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Algal response to nutrient inputs in some Iowa lakes[1]

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With 2 figures and 3 tables in the text

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Recent studies have indicated the importance of annual inputs of plant nutrients as determinants of the trophic status of lakes (EDMONDSON 1961, 1969, 1970, 1972; VOLLENWEIDER 1968, 1969; SCHINDLER et al. 1971; SCHINDLER et al. 1973; SHANNON & BREZONIK 1972 a, 1972 b). We wished to test this hypothesis on four lakes in northwestern Iowa, Lake West Okoboji, Lake East Okoboji (including Upper Gar Lake and Lake Minnewashta), Big Spirit Lake, and Lower Gar Lake (Fig. 1). All four are eutrophic, though to differing degrees, and some have heavy blooms of blue-green algae in the summer. Their physical characteristics are summarized in Tab. 1. The total area of the watershed is 36,200 ha, of which about 20 % is made up of wetlands or the lakes them-

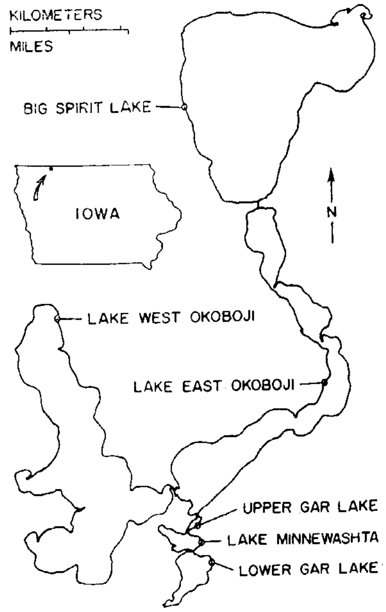

Fig. 1. Map of the Iowa lakes region.

selves. Most of the land is devoted to row-crop agriculture or pastures. The region is served by a modern sewage-collection and treatment system, which diverts most human wastes out of the watershed so that agricultural runoff and rainfall are the major sources of nutrient inputs.

Tab. 1. Morphometric characteristics and theoretical turnover time for lakes West Okoboji, Big Spirit, East Okoboji, and Lower Gar.

	West Okoboji	Big Spirit	East Okoboji	Lower Gar
Area (ha)	1540	2168	764	98
Volume (1×10^6 m^3)	184	112	21.2	1.1
Maximum depth (m)	42.7	7.3	6.7	1.7
Mean depth (m)	11.9	5.2	2.8	1.1
Turnover time (yr)	20	5.5	1.2	0.3
Thermally stratified	Yes	No	No	No

Materials and methods

Water samples were collected from all the tributary streams approximately weekly from March 1971 through August 1973. At the time of sample collection, stream flow was estimated by measuring the average stream depth, width, and velocity of flow. Orthophosphate phosphorus was determined with the stannous chloride method (APHA 1965). Starting in September 1971, total phosphorus also was determined by using the procedures of Murphy & Riley (1962) with a persulfate oxidation described by Menzel & Corwin (1965). From 750 samples on which both measurements were made, we found that the two were highly correlated ($r = 0.83$). We calculated the following least squares regression line to convert our early measurements to total phosphorus:

$$P_t = 0.035 + 1.68\, P_0$$

where P_t is the concentration of total phosphorus (mg/l) and P_0 is the concentration of orthophosphate phosphorus (mg/l). All our nutrient budgets were based on total phosphorus.

Flow measurements and total phosphorus concentrations were integrated over time to estimate the annual phosphorus inputs from each stream. Approximately 30 % of the watershed runoff was not carried in a sampled stream. Inputs from these areas were estimated on the assumption that phosphorus losses per unit area would be the same as in the metered areas.

The average concentration of total phosphorus in rainfall was 0.05 mg/l. Rainfall inputs were found by multiplying this value times the total volume of rainfall on each lake for each year.

During the summer, weekly water samples were collected from each lake for total phosphorus and algal chlorophyll concentrations. Chlorophyll *a* was extracted by use of the methods of Yentsch & Menzel (1963) and calculated according to the equations of Parsons & Strickland (1963).

Results

Annual inputs of phosphorus were calculated for the periods August 1970—July 1971, August 1971—July 1972, and August 1972—July 1973 (Tab. 2). These periods should provide the best estimates of the phosphorus available in the summers of 1971, 1972, and 1973. Inputs for August 1970—February 1971 had to be estimated on the basis of runoff and rainfall records for the region as well as average phosphorus concentrations in these sources because samples were not taken. The error should be small because most of the runoff and phosphorus inputs occurred during the spring and early summer.

Tab. 2. Estimated phosphorus inputs (kg), calculated potential phosphorus, and measured summer phosphorus values for lakes West Okoboji, Big Spirit, East Okoboji, and Lower Gar in 1971, 1972, and 1973.

	kg P from watershed and rainfall	Calculated potential P (mg/l)	Measured summer P (mg/l)
West Okoboji			
1971	3540	0.019	0.053
1972	1445	0.008	0.040
1973	2765	0.015	0.048
Spirit Lake			
1971	7550	0.067	0.088
1972	4765	0.042	0.025
1973	4655	0.042	0.036
East Okoboji			
1971	5855	0.249	0.227
1972	1880	0.080	0.180
1973	3540	0.150	0.106
Lower Gar			
1971	1630	0.204	0.248
1972	535	0.224	0.234
1973	1160	0.144	0.148

Annual differences in runoff from the watersheds account for differences in the nutrient budgets for the respective lakes from year to year. A heavy spring runoff in 1971 resulted in maximum inputs for that year. On the average, 0.35 kg/ha of total phosphorus annually was lost from the watersheds during the study. This is within the range of 0.18 to 1.0 kg/ha annually found for runoff from pastures and cropland by other researchers (Johnson et al. 1965; Vollenweider 1968; Biggar & Corey 1969).

Phosphorus delivered to each lake by rainfall depended upon surface area and total precipitation. During the study, approximately 0.032 gm/m^2 of phosphorus was contributed annually to the lake surfaces by precipitation. This is within the range of 0.015 to 0.060 gm/m^2 of phosphorus delivered to lakes by rainfall in other studies (Vollenweider 1968).

The annual phosphorus inputs to each lake were normalized by dividing by the respective lake volumes to yield potential concentrations (Tab. 2), as suggested by Edmondson (1961). In Lower Gar Lake the annual input of water is more than three times the lake volume; therefore, the potential concentration based on annual input could not be achieved. For this lake, we followed the suggestion of Edmondson (1961) and used the average concentration of the inflow as the potential concentration.

A comparison of the calculated potential concentrations with the actual measured summer total phosphorus concentrations (Tab. 2) shows a significant positive correlation (r = 0.91, p = 0.01). The highest measured values were found in the summer of 1971, which is in agreement with the high input values measured for that year. In subsequent years both the calculated and measured concentrations were less. This indicates that the phosphorus levels in the lakes are responsive to changes in inputs from year to year.

Potential concentrations differ among the lakes studied and are inversely proportional to their hydrologic turnover times (Tab. 1). In Lake West Okoboji, the annual input of water is a small fraction of the lake volume; thus, the annual phosphorus input is greatly diluted. In contrast, Lower Gar Lake has an inflow sufficient to exchange its volume several times each year so that the phosphorus concentration in the lake is approximately equal to that of the inflowing streams. Conditions in lakes East Okoboji and Big Spirit Lake are intermediate.

Our goal was to determine if the algal populations within the lakes were determined by the annual inputs of phosphorus. If plankton algae are able to use all the available phosphorus annually delivered to the lake, then the maximum algal crop should be related to the potential phosphorus concentration. This maximum would represent the largest standing crop attained from a given phosphorus load.

Maximum biomass conditions are critical determinants of lake water quality, but values are difficult to reproduce because much depends upon sampling frequency (Shannon & Brezonik 1972 a, 1972 b). To circumvent this problem, the mean July—August chlorophyll *a* value (as used by Edmondson 1972) was used to represent maximum algal biomass. The mean July—August chlorophyll *a* value encompasses the peak of the bloom which occurs in each lake in late summer. The algal genera constituting the plankton flora of each lake during the bloom period are given in Tab. 3.

Tab. 3. Predominant planktonic algal genera of lakes West Okoboji, Big Spirit, East Okoboji, and Lower Gar during July and August of 1971, 1972, and 1973.

West Okoboji	East Okoboji	Big Spirit	Lower Gar
Gloeotrichia *Anabaena* *Microcystis* *Coelosphaerium* *Aphanizomenon* *Botryococcus* *Stephanodiscus* *Fragilaria*	*Aphanizomenon* *Microcystis* *Anabaena*	*Aphanizomenon* *Anabaena* *Gloeotrichia* *Coelosphaerium* *Microcystis* *Stephanodiscus*	*Aphanizomenon* *Microcystis*

The mean July—August chlorophyll *a* value from each lake during the three years was regressed on the respective potential phosphorus concentrations (r =

0.95, p = 0.01) (Fig. 2). Two factors are noteworthy in Fig. 2. First, algal populations in the lakes are arranged in the order of increasing potential phosphorus values; the lake with the highest potential phosphorus concentration has the greatest chlorophyll concentration, and lakes with proportionally smaller phosphorus inputs had smaller algal standing crops. Second, algal populations in individual lakes are responsive to annual inputs; when natural changes in the annual runoff lowered the phosphorus input for a given year, the lakes responded with a smaller algal bloom.

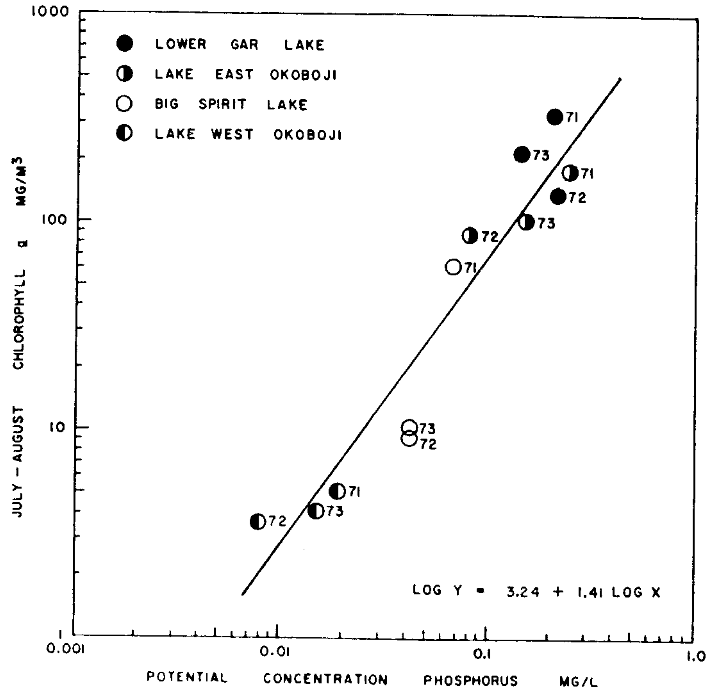

Fig. 2. The regression of mean July—August chlorophyll *a* (mg/m^3) on the potential phosphorus concentration (mg/l) in lakes West Okoboji, Big Spirit, East Okoboji, and Lower Gar in 1971, 1972, and 1973.

A similar relationship was found when we compared potential concentrations of inorganic nitrogen with summer chlorophyll *a* averages (r = 0.92, p = 0.01). This is not unexpected because the inputs of nitrogen and phosphorus are highly correlated with each other (r = 0.86) so that a correlation with one would result in a correlation with the other. We considered phosphorus as the controlling element because many of the blue-green algae composing the plankton flora of these lakes may be able to fix molecular nitrogen, and the ratio of nitrogen to phosphorus in the annual nutrient budgets ranged from 13 : 1 to 39 : 1, which is similar to the 15 : 1 N/P ratio found in algal cells (Vollenweider 1968).

Discussion

Although our approach is highly simplified and ignores other variables that might be expected to influence summer phosphorus levels and algal standing crops, it does seem to provide a means for using nutrient budgets to estimate both these variables in these lakes. The relationship between potential phosphorus concentrations and summer algal crops explains the differences among these lakes as well as much of the year-to-year differences within a single lake. We have recently extended this approach to a larger group of lakes covering a wide range of trophic types (Bachmann & Jones 1974). This approach should provide a basis for predicting the expected reduction in algal standing crops after a given reduction in phosphorus inputs.

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