Hydrobiologia vol. 57, 3, pag. 267-273, 1978

TROPHIC STATUS OF IOWA LAKES IN RELATION TO ORIGIN AND GLACIAL GEOLOGY*

John R. JONES & Roger W. BACHMANN

Department of Animal Ecology, Iowa State University, Ames, Iowa 50011

Received July 5, 1977

Keywords: Eutrophication, Iowa lakes, phosphorus, water chemistry

Abstract

Natural and artificial lakes in the most recently glaciated portions of Iowa have significantly greater total ion concentrations than those in other areas of the state. A similar distribution was found for total nitrogen concentrations. Lake origin seems of greater importance than location in determining trophic state. As a group, the artificial lakes have lower concentrations of total phosphorus, total chlorophyll, and greater Secchi disk transparency than do the natural lakes. This seems related to differences in the dynamics of the phosphorus cycles in these lake types.

Introduction

Relationships between the mineral composition of freshwaters and surface geology have been the basis of several studies of regional limnology (Deevey, 1940; Moyle, 1956; Bachmann, 1965). In Iowa, variation in the chemical content of lakes within the state is associated with the glaciation pattern. The Des Moines lobe of the Wisconsin glacial drift sheet reached its southernmost point in central Iowa (Fig. 1). Most natural lakes within Iowa are located on this glacial lobe and are relicts of the glacial retreat. Southern Iowa was last glaciated during the Kansan glacial age, and drainage patterns in these older soils are more developed. Glacial lakes have long since disappeared from this region, and artificial reservoirs have been constructed to meet needs for recreation and water-supply. In a prior study of the distribution of major anions and divalent cations in Iowa waters, Bachmann (1965) found greater ion concentrations in lakes located on the Des Moines lobe. These differences reflect the younger soils within the Wisconsin glacial sheet that have not leached to the same extent as have the older soils in southern Iowa (Walker, 1966). Such information about the edaphic influence on the mineral composition of lake water is important to separate lake types and provide background for interpreting biological differences (Armstrong & Schindler, 1971).

This study was designed as an extension of the previous work (Bachmann, 1965) to determine if the observed difference in chemical concentrations could be extended beyond conservative ions to include plant nutrients and

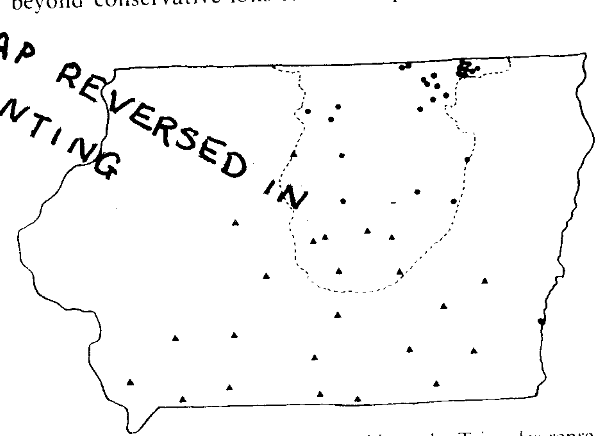

Fig. 1. Location of lakes sampled in this study. Triangles represent artificial lakes and, circles, natural lakes. The dashed line encloses the Des Moines lobe of the Wisconsin glacial drift.

* Journal Paper No. J-8810 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project 2051, financed in part by a grant from the U.S. Department of the Interior, Office of Water Resources Research under Public Law 88-379, and made available through the Iowa State Water Resources Research Institute.

algal standing crops. From data collected in this study we can determine also the chemical quality and trophic state characteristics of the Iowa lakes. Lakes and reservoirs across the state of Iowa were sampled during July-August 1974 and 1975 for these purposes.

Methods and materials

Preliminary sampling was carried out during 1974 on 19 Iowa lakes and reservoirs. In summer 1975, samples were collected on four occasions from 50 lakes and reser-

Table 1. Morphometric data and averages of limnological measurements made on some Iowa lakes and reservoirs in July and August of 1975.

No. Lake and County	Surface Area Ha	Mean Depth M	Watershed Area Ha	Specific Conductance Micromhos/cm 25 C	Alkalinity as mg/l $CaCO_3$	Total Hardness as mg/l $CaCO_3$	Calcium mg/l	Magnesium mg/l	Sodium mg/l	Potassium mg/l	Chloride mg/l	Sulfate mg/l	Total Phosphorus mg/l	Nitrate Nitrogen mg/l	Kjeldahl N mg/l	Secchi Depth M	Chlorophyll a mg m^3
Lakes within the Des Moines Loe																	
Natural Lakes																	
6. Blackhawk, Sac Co.	366	1.4	1463	417	171	217	44	26	11	3	17	41	.305	0.00	1.14	0.3	63.7
8. Center, Dickinson Co.	114	2.7	399	412	195	201	25	34	11	13	24	5	.098	0.00	2.80	0.6	80.8
9. Clear, Cerro Gordo Co.	1443	2.7	5853	280	138	154	31	19	6	4	13	6	.040	0.03	1.70	0.8	18.4
10. Cornelia, Wright Co.	85	1.4	282	305	159	163	30	21	8	6	12	6	.065	0.00	2.46	0.6	59.3
11. Crystal, Hancock Co.	108	1.5	684	343	138	179	56	10	6	3	20	29	.302	0.00	2.72	0.4	146.1
14. East Okoboji, Dickinson Co.	764	2.8	5903	408	175	206	32	31	9	7	13	36	.178	0.00	2.31	0.7	169.0
15. East Twin, Hancock Co.	72	0.2	927	312	122	169	34	20	6	3	13	19	.372	0.00	11.48	0.1	347.0
16. Five Islands, Palo Alto Co.	412	1.2	4325	378	141	195	37	25	7	3	24	36	.091	0.00	1.58	0.9	27.8
20. High, Emmet Co.	218	1.0	1774	488	176	243	52	27	7	7	17	84	.319	0.22	5.70	1.3	11.2
21. Ingham, Emmet Co.	144	1.5	4212	518	164	266	62	27	7	6	18	82	.184	0.27	1.72	1.4	15.5
22. Iowa, Emmet Co.	302	1.4	--	458	164	227	52	23	6	3	21	40	.210	0.00	2.15	0.4	90.0
25. Little Wall, Hamilton Co.	101	1.3	--	313	154	166	24	26	10	8	18	22	.107	0.04	3.54	0.3	71.3
26. Lost Island, Palo Alto Co.	465	3.1	5180	335	164	177	27	26	7	5	11	17	.146	0.00	2.33	0.4	123.8
27. Lower Gar, Dickinson Co.	98	1.1	4720	398	177	198	32	29	8	7	12	32	.131	0.00	1.77	0.4	175.0
30. Minnewashta, Dickinson Co.	47	2.6	--	383	170	198	32	29	9	7	13	31	.132	0.00	2.32	0.8	53.3
32. North Twin, Calhoun Co.	177	3.0	1259	408	137	216	38	29	9	3	17	72	.081	0.00	3.12	0.3	199.0
37. Silver, Dickson Co.	432	1.8	6475	640	167	344	82	34	11	5	15	150	.191	0.00	1.38	0.4	50.6
38. Spirit, Dickinson Co.	2168	5.2	9962	408	167	207	27	34	8	7	12	52	.042	0.00	2.01	1.0	23.6
40. Storm, Buena Vista Co.	1246	2.2	7330	463	123	207	41	25	18	5	36	71	.081	0.00	1.16	0.3	86.4
41. Swan, Emmet Co.	420	----	--	493	159	236	49	27	6	5	17	66	.094	0.00	2.46	0.6	52.2
43. Trumbell, Clay Co.	329	1.0	19426	337	124	174	31	23	6	2	16	29	.116	0.19	2.97	0.3	97.2
44. Tuttle, Emmet Co.	906	1.1	37297	512	154	281	69	26	9	4	29	108	.188	0.00	2.30	0.2	126.8
45. Twelve Mile, Emmet Co.	83	0.9	376	410	198	179	37	21	8	15	18	4	.444	0.12	4.92	0.5	93.7
47. Upper Gar, Dickinson Co.	14	1.1	--	375	166	190	29	27	9	8	13	33	.123	0.00	2.42	0.5	161.1
50. West Okoboji, Dickinson Co.	1540	11.9	7698	383	192	202	33	29	9	8	9	25	.019	0.00	1.22	3.0	3.2
Reservoirs																	
3. Bays Branch, Guthrie Co.	77	1.2	3191	355	157	192	43	20	8	2	25	26	.172	0.09	1.67	0.2	85.4
4. Beeds, Franklin Co.	43	2.9	8236	467	200	270	66	25	6	2	15	29	.045	5.57	0.84	1.1	43.7
5. Big Creek, Polk Co.	358	5.4	19453	422	178	241	63	20	5	2	11	26	.022	6.88	0.41	3.1	6.6
13. Don Williams, Boone Co.	65	5.1	7995	442	162	244	61	22	5	2	11	40	.031	--	--	1.3	23.0
19. Hickory Grove, Story Co.	40	4.9	1894	292	122	158	43	12	3	2	7	14	.041	2.10	1.12	1.0	30.6
28. Mcfarland, Story Co. Barrow Pit	3	2.5	175	430	199	240	72	15	6	2	15	19	.084	1.13	1.44	0.9	46.9
39. Spring, Greene Co. Oxbow Lake	21	0.8		407	142	209	41	26	8	3	12	65	.026	0.21	2.07	1.1	9.5
Lakes outside the Des Moines Lobe																	
Reservoirs																	
1. Ahquabi, Warren Co.	46	3.0	1322	200	100	110	36	5	6	3	6	15	.070	0.03	1.62	0.8	60.2
2. Anita, Cass Co.	65	4.2	1036	192	100	108	30	8	6	3	7	7	.038	0.00	1.34	1.6	22.7
7. Bob White, Wayne Co.	33	1.4	1420	210	74	102	30	6	9	5	7	29	.085	1.69	0.93	0.4	10.2
12. Darling, Washington Co.	111	2.7	5073	252	112	130	35	10	9	4	11	24	.163	0.00	1.27	0.3	74.7
17. Geode, Henery Co.	78	7.2	9478	292	130	159	39	15	9	3	12	30	.037	1.22	0.92	2.2	37.0
18. Green Valley, Union Co.	161	2.9	2048	198	91	105	32	6	7	5	6	25	.076	0.21	1.54	1.6	4.7
23. Keomah, Mahaska Co.	34	3.0	859	253	113	130	36	10	9	5	11	25	.065	0.00	1.61	0.6	69.6
24. Lacey-Keosauqua, Van Buren Co.	14	4.8	284	260	71	141	39	10	5	2	3	67	.014	0.06	0.73	2.4	9.8
31. Nine Eagles, Decatur Co.	10	4.0	464	143	78	84	25	5	2	2	1	7	.015	0.00	0.85	2.6	2.5
33. Pine, Hardin Co.	25	2.8	4118	325	138	179	37	21	6	2	12	21	.053	1.41	0.98	1.0	44.6
34. Prairie Rose, Shelby Co.	83	3.1	1817	247	137	141	37	12	8	4	5	15	.090	0.05	1.73	0.5	77.1
35. Red Haw, Lucas Co.	29	4.2	397	150	71	79	20	7	6	4	4	12	.037	0.00	1.29	1.3	31.2
36. Rock Creek, Jasper Co.	238	2.6	10790	318	172	190	61	10	6	3	7	23	.175	0.01	2.28	0.5	166.5
42. Three Fires, Taylor Co.	39	2.6	1593	162	87	89	28	5	5	4	3	7	.102	0.00	1.90	0.6	52.7
46. Union Grove, Tama Co.	47	1.8	2351	287	114	150	31	17	5	2	8	21	.060	2.11	1.00	0.7	41.0
48. Viking, Montgomery Co.	58	4.5	879	198	101	102	28	7	9	4	7	10	.037	0.00	1.04	1.6	18.6
49. Wapello, Davis Co. Oxbow Lake	114	1.1	2019	222	86	121	35	8	6	3	3	41	.030	0.00	1.05	1.2	24.4
Oxbow Lake																	
29. Manawa, Pottawattmie Co.	297	1.5	--	270	172	181	37	22	13	6	11	23	.107	0.00	1.69	0.3	62.2

voirs across the state (Fig. 1 and Table 1). Thirty-two of the water bodies sampled were located on the Wisconsin glacial drift sheet; of these six are artificial reservoirs and one is a former barrow pit supplied by groundwater. In southern Iowa, we sampled 17 artificial reservoirs and one oxbow lake.

The following chemical analyses were made on unfiltered samples collected in triplicate from the surface waters (0.5 m). Nitrate nitrogen concentrations were determined by cadmium reduction (Strickland & Parsons, 1968). Organic nitrogen analyses were run by using the phenate method (A.P.H.A., 1971) and a Technicon Auto Analizer II (Technicon Inst. Co., Tarrytown, N.Y.). Total phosphorus analyses (Murphy and Riley, 1962) were made after a persulfate oxidation (Menzel & Corwin, 1965). Total and calcium hardness concentrations were determined by using a complexometric titration with EDTA. Eriochrome Black T and Eriochrome Blue Black R indicators were used for end point determination (A.P.H.A., 1971). Total alkalinity was determined by titration with 0.02 N sulfuric acid by using bromcresol green-methyl red indicator (A.P.H.A., 1971). Chloride was determined by titration with 0.0141 N mercuric nitrate by using a diphenylcarbazone indicator (A.P.H.A., 1971). A Hach Conductivity Meter, Model 2511, was used to measure specific conductance in micromhos/cm at 25°C.

The following chemical analyses were made on sam-

Table 2. Mean and standard error of the mean for various limnological parameters measured in natural and artificial water bodies on the Des Moines glacial lobe and artificial lakes off the glacial lobe. Does not include the barrow pit lake nor the oxbow lake in this study.

	Water bodies on Des Moines Lobe						Waterbodies offf Des Moines lobe		
	Natural			Reservoirs			Reservoirs		
	N	$\bar{X}$	SE	N	$\bar{X}$	SE	N	$\bar{X}$	SE
Specific Conductance micromhos/cm 25 C	25	407	16.4	6	401	26.7	17	230	13.5
Total Hardness mg/l $CaCO_3$	25	208	8.42	6	224	16.7	17	125	7.8
Alkalinity mg/l $CaCO_3$	25	160	4.36	6	170	12.0	17	104	6.74
Calcium mg/l	25	40.2	2.95	6	58.0	4.98	17	34.1	2.10
Magnesium mg/l	25	25.9	1.06	6	19.0	1.93	17	9.53	1.10
Sodium mg/l	25	8.44	0.52	6	5.50	0.67	17	6.64	0.48
Potassium mg/l	25	5.88	0.62	6	2.00	0.0	17	3.41	0.26
Chloride mg/l	25	17.1	1.22	6	14.0	2.52	17	6.65	0.82
Sulfate mg/l	25	43.8	7.03	6	25.7	3.64	17	22.3	3.61
Total Nitrogen mg/m³	25	2800	421	6	4250	1095	17	1700	158
Total Phosphorus mg/m³	25	162	21.9	6	65.8	22.9	17	67.5	11.1
Chlorophyll a mg/m³	25	93.9	15.3	6	39.4	11.0	17	43.9	9.65
Secchi Depth m	25	0.66	0.12	6	1.27	0.40	17	1.17	0.18

ples filtered through a Type A Gelman glass fiber filter. Sodium and potassium concentrations were determined by using a Perkin-Elmer Flame Photometer, Model 205B. Sulfate was determined by using the turbidimetric method of Tabatabai (1974). With few exceptions, the agreement between positive and negative ions (as meq/l) in an ion balance of major elements in each individual lake was within the range found acceptable by Golterman (1969). For all 50 lakes, there is a good correlation between the cations and anions (as meq/l) ($r = 0.99$) with a slope of one between these variables.

For chlorophyll *a* determinations, a measured volume of lake water was filtered through a Type A Gelman glass fiber filter. Chlorophyll pigments were extracted by using the technique of Yentch & Menzel (1963). Spectrophotometric measurements were made following Richards with Thompson (1952) and the equations of Parsons & Strickland (1963).

Water transparency was determined by using a 20-cm Secchi disk.

Results

Results of the chemical analyses of conservative ions measured in 1975 (Table 1) are similar to values reported by Bachmann (1965) in his earlier study. The mineral content of Iowa lakes varies over a wide range of hard-water lakes of the bicarbonate type. Typical of natural freshwaters, calcium is the major cation, and bicarbonate is the major anion in most Iowa lakes. Unlike many lakes, in which the calcium fraction accounts for approximately 80% of the alkaline carbonates (Ruttner, 1963), magnesium bicarbonate is the dominant buffer in lakes of extreme northwestern Iowa. Calcium hardness ranged from 30 to 40% of the total in these lakes; for lakes in the remainder of the state the range was 60-80%.

As a group the lakes and reservoirs located on the Des Moines lobe have higher values for specific conductance and concentrations of major cations and anions with the exception of sodium (Table 2). The mean total ion concentration (as meq/l) of lakes on the glacial lobe is 1.6 times greater than the mean value of lakes without. This is most likely a reflection of the differences in the ages of the soils in the two areas.

This same grouping also is characteristic of the distribution of total nitrogen (nitrate nitrogen plus Kjeldahl nitrogen), with the lakes on the lobe having the higher values. A different grouping is found for the concentration of total phosphorus. In this instance, lake origin seems more important than location. The natural lakes on the lobe have higher values than the reservoirs either on or off the lobe. This probably results from the fact that phosphorus is not a conservative ion and is actively removed from lake waters by physical, chemical, and biological processes so that lake concentrations are less than those found in the inflowing waters. Previous research (Jones & Bachmann, 1967a) has indicated that the removal mechanisms are more effective in reservoirs than in natural lakes so that, with all other factors being equal, we would expect lesser total phosphorus concentrations in the reservoirs than in the natural lakes. There could also be a difference in the phosphorus loading rates of the natural and artificial lakes but we do not have sufficient data to test this idea.

In previous research on lakes in Iowa and elsewhere, we have found high correlations between total phosphorus and summer algal levels as measured by chlorophyll *a* concentrations (Jones & Bachmann, 1975; 1976a). The correlation between log total phosphorus and log chlorophyll *a* for our 1974 sample of lakes was 0.93 (Table 3). A similar comparison, using both the 1974 and 1975 data, yields a lower ($r = 0.74$), but still significant, correlation between these two variables. The average values for

Table 3. Mean July-August chlorophyll a and total phosphorus values from Iowa lakes in 1974.

	Chlorophyll a mg/m³	Total Phosphorus mg/m³
Beeds	25.5	50
Big Creek	9.0	34
Blackhawk	134.4	109
Center	81.2	84
Clear	18.4	36
Cornelia	42.8	75
Don Williams	15.3	24
East Okoboji	133.5	133
Five Islands	57.3	73
Hickory Grove	12.6	28
High	227.3	130
Ingham	63.4	88
Little Wall	137.4	156
Lost Island	100.4	127
Lower Gar	194.2	117
McFarland	40.2	50
North Twin	76.6	53
Pine	15.1	34
Silver	262.2	150
Spirit	29.1	43
Spring	7.4	19
Storm	48.8	66
Trumbell	53.6	104
West Okoboji	6.8	36

chlorophyll *a* in our three groups of lakes follow the total phosphorus means. The natural lakes have significantly greater levels of total phosphorus than the two reservoir groups considered either singly or combined.

Other investigators also have found strong relationships between phosphorus and chlorophyll levels in lakes (Dillon & Rigler, 1974; Edmondson, 1972; Sakamoto, 1966). Nitrogen is the other element likely limiting, but seems to be present in nonlimiting amounts in Iowa lakes. The ratio of N to P in aquatic plant materials is about 7 : 1 (Vallentyne, 1974). The mean N to P ratio in our sample was 24.2 with a standard error of 2.2. Only one lake had a ratio of less than 7 (Fig. 2); thus, phosphorus seems limiting in Iowa lakes.

High phosphorus concentrations and attendant high densities of plankton algae constitute the major water-quality problem in Iowa lakes. This is manifest in poor water transparency as measured with the Secchi disk. Edmondson (1972) has pointed out that there is a hyperbolic relationship between Secchi disk transparency and chlorophyll *a* concentrations. We have fitted an empirical curve to these data by using our data on Iowa lakes along with data from other lakes in the literature. Our lakes fit on the same curve (Fig. 3) as lakes from other areas. In general, they are clustered on the lower end of the scale. Transparencies of lakes with chlorophyll *a* values below 10 mg/m^3 are extremely sensitive to changes in algal abundance, whereas transparencies of lakes with chlorophyll *a* concentrations above this value differ little. Most Iowa lakes have summer concentrations well above this value of 10 mg/m^3, and as a result, have poor transparencies. Average Secchi disk values (Jones & Bachmann, 1976b) for the lakes sampled in 1975 were 1.34 m in May, 1.19 m in June, 0.94 m in July, and 0.88 m in August. Decreasing transparencies during the summer corresponded with the usual increase in algal densities in this period.

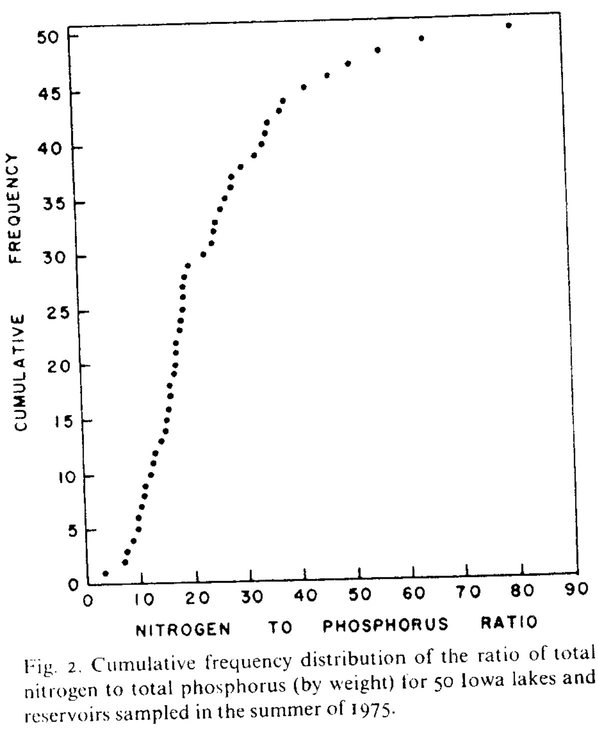

Fig. 2. Cumulative frequency distribution of the ratio of total nitrogen to total phosphorus (by weight) for 50 Iowa lakes and reservoirs sampled in the summer of 1975.

On the average (Table 3), the Secchi disk transparencies are poorer in the natural lakes than in the reservoirs, reflecting the higher chlorophyll *a* concentrations in those lakes. The exception is Lake West Okoboji. It is the deepest lake in the state, has a relatively small watershed, and hence, has a low concentration of total phosphorus, a low chlorophyll *a* concentration, and a high value for the Secchi disk transparency (Jones & Bachmann, 1974).

By conventional criteria (Vollenweider, 1968), all the lakes in Iowa are eutrophic, but some are more eutrophic than others. The concentration range of total P (14 to 444 mg/m^3), total N (0.79 to 11.48 mg/l), and algal biomass (2.5 to 347.0 mg/m^3 as chlorophyll *a*) in Iowa lakes are within eutrophic range set for these parameters (Sakamoto, 1966; Vollenweider, 1968, 1976). Using open-water P concentrations, Vollenweider (1976) suggests that to maintain oligotrophic characteristics, the lower limit is 10 mg P/m^3 with an upper limit of 20 mg P/m^3. None of the lakes that we sampled had summer phosphorus concentrations below this lower limit and only four lakes had concentrations below 20 mg P/m^3. Lake West Okoboji and three reservoirs (Big Creek, Lacey-Keosauqua, and Nine Eagles) had the lowest nutrient and algal concentrations and greatest clarity measured within the state. In contrast four natural lakes (East Twin, Tuttle, Crystal, and Little Wall) had the highest values for these parameters.

Discussion

Iowa lakes can be separated into two geological areas. Those lakes on the Des Moines glacial lobe have significantly greater concentrations of conservative ions than do those without. Soil formations on the lobe are younger than in the remainder of the state (Walker, 1966; Ruhe,

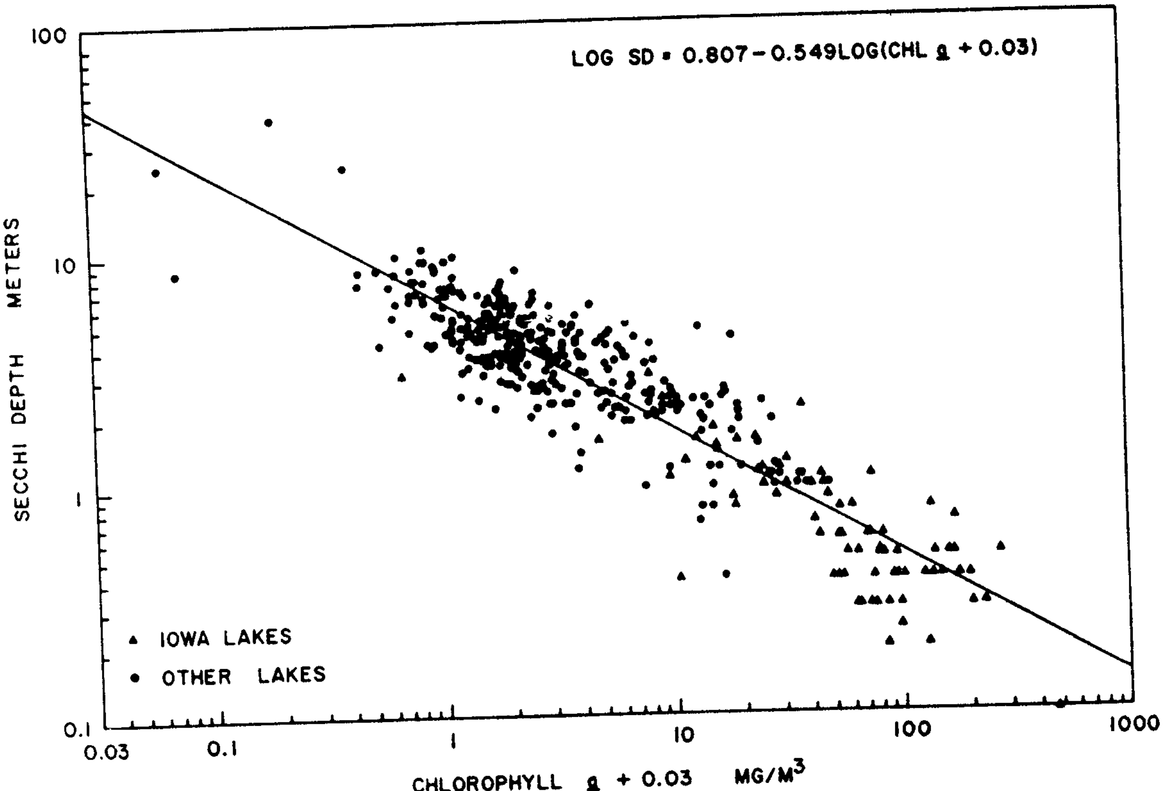

Fig. 3. Double logarithmic plot of Secchi disk depths against average chlorophyll *a* concentrations. Data for non-Iowa lakes were taken from the literature (Bachmann & Jones, 1976, Dillon, and Rigler, 1975; Oglesby & Schaffner, 1975), and from reports of lake self-help projects in Ontario and Michigan. The addition of the constant 0.03 to the chlorophyll values prevents the calculated Secchic disk values from approaching infinity as the chlorophyll levels approach zero.

1969) and are leaching at a faster rate. Water bodies in these two different geographic areas, therefore, reflect the composition of their watersheds.

Similar to the findings of this study, edaphic factors influence the mineral content and biological properties of lakes in Minnesota (Moyle, 1956). In Minnesota, however, there is a wide range, from the very oligotrophic northern lakes to the productive prairie lakes of the southwestern region. In Iowa, the differences between conservative ions are less extreme and are not considered of biological importance.

The lakes also can be separated on the basis of their origin. This factor seems to be of greater importance than location in determining the concentration of total phosphorus, total chlorophyll, and Secchi disk transparency. As a group, the artificial lakes, whether on or off the Des Moines lobe, are somewhat less eutrophic than the natural lakes. This seems to be related to differences in the dynamics of the phosphorus cycles in these two lake types. This hypothesis cannot be easily tested in a survey of this type, for, while there are artificial lakes located on the Des Moines lobe, our sample includes only one natural lake off the lobe. That lake is different from our other natural lakes in that it is an oxbow lake along the Missouri River and not a glacial lake basin.

Phosphorus concentrations account for the difference in algal biomass observed among the lakes. The general character of Iowa lakes is eutrophic because of these high phosphorus and nitrogen concentrations. Many lakes in the upper Midwest have similar plant nutrient and algal biomass values and are considered eutrophic (Shapiro *et al.*, 1975; USEPA, 1975).

Little could be done to change the Iowa lakes. Most have transparencies of less than 1 m as a result of chlorophyll concentrations above 10 mg/m^3. Phosphorus concentrations exceeded the upper limit of 20 mg P/m^3 in 94% of the lakes in our sample. Most Iowa lakes are located in agricultural watersheds and have no nutrient inputs from municipal sources. Steps could be taken to reduce inputs from agricultural watersheds (Jones *et al.*, 1976), but the probable reductions would be ineffective except for the protection of a few individual lakes (Bachmann & Jones, 1976).

Acknowledgements

Dr. Peter Dillon supplied us with data on Secchi disk transparencies from the Ontario lake self-help program, and Albert Massey provided us with similar information from the Michigan project. We wish to thank Gerald Abma, JoAnn Burkholder, Daniel Canfield, Daniel Dudley, Keith Govro, Marianne Moore, Cedo Ryan, and Mark Ryan for assistance with sample collection and laboratory analyses. We thank Dr. R. V. Bovbjerg for use of laboratory facilities at Iowa Lakeside Laboratory.

References

American Public Health Association. 1971. Standard methods for the examination of water and waste water. 13th ed., New York, American Public Health Association. 874 pp.

Armstrong, F. A. J. & Schindler, D. W. 1971. Preliminary chemical characterization of waters in the Experimental Lakes Area, northwestern Ontario. J. Fish. Res. Board Can. 28: 171-187.

Bachmann, R. W. 1965. Some chemical characteristics of Iowa lakes and reservoirs. Proc. Iowa Acad. Sci. 72: 238-243.

Bachmann, R. W. & Jones, J. R. 1976. Is nutrient removal worthwhile? Water Wastes Eng. 13: (2) 14-16.

Deevey, E. S., Jr. 1940. Limnological studies in Connecticut. V. A contribution to regional limnology. Am. J. Sci. 238: 717-741.

Dillon, P. J. & Rigler, F. H. 1974. The phosphorus-chlorophyll relationship in lakes. Limnol. Oceanogr. 19: 767-773.

Dillon, P. J. & Rigler, F. H. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish. Res. Board Can. 32: 1519-1531.

Edmondson, W. T. 1972. Nutrients and phytoplankton in Lake Washington. pp. 172-188 in Symposium on nutrients and eutrophication, the limiting nutrient controversy. American Society of Limnology and Oceanography. Special Symposium 1. Allen Press, Lawrence, Kansas.

Golterman, H. L. ed. 1969. Methods for chemical analysis of fresh waters. Int. Biol. Program Handb. 8. Oxford Blackwell Scientific Publications, 172 pp.

Jones, J. R. & Bachmann, R. W. 1974. Limnological features of some northwestern Iowa lakes. Proc. Iowa Acad. Sci. 81: 158-163.

Jones, J. R. & Bachmann, R. W. 1975. Algal response to nutrient inputs in some Iowa lakes. Verh. Int. Verein. Limnol. 19: 904-910.

Jones, J. R. & Bachmann, R. W. 1976a. Prediction of phosphorus and chlorophyll levels in lakes. J. Water Pollut. Control Fed. 48: 2176-2182.

Jones, J. R. & Bachmann, R. W. 1976b. A preliminary study of water transparency in Iowa lakes. Unpublished report. Dept. of Animal Ecology, Iowa State Univ., Ames. 9 p.

Jones, J. R., Borofka, B. P. & Bachmann, R. W. 1976. Factors affecting nutrient loads in some Iowa streams. Water Res. 10: 117-122.

Menzel, D. W. & Corwin, N. 1965. The measurement of total phosphorus in seawater based on the liberation of organically bound fractions by persulfate oxidation. Limnol. Oceanogr. 10: 280-282.

Moyle, J. B. 1956. Relationship between the chemistry of Minnesota surface water and wildlife management. J. Wildl. Manage. 20: 303-320.

Murphy, J. & Riley, J. P. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 27: 31-36.

Oglesby, R. T. & Schaffner, W. R. 1975. Response of lakes to phosphorus. In Porter, K. S., Ed. Nitrogen and phosphorus; food production, waste, and the environment. Ann Arbor Science Publ. Inc. Ann Arbor, Michigan.

Parsons, T. R. & Strickland, J. D. 1963. Discussion of spectrophotometric determination of marine-plant pigments, with revised equations of ascertaining chlorophylls and carotenoids. J. Mar. Res. 21: 155-163.

Richards, F. A. with Thompson, T. G. 1952. The estimation and characterization of plankton populations by pigment analyses: II. a spectrophotometric method for the estimation of plankton pigments. J. Mar. Res. 11: 156-171.

Ruhe, R. V. 1969. Quaternary landscapes in Iowa. Iowa State University Press, Ames, 255 p.

Ruttner, F. 1963. Fundamentals of limnology. (Translat. D. G. Frey and F. E. J. Fry.) Toronto, Univ. of Toronto Press, 295 pp.

Sakamoto, M. 1966. Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth. Arch. Hydrobiol. 62: 1-28.

Shapiro, J., Lundquist, J. B. & Carlson, R. E. 1975. Involving the public in limnology - an approach to communication. Verh. Int. Verein. Limnol. 19: 866-874.

Strickland, J. D. H. & Parsons, T. R. 1968. A practical handbook of seawater analysis. Fish. Res. Board Can., Bull. No. 167.

Tabatabai, M. A. 1974. Determination of sulphate in water samples. Sulphur Inst. J. 10: 11-13.

U.S. Environmental Protection Agency. 1975. A compendium of lake and reservoir data collected by the National Eutrophication Survey in the northeast and north central United States. Working Pap. 474. Corvallis and Las Vegas, p. 210.

Vollenweider, R. A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to phosphorus and nitrogen as factors in eutrophication. Technical Report to O.E.C.D., Paris, DAS/CSI 68.27: 1-182.

Vollenweider, R. A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. Dott Marco de Marchi 33: 53-83.

Vallentyne, J. R. 1974. The algal bowl; lakes and man. Dep. of the Environ., Fish. and Mar. Serv. Misc. Spec. Publ. 22.

Walker, P. H. 1966. Postglacial environments in relation to landscape and soils on the Cary drift, Iowa. Iowa Agric. Home Econ. Exp. Stn. Res. Bull. 549.

Yentch, C. S. & Menzel, D. W. 1963. A method for the determination of phytoplankton chlorophyll and phaeophytin by flourescence. Deep Sea Res. 10: 221-231.