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

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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 cycle 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 relics 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.

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

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

<table>
<thead>
<tr>
<th>No.</th>
<th>Lake and County</th>
<th>Surface Area (Acres)</th>
<th>Mean Depth (Ft.)</th>
<th>Watershed Area (Acres)</th>
<th>Specific Conductivity (kgs/Cm.2)</th>
<th>Alkalinity as CO3 (mg/L)</th>
<th>Total Hardness as CaCO3 (mg/L)</th>
<th>Calcium mg/L</th>
<th>Magnesium mg/L</th>
<th>Sodium mg/L</th>
<th>Potassium mg/L</th>
<th>Chloride mg/L</th>
<th>Total Phosphorus (ppm)</th>
<th>Nitrate Nitrogen (ppm)</th>
<th>Kjeldahl N (mg/L)</th>
<th>Scabbi Depth (Ft.)</th>
<th>Chlorophyll A (mg/L)</th>
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</thead>
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<tr>
<td>6.</td>
<td>Blackhawk, Sac Co.</td>
<td>366</td>
<td>1.4</td>
<td>1463.417</td>
<td>171</td>
<td>213</td>
<td>44</td>
<td>26</td>
<td>11</td>
<td>3</td>
<td>17</td>
<td>41</td>
<td>.305</td>
<td>0.00</td>
<td>1.14</td>
<td>0.3</td>
<td>63.7</td>
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<tr>
<td>7.</td>
<td>Linn, Linn Co.</td>
<td>114</td>
<td>2.7</td>
<td>399.412</td>
<td>195</td>
<td>201</td>
<td>25</td>
<td>34</td>
<td>11</td>
<td>12</td>
<td>4</td>
<td>5</td>
<td>598</td>
<td>0.00</td>
<td>2.31</td>
<td>0.7</td>
<td>68.9</td>
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<td>8.</td>
<td>Clinton, Jackson Co.</td>
<td>144</td>
<td>2.7</td>
<td>5853.280</td>
<td>138</td>
<td>1</td>
<td>31</td>
<td>109</td>
<td>4</td>
<td>13</td>
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<td>.040</td>
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<td>1.70</td>
<td>0.8</td>
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<tr>
<td>9.</td>
<td>Clear Creek, Cerro Gordo Co.</td>
<td>108</td>
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<td>288.102</td>
<td>219</td>
<td>292</td>
<td>13</td>
<td>20</td>
<td>11</td>
<td>11</td>
<td>2</td>
<td>11</td>
<td>16.3</td>
<td>0.00</td>
<td>1.50</td>
<td>0.3</td>
<td>40.5</td>
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<tr>
<td>10.</td>
<td>Conesville, Wright Co.</td>
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<td>0.2</td>
<td>2377.312</td>
<td>122</td>
<td>169</td>
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<td>20</td>
<td>6</td>
<td>3</td>
<td>13</td>
<td>19</td>
<td>.372</td>
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<td>3.18</td>
<td>0.9</td>
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<td>11.</td>
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<td>2.8</td>
<td>2903.408</td>
<td>114</td>
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<td>0.00</td>
<td>11.48</td>
<td>0.1</td>
<td>144.0</td>
</tr>
<tr>
<td>12.</td>
<td>East Okoboji, Dickinson Co.</td>
<td>272</td>
<td>2.2</td>
<td>9752.317</td>
<td>176</td>
<td>241</td>
<td>52</td>
<td>52</td>
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<td>144.0</td>
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<tr>
<td>13.</td>
<td>East Twin, Hancock Co.</td>
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<td>4333.378</td>
<td>141</td>
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<td>197</td>
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<td>57</td>
<td>3</td>
<td>3</td>
<td>28</td>
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<td>.84</td>
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<td>0.5</td>
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<td>14.</td>
<td>Four Seasons, Palo Alto Co.</td>
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<td>9752.317</td>
<td>176</td>
<td>241</td>
<td>52</td>
<td>52</td>
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<td>0.1</td>
<td>144.0</td>
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<tr>
<td>15.</td>
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<td>1774.468</td>
<td>176</td>
<td>241</td>
<td>52</td>
<td>52</td>
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<td>11.48</td>
<td>0.1</td>
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<tr>
<td>16.</td>
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<td>1.5</td>
<td>4212.518</td>
<td>126</td>
<td>246</td>
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<td>27</td>
<td>7</td>
<td>11</td>
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<td>18</td>
<td>18.2</td>
<td>.184</td>
<td>0.27</td>
<td>1.72</td>
<td>1.4</td>
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<td>17.</td>
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<td>302</td>
<td>1.4</td>
<td>--</td>
<td>354</td>
<td>164</td>
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<td>26</td>
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<td>8</td>
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<td>21</td>
<td>.22</td>
<td>0.00</td>
<td>3.54</td>
<td>0.3</td>
<td>71.3</td>
</tr>
<tr>
<td>18.</td>
<td>Iowa, Emmet Co.</td>
<td>101</td>
<td>1.3</td>
<td>--</td>
<td>313</td>
<td>156</td>
<td>24</td>
<td>24</td>
<td>10</td>
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<td>.22</td>
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<td>3.54</td>
<td>0.3</td>
<td>71.3</td>
</tr>
<tr>
<td>19.</td>
<td>Little Wall, Hamilton Co.</td>
<td>98</td>
<td>1.1</td>
<td>4720.398</td>
<td>177</td>
<td>198</td>
<td>27</td>
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<td>4</td>
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<td>11</td>
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<td>2.33</td>
<td>0.4</td>
<td>122.8</td>
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<td>20.</td>
<td>Lost Island, Palo Alto Co.</td>
<td>465</td>
<td>3.1</td>
<td>5180.335</td>
<td>164</td>
<td>177</td>
<td>27</td>
<td>27</td>
<td>4</td>
<td>4</td>
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<td>17</td>
<td>1.16</td>
<td>0.00</td>
<td>2.33</td>
<td>0.4</td>
<td>122.8</td>
</tr>
<tr>
<td>21.</td>
<td>Lower Gar, Dickinson Co.</td>
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<td>--</td>
<td>313</td>
<td>156</td>
<td>24</td>
<td>24</td>
<td>10</td>
<td>8</td>
<td>18</td>
<td>21</td>
<td>.22</td>
<td>0.00</td>
<td>3.54</td>
<td>0.3</td>
<td>71.3</td>
</tr>
</tbody>
</table>
| 22. | Masonville,回答被截断，无法提供完整内容。
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 Analyzer 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 bromocresol 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.

<table>
<thead>
<tr>
<th>Water bodies on Des Moines Lobe</th>
<th>Water bodies off Des Moines lobe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural</td>
</tr>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td></td>
</tr>
<tr>
<td>micromhos/cm 25°C</td>
<td>25</td>
</tr>
<tr>
<td>Total Hardness</td>
<td></td>
</tr>
<tr>
<td>mg/l CaCO₃</td>
<td>25</td>
</tr>
<tr>
<td>Alkalinity</td>
<td></td>
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<tr>
<td>mg/l CaCO₃</td>
<td>25</td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
</tr>
<tr>
<td>mg/l</td>
<td>25</td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
</tr>
<tr>
<td>mg/l</td>
<td>25</td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
</tr>
<tr>
<td>mg/l</td>
<td>25</td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
</tr>
<tr>
<td>mg/l</td>
<td>25</td>
</tr>
<tr>
<td>Chloride</td>
<td></td>
</tr>
<tr>
<td>mg/l</td>
<td>25</td>
</tr>
<tr>
<td>Sulfate</td>
<td></td>
</tr>
<tr>
<td>mg/l</td>
<td>25</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td></td>
</tr>
<tr>
<td>mg/m³</td>
<td>25</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td></td>
</tr>
<tr>
<td>mg/m³</td>
<td>25</td>
</tr>
<tr>
<td>Chlorophyll a</td>
<td></td>
</tr>
<tr>
<td>mg/m³</td>
<td>25</td>
</tr>
<tr>
<td>Secchi Depth</td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>25</td>
</tr>
</tbody>
</table>
amples 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 (1965). 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 hardwater 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 values 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

| Beeds    | 25.5 | 50   |
| Big Creek| 9.0  | 34   |
| Blackhawk| 134.4| 109  |
| Center   | 81.2 | 84   |
| Clear    | 18.4 | 36   |
| Cornell  | 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   |
| Trumbull | 53.6 | 104  |
| West Okoboji| 6.8 | 36   |

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

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 11.45 mg/l), and algal biomass (2.0 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,
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/m³. Phosphorus concentrations exceeded the upper limit of 20 mg P/m³ 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 Ahma, 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


