TROPHIC STATE CLASSIFICATION OF TWO NORTHERN WESTCHESTER LAKES

by

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Abstract

Two lakes in Northern Westchester were sampled for a period of fourteen months in order to determine their trophic status. When interpreted according to the trophic state index proposed by Carlson (1977), the data collected suggest that both lakes may be considered eutrophic. Although these results may be used to define trophic status, various other parameters (particularly specific uses for the water) must also be considered when drawing any conclusions about the quality of the lake water.

Our life is frittered away by detail.
. . . Simplify, simplify.

Henry David Thoreau
Walden I, Philanthropy

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Introduction

Philosophy of Trophic State Indices

Recently there has been a proliferation of trophic state indices in the published literature. (See for instance Ott (1978), Taylor et al. (1979), Winner (1972), Imboden (1978), Wezernak et al. (1976), Rawson (1956), and Carlson (1977)). Several reasons may account for the increase in these indices. First, the concept of eutrophication remains a subject of academic debate among limnologists (Vollenwieder 1970), (Welch 1976), (Hutchinson 1973). It is generally understood, however, that eutrophication is a complex process involving internal as well as external lake processes. These processes tend to integrate themselves in the phytoplankton community, thus, producing a change in primary production. The changes in primary production which take place within the system (lake), are in actuality changes in energy production and flow that represent changes in trophic state. A second reason for the growth of indices is public law 92-500 (PL 92-500), the Federal Water Pollution Control Act of 1972 and Amendments. Sections 304, 305 and 307 of PL 92-500 require states to prepare a report on water quality each year. In this report each state must identify and classify publicly owned lakes according to eutrophic conditions (FWPCA, 1972). Still another reason for the increase of indices is that it, becomes exceedingly difficult to communicate with the public on the condition or state of their lakes when the underlying concepts are still a subject of controversy. Finally, the diverse pressure from special interest groups competing for water and its uses (i.e., drinking, irrigation, recreational, etc.), may also account for the growth of water quality indices.

The characterization of lake trophic status is still a contentious topic among limnologists. There exist, however, three main interpretations of the trophic concept (Carlson, 1979), (Hutchinson, 1969):

1. Trophic state has to do either with the supply of nutrients coming into a lake or the concentration of these nutrients once in the lake. The greater the supply or concentration the more eutrophic the lake will be.
2. Trophic state has to do with the biology of the lake, either its productivity or biological structure. The higher the productivity or standing crop, the more eutrophic the lake will be.
3. Trophic state is a multi-variate concept incorporating aspects of both nutrients and biology.

As mentioned earlier, there is a wide variety of trophic indices in use today, however, their construction and application will differ depending on how one views the trophic concept. The definition of the words, oligo- (Greek for few), eu- (Greek for well), and meso- (Greek for middle), -trophic have become ambiguous. The meaning of the three words and their application to lakes have become so complicated that Shapiro (1979), has referred to the problem as a limnological tower of Babel."

How one views the concept, of trophic state will differ depending on which of the leading hypotheses are employed. One leading perspective employed states that trophic states are a series of types (Shapiro, 1979) (Carlson, 1979). The "typological" trophic concept which Naumann (1919) perceived, is similar to the type species used in taxonomy. Lakes may be classified in distinct groups or types in which oligotrophic and eutrophic are only two of the many possible types (See figure 6a.). Alternatively, the continuous trophic concept views a lake as being at a point in a continuum. Inherent in this view is the belief that there are no distinct trophic types, but a continuous and infinite variety of trophic possibilities. (See figure 1b.)

Carlson's (1977) trophic state index (TSI) attempts to provide an unambiguous classification system for lakes. The index was intentionally designed to be numerical rather, than nomenclatural so that it could be easily understood by the lay public, with no loss of information or sensitivity to change. The index is analogous to the Richter Scale used to measure the intensity of earthquakes. Carlson's TSI uses algal biomass present in the surface waters as the key indicator. TSI (equation I) is derived from a log base 2 transformation of the amount of algal biomass as measured by Secchi disc transparency. In this scale each 10 units represent a doubling in algal biomass, and the range is from 0 to 100:

$$TSI = l0(6 - \log_2 SD). \qquad \text{I.}$$

From the date of Shapiro and Pfannkuch (unpublished), Schelske et al. (1972), Powers et al. (1972), Lawson (1972), Carlson (1975,) and Megard (unpublished), Carlson was able to formulate regression equations from plots of secchi disc readings versus chlorophyll a (equation II), and total, phosphorus concentrations (equation III). The resulting equations are:

$$\ln SD = 2.04 - 0.68 \ln chl, \qquad \text{II.}$$

$$SD = 64.9/TP. \qquad \text{III.}$$

Carlson then plotted chlorophyll a against total phosphorus and obtained the following equation:

$$\ln chl = 1.449 \ln TP - 2.442. \qquad \text{IV.}$$

He then combined equations II and IV and obtained, yet another equation:

$$\ln SD = 3.876 - 0.98 \ln TP \qquad \text{V.}$$

Equations II and V are used in the computational which are outlined in the methods section.

Materials and Methods

Lakes Waccabuc and Oscaleta are located 80 km. north of New York City in northern Westchester County. Fast et al. (1975) calculated that Lake Waccabuc has a surface area of 53 ha, 4.053 X 10^6 m^3 total volume, 7.228 X 10^5 m^3 hypolimnetic volume, and 13m maximum depth. Lake Waccabuc is unique in that it contains two hypolimnetic aerators which were installed during the summer of 1972 by the Union Carbide Corporation. Although Fast et al. (1975), reported frequent summer algal blooms, I observed none during the 14 months of sampling. Lake Oscaleta is much smaller than Lake Waccabuc. Fung (unpublished) calculated a surface area of 23 ha, and I, measured 9.5 m as the maximum depth. During the 14 months of sampling I observed two bluegreen, (Myxophycean), surface blooms within the lake. There are well over 300 residents within the watershed all of whom are serviced by septic tanks. There is no system of storm water collection.

Water samples were collected and secchi disc transparency was measured in the two lakes from June 1979 until August 1980. Samples and measurements were taken once a week during the summer, twice a month during spring and fall, and once a month during the winter.

Surface water samples were collected in 2-l nalgene bottles which were immersed in the upper 0.3m of the epilimnion and filled.. The water samples were then transported to a laboratory in the Natural Sciences Building at SUNY, Purchase where filtration for Chlorophyll a analysis was performed.

Secchi disc transparency was determined using a standard (20 cm dia.) secchi disc attached to a line marked in centimeter intervals. The disc was lowered into the water until it disappeared at which point the line was pinched. The disc was lowered and then raised until it reappeared and the line was pinched again. The midpoint of the pinched intervals was used as the measure of secchi disc transparency.

Chlorophyll a determinations were performed using the method proposed by Lorenzen (1967), with two steps modified. The water samples from the two lakes were filtered (separately) through a millipore filter unit which contained a 47 mm (OD) Schleicher and Schuell glass fiber filter. The filter retains particles greater than 0.3u. The total volume of water filtered for chlorophyll a determination varied with the season. On the average 1-l was filtered during the summer, 1.5-l during the spring and fall and 2.0-1 during the winter. The pigment laden filters were then wrapped in aluminum foil and stored at -15 C in a Nalgene bottle, which contained anhydrous $CaSO_4$. As mentioned earlier, two steps were modified in Lorenzen's method. First, the absorbance of the extracted chlorophyll was determined using a spectronic 70 (Spec. 70), at 750 and 665NM before and after acidification with 0.IN HCL, instead of the l.0N HCL Lorenzen called for. Second, two different blanks were used to zero the spec 70. One blank, which was used for the readings before acidification, contained 90% acetone. The other blank contained the acetone plus one drop of 0.IN HCL and was used for the reading after acidification. The absorbance readings obtained were then placed into the following equation:

$$\text{CHL a (mg/m}^3) = \frac{A x K x (665_o - 665_a) x v}{V f x l}$$

A = 11.0
K = 2.43

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665_o = reading at 665 nm before acidification minus the 750 nm reading before acidification.

665_a = readings at 665 mm after acidification minus the 750 nm reading 'after acidification.

v = volume of 90% acetone" used in the extraction of the pigments minus the average volume of the glass fiber filter plug.

l = path length of cuvette (1cm).

V_f = volume of water filtered (this ranged from 1.0 1 to 2.01 depending on the season).

Carlson's (1977), TSI was calculated using secchi disc transparency and surface chlorophyll a concentration. The following equations were used to determine TSI_{sd} and TSI_{chl}.

TSI_{sd} = 10 x (6 – (ln SD/ln 2)) ,and

TSI_{chl} = l0 x (6 – ((2.04 - 0.68 ln chl)/ln 2))

sd = secchi disc transparency in meters

chl = chlorophyll a concentration in mg/m^3.

All results are monthly averages and are presented in Table 1.

Results

Lake Waccabuc:

During the 14 month sampling secchi disc transparency presented as monthly averages, (Figure 1a, Table 1) reached a maximum depth of 2.5m (September 1979). The lowest average of 1.5m occurred during July, 1980. Transparency appears to increase from July, 1979 until January, 1980 at which point it decreases until July,1980. The only exceptions were during September, 1979 and May, 1980 when transparency was much greater than the trend would predict. Secchi disc transparency averaged 2.08m during the sampling period.

Chlorophyll a (also presented as monthly averages) (Figure 2, Table 1), ranged from a low of 1.4 mg/m^3 during August, 1980 to a high of over 14 mg/m^3 during June, 1980. There are clearly three maxima visible during the sampling period. The two highest peaks occurred during July, 1979 and June, 1980 and the low point occurred during October, 1979. Notice that the spring maxima of 1980 was greater and occurred one month earlier than the spring maxima of 1979. Chlorophyll a averaged 6.4 mg/m^3 during the 14 months of sampling.

Carlson's TSI_{sd} again presented as monthly averages, (Figure 3a, Table 1) ranged from a low of 47 during January, 1980 to a high of 54 which occurred during July 1980. Notice that the trends parallel those of the secchi disc transparency. The average value for the 14 month sampling period was 50.

Carlson's TSI_{chl}, which are also presented as monthly averages, (Figure 3b, Table 1), ranged from a low of 34 during August, 1980 to a high of 56 during June, 1980. Again, it should be noted that the trends parallel those of the chlorophyll a concentrations. The average value for the 14 months sampling was 47.

Lake Oscaleta:

During the 14 month sampling period, secchi disc transparency, . (Figure lb, Table 1), once more presented as monthly averages, spanned from a low of 1m (September, 1979) to a high of 3.3m (July, 1980). Secchi disc transparency tends to decrease from July, 1979 until September, 1979. Then it begins to increase following September, 1979 until December, 1979. From December, 1979 until April, 1980 secchi disc transparency decreases, then increases until July, 1980. It should be noted that there appears to be a duplication of the pattern exhibited during the 3 summer months of 1979 and 1980. The mean secchi disc transparency during the 14 month sampling period was 2.46m.

Chlorophyll a concentration (Figure 4, Table 1) (also presented as monthly' averages) ranged from a low of 1.7 mg/m^3 during February, 1979 to a high of over 17 mg/m^3 during April, 1980. As figure 4 clearly shows, there are two maxima which occurred during the 14 months of sampling. One appears between Sept, Oct, 1979 and the other appears between April, May, 1980. It should be noted that it appears as if the chlorophyll a concentration reaches a baseline of between l.5 and 2.0 mg/m^3, during the 14 months of sampling. The mean chlorophyll a concentration for the sampling period was 5.1 mg/m^3.

Carlson's TSI_{sd} again presented as monthly averages, (Figure 5a, Table 1) varied from a low of 42, which occurred during July, 1980, to a high of 59, during September, 1979. Again, it should be noted that the results of TSI_{sd} parallel those of secchi disc transparency. The mean TSI_{sd} for the sampling period was 51. Carlson's TSI_{chl} (Figure 5b, Table 1) ranged from a low of 36 (during April, 1979 and February, July, 1980) to a high of 59 occurring during April, 1980. Again it should be noted that the trends exhibited parallel those of the chlorophyll a concentration.

Discussion:

In the introduction I have referred to a multitude of trophic indices and the rationale behind their construction. (For a more detailed discussion of .the many types of trophic indices see Taylor et al. (l972),Shapiro (1975), Brezonik (1976), Winner (1972), Wezernaketal (1976), and Boland (1976)). I have chosen to apply Carlson's (1977) trophic state index to the two lakes for'~ number of reasons. First, the index meets all of the requirements of a valid index, according to Shapiro (1979). 'The index should be:

1. Simple
2. Objective
3. Absolute
4. Scientifically Valid
5. No loss of Information
6. Unequivocal Data
7. Easily Understood by Policy Makers as well as the Lay Public

Second, Carlson's index is a single-variate index in which the potential for predictability is large. It must be remembered however, that the prediction is limited by the amount of information which exists concerning the relationships between the components. (For a detailed discussion of single vs. multi-variate 'indices see Maloney (1979)).

It appears at first as if Carlson's trophic state index is ideal. However, the index has been criticized by a number of authors. Carlson noted that his regression equation,

$$\ln SD = 2.04 - 0.68 \ln chl\ a,$$

did not fit a function of the form

$$\frac{Iz}{Io} = e^{-(\alpha + BC)z}$$

where

Io = surface light
Iz = light at depth z
α = extinction coefficient for non-algal material
B = incremental extinction coefficient for algae
C = algal concentration

He postulated that the data did not fit the function because of the changing chlorophyll content per cell as a result of changing light conditions. Lorenzen (1980), Megard et al. (1980) and Edmondson (1980) argue that Carlson's data did not fit the function because values for α, (extinction coefficient for non-algal material) vary from lake to lake. Megard (1980) concludes that contrary to Carlson's assertion, the index is ambiguous and potentially misleading. Lorenzen (1980) suggests that the value of α should be determined for any particular lake under study.

Carlson (1980) counters this argument by noting that the major ambiguity inherent in the index is not the possibility of misinterpretation of the trophic state due to variations in α, but that the index assumes that chlorophyll increases exponentially relative to algal biomass. Carlson then presents data which suggest that chlorophyll is linearly related to biomass, and therefore, the index distorts changes in algal biomass. Carlson recommends that the user assume that each 7 rather than 10 units represents a doubling. However, he also warns the user that the dual scale should be employed with caution because it still implies a strong relationship between biomass and transparency. Furthermore, the scales can be expected to deviate significantly at low chlorophyll concentrations when the effect of α is the greatest.

Carlson (1977) intended his TSI to be objective rather than subjective so that the value generated is merely an index of the trophic status of a lake. He cautions that the index is not an estimate of water quality which requires a subjective judgment. Employing the terms of classical limnology, Carlson offers two major divisions in the scales which correspond to traditional trophic classes. He suggests that 40 be the upper limit of a oligotrophic lake, and any value above 40 a eutrophic lake. He also suggests that the index should be calculated from samples taken from the epilimnetic waters during the period of thermal stratification when there should be the best agreement between the parameters. I will present data which show that not only do both lakes exhibit the classical attributes of a eutrophic lake but that Carlson's (1977) TSI gives the same results.

Lake Waccabuc exhibits patterns of seasonal phytoplankton periodicity which are also an indication of the lake's eutrophic state. Figure 2, clearly shows a trend which indicates that during the fourteen months of sampling two spring maxima (one in 1979, the other in 1980), and one fall maximum in chlorophyll a concentration had occurred. Seasonal variations in secchi disc transparency (Figure la) show three minimum values while seasonal 'variations in chlorophyll a (Figure 2) show three corresponding maxima (July, October 1979 and June, 1980). These minima in secchi disc transparency and maxima in chlorophyll are undoubtedly due to the seasonal rise and fall of the phytoplankton population. It is important to note that the spring maximum of 1979 occurs as an "extended" midsummer peak with the maximum chlorophyll concentration not occurring until July. Fogg (1975) considers an extended midsummer peak as an attribute of a eutrophic lake. It is interesting to note, however, that the same trend did not occur in the 1980 spring maximum. Another pattern exhibited is the chlorophyll a concentration, which is greater in the spring maximum of 1980 than it is in the spring maximum of 1979. Is this an indication of an increased degree eutrophication, even though the extended midsummer peak did not occur in 1980?

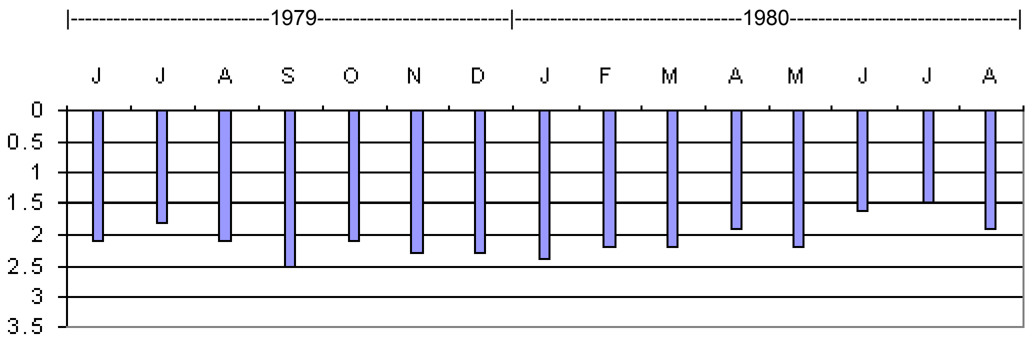
At first glance, there appears to be little correlation between the TSI_{sd} and the TSI_{chl} indices (Figures 3a, b). If however, the extreme values are excluded (Figure 3b overlay), both indices do not vary significantly, and a much stronger correlation between indices appears. When chlorophyll a is at a minimum the effects of will be great, and the scales can be expected to deviate, significantly (Carlson, 1980). This effect is clearly exhibited in my results. When the extreme TSI_{chl} values are excluded, (Figure 3b overlay) both scales range from 45 to 55, (except in June, 1980) and show no significant variation between seasonal TSI values. Carlson (1977) attributes the rise and fall of both scales to the changing phytoplankton population. It is important to note that after the TSI_{chl} scale is corrected, minor variations in the seasonal TSI values of both scales still occur. Carlson (1977) suggests that further study is needed to determine the cause of these minor variations. Perhaps the phosphorus based index, which I chose not to examine, could account for the variations. However, this is only speculation, and the reason(s) for the variations are beyond the scope of this study. Carlson (1977, 1980) suggests using the TSI_{chl} index as the basis of trophic state evaluation. In Lake Waccabuc

I obtained an uncorrected TSI_{chl} mean of 47 (Table la). When the TSI_{chl} index was corrected for extreme values, I obtained an index value of 50 (Table la). Observe that when the extremes are excluded both the TSI_{sd} and the TSI_{chl} yield the same mean value (Table la).

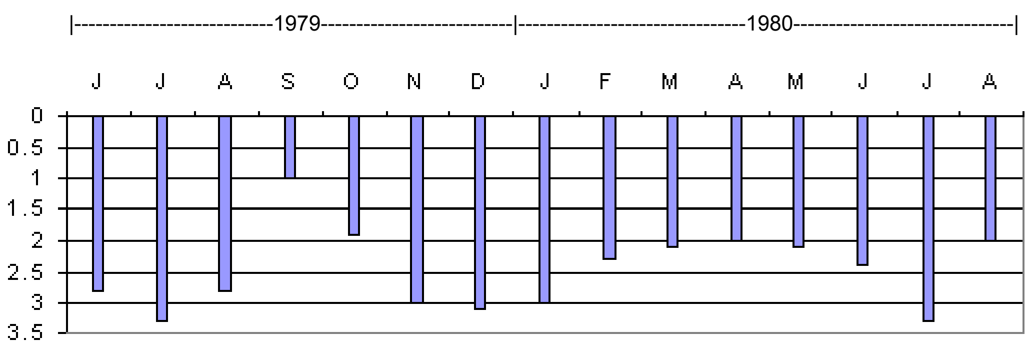
Lake Oscaleta exhibits patterns of seasonal phytoplankton periodicity similar to those exhibited in Lake Waccabuc. Figure 4 shows a trend which indicates that during the fourteen months of sampling one spring maximum and one fail maximum in chlorophyll a had occurred. Secchi disc transparency (Figure lb), like that of Lake Waccabuc, shows two minima while the chlorophyll a concentration (Figure 4) shows two corresponding maxima (October, 1979 and April, 1980). Again, these maxima and minima are undoubtedly due to the seasonal rise and fall of the phytoplankton population. Observe that the chlorophyll a concentration, (Figure 4) was greater in the spring maximum of 1980 than it was in the fall maximum of 1979. Notice, however, that the maxima are separated by less than $3 mg/m^3$. Is this trend an indication that phytoplankton growth becomes light limited during the fall and phosphorus limited during the spring? It is important to note that both maxima in chlorophyll a concentration (Figure 4) correspond with the appearance of two surface blooms of blue-green algae.

Seasonal Variation in Secchi Disk Transparency

Lake Waccabuc
Figure 1a



Lake Oscaleta
Figure 1b



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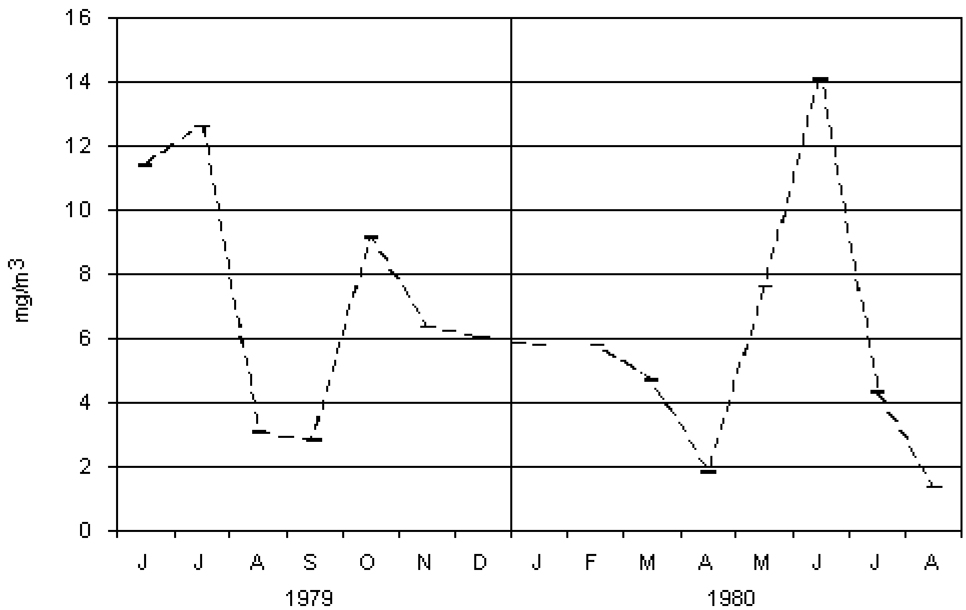
Lake Waccabuc Seasonal Variation in Chlorophyll a Concentration

Figure 2



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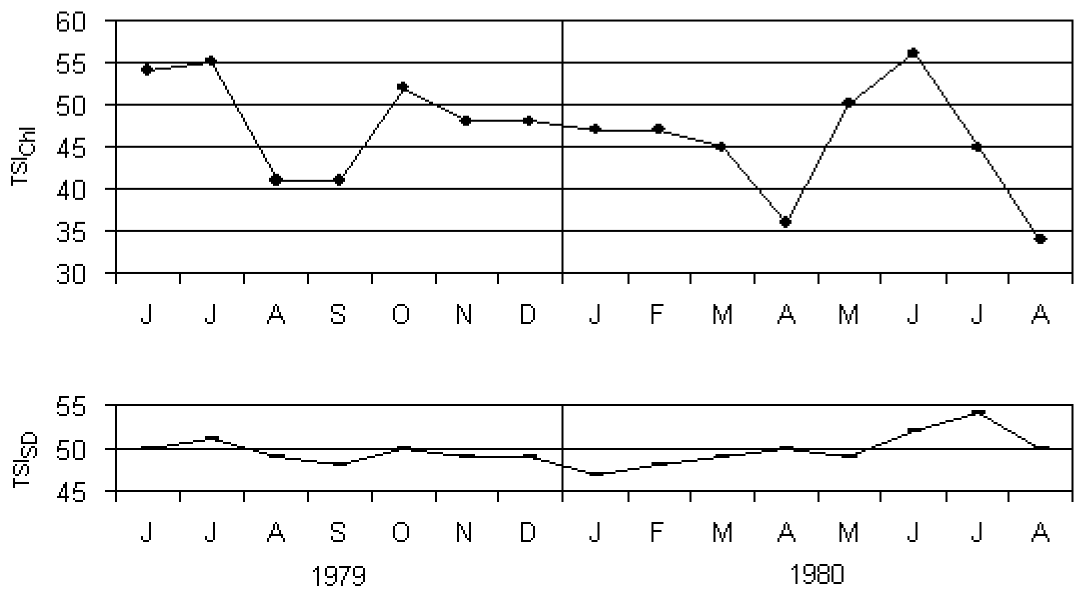
Lake Waccabuc
Seasonal Variation in Trophic State Indicators

(-) Secchi Disk Transparency
(•) Chlorophyll a

Figure 3b

Figure 3a



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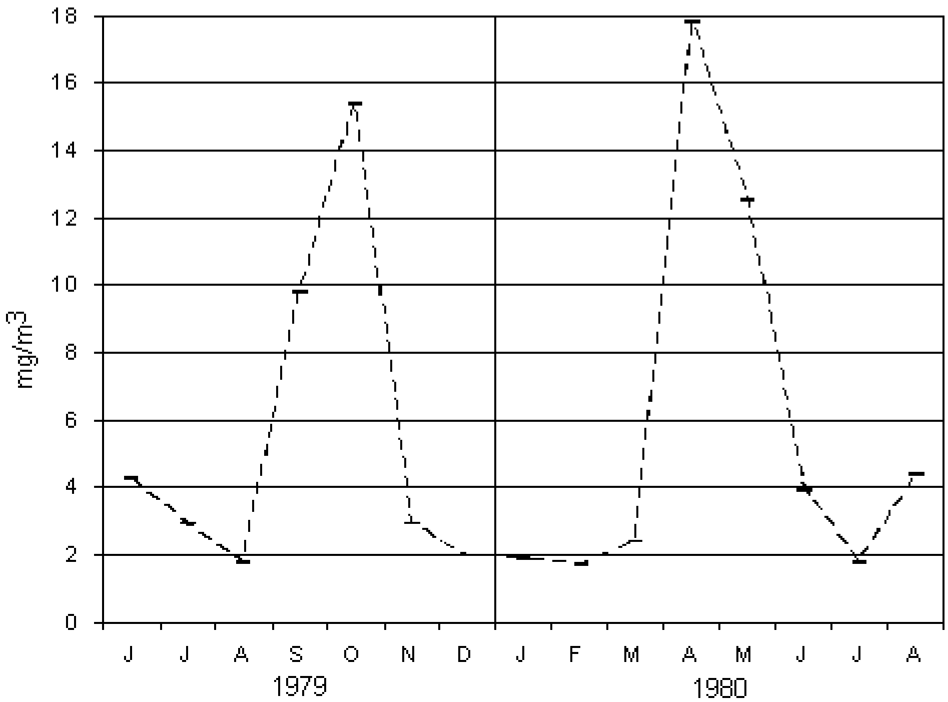
Lake Oscaleta Seasonal Variation in Chlorophyll a Concentration

Figure 4



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Lake Oscaleta
Seasonal Variation in Trophic State Indicators

(-) Secchi Disk Transparency
(•) Chlorophyll a

Figure 5b

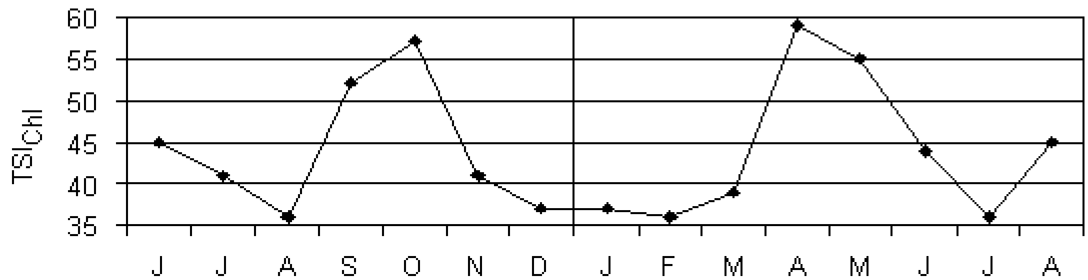

Figure 5a

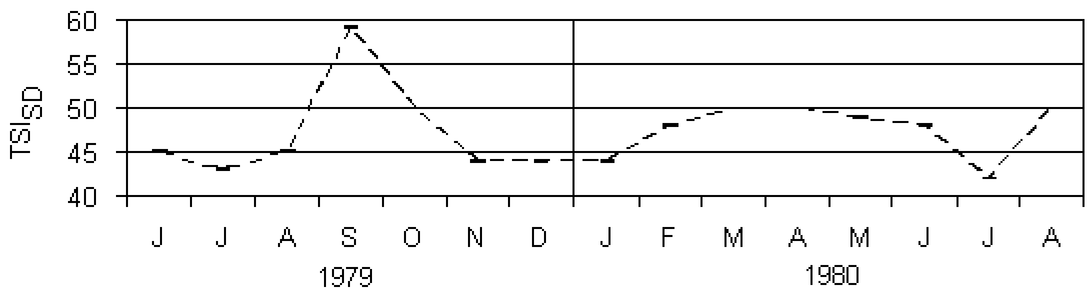

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	Table 1a Lake Waccabuc				Table 1b Lake Oscaleta			
Month	Secchi Disc Trans. (M)	TSI_{sd}	CHLa (mg/m^3)	TSI_{chl}	Secchi Disc Transp. (M)	TSI_{sd}	CHLa (mg/m^3)	TSI_{chl}
June	2.1	50	11.4	54	2.8	45	4.3	45
July	1.8	51	12.6	55	3.3	43	2.9	41
August	2.1	49	3.0	41	2.8	45	1.8	36
September	2.5	48	2.8	41	1.0	59	9.8	52
October	2.1	50	9.1	52	1.9	50	15.4	57
November	2.3	49	6.3	48	3.0	44	2.9	41
December	2.3	49	6.0	48	3.1	44	2.0	37
January	2.4	47	5.8	47	3.0	44	1.9	37
February	2.2	48	5.8	47	2.3	48	1.7	36
March	2.2	49	4.7	45	2.1	50	2.4	39
April	1.9	50	1.8	36	2.0	50	17.8	59
May	2.2	49	7.6	50	2.1	49	12.5	55
June	1.6	52	14.1	56	2.4	48	3.9	44
July	1.5	54	4.3	45	3.3	42	1.8	36
August	1.9	50	1.3	34	2.0	50	4.4	45
Average	2.08	50	6.4	47	2.46	51	5.1	44
Average	minus extreme values			50				49

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Hutchinson (1967) considers surface blooms of blue-green algae as an attribute of a eutrophic lake.

Seasonal variations in TSI_{sd} and TSI_{chl} values for Lake Oscaleta show, as expected, similar fluctuations to those exhibited in Lake Waccabuc. This would seem to indicate that the same conclusion may be drawn for both lakes. There are, however, two deviations in the TSI_{sd}, (Figure 5a) and the TSI_{chl}, (Figure 5b) which require further discussion. Observe that during the fall phytoplankton maximum the TSI_{sd} value, (Figure 5a) peaks in September while the TSI_{chl} value, (Figure 5b) peaks in October... The variation between the indices may be due to sampling error. The only other possible explanation I can offer is that a series of optical density profiles taken during September and October revealed a dense metalimnetic bluegreen algae population. Could the vertical migration of the algae during September and October account for the variation exhibited between the indices? The other significant variation between the TSI_{sd} value, (Figure 5a) and the TSI_{chl} value, (Figure 5b) occurred during the spring maximum of 1980. The variation exhibited represents a doubling in biomass. Observe that the maximum values of TSI_{sd} and TSI_{chl} (Figures 5a, b) occurred at the same time. However, the TSI_{sd} peak, (Figure 5a) is not as high, (50 vs. 59) as the TSI_{chl} peak. The only explanation I can offer for the variation exhibited is that this is the distortion of the index which Carlson (1980) suggests will occur in the uncorrected TSI_{chl} scale. The uncorrected TSI_{chl} mean (Table lb) was 44. When the scale was corrected for extreme values the mean TSI_{chl} was 49, and TSI_{sd} 51.

Conclusion

The data collected from both lakes, classical as well as Carlson's (1977) trophic state index, suggest that the lakes may be considered eutrophic. However, the degree of eutrophy cannot be determined from the small data set. Further study is needed, particularly in Lake Waccabuc, in order to determine if the degree of eutrophy is increasing or decreasing. I caution the reader to use the index only to draw inferences on the lake's trophic state, and not on its water quality.

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