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LAKE CLASSIFICATION IN NOVA SCOTIA FROM PHOSPHORUS LOADING, TRANSPARENCY AND HYPOLIMNETIC OXYGEN CONSUMPTION

PAUL Y. SCHWARTZ AND JOHN K. UNDERWOOD
Nova Scotia Department of the Environment
P.O. Box 2107
Halifax, Nova Scotia
B3J 3B7

Three indices of eutrophication are used to compare effects of urbanization on seven headwater lakes near Halifax, Nova Scotia. Annual (1983) inputs of phosphorus were calculated and compared with lake Secchi transparencies and rates of consumption of hypolimnetic oxygen (Thienemann index). Results from transparency and oxygen deficits were similar but implied greater eutrophication than did the phosphorus index. Brief discussion of some inherent problems of each index is included.

Les auteurs emploient trois indices d'eutophication pour comparer les effets d'urbanization sur sept lacs sources de rivière près d'Halifax, Nouvelle Ecosse. Les apports annuels (1983) de phosphore sont calculés et comparés avec la limpidité "Secchi" des lacs et avec les taux de consommation d'oxygène hypolimnétique (indice de Thienemann). Les resultats des études de limpidité et de déficit en oxygène sont comparables mais indiquent une plus grande eutrophication que l'indice de phosphore. Les auteurs discutent les problèmes associés avec chaque indice.

Introduction

It has been predicted that land from Halifax to Subenacadie will be subjected to intense development pressures before the turn of the century (Anonymous 1981). Consequently, in 1975 a Federal-Provincial water quality agreement was signed to initiate studies of the watershed of the Shubenacadie River. Several of the 30 resultant reports discussed headwater lakes, and listed a variety of concerns ranging from sensitivity to nutrient enrichment (Hart et al. 1978), to accumulations of metals in sediments (Mudroch and Sandilands 1978).

In 1983 several of the headwater lakes were re-evaluated for their sensitivity to watershed disturbances. While the particular concerns focussed on arsenic and mercury in lake sediments, it was recognized that biogeochemical cycles of these metals are intricately linked to oxidation - reduction phenomena which, in turn, are very much a function of biological productivity in lakes. Thus, the present study was conducted in order to assess the current trophic status of seven lakes. The methods of assessment incorporated phosphorus and transparency concepts that were developed by Vollenweider and Kerekes (1980) and rates of consumption of dissolved oxygen, according to Chapra and Dobson (1981).

Methods

Water was sampled in lakes Powder Mill, Third, Three Mile, Perry, Thomas, Fletcher and Muddy Pond and in the connecting streams (Fig. 1) four times during the study period between April and December of 1983. Samples were collected at the deepest point of each lake, except for Perry Lake, where only shore sampling was possible. A two-litre Van Dorn sampler was used to collect samples from 1 m below surface, mid-depths of the water columns and from 1.5 m above the bottoms. Additional mid-column water samples were taken during the months when the lakes were thermally stratified.

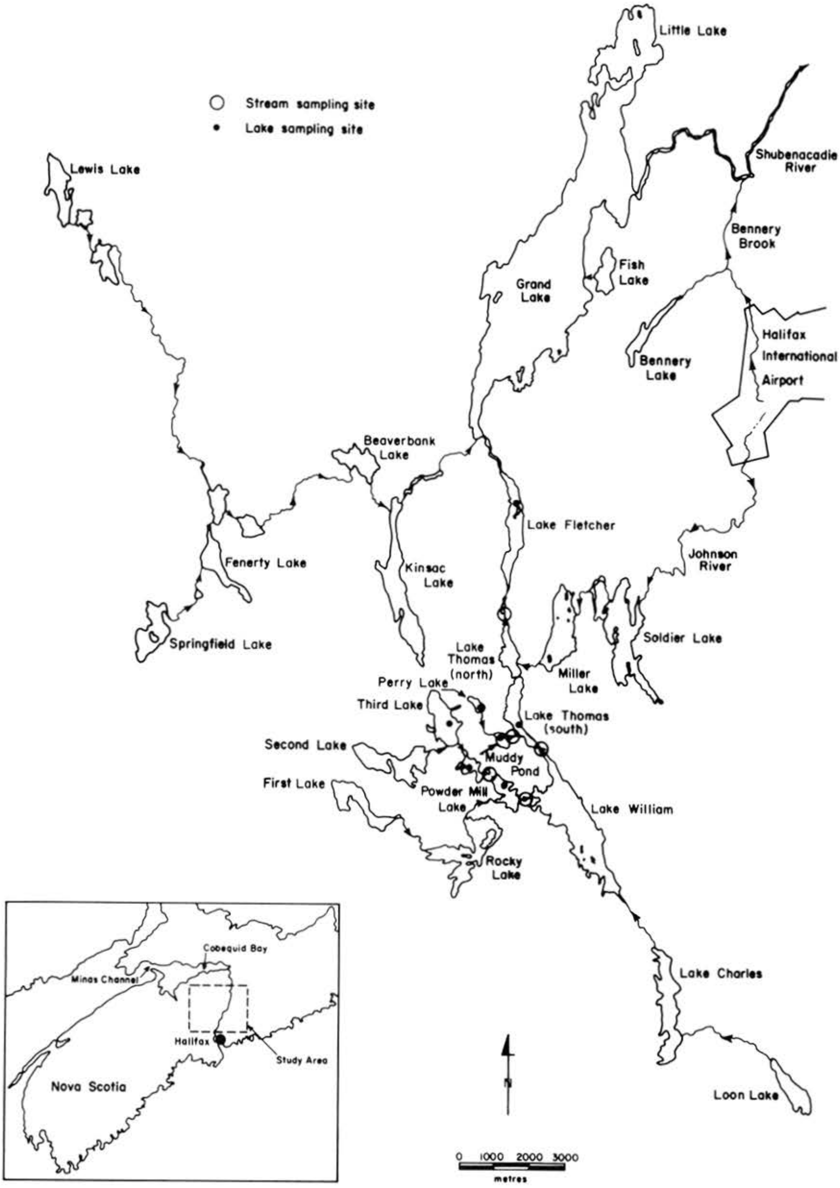

Fig 1 Headwater lakes of the Shubenacadie River.

Dissolved oxygen and temperature was measured in the field on a YSI oxygen meter (model no. 57). A 20 cm Secchi disc with alternating black and white quadrants was used to measure transparency. Phosphorus and nitrogen were analyzed in water samples by the Water Quality Branch, Inland Waters Directorate, in Moncton, N.B.

Morphometric data on most study lakes were acquired from the Shubenacadie Headwaters Environmental Survey (Table 14 in IWD 1974). Morphometric data for Three Mile Lake were obtained from Ogden (1972). The morphometry of Muddy Pond was calculated from bathymetric soundings conducted by Nova Scotia Department of the Environment (NSDOE). Flushing rates for the study lakes were obtained from Ogden (1972) and Johnson (1978). The flushing rate for Muddy Pond was calculated using a runoff coefficient of 0.64 found in the Hydrological Atlas of Canada (CNC/IHD 1978). Watershed areas of Muddy Pond and Perry Lake were calculated from a 1:10,000 orthophoto, with the assumption that the roads within the drainage area contained culverts that would not impede natural drainage. Stream flow measurements were obtained from Water Resources Branch (1984).

Trophic classifications were derived from probability curves for phosphorus and Secchi readings (Vollenweider and Kerekes 1980) and from hypolimnetic oxygen deficits, using the Thienemann trophic scale (1981).

Mean phosphorus concentrations in the lakes were calculated by adjusing for water volumes in each depth. In addition to whole-lake mean values for phosphorus, theoretical input from watershed soils were estimated by rearranging Fig. 6.11 of Vollenweider and Kerekes (1980) as follows:

$$\overline{[P]}_i = \frac{\overline{[P]}_\lambda^{1.22}}{1.55} \cdot (1 + \sqrt{Tw}) \tag{1}$$

Symbols for watershed parameters discussed in the paper follow Vollenweider and Dillon (1974), where possible, such that:

- Ad is the area of the watershed to the outlet of a lake, exclusive of that lake, measured in m^2.
- Ad_i is the area of the immediate watershed surrounding a lake in m^2.
- Ad_c is the total or cumulative drainage area of a lake, measured in m^2. This includes watersheds and lakes upstream of the lake of immediate interest, but excludes the surface area of the study lake.
- q_s is the areal water loading to a lake, measured in $m^3.yr^{-1}$.
- Tw is the residence time of water in years.
- $\overline{[P]}_\lambda$ is the mean annual phosphorus concentration in the lake, measured in $mg.m^{-3}$.
- P_λ is the total amount of phosphorus in the lake, measured in mg.
- $\overline{[P]}_i$ is the mean phosphorus concentration of inlet waters ($mg.m^{-3}$) according to equation 1.
- P_i is the total annual input of phosphorus ($mg.yr^{-1}$) from the watershed according to concentration ($[P]_i$) and volumes of inlet streams.
- L(P) is the annual loading of total phosphorus per unit lake surface area ($mg.m^{-2}.yr^{-1}$).
- Es_i is the phosphorus export coefficient from soils in the immediate watershed area, measured in $mg.m^{-2}.yr^{-1}$ of watershed.
- Es_c is the phosphorus export coefficient from soils in the cumulative watershed area ($mg.m^{-2.yr-1}$).

Results

Phosphorus and Nitrogen Ratios and Classification of Lake Trophic Status

Mean annual total phosphorus $[\bar{P}]$ and total nitrogen $[\bar{N}]$ concentrations are presented in Table I. Third Lake was found to contain the lowest [P] with 3.5 mg.m^{-3}. Concentrations ranged up to 18 mg.m^{-3} while the mean value was 7.6 mg.m^{-3}. Lakes from several areas of the world (OECD lakes) ranged from 3.0 to 750 mg.m^{-3} (mean value of 47.1), while other Nova Scotian lakes are reported to range from 2 to 20 mg.m^{-3} with a mean value of about 8 mg.m^{-3} (Vollenweider and Kerekes 1980; Kerekes 1983).

Total nitrogen concentrations (Table I) varied from 100 to 190 mg.m^{-3} (mean value, 140 mg.m^{-3}) and were less than those reported for OECD lakes (263 to 6095, mean value, 1244 mg.m^{-3}; Vollenweider and Kerekes 1980).

Table I Mean annual concentration of phosphorus and nitrogen and corresponding trophic classifications.

Lake	Mean annual Total P mg.m^{-3}	Mean annual Total N mg.m^{-3}	$\frac{TN}{TP}$	Classification
Third	3.5	140.0	40	Ultra-Oligotrophic
Three Mile	7.0	120.0	17	Oligotrophic
Powder Mill	6.5	120.0	18	Oligotrophic
Perry	4.5	150.0	33	Oligotrophic
Muddy Pond	18.0	190.0	11	Mesotrophic
Thomas	8.0	160.0	20	Oligotrophic
Fletcher	6.0	100.0	16	Oligotrophic

Ratios of [N] : [P] were calculated to investigate if phosphorus was the probable limiting nutrient. Fricker (1981) reported that P is the limiting nutrient when the ratio is greater than 17. Table I indicates that N/P was slightly less than 17 in Muddy Pond and lakes Three Mile and Fletcher. This ratio implies that nitrogen could stimulate production in these lakes. However, more data are required to verify this speculation since concentration of N and P are low relative to the working range of the OECD lakes.

Phosphorus concentrations were compared with probablity curves of Vollenweider and Kerekes (1980) in order to classify the study lakes. Table I indicates that while most of the lakes are oligotrophic, Third Lake would appear to be ultra-oligotrophic, and Muddy Pond is mesotrophic.

Table II Estimation of phosphorus export from watersheds of study lakes.

Lake	Ad_i m^2 x 10^6	Ad_c m^2 x 10^6	q_s m^3 x 10^6	Vol m^3 x 10^6	T(w) year	$[\bar{P}]_\lambda$ mg.m^{-3}
Third	2.89	9.81	31.1	5.53	0.75	3.5
Three Mile	0.78	11.50	3.9	0.324	0.083	7.0
Powder Mill	2.93	26.22	48.4	1.84	0.038	6.5
Muddy Pond	0.29	1.26	1.3	0.032	0.025	18.0
Thomas	7.04	126.79	109.3	4.59	0.042	8.0
Fletcher	14.33	142.25	135.4	3.79	0.028	6.0

Hart (1979) undertook an environmental assessment of the surface waters of five lakes (all included in this study), in the vicinity of a proposed Industrial Park near Third Lake. His study provided some contemporary baseline data, as well as possible effects which the proposed development could have on the surface waters in the area. Sampling was carried out in the Spring, a time when phosphorus concentrations have been linked to the rate of algal growth during the following summer (Vollenweider and Kerekes 1980). Phosphorus concentration in three of the five lakes Hart studied were similar to those found in this study. Hart concluded that surface waters in the area were of high quality.

If sewage systems contributed significantly to the nutrient budget of a lake, a relationship between phosphorus and nitrogen would be expected (Vallentyne 1974). Table I shows that a greater variation exists for mean annual phosphorus concentrations between lakes than for nitrogen. Thus it is concluded that there is little evidence of phosphorus input through sewage systems.

Whole Lake Phosphorus Concentrations and Estimates of Phosphorus Loadings from Watersheds

In order to determine the input of total phosphorus from the various watersheds, a phosphorus budget was developed based on the mean phosphorus concentrations of inlet waters, calculated according to equation 1. It is necessary to consider phosphorus concentrations of inlet waters in addition to the total lake phosphorus concentrations, as use of inlet values allows for accommodation of phosphorus that is lost through sedimentation, macrophyte assimilation, and flow through the lakes. Table II shows the calculated export coefficients of phosphorus from both the immediate and cumulative watersheds of the study lakes. The export coefficients Es$_i$ and Es$_c$ are calculated by dividing the total input of phosphorus (P$_i$) from the watershed, by the areas of the immediate (Ad$_i$) and cumulative (Ad$_c$) watersheds respectively. The export coefficients are calculated from column 1, 2, and 9 in Table II.

The phosphorus export coefficient (Es$_i$), calculated for the immediate watershed area of the lakes ranged from 40.5 mg.m^{-2}.yr^{-1} for Three Mile Lake watershed to 138.2 mg.m^{-2}.yr^{-1} for Lake Thomas watershed. The arithmetic mean phosphorus export coefficient was found to be 84.5 mg.m^{-2}.yr^{-1}. Lakes Thomas, Powder Mill, and Muddy Pond show export coefficients greater than the calculated mean.

Estimates for the phosphorus export coefficient (Es$_c$), based on the cumulative watershed areas of study lakes, ranged from 2.8 mg.m^{-2}.yr^{-1} for Three Mile Lake to 23.7 mg.m^{-2}.yr^{-1} for Muddy Pond; the mean being 10.7 mg.m^{-2}.yr^{-1}. Muddy Pond, Third and Powder Mill lakes all showed phosphorus export coefficients greater than the mean. Three Mile Lake exports the least amount of total phosphorus per unit area of both immediate and cumulative watersheds.

Abbreviations explained in Methods.

			— per annum —		
P_λ mg x 10^6	$\overline{[P]}_i$ mg.m^{-3}	P_i mg x 10^6	L[P] mg.m^{-2}	Es$_i$ mg.m^{-2}	Es$_c$ mg.m^{-2}
27.1	3.8	155.5	187.4	53.8	15.9
2.9	8.1	31.6	195.2	40.5	2.8
14.4	6.9	334.0	786.0	113.9	12.7
0.67	23.0	29.9	598.3	103.1	23.7
44.1	8.9	972.8	858.5	138.2	7.7
26.5	6.1	825.9	784.9	57.6	5.8

Total phosphorus loadings (L(P)) were also calculated in order to compare them with the minimum, maximum and geometric mean values listed in the OECD report (Vollenweider and Kerekes 1980). Annual loadings (P_i in Table II divided by lake surface areas) ranged from 187 mg.m^{-2}.yr^{-1} for Third Lake to 858 mg.m^{-2}.yr^{-1} for Lake Thomas, with a geometrical mean of 475 mg.m^{-2}.yr^{-1} for all study lakes. The minimum OECD L(P) value was 17 mg.m^{-2}.yr^{-1}, with a geometrical mean of 1200 mg.m^{-2}.yr^{-1}. Kerekes (1983), using the OECD phosphorus relationships, found a L(P) value of 133 mg.m^{-2}.yr^{-1} for Freshwater Lake in Cape Breton.

Estimates of Phosphorus Load to Lakes from Streams

Table II lists whole-lake phosphorus concentrations which are used with equation 1 to estimate inlet concentrations and export coefficients. However, five streams interconnecting the study lakes were sampled during the study period, and daily discharge readings were taken at four of them. These measurements have provided an opportunity to compare the total phosphorus loading from the cumulative watershed areas calculated from estimates of inlet concentrations (last column in Table II) to that of the whole lake phosphorus measurements (last column in Table III).

Based on the mean total phosphorus concentrations and average discharges measured for the inlet streams (column 1 and 2 respectively in Table III), the annual total phosphorus loading to three downstream lakes was calculated. This calculation was performed by multiplying the average total phosphorus concentration measured in the streams by the average discharge rate. The result was an estimate of the amount of phosphorus loading via the streams, measured in mg per second (column 3, Table III), which was used to calculate the total annual phosphorus loading in mg.m^{-2}.yr^{-1} of lake area (column 4 of Table III). In order to calculate the total phosphorus input from the immediate upstream watershed area the immediate upstream watershed area including the lake was divided by the total annual loading from the streams (column 5, Table III). The calculation can be carried further to ascertain the total phosphorus loading per unit of cumulative upstream watershed area (column 6, Table III). The lowest annual total phosphorus loading, calculated per unit immediate watershed area (Es_i), was from Lake William watershed to Lake Thomas, (15 mg.m^{-2}.yr^{-1}). The

Table III Estimation of phosphorus export via measured concentrations in inlet waters.

Stream	Mean TP conc. mg.m^{-3}	Average discharge m^3.s^{-1}	Transp. TP; mg.s^{-1}	Annual TP loading mg.m^{-2}.yr^{-1} on lake from stream measurements
Power Mill to William	8.75	0.740	6.47	64.8 on William (204.1 x 10^{6}mg)
William to Thomas	7.4	1.99	14.70	409.8 on Thomas (464.4 x 10^{6}mg)
Muddy Pond to Thomas	15.4	0.052	0.80	22.2 on Thomas (25.1 x 10^{6}mg)
Thomas to Fletcher	5.2	3.76	21.1	631.1 on Fletcher (664.0 x 10^{6}mg)

highest was 94 mg.m^{-2}.yr^{-1} calculated for phosphorus loading from Lake Thomas watershed to Lake Fletcher. The mean phosphorus contribution from the immediate watersheds of the four upstream lakes was 66 mg.m^{-2}.yr^{-1}. The total phosphorus loading, calculated per unit cumulative watershed (Es$_c$) ranged from 5.2 mg.m^{-2}.yr^{-1}, contributed by the total drainage area of Lake Thomas, to 19.2 mg.m^{-2}.yr^{-1} contributed by the total drainage area of Muddy Pond. The mean contribution from cumulative watersheds was 9.6 mg.m^{-2}.yr^{-1}.

Comparisons of the export coefficients per cumulative watershed area calculated using whole lake phosphorus concentrations and stream concentration are listed as follows. The export coefficient of phosphorus (Es$_c$) calculated for the Lake Thomas watershed using whole-lake concentrations was 5.8 mg.m^{-2}.yr^{-1} and 5.2 mg.m^{-2}.yr^{-1} using stream concentrations. For the Muddy Pond watershed, the Es$_c$ calculated from whole-lake concentrations was 23.7 mg.m^{-2}.yr^{-1} and 19.2 mg.m^{-2}.yr^{-1} based on stream concentrations. Lake William watershed had Es$_c$ of 7.7 mg.m^{-2}.yr^{-1} calculated from whole-lake concentrations and 6.1 mg.m^{-2}.yr^{-1} based on stream concentrations. In the case of Powder Mill Lake watershed the Es$_c$ calculated from whole-lake concentrations was 12.7 mg.m^{-2}.yr^{-1} and 7.7 mg.m^{-2}.yr^{-1} based on stream concentrations.

Different figures calculated for Es$_c$ using whole-lake concentrations as opposed to stream concentrations, result from the fact that because of fluctuating stream flows, they are more instantaneous and therefore variable indicators of watershed conditions. Lakes, however, might be considered as integrators of fluctuations over time because their larger volumes tend to dampen fluctuations in inlet waters. Despite modest differences between measured inputs of phosphorus via streams and estimates produced from whole-lake concentrations according to Vollenweider and Kerekes (1980) we conclude that equation (1) is applicable to the watersheds we examined.

Oxygen Content of Lakes

Oxygen concentrations were influenced by stratification in all study lakes. This is evident from the isopleths for oxygen saturation (Figures 2 to 7). Third Lake, Three Mile Lake and Muddy Pond, showed hypolimnetic oxygen deficits of up to 70% less

TP discharge per unit immediate watershed area (including lake) Es$_i$; mg.m^{-2}.yr^{-1}	TP discharge per unit cumulative watershed area Es$_c$; mg.m^{-2}.yr^{-1}
P.M. W'shed to Wm.	
69.66 from	7.7
P.M. W'shed (2.93 km^2)	P.M. W'shed + (26.6 km^2)
Wm. W'shed to Th.	
15.00 from	6.1
Wm. W'shed (30.95 km^2)	Wm. W'shed + (76 km^2)
M.P. W'shed to Th.	
86.55 from	19.2
M.P. W'shed (.29 km^2)	M.P. W'shed + (2.3 km^2)
Th. W'shed to Fl.	
94.32 from	5.2
Th. W'shed (7.04 km^2)	Th. W'shed + (128 km^2)

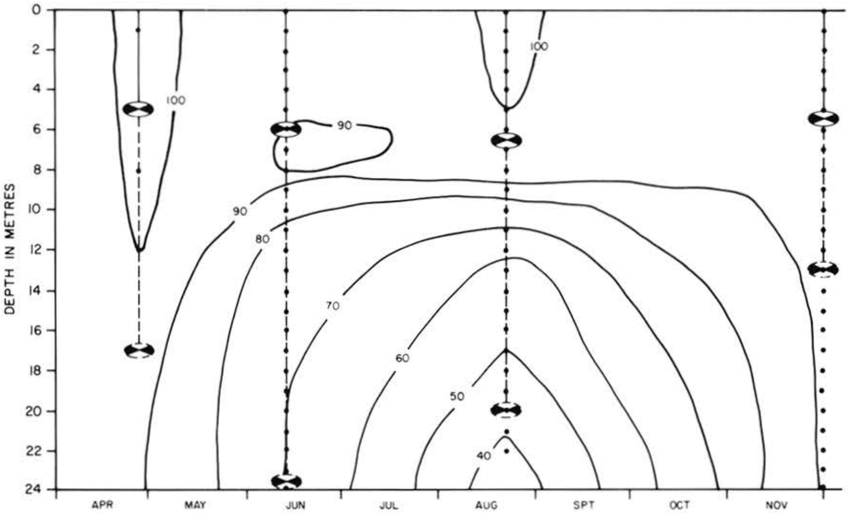

Fig 2 Third Lake 1983, isopleths for % oxygen saturation and actual (—) and theoretical (--) Secchi readings.

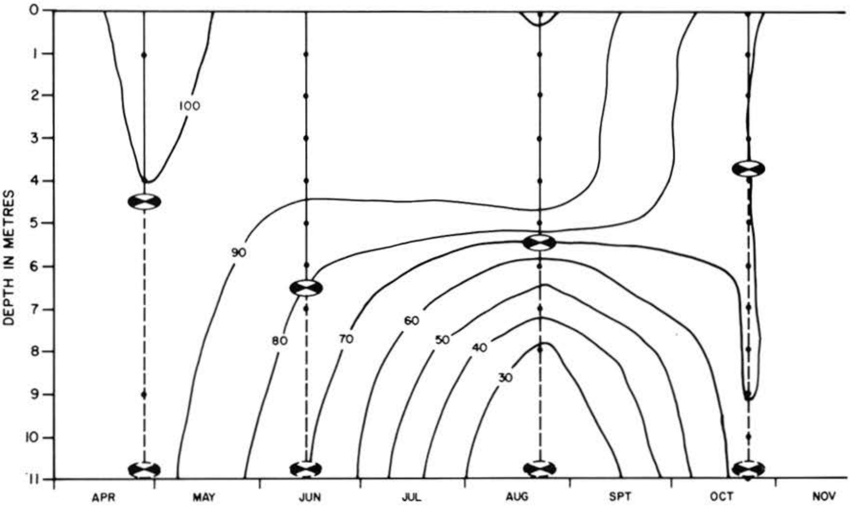

Fig 3 Three Mile Lake 1983, isopleths for % oxygen saturation and actual (—) and theoretical (--) Secchi readings.

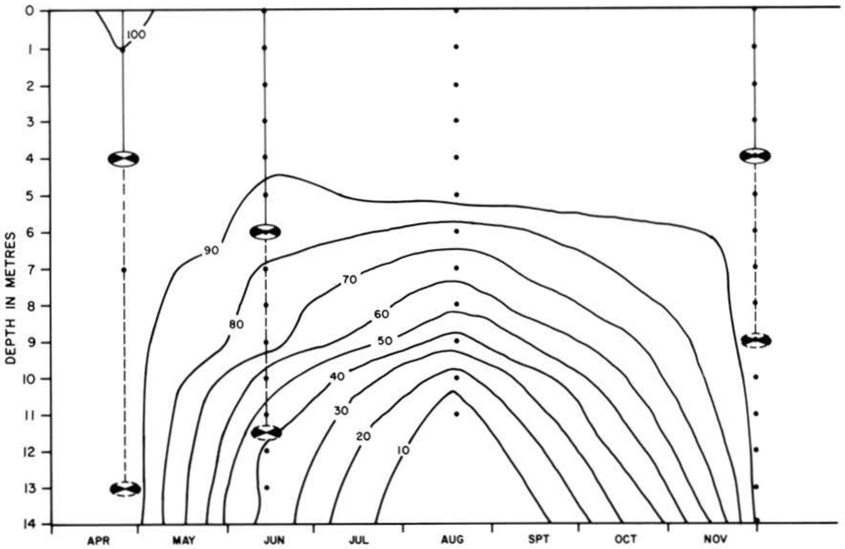

Fig 4 Powder Mill Lake 1983, isopleths for % oxygen saturation and actual (—) and theoretical (--) Secchi readings.

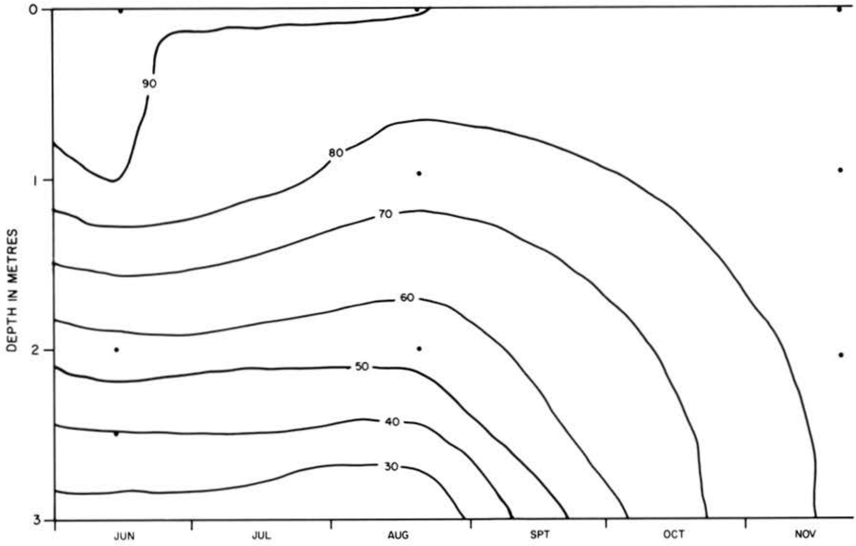

Fig 5 Muddy Pond 1983, isopleths for % oxygen saturation and actual (—) and theoretical (--) Secchi readings.

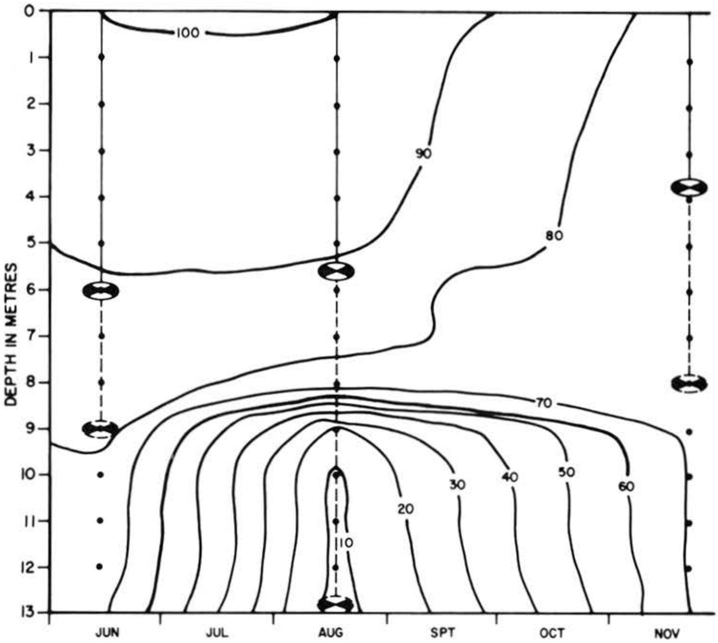

Fig 6 Lake Thomas 1983, isopleths for % oxygen saturation and actual (—) and theoretical (--) Secchi readings.

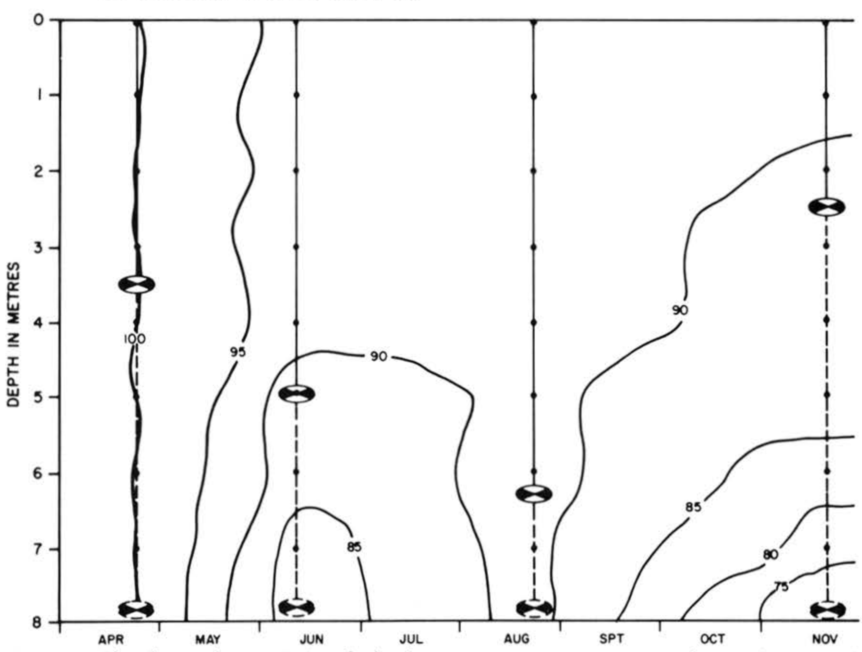

Fig 7 Fletcher Lake 1983, isopleths for % oxygen saturation and actual (—) and theoretical (--) Secchi readings.

than saturation. However, all lakes were above the threshold of 10% oxygen saturation, when a variety of chemical and biological process begin to display adverse effects (Chapra and Dobson 1981). The rapid flushing rate of Fletcher Lake (35 times per annum) kept oxygen saturation greater than 75% during the entire study period. Lakes Powder Mill and Thomas showed hypolimnetic oxygen deficits to as low as 10% of saturation during the summer months.

Thienemann Classification of Lake Trophic Status

Thienemann classification of lake trophic status is based on the oxygen depletion rates in the hypolimnion, initial oxygen concentrations at Spring turnover and the duration of thermal stratification (Chapra and Dobson 1981).

The Thienemann index was calculated for lakes Powder Mill, Thomas, and Third. The first two lakes were found to have low levels of oxygen in the hypolimnion during mid-summer.

The Thienemann index, TI_T can be expressed as:

$$TI_T = 11.1 \times \frac{Dv\, t_s}{C_i} \tag{2}$$

where Dv is the volumetric oxygen depletion rate expressed in $mg.L^{-1}$ per month, t_s is the duration of the stratified period in months, and C_i is the oxygen concentration at the onset of stratification expressed in $mg.L^{-1}$ (Chapra and Dobson 1981). A Thienemann index between 0 and 5 indicates oligotrophy, between 5 and 10 mesotrophy and above 10 eutrophy. The duration of thermal stratification in the lakes was estimated at five months. The sampling schedule did not permit a more precise delineation of autumn turnover in the study lakes.

According to Thienemann index both Third and Powder Mill Lakes are considered mesotrophic, Lake Thomas eutrophic (Table IV), its Thienemann index being similar to that calculated for Central Erie (Chapra and Dobson 1981). The classification of the study lakes by the Thienemann index placed the lakes in a higher trophic status than the OECD phosphorus classification. This difference could be generated by the over-estimation of the stratification period for the study lakes, although basin morphometry also influences oxygen depletion rates (Hutchinson 1957).

Table IV Nova Scotian and Great Lakes data relevant to oxygen depletion along with calculated values of the Thienemann index.

Lake or basin	Thickness of Hypolinnion (m)	Volumetric oxygen depletion rate ($mg.L^{-1}.mo^{-1}$)	Initial oxygen con. ($mg.L^{-1}$)	Duration* of stratification (mo)	Thienemann** index, TI_T
Third	15	1.3	12	5*	6.0
Powder Mill	5	1.46	11	5*	7.4
Thomas	5	2.6	11*	5*	13.1
Superior	134	0.14	13	3.5	0.4
Huron	50	0.24	13	4.0	0.8
Central Erie	3.9	3.2	11	4.0	12.9
Eastern Erie	14.7	1.73	12	4.5	7.2
Ontario	71	0.33	13	4.5	1.3

* Estimated

** 0 - 5 oligotrophic, 5 - 10 mesotrophic, 10+ eutrophic

Trophic Classification by Lake Transparency

Actual and theoretical Secchi depth are presented in Fig. 2, 3, 4, 6, and 7. The theoretical Secchi depth was obtained by transposing point locations on phosphorus probability curves to Secchi probability curves (Vollenweider and Kerekes 1980). Theoretical Secchi depths were then interpolated from the abcissal axis on the Secchi curve. Mean annual Secchi depths were calculated from the four readings taken at each lake during the study period, except for Lakes Powder Mill and Thomas where only three readings were taken. The average was then used to classify each lake based on Secchi disc transparency.

The average Secchi depth for study lakes was 5 m, which was greater than the 3 m average found for a study of 288 lakes in the province (Underwood unpublished data). However, the actual Secchi depths were always lower than the theoretical value, and based on Secchi disc transparency, all study lakes were classified mesotrophic.

Table V Comparison of trophic classifications based on phosphorus, secchi and oxygen.

Lake Name	Trophic classification based on phosphorus	Trophic classification based on Secchi	Trophic classification based on Thienemann's oxygen index
Third Lake	Ultra-oligotrophic	Mesotrophic	Mesotrophic
Three Mile	Oligotrophic	Mesotrophic	
Powder Mill	Oligotrophic	Mesotrophic	Mesotrophic
Perry	Oligotrophic		
Muddy Pond	Mesotrophic		
Thomas	Oligotrophic	Mesotrophic	Eutrophic
Fletcher	Oligotrophic	Mesotrophic	

Discussion

Comparison of Trophic Indices Used

The trophic states of the studied lakes were determined by three techniques: mean annual phosphorus concentrations; Secchi disc transparencies; and hypolimnetic oxygen depletion rates. The results of the comparison are shown in Table V. Classifications of trophic states of the lakes based on Secchi disc transparency and oxygen depletion are similar but result in higher estimates of eutrophy than classifications based on phosphorus concentrations.

Phosphorus concentrations have been widely used to estimate the degree of eutrophication experienced in a water body, but are complex and expensive compared to the other limnological measurements used in this study. One drawback of the phosphorus probability index is that it does not fully accommodate differences in sizes of hypolimnions, and consequent relative demands on available oxygen supplies in deeper waters. This could influence both the availability of cool mid-summer refugia for poikilotherms, and recycling of toxic metals from sediments.

Measurement of Secchi disc transparency in order to ascertain trophic conditions, although not as sound as the phosphorus method, produced results that were comparable to the calculated Thienemann index. This method is not only simple but inexpensive, requiring only the use of a boat and a Secchi disc. Since the average Secchi disc reading is used to assign a trophic status, frequent readings are necessary during the study period. Factors that affect turbidity other than plankton growth, such as suspended material due to siltation from high runoff, would alter the findings. Highly colored water would also impair reliability of the Secchi index.

Determination of hypolimnetic oxygen depletion rates, provides another method of trophic classification, while remaining relatively simple and inexpensive. Delineation of the stratification period plays a very important role in arriving at the proper index, and it is necessary to take oxygen measurements with almost the same frequency as samples for phosphate analysis. For example, if a stratification period of 3 months is assumed for Third Lake, the resultant Thienemann index is 3.6 which is the oligotrophic range. A further note of caution is that oxygen depletion can be misleading if the water color is greater than about 10. Humic substances contribute to oxygen depletion in the hypolimnion, which can be incorrectly interpreted as oxygen depletion resulting from organic matter produced within the lake (Kerekes 1974). Color was low in Third, and Thomas lakes, but exceeded 35 in Muddy Pond.

Another important consideration in using the Thienemann index is lake morphology, as this controls the ratio of the volume of the epilimnion to the hypolimnion. The bottom waters of a deep stratified lake would therefore have a greater supply of oxygen than those of a shallower stratified lake (Hutchinson 1957).

As we had no chlorophyll data for comparison, it is inappropriate to recommend one of the three indices as best choice. But even if that measure of production of autochthonous carbon were available it fails to account for oxygen stress resulting from inputs of allochthonous carbon. Perhaps the most satisfactory application of indices would be to develop a method of averaging them in order to produce a type of composite index (cf. Carlson 1977). The use of a single index could result in misinterpretation of water quality in our local lakes.

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