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Climatic Influences on Annual Variations in Water Transparency in Lake West Okoboji[1]

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Secchi disk transparencies, chlorophyll *a* concentrations, and total phosphorus concentrations were studied in Lake West Okoboji, Iowa, in the summers of 1971-73 and 1987-89. The average summer Secchi disk transparencies varied from a low of 2.5 to a high of 5.5 m during the study. The variations in the transparency of Lake West Okoboji from year to year seem to be related to climatic factors such as the amounts of spring precipitation in the watershed and probably reflect changes in the annual inputs of plant nutrients. There is some indication that climatic conditions that cause the period of deep mixing to extend into the early summer lead to a greater Secchi disk transparency, but more data are needed to confirm this hypothesis. Other than these fluctuations related to climatic variables, there is no indication of any systematic changes in water quality in the period from the early 1970s to the late 1980s.

INDEX DESCRIPTORS: Lakes, Secchi disk transparency, Eutrophication, Phytoplankton

Lake West Okoboji in northwest Iowa is unique in many respects. It is the deepest natural lake in Iowa and ranks at the top in water quality for the large lakes in the state (Jones and Bachmann 1978b). For this reason it is an important recreational resource, and much effort has been directed toward preserving its quality. A monitoring study was carried out in the period 1971-1973 (Bachmann and Jones 1974) to establish baseline information on the level of eutrophication in the lake, and follow-up studies have been undertaken in recent years to look for changes. This report looks at annual variations in water transparency observed in these studies. Analyses were carried out to determine what causes the water clarity to change from year to year and whether these changes signal a change in the trophic state of the lake.

METHODS

This study is based on data from 6 summers. The first 3 were in 1971-73 and the next 3 in 1987-1989 used the same six sampling stations. In 1971 and 1972 summer samples were taken monthly and in 1973 twice a month. In the last 3 years water sampling on the lake started in the fourth week of May and continued on a weekly basis for 12 weeks with the last samples taken in early August. Although isolated data on limnological conditions in this lake are available for portions of several other summers, these data were not used, because they did not cover comparable time periods or did not use all of the six stations.

Jones and Bachmann (1974) presented the methods for the first 3 summers. In the most recent 3 summers, at the deepest station a temperature probe was used to measure water temperatures at each meter of depth. A Van Dorn water bottle was used to take water samples at the surface, 5 meters, and 10 meters for determinations of algal chlorophylls and total phosphorus. A measurement of the Secchi disk depth also was made. At the other 5 stations Secchi disk readings were made, and surface water samples were collected for measurements of chlorophyll *a* and total phosphorus. Averages were used of the measurements at all six sampling stations.

At the Lakeside Laboratory samples of water for total phosphorus measurements were stored in prewashed, screw-capped test tubes. For algal chlorophylls measured amounts of lake water (500 to 750 ml) were filtered through glass-fiber filters. Each filter was placed on a labeled piece of absorbent paper. The paper was folded, secured with a paper clip, placed in a jar with desiccant and stored in a freezer.

The remaining analyses were carried out in the Limnology Research Laboratory at Iowa State University. Each chlorophyll filter was extracted in 5 ml of 90% ethanol according to the procedures of Sartory and Grobbelaar (1984). The tube holding the filter and the ethanol were heated to 78 C for 5 minutes and then extracted in the dark at room temperature for 24 hours to complete the extraction. After extraction, the samples were transferred to a 1-cm cuvette for spectrophotometric analyses. Optical densities were read at 665 and 750 nm. The optical density at 750 nm (the turbidity correction) was subtracted from that at 665. The difference was multiplied by 11.7 to find the concentration of chlorophyll *a* in the extracting solution. This value was multiplied by the volume of extractant used (5 ml) and divided by the number of liters of lake water filtered. This calcuation yields milligrams of chlorophyll *a* per cubic meter.

The total phosphorus samples were oxidized with ammonium persulfate in an autoclave to convert all the phosphorus to orthophosphate, in accordance with the procedure of Menzel and Corwin (1965). This phosphorus concentration was determined with the modified single-solution method of Murphy and Riley (1962).

Because nutrients can be carried into the lakes by land runoff and, to a lesser extent, directly by rainfall, precipitation data from Milford, Iowa were obtained from the published records of the National Oceanic and Atmospheric Administration (1971-73, 1987-89).

RESULTS AND DISCUSSION

Although mean Secchi disk depths in Lake West Okoboji (Figure 1) were always great relative to other Iowa lakes (Jones and Bachmann 1978a), there was considerable variations from year to year, ranging from a low of 2.5 m in 1971 to a high of 5.5 m in 1988. Summer average concentrations of algal chlorophylls and total phosphorus (Figure 1) were less relative to other Iowa lakes (Jones and Bachmann 1978b) and showed annual variations that were not as great as those found for the Secchi depths. It has been found previously (Jones and Bachmann 1978b) for most Iowa lakes that the water transparency is closely related to the concentrations of algal chlorophylls. For the 6 years of this study Lake West Okoboji followed the same pattern (Figure 2) with the greatest transparencies found in the years with the least amounts of chlorophylls. In as much as the relationship is logarithmic, the Secchi disk transparencies in Lake West Okoboji are more sensitive to small changes in the concentrations of algal chlorophylls than are those of most other Iowa lakes where the

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chlorophyll concentrations are much greater. For example using the equation in Figure 2 to calculate Secchi disk depths from concentrations of chlorophyll *a*, I find that if the chlorophyll concentration in

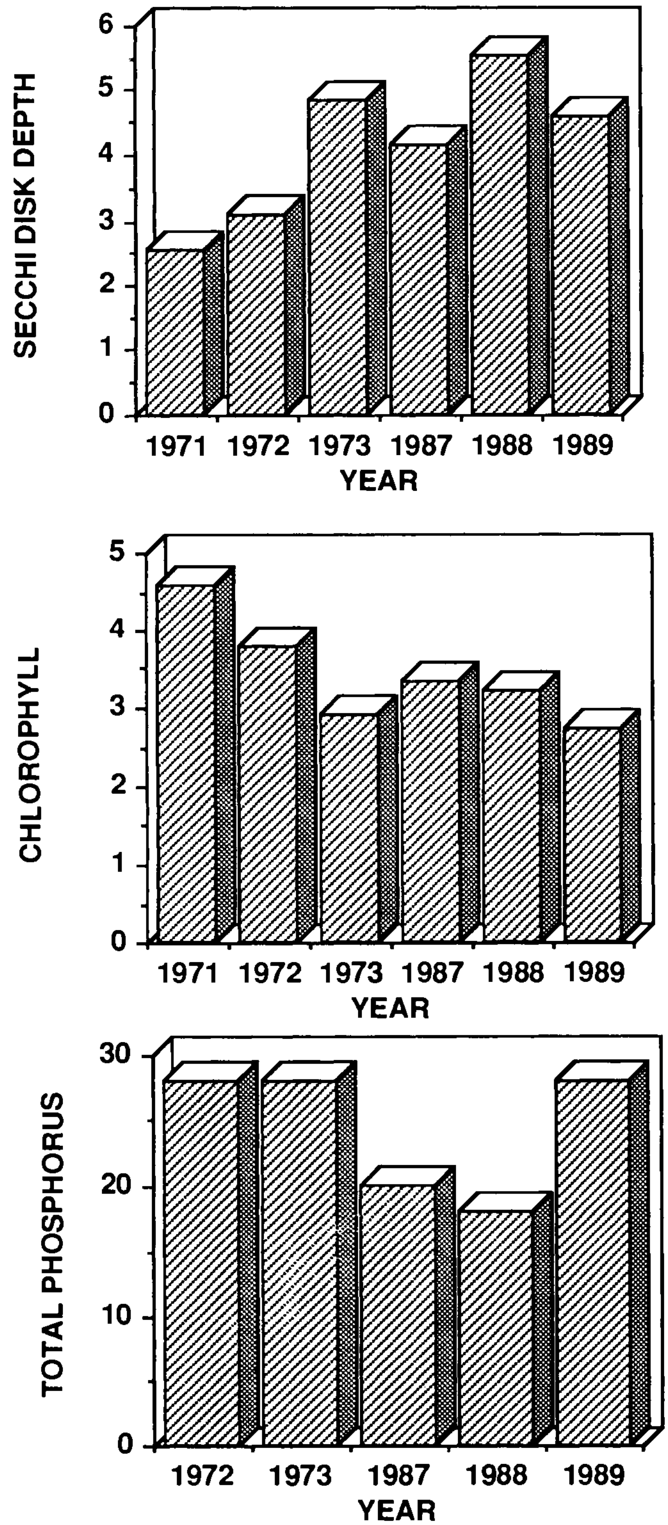

Fig. 1. Summer average values for Secchi disk depths (m), chlorophyll *a* concentrations (mg m^{-3}), and total phosphorus concentrations (mg m^{-3}) for Lake West Okoboji during the study period.

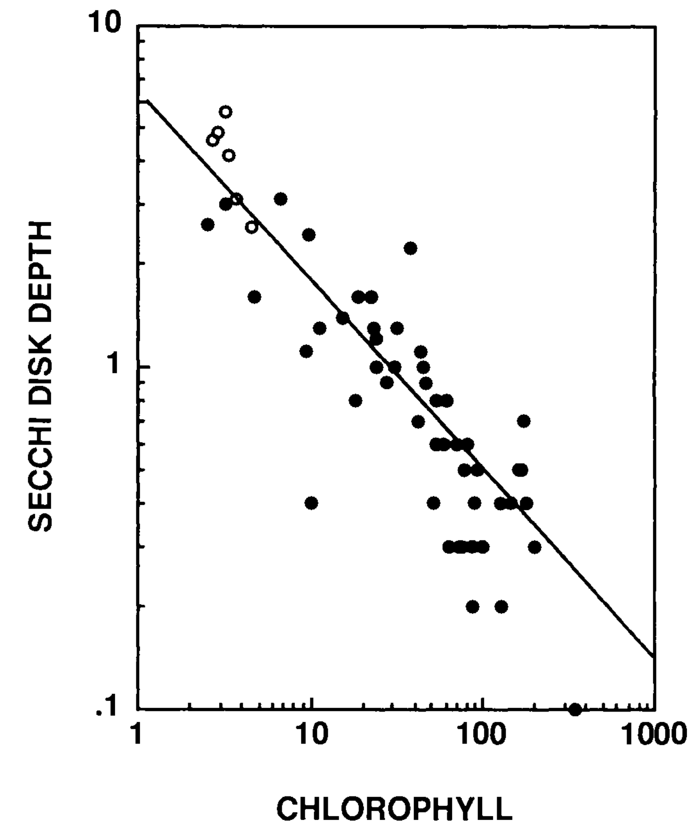

Fig. 2. Summer Secchi disk depths (m) and chlorophyll *a* concentrations (mg m^{-3}) for Lake West Okoboji in 1971-73 and 1987-89 (open circles) and several Iowa lakes (solid circles) sampled in 1975 (Jones and Bachmann 1978b). The regression line, $\mathrm{Log\ SD} = 0.807 - 0.549\ \mathrm{Log}(\mathrm{CHL} + 0.03)$, was based on a large sample of North American lakes covering a broad range of trophic states (Jones and Bachmann 1978b).

West Okoboji increased by 1 mg m^{-3}, from 3 to 4 mg m^{-3}, the Secchi disk depth would decrease by 0.51 m. On the other hand, in a lake with a concentration of chlorophyll *a* of 30 mg m^{-3}, the same increase of 1 mg m^{-3} would cause a change in the Secchi disk depth of only 0.02 m. Because the measured chlorophyll values in West Okoboji are so low, and the Secchi disk depths are so sensitive to changes in chlorophyll *a* concentrations, the Secchi depths might be a better of index of algal biomass in this lake than the actual measurements of the pigments themselves.

In looking for causes for the year-to-year variations in chlorophyll *a* it is natural to look at variations in total phosphorus, because it has been found that the summer concentrations of chlorophyll *a* in Iowa lakes often are highly correlated with the concentrations of total phosphorus (Jones and Bachmann 1975). In this study (Figure 3) the points for Lake West Okoboji seem to fall on the same curve as other Iowa lakes. However, the changes in total phosphorus in Lake West Okoboji are small relative to the errors around the regression line for this relationship, so that the relationship between chlorophyll *a* and total phosphorus within this lake is difficult to determine from the data available. Like the algal chlorophylls, the concentrations of total phosphorus measured in Lake West Okoboji are small relative to the sensitivity of the analytical method used, so that it is difficult to derive direct proof that changes in total phosphorus are responsible for changes in algal chlorophylls and, hence, changes in the Secchi disk transparency.

Jones and Bachmann (1975) found that annual variations in the

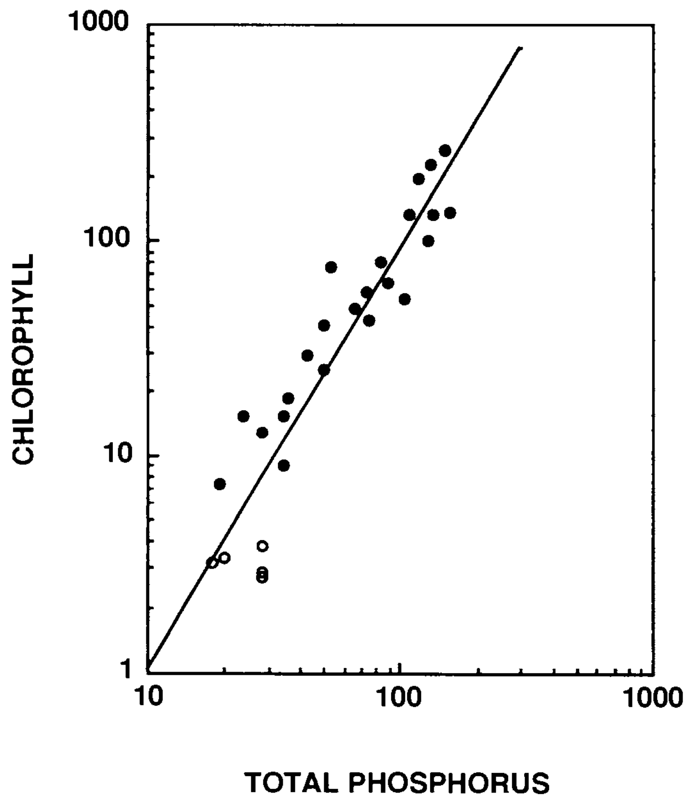

Fig. 3. Summer concentrations of chlorophyll *a* and total phosphorus (mg m^{-3}) for Lake West Okoboji in 1971-73 and 1987-89 (open circles) and several Iowa lakes (solid circles) sampled in 1974 (Jones and Bachmann 1978b). The regression line, Log CHL − 1.94 + 1.95 Log TP, was fitted to all points.

inputs of water and total phosphorus to Lake West Okoboji were correlated with corresponding changes in the average concentrations of chlorophyll *a* in July and August for the years 1971, 1972, and 1973. Due to the high costs of directly measuring annual phosphorus inputs to this lake, comparable data are not available for the last 3 years of this study. As an index of the potential annual inputs of phosphorus from rainfall on the lake and from surface runoff, I have used the total precipitation at nearby Milford, Iowa for the period January 1 through June 30 (NOAA 1971-73, 1987-89). This time period was chosen because it would include the spring runoff period, which would be expected to bring in nutrients that would contribute to algal growth in the late spring and early summer. The average summer Secchi disk transparencies for the study period were significantly correlated ($R^2 = 0.53$) with this index of nutrient input (Figure 4). This is the expected relationship and is in agreement with the findings of Goldman and deAmezaga (1984) who found that the annual variations in primary production in Castle Lake, California were correlated with variations in annual precipitation on that lake. Jones and Novak (1981) also found highest total phosphorus concentrations and greatest water clarity during a drought year in Lake of the Ozarks, Missouri. It would seem that in years with more precipitation, enhanced runoff would bring greater amounts of phosphorus and perhaps other critical nutrients into the lake, which in turn would lead to greater chlorophyll *a* concentrations and thus to decreased Secchi disk depths. Conversely a drought year with reduced spring precipitation and runoff should lead to increased Secchi depths in the next summer.

It has been previously noted (Stromsten 1927) that the pattern of circulation in this lake varies from year to year, depending upon variations in air temperatures and wind velocities. In some years the lake develops a thermal stratification early in the spring, and in other years the spring circulation may persist into the early summer. Dr. Bovbjerg (personal communication) has observed that years with a late development of stratification seem to have greater Secchi disk depths. To see if this might account for some of the residual variance in my Secchi disk model, I needed some index of the pattern of spring circulation. Because years with a later circulation had warmer temperatures in the hypolimnion (Stromsten 1927), I chose to use the water temperature at 35 meters of depth on July 15th. I found a significant correlation (Figure 5) between this temperature and the residuals (the differences between the measured summer Secchi disk depths and the Secchi disk depths calculated from the above regression of Secchi depths against precipitation). The changes in the deepwater temperatures were associated with 86% of the variance in the Secchi depth residuals suggesting that water circulation patterns in the spring and early summer may play some role in water transparency. It should be noted that when both precipitation and 35-m temperatures are used as independent variables in a multiple regression, the reduction in the unexplained portion of the variance brought about by the addition of the deepwater temperatures was significant at only the 12% level of probability, so there is some degree of uncertainty in its use. It could just be coincidence, or it could be that the 35-meter temperature in July is not the best way to quantify the effects of early or late stratification in the lake.

The mechanism by which early summer circulation patterns might control Secchi disk transparencies is not clear. Because the lake is so deep, resuspension of bottom sediments can be ruled out as a factor. One might expect that in a year with an early stratification there would be a restriction on the reuse of plant nutrients that had been sedimented with dead plankton into the hypolimnion and could not move back into the lighted zone of the epilimnion. This mechanism, however, would work in the wrong direction, for it would lead to the clearest water in the years with the earliest stratification. Two other possibilities might be operating. Current research (e.g. Carpenter et

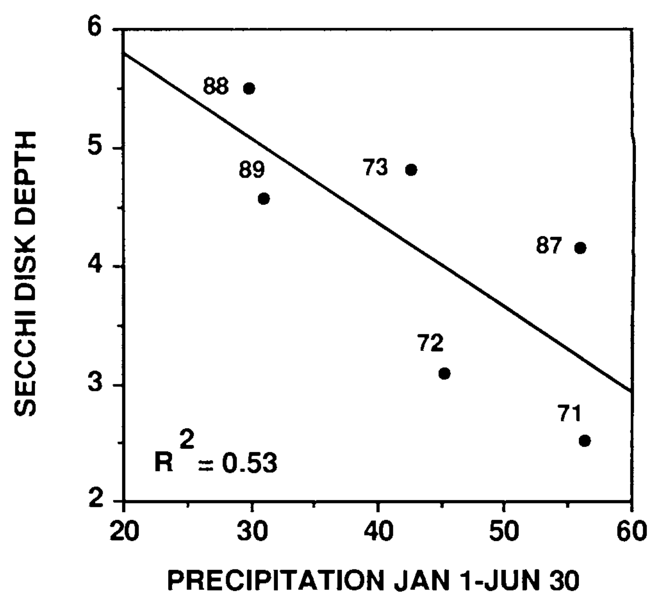

Fig. 4. Average summer Secchi disk depths (m) in Lake West Okoboji in 1971-73 and 1987-89 as a function of precipitation (cm) measured at Milford, Iowa. The regression line is SD = 7.22 − 0.0715 PPT.

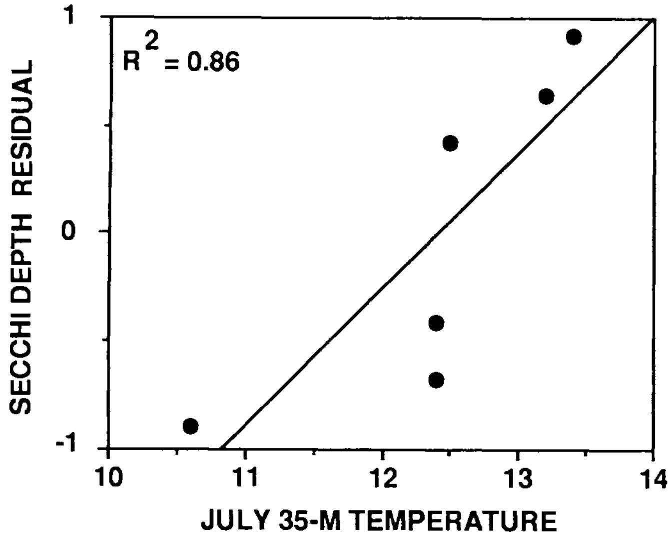

Fig. 5. Residual differences (m) between average summer Secchi disk depths and those calculated from the regression of Secchi depths on precipitation and water temperatures (C) at the 35-meter depth.

al. 1987, Lampert et al. 1986) has emphasized the role that zooplankton grazing can have in regulating phytoplankton densities and hence water transparency. It could be that for one reason or another, a year with a late establishment of stratification favors the development of more effective zooplankton grazing on the phytoplankton, though I have no data to test this hypothesis. There also could be a direct effect of mixing on the phytoplankton populations, because this lake has a maximum depth of 42 m and a mean depth of 11.9 m (Bachmann, Bovbjerg, and Hall 1966). During non-stratified periods the phytoplankton would be mixed downward to depths several times deeper than the Secchi disk transparency, and thus light could become a limiting factor in the development of the maximum phytoplankton biomass in those years in which the spring circulation was extended into the early summer. Further research is needed to determine the link between summer phytoplankton biomass and circulation patterns in this lake.

A practical question for those who are trying to protect the lake from degradation is whether the lake is changing over time. Although we do not have measurements of transparency, plant nutrients, and algal chlorophylls from the early part of the century, an earlier study based on oxygen depletion in the hypolimnion indicated that the lake was somewhat more euthrophic in the early 1970s than it was in the 1920s (Jones and Bachmann 1974). The previous work indicated that phosphorus was the key element in this lake and that most of it came in from non-point sources in the watershed (Jones, Borofka, and Bachmann 1976), but I have no current measurements of phosphorus loading. The recent measurements in the lake do not indicate continued eutrophication. Comparing the measurements in the period 1987-89 with those in 1971-73, we find that the average summer total phosphorus concentration went from 0.028 to 0.020 mg m^{-3}, the chlorophylls from 3.8 to 3.1 mg m^{-3}, and the Secchi depths from 3.5 to 4.8 m. Because the average Jan. 1-June 30 precipitation dropped from 48.0 cm in the first period to 37.0 cm in the second, however, this apparent improvement in water quality probably just reflects the decreased precipitation in recent years. Detailed studies of land use changes and the quality of surface runoff would be needed to answer this question.

In conclusion, variations in the water transparency of Lake West Okoboji from year to year seem to be related to climatic factors such as the amounts of spring precipitation in the watershed and probably reflect changes in the annual inputs of plant nutrients. There is some indication that climatic conditions that cause the period of deep mixing to extend into the early summer lead to a greater Secchi disk transparency, but more data are needed to confirm this hypothesis. Other than these fluctuations related to climatic variables, there is no indication of any systematic changes in water quality in the period from the early 1970s to the late 1980s.

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