple range test (Steel and Torrie 1970). Data for the following seasons and years were available from Lake Hendricks: 1970, late summer; 1971, 1975, 1978, all three seasons; 1972, 1979, spring and early summer. Data were available from Oak Lake for 1970, 1979, spring and early summer; 1978, all 3 seasons.

In Situ Experiments

Six *in situ* water quality experiments were conducted during the spring and summer of 1979, two in Lake Hendricks, two in Oak Lake and two in Lake Cochrane (southeast Deuel County). Twenty-liter semi-transparent polyethylene containers were filled and suspended at 1 m depth for 3-9 days. Water was pumped into the containers using a PVC bilge pump. The water used to fill each container was taken partly from the surface and partly from a depth of 1.5 m to represent water at different depths. The containers were clamped onto metal rings attached to a rope having a float at one end and an anchor at the opposite end.

One set of 4 containers in each experiment included lake water with its natural density of algae and zooplankton and served as the control treatment. Two sets of 4 containers in each experiment contained a fish treatment in which variable concentrations of fathead minnows (*Pimephales promelus*) or yellow perch (*Perca flavescens*) were added to containers filled with natural lake water. The minnows were obtained from a local bait farm and transported to the lakes in oxygen-filled plastic bags. Perch were obtained by beach seining along the shore of Lake Cochrane.

Individual algal and chemical sample bottles were filled with water using a bilge pump at intervals while pumping water into each container. At the end of the incubation time, each container was removed from the lake, inverted to allow mixing of the contents, and algal and chemical individual sample bottles were again filled from the containers. Zooplankton counts were taken at the end of each experiment by filtering the water remaining in the entire container. The fish from each container were extracted with a net. Total fish biomass per container was determined by collectively weighing all the fish in each container (wet weight). Water was only analyzed chemically in the spring experiments. Chlorophyll *a*, algal cell counts, and zooplankton counts were taken in all six experiments. The same parameters and methods were used as in sampling lake water quality.

Measures of algal cell counts, chlorophyll *a*, and chemical parameters taken from each container at the end of each experiment were subtracted from measures taken at the beginning of each experiment. The differences (+ or −) in concentrations of these parameters were used in statistical tests. Final densities of zooplankton and fish were used in statistical tests. Statistical tests used included (1) analysis of variance and Duncan multiple range to determine if significant differences were present between treatments, and (2) correlation analysis to determine which variables were significantly correlated with fish biomass (Steel & Torrie, 1970).

RESULTS

Analysis of Water Quality and Plankton

Many significant differences were found between years for the chemical variables tested in Lake Hendricks (Tables 1-3). Levels of orthophosphate, total phosphate, and ammonia-N were high for all three seasons in 1978, the year of most extreme winterkill. The other chemical variables tested did not show a consistent pattern of elevation in 1978. There was also no consistent pattern of elevation of nutrient chemicals following the less extensive winterkill in 1975.

TABLE 1

Ranking of Spring Season (Least Square Mean Values) of Chemical Variables (ppm) by Year in Lake Hendricks. Values Underscored by the Same Line Are Not Significantly Different From Each Other at the .05 Level.

NO_3-N	1972	1971	1975	1978	1979
	.036	.091	.143	.218	.443
NH_3-N	1971	1972	1975	1979	1978
	.000	.000	.323	.533	.833
Organic N	1975	1978	1972	1971	1979
	1.31	1.47	1.59	1.87	3.08
Total N	1972	1975	1971	1978	1979
	1.63	1.78	1.97	2.52	4.11
Ortho-P	1972	1971	1979	1975	1978
	.073	.086	.089	.101	.170
Total P	1979	1975	1978		
	.134	.218	.262		
Silicate	1972	1978	1971	1979	
	4.93	8.67	11.58	16.49	

TABLE 2

Ranking of Early Summer Season Least Square Mean Values of Chemical Variables (ppm) by Year in Lake Hendricks. Values Underscored by the Same Line Are Not Significantly Different From Each Other at the .05 Level.

NO_3-N	1975	1979	1972	1971	1978
	.066	.087	.124	.132	.400
NH_3-N	1971	1972	1979	1975	1978
	.000	.026	.100	.123	.587
Organic N	1979	1978	1971	1975	1972
	1.373	1.707	1.893	2.243	2.514

Total N	1979	1971	1975	1978	1972
	1.560	2.029	2.605	2.693	2.699
Ortho-P	1975	1979	1971	1972	1978
	.094	.110	.166	.201	.242
Total P	1979	1975	1978		
	.200	.215	.278		
Silicate	1971	1979	1978	1972	
	12.97	14.50	17.83	20.48	

TABLE 3

Ranking of Late Summer Season Least Square Mean Values of Chemical Variables (ppm) by Year in Lake Hendricks. Values Underscored by the Same Line Are Not Significantly Different From Each Other at the .05 Level.

NO_3-N	1975	1978	1972	1971
	.050	.074	.104	.201
NH_3-N	1971	1970	1975	1978
	.052	.156	.386	.406
Organic N	1978	1970	1971	1975
	1.561	1.583	3.330	3.360
Total N	1978	1970	1971	1975
	1.851	1.925	3.457	3.796
Ortho-P	1975	1970	1971	1978
	.026	.127	.212	.263
Total P	1975	1978		
	.175	.330		
Silicate	1970	1971	1978	
	17.09	21.74	31.13	

Almost no significant differences were found between years in Oak Lake. The only exceptions were silicate, which was significantly higher in 1978, spring, and organic nitrogen, which was significantly higher in 1978, early summer. The range of least square means (ppm) encountered in Oak Lake was: Nitrate-N, 0.08-0.30; ammonia-N, 0.14-0.49; organic-N, 1.55-2.32; total-N, 2.06-2.63; orthophosphate-P, 0.02-0.04, total phosphate-P, 0.34-0.71, silicate, 16.2-23.3. The lack of significant differences between years in Oak Lake may have been because Oak Lake was winterkilled less extensively in 1978 than Lake Hendricks; the average catch of fish/linear meter towed in Lake Hendricks in 1978 was 0.17 fish; in Oak Lake it was 6.87 fish principally because of survival of a few perch and many fathead minnows.

TABLE 4

Ranking of Spring Season Least Square Mean Values of Secchi Disc and Biological Variables by Year in Lake Hendricks. Values Underscored by the Same Line Are Not Significantly Different From Each Other at the .05 Level.

Secchi (m)	1971	1972	1975	1979	1978
	.56	.79	1.12	1.50	2.21
Chlorophyll *a*	1979	1978	1971	1972	1975
(mg/m^3)	4.84	10.01	15.23	30.10	42.55
Total cells	1978	1979	1971	1972	1975
(10^3 cells/1)	4.02	15.19	19.57	102.79	221.28
Anacystis incerta	1971	1972	1978	1979	1975
(10^3 cells/1)	0.00	0.00	1.08	11.39	210.45
Aphanizomenon	1978	1979	1975	1971	1972
holsatica (10^3 cells/1)	0.02	0.07	0.32	13.94	101.15
Total zooplankton	1972	1979	1978	1971	1975
(#/1)	100.25	140.47	173.74	248.70	287.05
Daphnia spp.	1971	1972	1979	1978	1975
(#/1)	37.80	53.11	63.05	98.51	107.88

Water transparency (Secchi disc) was significantly higher in Lake Hendricks in 1978 in spring and late summer seasons than in previous years (Tables 4 and 6). Water transparency was significantly elevated in 1975 in the early summer season when compared to both previous and subsequent years (Table 5). In Oak Lake, water transparency was significantly elevated in 1970 (0.57m) and 1979 (0.53m) during the spring season and in 1979 (0.83m) during the early summer season. Seasonal least square means of Secchi disc readings varied only from 0.34-0.37m in Oak Lake in 1978 (all 3 seasons) and 1970 (early summer). Oak Lake may have winterkilled more severely in 1979 than in 1978, accounting for the higher Secchi disc readings. The authors found no oxygen in a sample taken below the ice 21 March 1979, and many dead minnows were frozen into the ice at that time.

TABLE 5

Ranking of Early Summer Season Least Square Mean Values of Secchi Disc and Biological Variables by Year in Lake Hendricks. Values Underscored by the Same Line Are Not Significantly Different From Each Other at the .05 Level.

Secchi (m)	1972	1971	1978	1979	1975
	0.42	0.59	0.68	0.75	1.40
Chlorophyll *a*	1978	1979	1971	1975	1972
(mg/m³	15.13	15.19	32.05	36.60	43.81
Total cells	1978	1971	1979	1972	1975
(10³ cells/1)	2.73	100.11	184.50	241.44	619.98
Anacystis incerta	1971	1972	1978	1979	1975
(10³ cells/1)	0.00	0.00	0.84	23.32	564.54
Aphanizomenon holsatica	1978	1975	1971	1979	1972
(10³ cells/1)	0.00	35.36	99.48	156.09	234.48
Total zooplankton	1972	1979	1975	1978	
(#/1)	130.12	130.25	440.83	686.00	
Daphnia spp.	1972	1979	1975	1978	
(#/1)	72.99	82.52	145.03	223.96	

TABLE 6

Ranking of Late Summer Season Least Square Mean Values of Secchi Disc and Biological Variables by Year in Lake Hendricks. Values Underscored by the Same Line Are Not Significantly Different From Each Other at the .05 Level.

Secchi (m)	1971	1975	1970	1978
	0.36	0.46	0.51	0.78
Chlorophyll *a*	1978	1971	1970	1975
(mg/m³)	17.93	80.41	90.10	125.81
Total cells	1978	1970	1971	1975
(10³ cells/1)	1.88	288.25	332.94	392.24
Anacystis incerta	1970	1971	1978	1975
(10³ cells/1)	0.00	0.00	0.97	108.20
Aphanizomenon holsatica	1978	1975	1970	1971
(10³ cells/1)	0.00	278.96	287.63	332.57
Total zooplankton	1970	1978	1971	1975
(#/1)	125.74	140.64	173.17	585.63
Daphnia spp.	1970	1978	1971	1975
(#/1)	36.52	43.12	57.33	320.87

Algal concentrations showed opposite results in Lake Hendricks after the 2 years of winterkill. In 1978 algal populations, as measured by both total cells and chlorophyll *a* concentrations, were severely depressed and remained low through 1979 (Tables 4-6). After the partial winterkill in 1975, however, algal populations were significantly enhanced. A noticeable species shift occurred in the phytoplankton after both years of winterkill. *Anacystis incerta* (which was not recorded from Lake Hendricks before 1975) replaced *Aphanizomenon holsatica* as the dominant summer blue-green algal species after both winterkill years.

Algal populations were not significantly different between years in the spring season in Oak Lake. In the early summer season algal populations were low in 1979 relative to 1978 and in 1978 relative to 1970, as the following results show (means not underscored by the same line are significantly different .05).

Chlorophyll *a*	1979	1978	1970
(signifiant .10)	19.00	26.92	37.76
Total Cells	1979	1978	
(significant .05)	120.32	268.81	

Zooplankton populations in Lake Hendricks were increased following the 1975 winterkill in spring and late summer seasons (Tables 4 and 6). They were increased in the early summer season following the 1978 winterkill season (Table 5). The zooplankters particularly associated with high filtration rates and increased water clarity, *Daphnia* spp., were high during early spring and summer seasons after both years of winterkill, but differences were not significant because of high variability between replicate zooplankton tows.

Zooplankton densities in Oak Lake showed no significant differences between years because of high variability between replicate tows. Total zooplankton ranged from 259/1 in 1979 to 1324/1 in 1978. *Daphnia* ranged from .04/1 in 1970 to 91.4/1 in 1979.

In situ experiments

Measures of the various form of nitrogen and phosphorous were higher in treatments with fish present than in controls (Tables 7 and 9). More significant results were obtained in experiments with higher biomass of fish than in low biomass experiments. All experiments showed positive correlations between the various forms of nitrogen and phosphorous and fish biomass (Table 8). However, high variability between replicates prevented many of the results from being significant. Silicate was depleted in the presence of fish in all experiments (Tables 7, 9).

Algal densities were increased in the presence of fish whenever significant differences in algal density were present (Table 8). The correlation between fish and algal concentration was almost always positive (Table 9), but high variability between replicates prevented some of the results from being significant.

Zooplankton densities were depleted in the presence of fish whenever significant differences in zooplankton density were present (Table 8). The correlations between zooplankton abundance and fish biomass was almost always negative (Table 9), but again, high variability between replicates prevented some of the results from being significant.

TABLE 7

Nutrient Levels Significantly Increased (+) or Decreased (−) in the Presence of Fathead Minnows or Yellow Perch in *in situ* 20-liter Container Experiments. Variables in Parenthesis Significant .10, All Others Significant .05.

Lake	Hendricks	Oak	Cochrane	
Date	5/30-6/3/79	5/15-22/79	5/22-30/79	
Fish species present	minnow	minnow	minnow	perch
Avg gms fish/container	12.8	7.9	5.1	16.5
NO_3-N	(+)			
NH_3-N				+
Organic N	+			(+)
Total N	+	+		+
Ortho-P				+
Total P	(+)			+
Silicate		−		

TABLE 8

Biological Variables Significantly Increased (+) or Decreased (−) in the Presence of Fathead Minnows or Yellow Perch in *in situ*, 20-liter Container Experiments. Variables in Parentheses Significant .10; All Others Significant .05. na = Data Not Available.

Lake	Hendricks		Oak			Cochrane			
Date	5/30-6/3/79	7/17-20/79	5/15-22/	7/13-17/79		5/22-30/79		7/10-13/79	
Fish species present	minnow	minnow	minnow	minnow	perch	minnow	perch	minnow	perch
Avg gms fish/container	12.8	11.9	7.9	9.6	6.4	5.1	16.5	12.7	18.5
Chlorophyll *a*	+	(+)	+						
Algal cell counts									
Total Bluegreens	+					na	na		
Total Diatoms	+	+		+		na	na		
Total Greens				+		na	na		
Zooplankton counts							−	−	−
Total Rotifers								(−)	
Total Copepods			−			−	−	−	
Total Cladocerans		(−)					(−)	−	

TABLE 9

Linear Correlation Coefficients (r) Between Fish Biomass and Measured Chemical and Biological Variables

Lake	Hendricks		Oak			Cochrane			
Date	5/30	7/17	5/15	7/13		5/22		7/10	
Fish species present	minnow	minnow	minnow	minnow	perch	minnow	perch	minnow	perch
Silicate	−.77*		−.85**			−.85**	−.11		
NH_3-Nitrogen	.81*		.47			.85**	.82*		
NO_3-Nitrogen	.94**		.20			.32	−.43		
Organic Nitrogen	.98***		.39			−.64+	.86**		
Total Nitrogen	.95**		.59+			.91**	.97***		
Orthophosphate	.69+		.37			.25	.93***		
Total Phosphate	.85*		.41			.21	.92**		
Chlorophyll *a*	.89**	.82**	.69*	.57	.23	.39	.40	.79*	.38
Total Algal Cells	.70*	.20	.33	.81*	.37			.73*	.59
Total Greens	.63	.29	.87***	.72*	.54			.57	.64
Total Diatoms	.37	.58+	.57+	.63+	.75			.05	.36
Total Bluegreens	.53	.17	.14	.80*	.28			.70+	.57
Total Zooplankton	−.67+	.51	−.57+	.14	.17	−.62	−.81*	−.86**	−.72+
Total Cladocerans	−.63	−.60+	−.34	−.52	−.37	−.57	−.58	−.97***	−.65
Total Copepods	−.53	−.31	−.57+	−.83*	.53	−.86**	−.96***	−.87**	−.58
Total Rotifers	−.27	.54+	−.36	.21	.11	−.23	−.65+	−.64+	−.60

***Indicates significance at .001 level.
**Indicates significance at .01 level.
*Indicates significance at .05 level.
+Indicates significance at .10 level.

DISCUSSION

The extensive winterkill in 1978 in Lake Hendricks was followed by significant increases of ortho and total phosphate, ammonia nitrogen, zooplankton density and water transparency. It was also followed by decreased algal abundance. The effect on zooplankton was most pronounced in the early summer season. Even though increased zooplankton densities are usually correlated with increased water transparency, the early summer water transparency values were not significantly high, probably because of the unusually high wind velocities on two of the three sampling dates (up to 33 km/h average hourly velocity on 6/14 and up to 23 km/h average hourly velocity on 7/12). Winds of that velocity generate large waves which suspend lake bottom sediments throughout the water column (Haertel 1976). The increased nutrient concentrations during all three seasons of 1978 could have been caused by the decomposition of large numbers of dead fish. Increased grazing by the larger numbers of zooplankton may have been responsible for the algal populations remaining low despite higher nutrient levels.

The continuing significantly lowered algal populations in the 1979 spring and early summer seasons is surprising, as the zooplankton populations did not remain high in 1979. Several possibilities could explain this: (1) Some chemical substance could have been released into the water from the very extensive decomposition taking place that inhibited the growth of algae; (2) The zooplankton populations, though small in numbers, were able to effectively graze and utilize the particular species that were present; (3) Increased fish predation in 1979 may have kept the zooplankton numbers low, even though the zooplankton were grazing and reproducing rapidly. Although no evidence exists to support or refute possibilities one or two, indirect evidence supports the third possibility. Fishermen were successful in bullhead (*Ictaluras melas*) fishing in 1979, unlike 1978, suggesting a recovery of the bullhead population. The only bullhead seined from Lake Hendricks by the senior author in 1978 (total length 320 mm) had 44 *Daphnia* in its stomach, and bullheads have been shown to be selective for large *Daphnia* in a nearby prairie lake (Repsys *et al.*, 1976). A recovery of the bullhead population would be expected to lower the *Daphnia* population.

The less extensive winterkills in Lake Hendricks in 1975 and Oak Lake in 1978 were not followed by decreases in algal populations. In both cases, the biomass of fish killed may have been quite small compared to the biomass of fish still surviving. In Lake Hendricks, algal populations were actually significantly increased in 1975, even though zooplankton populations were also high. The factors that determine whether or not zooplankton will graze given algae populations are complex and poorly understood. Even with the same species of zooplankton and algae, the algae may vary in nutrient value and palatability from lake to lake and year to year (Provasoli 1958; Sorokin, 1968; Haertel, 1979). The only algal species abundant in Lake Hendricks in 1975, *Anacystis incerta,* had never been recorded from that lake before. This might also have been a cause of its apparent escape from grazing control when it first appeared. Also, the increased availability of nutrients from decomposition with partial winterkill would be expected to increase algal populations in the absence of effective zooplankton grazing control.

Container experiment results resembled the water quality changes following the more extensive winterkill in 1978 rather than the partial winterkill of 1975. Algal populations were significantly lower and zooplankton population significantly higher in the containers without fish, as was true in Lake Hendricks water in 1978. The nutrient levels showed the opposite results however, as containers without fish had the lower nutrient levels, but in Lake Hendricks water 1978, showed the higher nutrient levels. This discrepancy might possibly be explained by the dead and decomposing fish in Lake Hendricks in 1978 releasing nutrients. No dead and decomposing fish were placed in the containers without living fish.

CONCLUSIONS

Both container experiments and changes in lake water quality following severe winterkill indicate that extensive reduction in fish populations may be accompanied by greatly lowered populations of nuisance bluegreen algae. Since severe winterkill may also be followed by increased nutrient levels, the most likely mechanism for the observed reduction of algal populations in both container experiments and following severe winterkill, is increased grazing of the algae by zooplankton. Although winterkill of fish is not a desirable method of improvement of water quality, reduction of algal populations has been shown to occur following introductions of piscivorous fish species which lower the abundance of zooplanktivorous fish species and result in higher zooplankton populations (Zaret and Paine, 1973). Introduction of large numbers of fingerlings of piscivorous species such as northern pike (*Esox lucius*) and muskellunge (*Esox masquinongy*) may be an effective method of bluegreen algal control, and though expensive, may be much less expensive than any of the following alternatives: (1) chemical control which has the additional hazard of chemical contamination; (2) watershed control of incoming nutrients with expensive dredging and removal of the large nutrient load already present in sediments; and (3) toleration of present bloom levels of nuisance bluegreen algae and resulting autochtanous sedimentation, premature filling of the lakes, and loss of the financially valuable prairie lakes resource.

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