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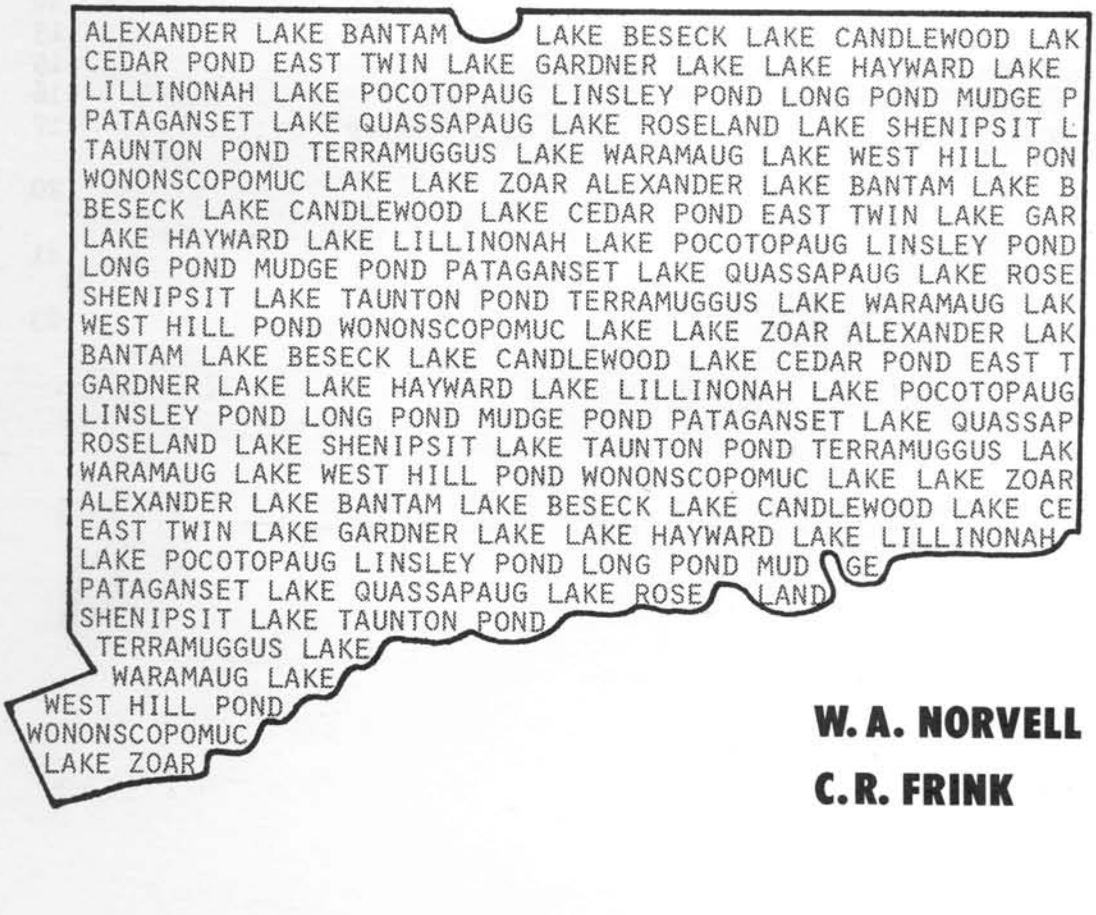
WATER CHEMISTRY AND FERTILITY OF TWENTY-THREE CONNECTICUT LAKES



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WATER CHEMISTRY AND FERTILITY OF TWENTY-THREE CONNECTICUT LAKES

W. A. Norvell and C. R. Frink

Connecticut's lakes are a valuable natural resource sought increasingly for recreation and aesthetic pleasure. Unfortunately, many lakes in our state and the world-over are undergoing accelerated eutrophication because of human activities. To preserve or improve the condition of our lakes we must first know which are declining in quality, how rapidly, and what factors are responsible for this decline.

Eutrophication is a related group of changes in the condition of a water body, including increases in the growth of aquatic plants and in the availability of plant nutrients. As such, the term describes a mixture of causes and effects that are inextricably linked in both popular and scientific thought.

Eutrophic lakes are usually rich in plant nutrients, highly productive of algae or other aquatic plants, deficient in oxygen near the bottom, low in transparency, and frequently shallow. Algal blooms and excessive weed growth frequently create nuisance conditions in eutrophic lakes. At the other extreme are oligotrophic lakes, which are usually poor in plant nutrients, low in productivity of aquatic plants, well-supplied with oxygen at most depths, clear, and frequently deep. Between these extremes are mesotrophic lakes with intermediate characteristics. Although each trophic category encompasses a range of characteristics, these categories provide valuable integrated assessments of lake fertility and productivity.

Our report summarizes a study of the water chemistry of 23 Connecticut lakes carried out during the fall of 1973 and the spring and summer of 1974. The main objectives were three:

- To evaluate the current condition of the lakes, especially with respect to the plant nutrients nitrogen and phosphorus.
- To know which lakes had changed significantly during the last few decades.
- To understand more quantitatively the factors contributing to eutrophication of Connecticut lakes.

The 23 lakes are distributed throughout the state and provide a wide and representative range of water and watershed characteristics. Most characteristics including area, depth, fertility, transparency, and chlorophyll vary among the lakes by 10 to 100-fold. In addition, most of these lakes were surveyed in 1937-39 by the Lake and Pond Survey Unit of the (Connecticut) State Board of Fisheries and Game (Deevey, 1940; Deevey and Bishop, 1942), permitting comparisons between conditions measured 35 years apart.

METHODS

Locations of the 23 lakes are shown in Fig. 1. Three (East Twin, Mudge, and Wononscopomuc) are in the limestone region; six (Bantam, Candlewood, Quassapaug, Taunton, Waramaug, West Hill) are in the western highlands; two (Lillinonah and Zoar) are in the Housatonic Valley; three (Beseck, Cedar, and Linsley) are in the central or coastal lowlands; and, nine (Alexander, Gardner, Hayward, Long, Pataganset, Pocotopaug, Roseland, Shenipsit, and Terramuggus) are in the eastern highlands. Four of these (Beseck, Candlewood, Lillinonah, and Zoar) are artificial; the latter two are major impoundments of the Housatonic River. All the other lakes are natural although the levels of many have been raised by small dams (State Board of Fisheries and Game, 1959).

Water samples were collected during the fall of 1973 and the spring and summer of 1974. Sixteen or more surface samples were taken at each visit. More surface samples (20 to 56) were collected from larger or morphologically complex lakes. In the fall, spring, and early summer, surface samples were taken from a depth of about 20 cm while, during the remainder of the summer, surface samples were taken with a 2 or 3 m P.V.C. pipe. Samples at greater depths were obtained with a non-metallic Kemmerer sampler at intervals of 2 to 5 m at two or more sites in the deepest parts of each lake. All samples were placed in one liter polyethylene bottles, which were packed in ice in insulated chests. Dissolved oxygen and temperature were measured *in situ* at several depths at the deepest site with an oxygen-temperature probe (YSI 54RC). Transparency was measured at two or more sites with a 20 cm Secchi disk.

In the laboratory, samples from the same depth within a lake were combined because we found such samples to be reasonably uniform. A portion was frozen and saved for analysis for total phosphorus (P) and total nitrogen (N). Another portion was filtered through a well-rinsed 0.45 μm filter (Millipore HAWP) and then frozen and saved for analysis of soluble constituents. During the summer, a 100 to 500 ml aliquot of surface samples was filtered with a little $MgCO_3$, and the plant material collected was extracted with 90% acetone for chlorophyll-a analysis (Golterman, 1969). Water color (generally brownish, from dissolved organic compounds) was measured by comparing centrifuged aliquots with a graded series of chloroplatinate solutions. A further portion of the sample was refrigerated overnight and analyzed the following day for bicarbonate alkalinity and conductivity.

Later, the frozen samples were thawed and acidified with H_2SO_4. Chloride was measured in filtered samples by titration with $AgNO_3$ (Standard Methods, 1971), and Ca, Mg, Na, and K were determined by atomic absorption spectrophotometry. Concentrations of these elements were expressed as milliequivalents per liter (meq/l).

Soluble P (inorganic and organic) was measured in 50 or 75 ml aliquots of filtered samples by the method of Murphy & Riley (1962) following persulfate

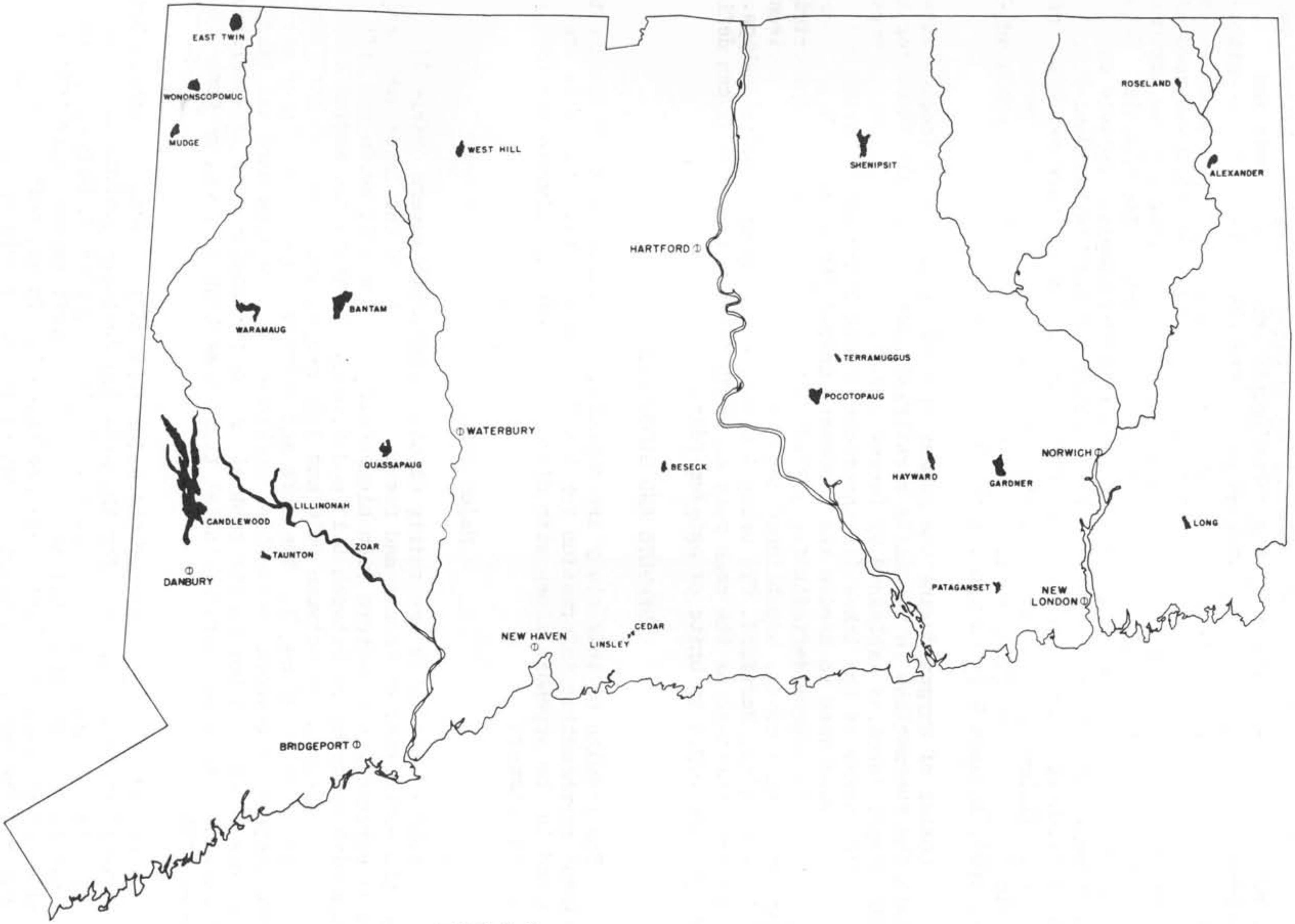


FIGURE 1. Locations of the 23 lakes.

digestion (Gales, Julian, and Kroner, 1966; Harwood, van Steenderen, and Kuhn, 1969). Total P was determined similarly on unfiltered samples. Nitrate was measured in filtered samples by the chromotropic acid method (West and Ramachandran, 1966). Ammonia was measured by the phenol-hypochlorite-nitroprusside method (Wetherburn, 1967). Soluble Kjeldahl-N (NH_4 + organic N) was measured in 250 to 350 ml aliquots of filtered sample. Selenium was used as the catalyst (Kammerer et al., 1967) and N released by digestion was determined as NH_4 in the diluted neutralized digest using the method for ammonia. Total Kjeldahl-N was determined similarly on an unfiltered sample. Soluble and total N were calculated as the sum of nitrate-N and soluble Kjeldahl-N or total Kjeldahl-N, respectively. Concentrations of N and P were expressed as parts per billion (ppb) of the element. Analytical uncertainties were: soluble P (± 4 ppb or 15%), total P (± 4 ppb or 15%), NO_3-N (± 40 ppb), NH_4-N (± 20 ppb), soluble N (± 60 ppb), total N (± 60 ppb).

Losses of oxygen during the summer from the hypolimnion (cooler water beneath the thermocline in thermally stratified lakes) were calculated for 11 of the deeper lakes as explained by Deevey (1940). Revised bathymetric maps and surface areas of the lakes ((Connecticut) State Board of Fisheries and Game, 1959) were used to derive the necessary area-depth relationships. For comparison, the oxygen deficits for 1937-39 were recalculated from the original oxygen profiles (Deevey, unpublished data on file with Department of Environmental Protection, Hartford, CT) using the revised area-depth relationships. Results are expressed as the mean rate at which the hypolimnetic oxygen deficit developed (ΔH.O.D.) in units of $\mu g O_2/cm^2/day$.

RESULTS AND DISCUSSION

The results of this study are summarized in Tables 1 and 2 along with pertinent morphometric information for the 23 lakes. Detailed results are presented in the appendix along with dissolved oxygen and temperature data for mid or late summer.

Major Ions

Most of the lakes are fairly dilute bicarbonate waters (Table 1). Using the categories of Brooks and Deevey (1963), six of the lakes are classified as extremely soft waters with bicarbonate <0.17 meq/l; seven are soft waters with bicarbonate between 0.17 and 0.46 meq/l; three are medium hard waters with bicarbonate between 0.46 and 1.38 meq/l; and seven are hard waters with bicarbonate >1.38 meq/l. The soft and extremely soft water lakes are in the eastern or western crystalline highlands. The medium hard and hard waters are located either in the central or coastal lowlands or in watersheds that include limestone-bearing glacial till, limestone bedrock, or both (Deevey, 1940).

The relative abundance of the major ions varies among the lakes, but the variability is not unusual for the Atlantic drainage systems of North America (Livingston, 1963). Bicarbonate is the major anion in most of the lakes but in the extremely soft and a few of the soft waters other anions, chloride and presumably sulfate, are predominant. In all soft and extremely soft waters, the relative concentrations of the major cations are $Ca \gtrless Na > Mg > K$,

TABLE 1. Selected physical and chemical characteristics of 23 lakes.

					Mean Values for Fall 1973 through Summer 1974								
Lake	Surface area[a]	Watershed / Lake area	Mean[a] depth	Max.[a] depth	Transparency	Color[b]	Conductivity[c]	Alkalinity	Calcium	Magnesium	Sodium	Potassium	Chloride
	ha		m			ppm	µmho/cm	meq/l					
Alexander	76.1	4.0	7.38	16.2	7.5	7	27	0.12	0.16	0.05	0.13	0.03	0.06
Bantam	366.4	23.2	4.36	7.6	2.1	20	96	0.61	0.45	0.32	0.27	0.03	0.20
Beseck	47.8	11.2	3.48	7.3	2.5	10	103	0.53	0.51	0.29	0.32	0.02	0.20
Candlewood	2195.0	4.8	8.93	25.9	5.2	5	130	0.94	0.72	0.41	0.28	0.03	0.20
Cedar	8.7	14.1	3.32	5.2	1.3	15	237	1.76	0.80	0.48	1.27	0.03	0.23
East Twin	224.9	4.7	9.88	24.4	5.5	9	219	2.11	1.43	0.88	0.12	0.04	0.08
Gardner	194.7	7.3	4.18	13.1	3.8	15	50	0.20	0.18	0.07	0.27	0.02	0.17
Hayward	79.6	8.0	3.05	11.3	3.8	15	39	0.15	0.12	0.08	0.19	0.03	0.06
Lillinonah	769.5	470.0	11.80	30.5	2.2	10	184	1.54	1.21	0.71	0.39	0.04	0.23
Linsley	9.3	25.0	6.25	13.4	2.0	15	241	1.61	0.90	0.51	0.95	0.03	0.28
Long	39.9	29.6	4.63	22.0	3.7	10	51	0.19	0.19	0.10	0.22	0.02	0.14
Mudge	80.4	36.6	6.71	10.7	3.5	7	262	2.63	1.43	1.38	0.18	0.04	0.14
Pataganset	49.2	20.3	3.78	10.7	2.9	25	63	0.19	0.11	0.09	0.24	0.02	0.11
Pocotopaug	204.7	5.6	3.45	11.6	3.6	11	57	0.14	0.19	0.09	0.27	0.03	0.20
Quassapaug	108.4	4.3	8.69	19.8	5.0	3	46	0.13	0.17	0.11	0.18	0.03	0.17
Roseland	35.2	221.0	3.05	6.1	2.5	20	73	0.45	0.47	0.14	0.22	0.06	0.17
Shenipsit	209.1	20.1	9.15	20.7	3.4	15	52	0.16	0.16	0.10	0.23	0.03	0.14
Taunton	50.6	6.7	6.55	9.0	3.8	10	106	0.45	0.44	0.23	0.37	0.03	0.34
Terramuggus	33.2	4.1	6.52	13.1	5.3	7	86	0.23	0.29	0.16	0.48	0.04	0.35
Waramaug	272.1	13.4	6.74	12.2	2.4	10	66	0.39	0.31	0.19	0.25	0.03	0.14
West Hill	95.3	3.5	9.70	18.0	6.5	5	24	0.14	0.15	0.07	0.12	0.02	0.06
Wononscopomuc	141.0	4.7	11.07	32.9	5.2	5	217	2.19	1.12	1.23	0.25	0.04	0.23
Zoar	394.8	1014.0	7.50	22.9	1.9	12	217	1.76	1.14	0.68	0.38	0.04	0.28

[a] (Connecticut) State Board of Fisheries and Game, 1959.
[b] Results for summer 1974 only
[c] Results for spring and summer only for most lakes.

with Na dominant in 8 of the 13. In the medium hard waters Ca and Mg are more abundant and the relative concentrations are $Ca>Mg\gtrless Na\gg K$. The seven hard water lakes are both different from the above and more variable among themselves. In the two small coastal lakes (Linsley and Cedar), concentrations of Na are high with $Na>Ca>Mg\gg K$. The other five hard water lakes receive drainage from regions rich in dolomitic limestone and are enriched in Mg as well as in Ca so that $Ca\gtrless Mg>Na\gg K$.

Fertility, Productivity, and Trophic Condition

Many interacting characteristics influence the fertility, productivity, and trophic status of lakes (Hooper, 1969; Vollenweider, 1968). Within the restrictions of the primarily chemical information collected during this survey the most useful characteristics are: 1) Concentrations of plant nutrients, especially P and N, as a measure of available supplies as well as a reflection of the fertility of the watershed. Concentrations in the spring are usually assumed to represent the supplies available for spring and early summer algal growth. Concentrations in surface waters during the summer provide an estimate of remaining nutrient supplies and an indirect measure of algal populations. 2) Concentrations of chlorophyll-a as a measure of the total crop of algae. 3) Transparency as a measure of apparent water quality and an indirect measure of algal numbers. And 4) rates of oxygen depletion below the thermocline (ΔH.O.D.) as an indirect measure of productivity because oxygen is consumed as the organic remains of algae decompose.

These characteristics are summarized in Table 2 where the lakes are listed in order of their mean total phosphorus concentration for spring and summer. This order provides a convenient ranking of the lakes because phosphorus appears most likely to limit the total crop of algae in lakes in this region (Deevey, 1940; Frink, 1971; Schindler *et al*., 1971; Schindler, 1974; Vollenweider, 1968; Hutchinson, 1973).

It is clear that the various characteristics of the lakes are moderately-well related (Table 2). Low concentrations of total P tend to accompany low concentrations of total N and chlorophyll-a, low rates of oxygen consumption, and greater transparency. The converse is also true. Although exceptions occur, the lakes toward the end of the list are very well-nourished or eutrophic, while lakes high in the list are relatively infertile or oligotrophic.

More quantitative distinctions among the lakes are possible with guidelines from other studies of lakes in the humid-temperate zone. Vollenweider (1968) and others (Sakamoto, 1966; Hutchinson, 1957) suggest typical ranges for four of the characteristics in Table 2: spring total N and P, summer chlorophyll-a, and hypolimnetic oxygen deficit (ΔH.O.D.). These ranges are amended slightly and presented as four useful categories in Table 3. The ranges overlap because of the complexity and, to some extent, the subjectivity of trophic classifications.

Comparison of these ranges with Table 2 suggests that only a few of the lakes should be considered oligotrophic. West Hill and Alexander are the clearest examples. These are infertile, clear, relatively unproductive lakes

TABLE 2. Total P, total N, chlorophyll-a, transparency, and incremental hypolimnetic oxygen deficit for 23 lakes ranked by total P averaged for spring and summer, 1974.

	Spring		Summer				
Lake	Total P	Total N	Total P	Total N	Chl-a	Transparency	ΔH.O.D.
	ppb	ppb	ppb	ppb	ppb	m	μg/cm²/day
West Hill	8.6	262	7.0	215	1.5	7.0	25
Alexander	10.2	308	7.5	405	0.8	7.2	17
Long	10.5	298	13.0	640	2.8	4.8	22
Gardner	14.2	472	13.0	595	6.9	4.1	
Candlewood	13.0	358	14.6	436	4.5	5.2	
Shenipsit	18.4	434	10.5	495	5.6	4.0	53
Pataganset	15.0	388	15.0	680	14.0	2.8	29
Quassapaug	15.6	426	14.0	460	2.9	6.8	45
East Twin	20.2	425	15.6	510	2.4	5.3	56
Terramuggus	21.8	453	14.0	590	2.4	6.0	
Hayward	22.8	353	15.0	370	7.8	3.3	
Pocotopaug	17.3	510	24.6	416	6.8	3.8	17
Mudge	26.5	553	18.7	483	3.9	4.1	
Taunton	23.3	370	22.0	690	5.5	3.2	
Waramaug	26.5	473	24.0	635	11.0	2.7	42
Wononscopomuc[a]	44.2	692	14.0	510	1.6	7.8	67
Beseck	25.8	550	34.0	647	18.0	2.8	
Bantam	26.3	493	35.0	893	31.0	1.8	
Roseland	33.0	953	38.0	935	20.0	2.8	
Linsley[a]	50.8	1330	28.0	440	5.2	3.5	> 75
Cedar	46.8	1540	71.0	1830	64.0	0.9	
Lillinonah	58.6	751	67.0	1100	38.0	1.6	
Zoar	68.2	732	66.3	906	54.0	1.9	

[a] In these lakes a bloom of algae (apparently Oscillatoria rubescens) was present near the thermocline and was not included in the summer surface samples which were, consequently, unexpectedly low in P, N, and chlorophyll and high in transparency. These blooms were confirmed by cell counts in the case of Linsley (K. Keating, 1974, unpublished data) and chlorophyll analyses in the case of Wononscopomuc (14.6 ppb at 10 m, see appendix).

of moderate depth. Long Pond is somewhat more fertile and productive but at least the isolated, deep, oxygen rich, northern basin of this lake should also be considered oligotrophic. The next group of nine lakes from Gardner through

TABLE 3. Typical ranges of four lake characteristics for oligotrophic, mesotrophic, eutrophic, and highly eutrophic lakes.

	Spring Overturn		Summer	
Lake	Total P	Total N	Chlorophyll-a	Δ H.O.D.
	ppb	ppb	ppb	$\mu g/cm^2/day$
oligotrophic	0-15	0-300	0-4	0-25
mesotrophic	10-30	200-600	2-15	15-55
eutrophic	20-50	400-1100	10-40	45-75
highly eutrophic	>40	>800	>30	>55

Pocotopaug are intermediate in fertility and should probably be classified as mesotrophic. This diverse group is distributed throughout the state and includes almost as much variation in alkalinity, mean depth, color, transparency, and size as the entire group of 23 lakes in the survey.

The next three lakes, Mudge, Taunton, and Waramaug, are more difficult to classify but they clearly border on eutrophy in many respects. In fact, the low chlorophyll-a concentrations in Mudge and Taunton (Table 2) are misleading indicators of overall productivity because rooted weeds grow abundantly in Mudge, and Taunton is a water supply, treated with copper sulfate to control algae. The next four lakes, Wononscopomuc, Beseck, Bantam, and Roseland, are best described as eutrophic. These lakes are relatively rich in P and N and are subject to occasional algal blooms and nuisance growth of rooted weeds. Wononscopomuc has become eutrophic only recently, and total P was exceptionally high and transparency was only one meter during a heavy spring bloom (probably Oscillatoria rubescens). During the summer, however, the algae were concentrated near the thermocline, total P and chlorophyll-a near the surface were low, and some of the greatest transparencies of the survey were measured. In contrast to the low fertility and remarkable clarity of the surface water, oxygen was seriously depleted in the hypolimnion by late summer, and the odor of hydrogen sulfide was obvious. Many wild geese have frequented Wononscopomuc in recent winters and we estimate that their wastes contribute significantly to the relatively high concentrations of P now in the lake (e.g. about 47 ppb P during spring overturn in 1974).

The last group of four lakes includes the two smallest and second and third largest in the study. These are highly eutrophic waters, richly supplied with N, P, and other nutrients and subject to heavy blooms of blue-green algae and excessive growth of other aquatic weeds. Oxygen is rapidly depleted below the photosynthetic zone in early summer, even in the relatively deep impoundments where thermal stratification is delayed in the spring and frequently disrupted during the summer by flow. In Linsley, the surface waters were uncharacteristically clear and low in N and P at the time of the summer sampling because the algae were concentrated near the thermocline as in Wononscopomuc.

The 23 lakes may also be classified by an analysis of lake similarities using the mathematical technique of cluster analysis. In this procedure each lake is grouped with the lake or previously formed group with which it is most similar. Although the mathematical procedures are objective, the overall process is largely subjective because one selects the characteristics for analysis and choses the degree of clustering.

The lakes were grouped by five characteristics that were available for all lakes: spring total P and total N and summer total P, total N, and chlorophyll-a. Logarithmically transformed data were used to emphasize relative rather than absolute comparisons during clustering (Program BMDP2M, Health Sciences Computing Facility, U.C.L.A.). The resulting clusters are shown graphically in Fig. 2 where the horizontal distance represents the similarity level at which clustering occurred. At the level of similarity selected, 20 of the lakes have formed four clusters that correspond nicely to the oligotrophic, mesotrophic, eutrophic, and highly eutrophic groups discussed above. It is reassuring that most of the lakes cluster fairly naturally into groups that correspond to trophic classifications based on independent criteria (Table 3).

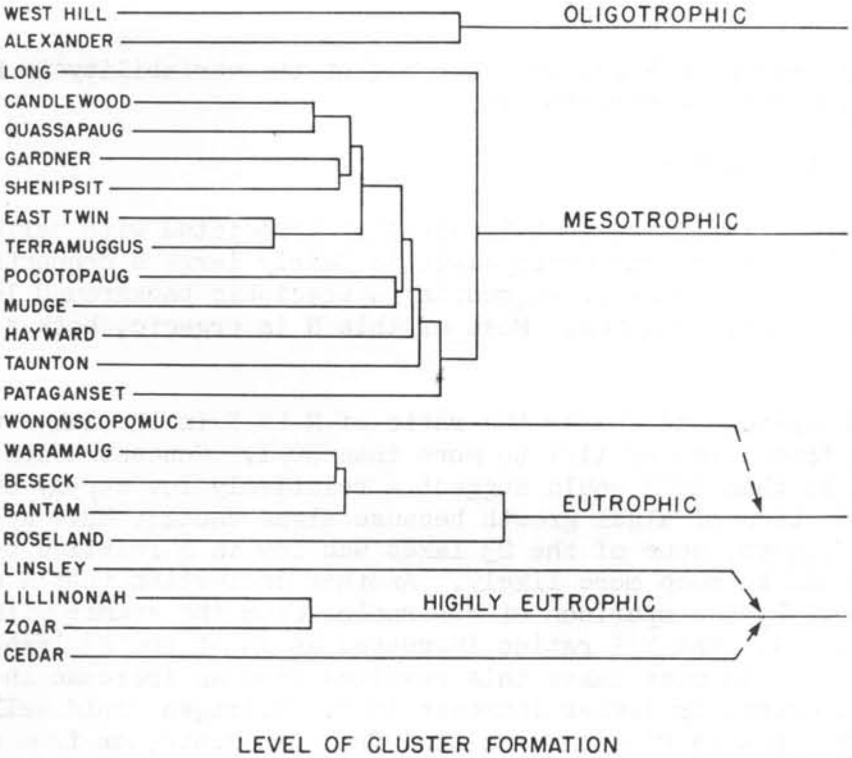


FIGURE 2. Aggregation of lakes into trophic groups by cluster analysis based on spring and summer nutrient concentrations and summer chlorophyll-a concentrations.

Three lakes, Linsley, Cedar, and Wononscopomuc, failed to join any group, partly because eutrophic and highly eutrophic lakes are inherently more variable than less fertile waters. Consequently they clustered less easily, even with logarithmically transformed data. Another obvious reason why Linsley and Wononscopomuc failed to cluster is the already mentioned discrepancy between spring and summer conditions which makes these lakes unlike any of the others. The dashed arrows (Fig. 2) indicate the appropriate trophic groups for these three lakes.

Relationships Among Lake Characteristics

Many lake characteristics are strongly related. Table 4 shows linear correlation coefficients among 11 characteristics from Tables 1 and 2. Of the 55 relationships shown, 27 are statistically significant including all 15 relationships among indices of fertility and productivity. The important relationships are discussed below. More detailed evaluation of the interrelationships among lake characteristics and watershed characteristics is continuing and will be reported later.

Total P and Total N: Total P and total N show a fair linear association in both spring and summer (Fig. 3). Expressing N as a function of P, the regression equation for spring concentrations is:

$$N = 14.1\ P + 191$$

in which the variation in P accounts for 51% of the variability in N. For the summer concentrations the equation is:

$$N = 14.6\ P + 278$$

in which 78% of the variation in N is directly associated with variation in P. Interestingly, both equations extrapolate to fairly large N concentrations as P concentrations approach zero, suggesting appreciable background levels of N even in the least fertile lakes. Most of this N is organic, both soluble and particulate.

In both spring and summer the ratio of N to P in the lakes was fairly large, ranging from a low of 11/1 to more than 50/1. Concentration ratios in the water of less than 10/1 would suggest a relatively low supply of N and possible N limitation of algal growth because algae usually have N/P ratios of 7/1 to 14/1. However, none of the 23 lakes was low in N relative to P. Thus, P limitation would be much more likely. Another indication that N was fairly abundant is shown by a comparison of N/P ratios from the summer with those of the spring (Fig. 4). The N/P ratios increased in 18 of the 23 lakes between spring and summer. In most lakes this resulted from an increase in N combined with either a decrease or lesser increase in P. Nitrogen could well have increased through nitrogen fixation, release from sediments, or from external sources. Decreases in P tended to be largest in the deeper, stratified lakes where sedimentation of planktonic debris during the summer undoubtedly depleted P from the surface waters. Increases in P between spring and summer occurred typically in shallow lakes where sedimented P was released and easily mixed with surface waters. However, even in these lakes, the relative increase in N

TABLE 4. Linear correlation coefficients among 11 characteristics of 23 lakes.

		Spring		Summer					Mean			
		Phosphorus	Nitrogen	Phosphorus	Nitrogen	Chlorophyll-a	Color	Transparency	Alkalinity	Conductivity	Watershed/Lake area	Mean depth
Spring	Phosphorus											
	Nitrogen	0.71										
Summer	Phosphorus	0.82	0.69									
	Nitrogen	0.55	0.67	0.88								
	Chlorophyll-a	0.70	0.61	0.94	0.88							
	Color	n.s.	n.s.	n.s.	n.s.	n.s.						
	Transparency	-.50	-.47	-.75	-.68	-.74	-.67					
Mean	Alkalinity	0.64	0.50	n.s.	n.s.	n.s.	n.s.	n.s.				
	Conductivity	0.72	0.63	0.51	n.s.	n.s.	n.s.	n.s.	0.96			
	Watershed/Lake area	0.71	n.s.	0.66	n.s.	0.62	n.s.	n.s.	n.s.	n.s.		
	Mean depth	n.s.	n.s.	n.s.	n.s.	n.s.	-.62	0.47	n.s.	n.s.	n.s.	

n.s. = Not significant at 95% confidence level, /r/ < 0.42.

was usually greater. Consequently, the relative availability of P, which was low during the spring, became even lower during the summer when in all lakes the N/P ratio exceeded 13/1, in 18 lakes it exceeded 20/1 and in 7 lakes it

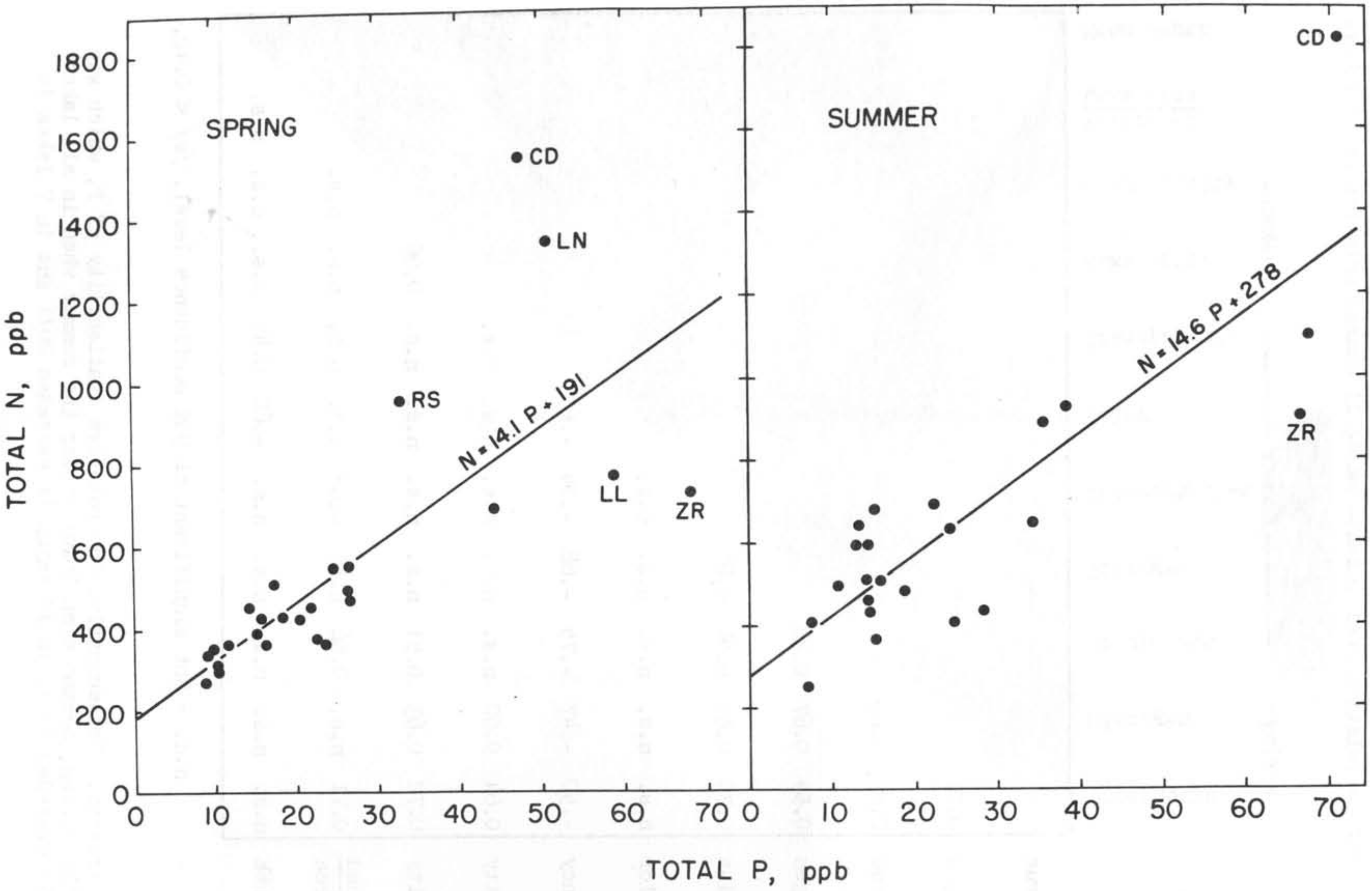


FIGURE 3. Relationship between total nitrogen and phosphorus in surface waters of 23 lakes during the spring and summer of 1974. Lakes with nutrient concentrations falling relatively far from the linear regression lines are: Cedar (CD), Linsley (LN), Roseland (RS), Lillinonah (LL), Zoar (ZR).

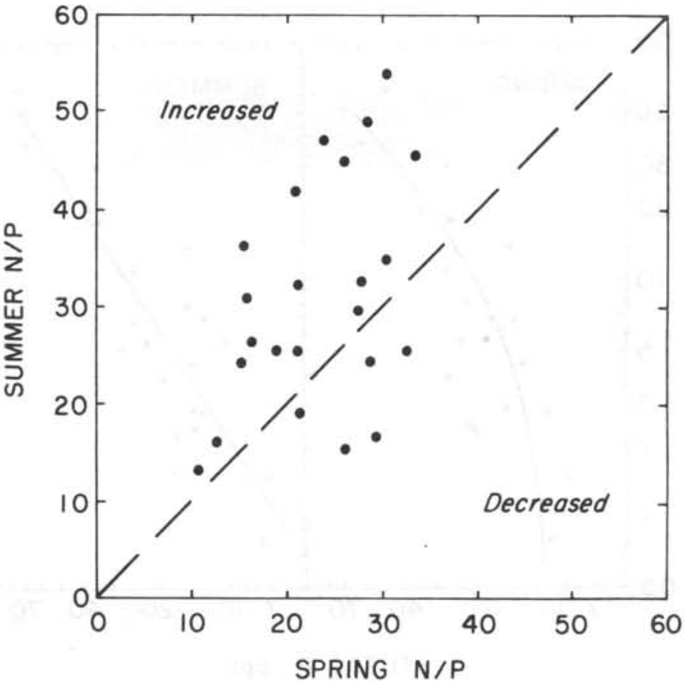


FIGURE 4. Comparison of nitrogen to phosphorus ratios in surface waters of 23 lakes during the spring and summer of 1974.

exceeded 40/1. Clearly, P is much more likely than N to limit the growth of algae in most of the lakes studied and, by inference, in most Connecticut lakes.

Chlorophyll-a, Total P, and Total N: Chlorophyll-a in the surface waters of the 23 lakes was well correlated with total P and to a lesser extent with total N in both spring and summer. Presumably this reflects the greater importance of P as a limiting nutrient for algae in these lakes. Figure 5 shows the relationships between chlorophyll-a and both spring and summer total P.

Although the concentrations of chlorophyll-a and total P are clearly related, variability prevents an unequivocal choice of a linear, exponential, or other functional relationship. Linear regression yields:

$$\text{Chl-a} = 0.99\ P - 10.1,\ (r^2 = 0.74)$$

for spring P (Fig. 5) and

$$\text{Chl-a} = 0.86\ P - 8.2,\ (r^2 = 0.88)$$

for summer P. In either case, total P is a good predictor of chlorophyll-a. However, both equations indicate that chlorophyll-a concentrations should approach zero as total P concentrations fall below 10 ppb, whereas small but nonetheless important amounts of chlorophyll-a are actually present in most

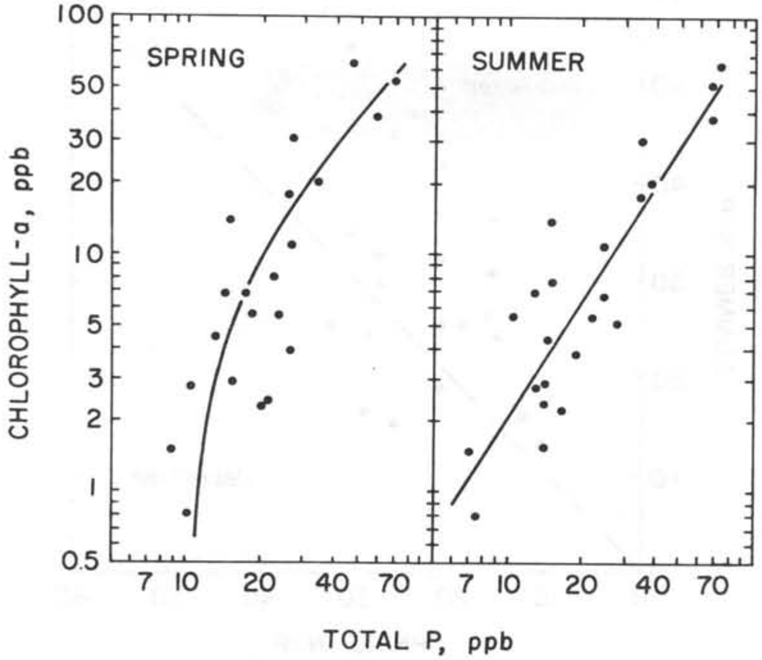


FIGURE 5. Relationships between summer chlorophyll-a concentrations and spring and summer total phosphorus concentrations in surface waters of 23 lakes during 1974. The relationship chlorophyll-a = 0.99 P - 10.1 is shown for spring phosphorus, while log chlorophyll-a = 1.62 log P - 1.28 is shown for summer phosphorus. (Data for Linsley and Wononscopomuc are omitted from the spring comparison for reasons discussed in text).

oligotrophic lakes. For this reason, a simple exponential relationship (Sakamoto, 1966; Dillon and Rigler, 1974), is more realistic at low P concentrations because small, not zero, chlorophyll-a concentrations are predicted. For spring P the appropriate relationship is

$$\log \text{Chl-a} = 1.80 \log P - 1.52, \ (r^2 = 0.68)$$

and for summer P

$$\log \text{Chl-a} = 1.62 \log P - 1.28, \ (r^2 = 0.79)$$

which is illustrated in Fig. 5. Although our results may be explained by linear or exponential relationships between chlorophyll-a and total P, neither has predictive value when P concentrations are very large or do not limit algal populations.

Although P appears more likely than N to limit algae in these lakes, the consideration of both P and N in the regression improves the correlation significantly. For spring P and N, multiple linear regression yields:

$$\text{Chl-a} = 0.64\ P + 0.028\ N - 16.3$$

with an increase in R^2 from 0.74 to 0.85. For summer P and N:

$$\text{Chl-a} = 0.61\ P + 0.017\ N - 12.9$$

with an increase in R^2 from 0.88 to 0.92. These results suggest that N has a small but significant influence on chlorophyll-a concentrations even though N is less important than P. A similar conclusion was reached by Deevey (1940).

Transparency, Chlorophyll-a, and Color: Because the transparency of lakes is reduced by light-absorbing and light-scattering materials, it is negatively correlated with concentrations of such materials (Table 4). However, linear correlations are poor because transparency is more nearly related inversely to concentrations of light-attenuating substances or to fractional powers of these concentrations. For example, the association between transparency, measured with the Sechhi disk (S), and chlorophyll-a in Fig. 6 may be described by the inverse relationship $S = 1/(0.137 + 0.0166\ \text{Chl-a})$, which accounts for 80% of the variance in S or by the exponential relationship $\log S = 0.857 - 0.383 \log \text{Chl-a}$, which accounts for 69% of the variance.

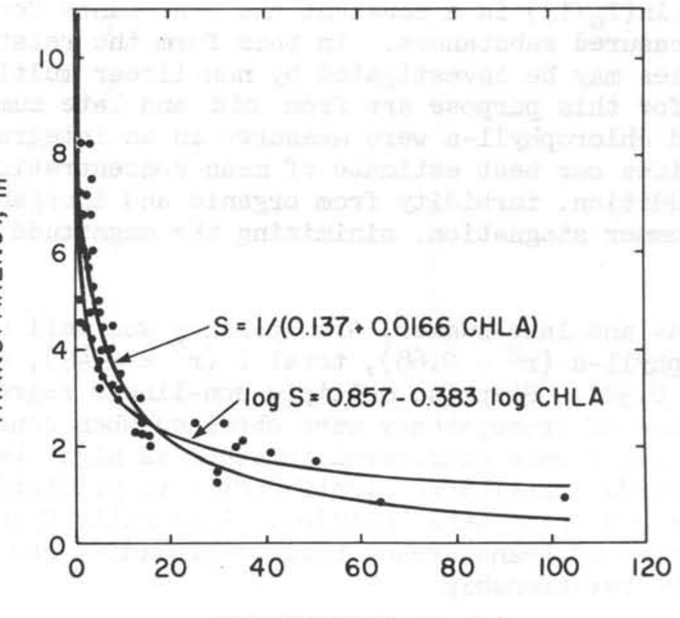


FIGURE 6. Relationship between transparency and concentrations of chlorophyll-a in 23 lakes during the summer of 1974.

A theoretical basis for inverse relationships between transparency and light-attenuating substances is found in the Beer-Lambert-Bouguer Law. This states that the ratio of the intensities of transmitted to incident light (I/I_o) is exponentially related to the length of the light path (S) and to the concentration (C) of light absorbing substance in the path. Thus,

$$I/I_o = a^{-kCS}$$

where k is the absorption coefficient and a is a constant. Assuming a = e, the base of natural logarithms,

$$S = \frac{\ln(I_o/I)}{kC}$$

where the inverse linear relationship between S and C is obvious. For a mixture of n light absorbing materials the expression expands to

$$S = \ln(I_o/I)/(k_1C_1 + k_2C_2 + \dots + k_nC_n).$$

At a depth equal to the transparency, as measured by Secchi disk, the ratio I_o/I tends to have a fairly constant value in lakes (Beeton, 1957; Hutchinson, 1957). Accepting this approximation, we may write:

$$S = 1/(K_1 \text{ Chl-a} + K_2 \text{ Color} + \dots + M)$$

where each $K = k/(\ln(I_o/I))$ is a constant and M accounts for absorption by water and all unmeasured substances. In this form the relationship between S and water properties may be investigated by non-linear multiple regression. The best results for this purpose are from mid and late summer. During these periods, color and chlorophyll-a were measured in an integrated 0 to 3 meter sample which provides our best estimate of mean concentrations in the illuminated zone. In addition, turbidity from organic and inorganic debris tends to be least during summer stagnation, minimizing the magnitude and variability of M.

During mid- and late-summer, transparency was well correlated with the inverse of chlorophyll-a ($r^2 = 0.68$), total P ($r^2 = 0.47$), color ($r^2 = 0.41$), and total N ($r^2 = 0.32$). Stepwise multiple non-linear regression showed that the best predictions of transparency were obtained when concentrations of chlorophyll-a and color were considered together as might be expected. No other water properties contributed significantly to predictions of transparency when chlorophyll-a and color were included. Presumably N and P contributed little to predictions of transparency besides providing redundant measures of chlorophyll-a. The relationship

$$S = 1/(0.0171 \text{ Chl-a} + 0.00662 \text{ Color} + 0.0777)$$

accounts for 89% of the variation in transparency for all 23 lakes based on just two measurements, chlorophyll-a and color. In addition the relatively large value of 0.0777 for the term, M, indicates that turbidity and other unmeasured factors would have limited transparency to approximately 13 meters even in the absence of chlorophyll-a and dissolved color.

Other Relationships: Carbon limitation of algal population size in these lakes seems unlikely (Schindler *et al.*, 1971; Schindler, 1974; Hutchinson, 1973) even though temporary reduction in growth rate during rapid photosynthesis is possible in the softer waters. We did not investigate this question directly, but it is obvious from Table 4 that no significant relationship was found between alkalinity (dissolved inorganic carbon) and chlorophyll-a concentrations.

Alkalinity and conductivity were highly related as expected for primarily bicarbonate-type waters. Both alkalinity and conductivity were moderately well related to spring P and N even though neither was significantly correlated with chlorophyll-a.

Although lake depth and watershed size influence the trophic condition of lakes, their correlations with measures of fertility and productivity were generally poor. Even the apparent relationships of total P and chlorophyll-a to watershed to lake area ratio are misleading because the correlations are unduly weighted by the enormous watersheds of the river impoundments and would not otherwise be significant. The lack of a good relationship between morphometric characteristics and trophic conditions suggests that other factors, such as differences in land use, have a much greater effect on the fertility and productivity of the 23 lakes.

Changes in Twenty Lakes During a Third of a Century

Since the lakes were surveyed in 1937-39 (Deevey, 1940; Deevey and Bishop, 1942) the population of Connecticut has nearly doubled and development has increased enormously, while the acreage of active agriculture has decreased. During this time some of Connecticut's lakes appear to have become increasingly eutrophic (Benoit and Curry, 1961; Benoit, 1969 and unpublished data) and in one lake these changes are extensively documented (Cowgill, 1970). A more precise assessment of these changes is now possible for 20 lakes that were in both the 1937-39 and the 1973-74 surveys.

Eight properties were measured in both surveys but only five were obtained by reasonably comparable methods: total P, chlorophyll, hypolimnetic oxygen deficit, transparency, and alkalinity. Even in these properties, however, small changes should be discounted, and all changes interpreted with caution because of unavoidable differences in equipment, methods, and personnel, as well as normal day-to-day and year-to-year fluctuations in lake characteristics.

During the last 35 years there appears to have been a fairly general increase in total P in the 20 lakes. This is shown in Fig. 7 where the total P in 1973-74 is plotted against the concentration in 1937-39. We estimate conservatively that a change of 50% or 5ppb (whichever is larger) should be required to provide reasonable confidence that a significant change has occurred. Even with these limits, however, total P had increased in at least 11 of the 20 lakes and more than doubled in most of these. Other measures of the extent of change are increases in the mean, median, and range of total P concentrations (Table 5).

Changes are evident also in the rate of depletion of oxygen in the hypolimnia of the deeper, thermally stratified lakes. Consumption of oxygen has increased in all 11 lakes for which ΔH.O.D. comparisons were possible (Fig. 8).

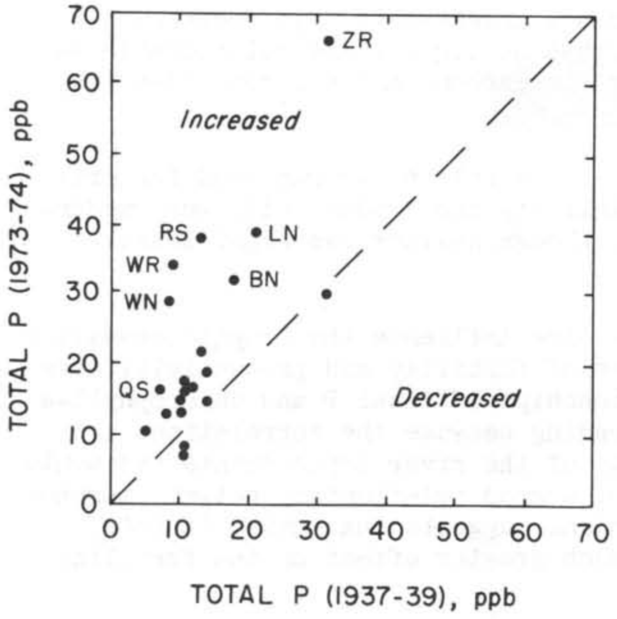


FIGURE 7

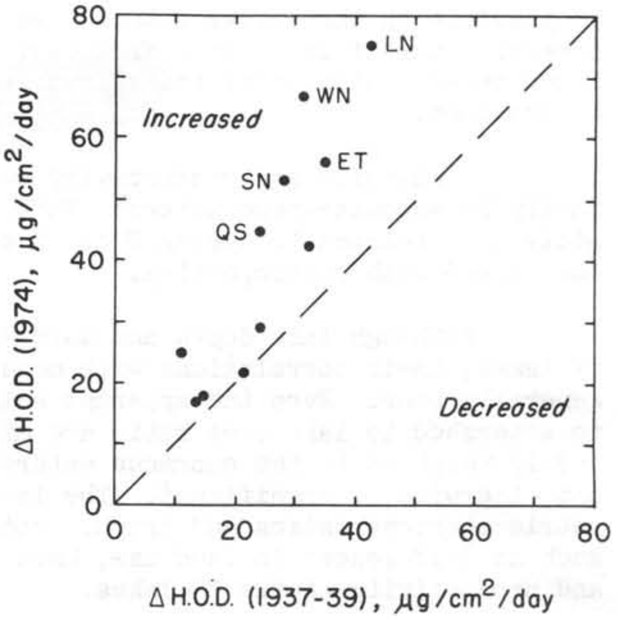


FIGURE 8

FIGURE 7 (left). Total phosphorus concentrations in surface waters of 20 lakes during 1973-74 and 1937-39. Large increases are shown for Bantam (BN), Linsley (LN), Quassapaug (QS), Roseland (RS), Wononscopomuc (WN), Waramaug (WR), and Zoar (ZR). FIGURE 8 (right). Development of oxygen deficits in the hypolimnia of 11 lakes during the summers of 1974 and 1937-39. Large increases are shown for East Twin (ET), Linsley (LN), Quassapaug (QS), Shenipsit (SN), and Wononscopomuc (WN).

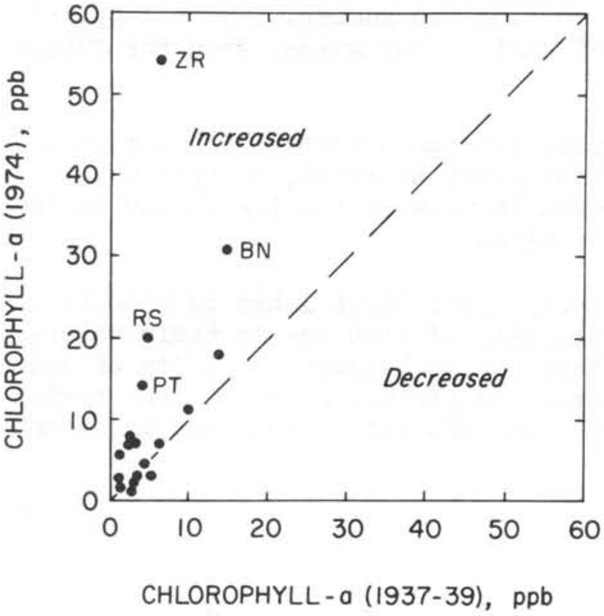
TABLE 5. Comparison of the median, mean, and range of five lake characteristics in 1937-39 and 1973-74.

Property	Year	Median	Mean	Range
Total P (ppb)	1937-39	11.0	13.4	5-31
	1973-74	16.5	22.8	8-66
ΔH.O.D. (μg/cm²/day)	1937-39	24	25	11-42
	1973-74	42	41	17-75+
Chlorophyll (ppb)	1937-39	4.5	5.5	1.1-15
Chlorophyll-a (ppb)	1973-74	5.5	10.2	0.8-54
Transparency (m)	1937-39	4.3	5.0	1.5-8.8
	1973-74	3.8	4.3	1.8-7.8
Alkalinity (meq/l)	1937-39	0.27	0.61	0.19-2.20
	1973-74	0.24	0.63	0.12-2.19

In six lakes, West Hill, Quassapaug, Shenipsit, East Twin, Wononscopomuc, and Linsley the increase exceeds 50%. This rise in ΔH.O.D. undoubtedly reflects increases in productivity since 1937-39. The increases in the mean, median, and range of ΔH.O.D. values (Table 5) are of about the same magnitude as for total P.

Accurate comparisons of chlorophyll concentrations during the summers of 1937-39 with concentrations in 1973 are hindered by differences in method. Chlorophyll concentrations were apparently overestimated by the colorimetric method (Riley, 1938) employed in 1937-39. Turbidity and extraneous colored matter contributed to the overestimation which was especially serious at low concentrations and may have been as large as 50 to 100% (Riley, personal communication, 1975). Consequently, the increases shown in Fig. 9 clearly understate the extent of change. Even so, chlorophyll increased substantially in 10 lakes and, in 6 of these, chlorophyll concentrations more than doubled. Increases in the median, mean, and range of concentration are listed in Table 5. Results for Linsley and Wononscopomuc are omitted from these comparisons for reasons already discussed.

Two lakes, Beseck and Candlewood, appeared clearer during 1974 than in 1937-39, but most lakes were less transparent and rather large decreases were found in Zoar, Waramaug, and Taunton (Fig. 10). Because of normal variation



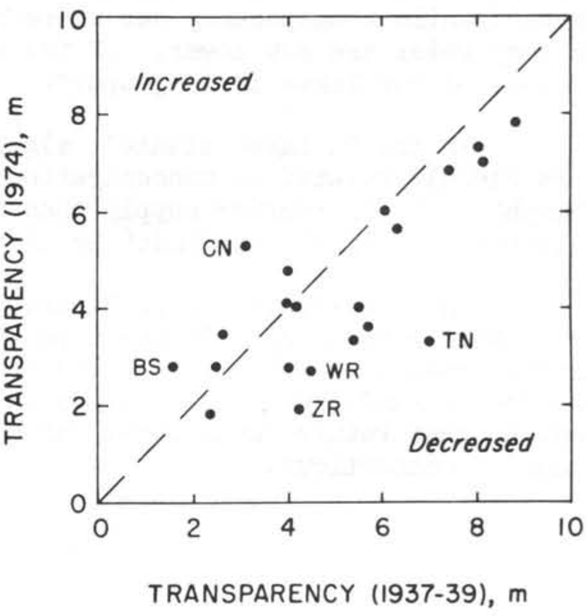


FIGURE 9 FIGURE 10

FIGURE 9 (left). Chlorophyll-a concentrations in surface waters of 20 lakes during the summers of 1974 and 1937-39. Large increases are shown for Bantam (BN), Pataganset (PT), Roseland (RS), and Zoar (ZR) among others. FIGURE 10 (right). Transparency of 20 lakes during the summers of 1974 and 1937-39. Relatively large decreases are shown for Taunton (TN), Waramaug (WR), and Zoar (ZR), while transparencies in Beseck (BS) and Candlewood (CN) were greater in 1974.

in transparency, conclusions concerning any particular lake should be drawn with caution, but the trend shown in Fig. 10 and Table 5 toward lower transparency in the 20 lakes is obvious.

Comparisons of alkalinity between 1937-39 and 1973-74 are also possible. Little or no change was noted in most lakes as shown in Table 5 for the median, mean, and range of alkalinity for the 20 lakes. In Linsley, however, the mean alkalinity during 1973-74 was nearly 60% higher than in 1937-39. A similar increase also occurred in Cedar based on values for 1937-39 reported by Brooks and Deevey (1963).

The two surveys show five lakes have changed relatively little: Alexander, Beseck, Candlewood, Long, and West Hill. Moderate increases in fertility and productivity have occurred in seven lakes: East Twin, Gardner, Pataganset, Pocotopaug, Quassapaug, Terramuggus, and Waramaug. Eight lakes have become considerably more eutrophic: Bantam, Hayward, Linsley (and presumably Cedar), Roseland, Shenipsit, Taunton, Wononscopomuc, and Zoar.

CONCLUSION

Connecticut's lakes range from clear, infertile, oligotrophic waters to turbid, highly fertile, eutrophic waters subject to excessive growth of algae and aquatic weeds. Many have become more eutrophic during the last few decades. Concentrations of phosphorus and chlorophyll-a have generally increased while transparency has decreased. During the summer, oxygen supplies in deep water are now lower. If the recent past is any guide, then the future of many of our lakes is in jeopardy.

In the 23 lakes studied, algal populations as measured by chlorophyll-a were closely related to concentrations of the plant nutrient, phosphorus. Phosphorus is in shorter supply than nitrogen in most of the lakes, and is the nutrient most likely to limit the growth of algae.

The accelerated eutrophication of many Connecticut lakes is undoubtedly associated with changes in the type and intensity of land use in their watersheds. Hence, we are now studying the relationships between fertility of lakes and use of land. We hope to learn to control the processes of nutrient enrichment so that future generations can use the land and still enjoy the lakes and ponds of Connecticut.

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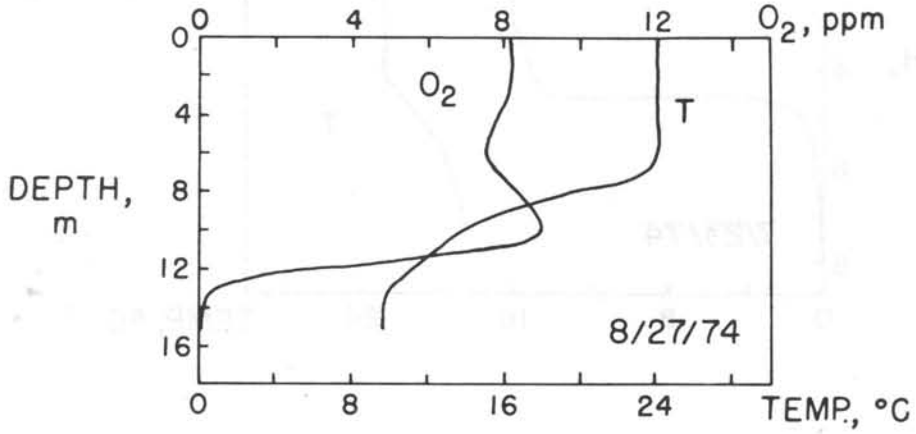
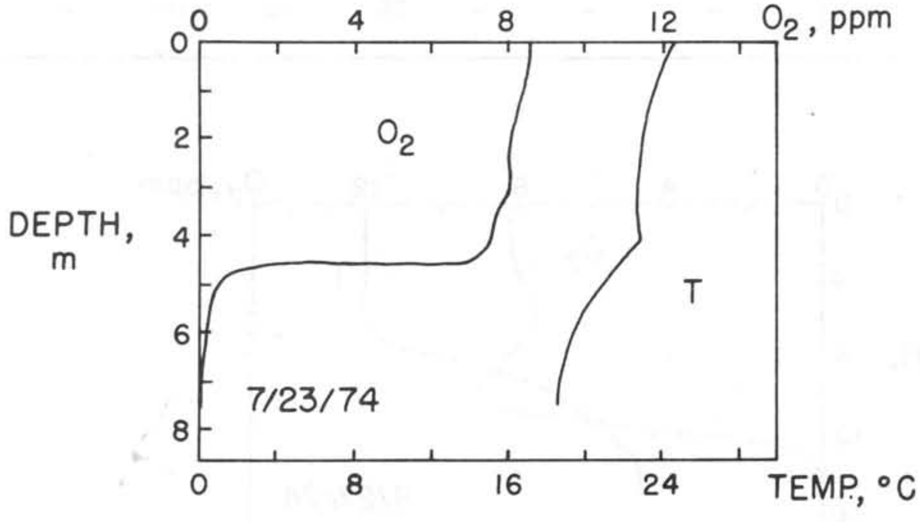
ALEXANDER LAKE
(Killingly, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
10/23/73	5.7	.2	.10	-	4	8	40	10	200	250
		5	-	-	3	8	40	10	190	250
		10	-	-	3	8	50	10	190	250
		13	-	-	4	16	190	20	240	370
5/2/74	9.7	.2	.12	-	2	7	40	40	280	330
		4	-	-	5	10	40	40	240	260
		8	-	-	5	13	30	40	260	300
		13	-	-	5	14	10	40	240	320
7/17/74	6.3	0-3	.13	.6	3	6	0	40	310	340
		4	-	-	3	8	0	50	320	360
		8	-	-	3	14	0	50	290	370
		13	-	-	5	14	140	110	510	600
8/27/74	8.2	0-3	.11	.9	3	9	60	70	380	470
		5	-	-	3	8	40	30	260	370
		9	-	-	4	13	40	30	280	410
		13	-	-	-	16	30	60	-	380



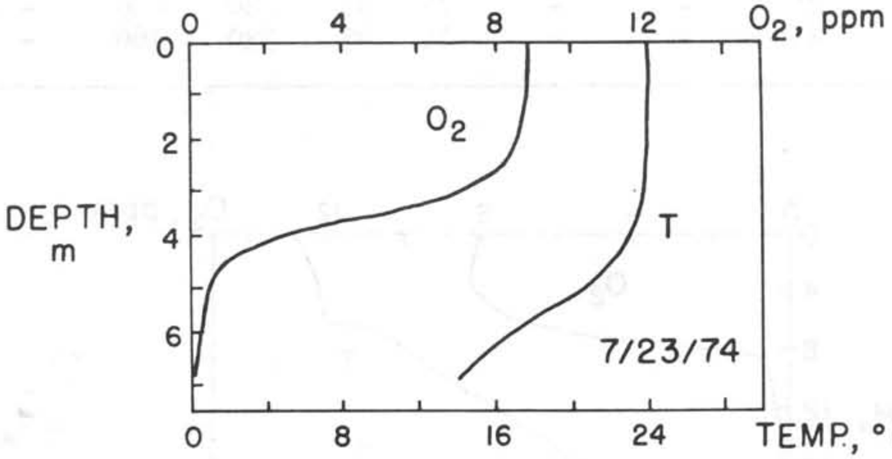
BANTAM LAKE
(Litchfield, Morris, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	—— m ——		meq/l	——————			ppb	——————		
9/26/73	2.0	.2	-	-	18	36	90	60	-	670
		5	-	-	16	35	110	50	-	680
4/24/74	3.0	.2	.50	-	9	25	20	160	360	520
		5	-	-	8	29	0	50	290	440
6/24/74	1.8	.2	.58	50	7	28	50	30	300	660
		3	-	-	7	28	20	40	280	700
		5	-	-	-	40	80	100	-	710
7/23/74	1.5	0-2	.70	30	7	37	40	60	520	1150
8/22/74	2.2	0-3	.67	14	31	40	80	10	670	870
		5	-	-	10	70	100	10	550	940



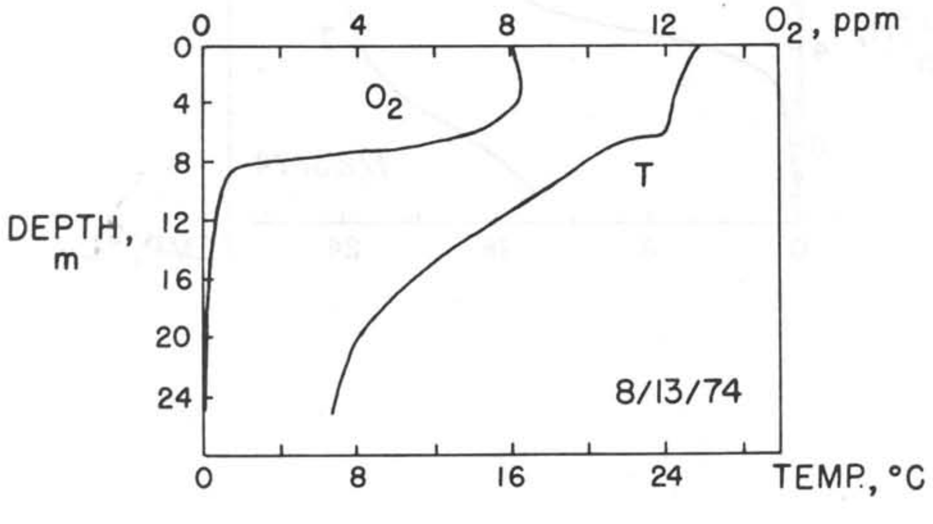
BESECK LAKE
(Middlefield, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
10/31/73	2.0	.2	.59	-	7	36	110	70	360	780
		3	-	-	11	38	100	90	600	800
		6	-	-	10	36	120	60	420	750
4/3/74	2.2	.2	.34	-	10	21	0	260	410	530
		3	-	-	9	27	10	340	480	600
		5	-	-	8	34	10	340	480	540
6/21/74	4.0	.2	.54	7.2	6	15	20	60	310	410
		4	-	-	7	22	30	20	220	340
		6	-	-	-	35	180	40	-	650
7/23/74	2.5	0-3	.55	13.9	7	34	50	50	250	570
8/26/74	2.0	0-3	.64	34	10	52	50	30	430	960
		5	-	-	-	43	160	150	-	850
		6	-	-	-	165	950	150	-	1580



CANDLEWOOD LAKE
(Brookfield, Danbury, New Fairfield, New Milford, Sherman, CT)

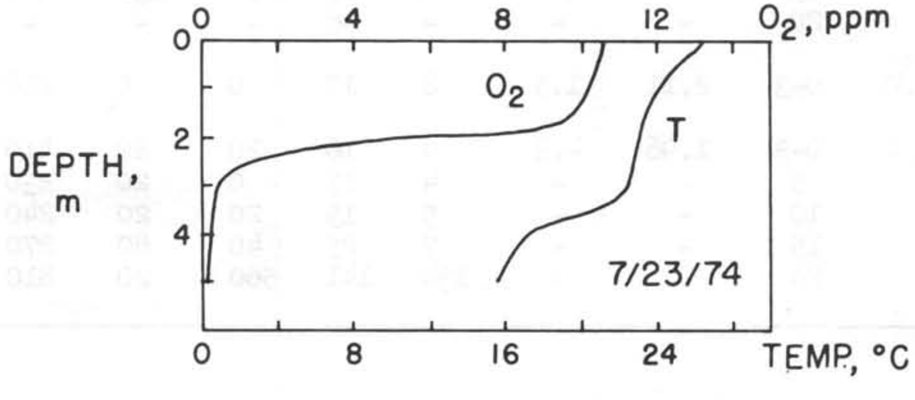
Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/20/73	5.4	.2	.97	-	8	19	60	90	320	410
		5	-	-	9	24	50	90	310	370
		10	-	-	16	24	80	100	280	330
		15	-	-	34	61	130	340	340	660
5/8/74	5.3	.2	.92	-	3	10	10	60	220	330
		5	-	-	3	14	10	60	260	370
		10	-	-	3	14	10	60	240	390
		20	-	-	4	17	40	60	240	370
7/15/74	5.7	0-3	.80	2.4	6	15	40	20	330	440
		5	-	-	6	17	40	50	230	420
		10	-	-	6	20	40	70	250	330
		20	-	-	-	27	190	510	-	770
8/13/74	4.5	0-3	.91	7.5	4	16	40	0	320	520
9/10/74	5.3	0-3	.97	3.6	3	13	0	30	280	350
		5	-	-	4	17	10	30	220	310
		10	-	-	4	38	150	30	400	480
		15	-	-	14	49	80	200	-	420
		20	-	-	15	47	330	160	-	680



CEDAR POND
(North Branford, CT)

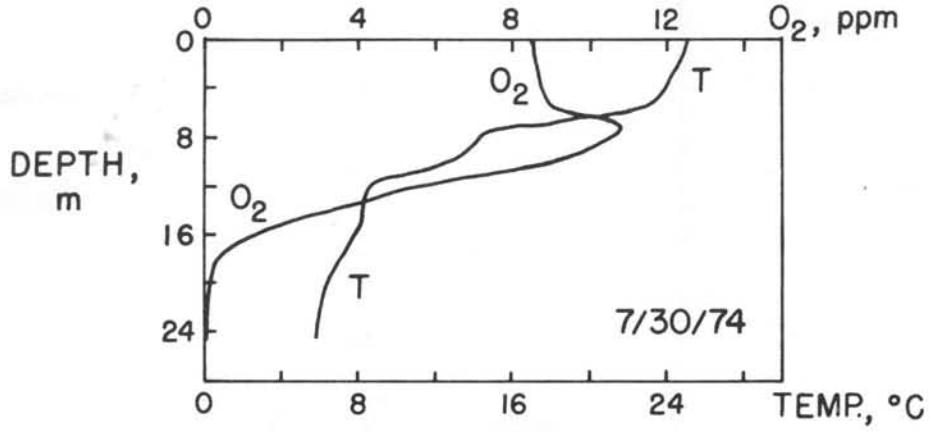
Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/9/73	2.0	.2	2.2	-	24	80	380	100	970	1450
		2	-	-	22	89	350	70	960	1470
		4	-	-	24	94	360	80	880	1470
4/3/74	1.1	.2	1.5	-	8	42	30	1050	1380	1520
		2	-	-	9	48	30	1050	1330	1580
		4	-	-	9	55	60	1060	1340	1550
7/23/74	0.9	0-2	1.7	64*	16	71	20	40	430	1830
		4	-	-	16	98	80	10	430	1470

* Treated with $CuSO_4$ in late June. No suppression of algae apparent on 7/23/74.



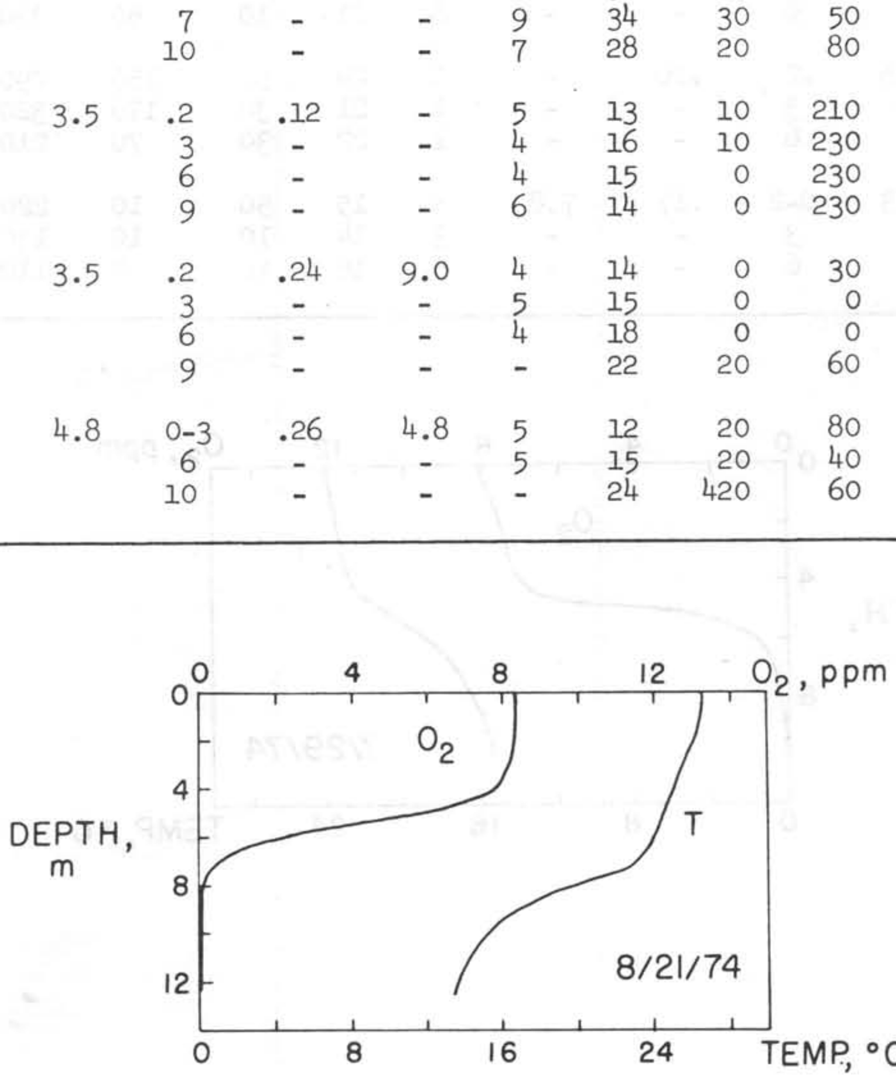
EAST TWIN LAKE
(Salisbury, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m		meq/l	ppb						
10/17/73	6.2	.2	2.03	-	2	10	20	70	380	410
		5	-	-	3	12	20	30	240	310
		10	-	-	2	8	20	20	280	410
		15	-	-	7	17	110	10	390	560
		20	-	-	52	72	640	0	790	910
5/7/74	5.3	.2	2.32	-	9	21	40	40	250	470
		5	-	-	9	22	10	40	320	450
		10	-	-	10	17	40	40	320	400
		15	-	-	9	19	40	40	290	380
		20	-	-	12	21	40	20	330	380
7/10/74	5.0	0-3	2.12	.6	2	14	30	80	360	530
		5	-	-	5	11	20	80	320	430
		10	-	-	5	13	20	80	310	340
		15	-	-	4	13	60	130	440	490
		20	-	-	-	46	-	-	-	520
7/30/74	6.0	0-3	2.11	1.5	8	17	0	0	240	420
9/4/74	5.0	0-3	1.96	4.8	4	16	20	20	410	580
		5	-	-	4	13	0	20	230	260
		10	-	-	5	15	20	20	240	380
		15	-	-	7	25	40	80	270	380
		20	-	-	134	141	560	20	810	950



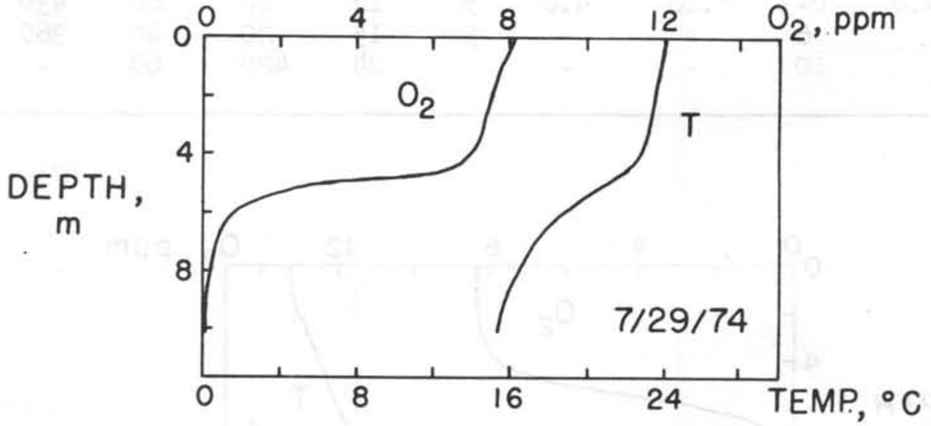
GARDNER LAKE
(Salem, Montville, Bozrah, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/13/73	3.3	.2	.17	-	9	28	40	60	430	510
		4	-	-	8	30	50	100	330	480
		7	-	-	9	34	30	50	260	410
		10	-	-	7	28	20	80	260	390
4/25/74	3.5	.2	.12	-	5	13	10	210	330	450
		3	-	-	4	16	10	230	370	500
		6	-	-	4	15	0	230	380	450
		9	-	-	6	14	0	230	390	510
7/1/74	3.5	.2	.24	9.0	4	14	0	30	330	450
		3	-	-	5	15	0	0	270	400
		6	-	-	4	18	0	0	350	510
		9	-	-	-	22	20	60	-	780
8/21/74	4.8	0-3	.26	4.8	5	12	20	80	430	740
		6	-	-	5	15	20	40	360	470
		10	-	-	-	24	420	60	-	970



LAKE HAYWARD
(East Haddam, CT)

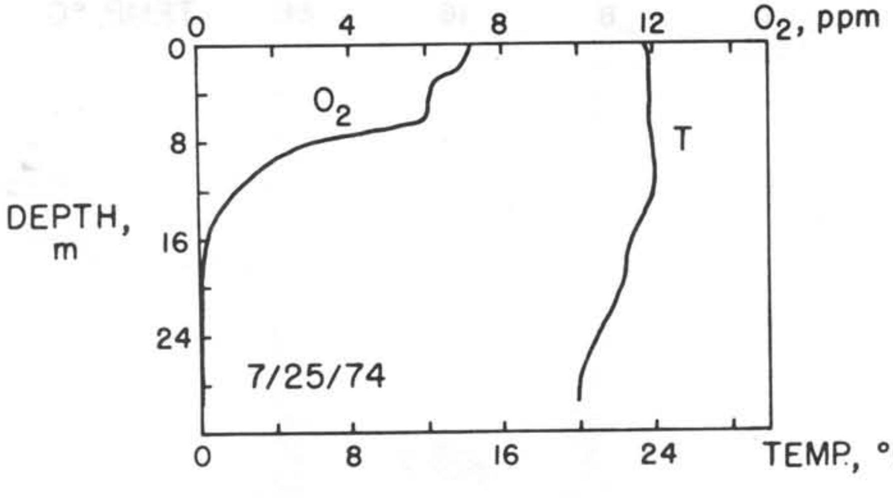
Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/20/74	3.3	.2	.19	-	5	13	20	90	390	510
		3	-	-	7	16	10	80	350	460
		6	-	-	8	21	10	60	330	590
4/25/74	4.8	.2	.10	-	5	24	50	150	290	420
		3	-	-	1	21	30	170	320	380
		6	-	-	1	22	30	70	210	260
7/29/74	3.3	0-2	.17	7.8	5	15	50	10	220	370
		3	-	-	3	14	10	10	130	200
		6	-	-	5	16	40	0	110	190



LAKE LILLINONAH
(Bridgewater, Brookfield, New Milford, Newtown, Southbury, CT)

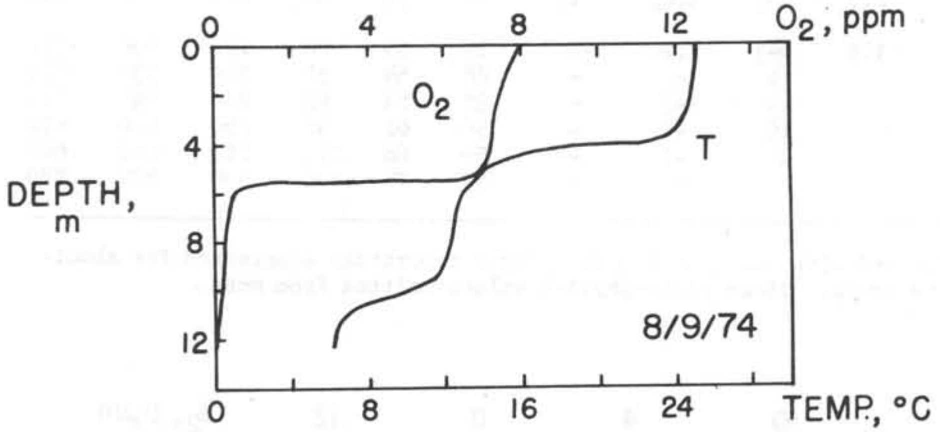
Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
10/19/73	2.0	.2	1.95	-	19	48	90	250	540	790
		5	-	-	27	56	120	300	640	790
		10	-	-	19	59	110	280	620	820
		15	-	-	23	57	130	280	590	770
		20	-	-	41	62	320	190	720	770
		25	-	-	-	119	340	270	-	910
5/31/74	3.2	.2	1.18	-	16	45	50	230	480	720
		5	-	-	23	55	70	290	420	730
		10	-	-	25	68	130	290	530	730
		15	-	-	-	62	170	310	-	760
		20	-	-	-	77	140	340	-	820
		23	-	-	-	76	340	340	-	870
7/8/74	1.3	.2	-	9.3*	29	75	40	150	640	1180
		5	-	-	37	69	100	260	750	950
		10	-	-	34	63	180	260	750	890
		15	-	-	38	48	220	220	870	970
		20	-	-	-	66	240	420	-	1120
		25	-	-	-	22	110	260	-	830
7/25/74	2.5	0-3	1.23	7.8*	11	35	60	110	480	610
9/12/74	1.9	0-3	1.78	38	13	59	20	120	590	1010
		5	-	-	28	54	50	240	530	710
		10	-	-	38	83	90	220	590	710
		15	-	-	50	61	90	250	600	670
		20	-	-	59	68	110	250	640	640
		25	-	-	53	78	140	300	720	770

* Treated with $CuSO_4$ on 7/5/74. Algae reportedly suppressed for about one month. These chlorophyll-a values omitted from mean.



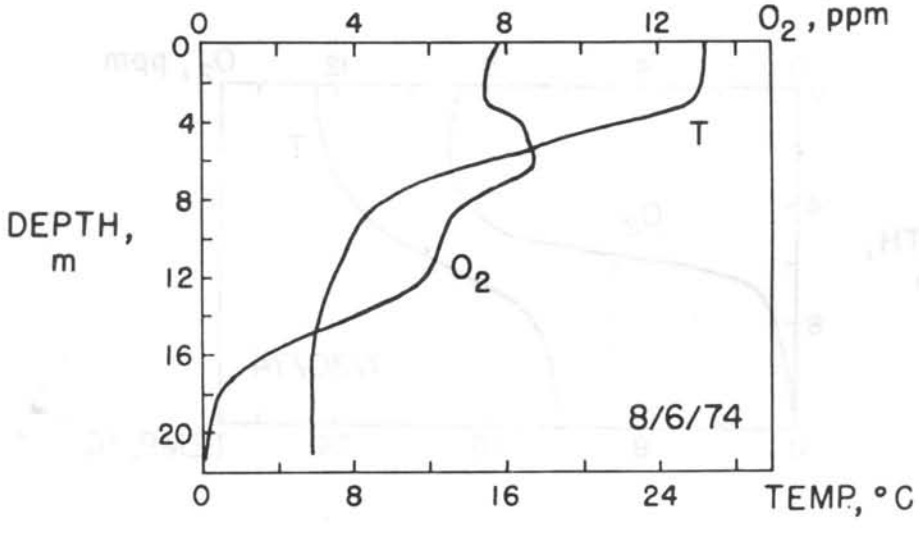
LINSLEY POND
(Branford, North Branford, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/9/73	1.5	.2	1.83	-	9	36	260	0	540	710
		3	-	-	7	29	250	0	450	680
		7	-	-	8	38	280	120	640	830
		11	-	-	-	177	2100	150	2300	2750
4/3/74	1.1	.2	1.30	-	8	54	30	750	1060	1340
		5	-	-	8	48	30	680	990	1180
		10	-	-	10	47	0	880	1280	1440
8/9/74	3.5	0-3	1.71	5.2	8	28	30	80	370	520
		5	-	-	8	37	20	20	250	610
		9	-	-	-	122	970	100	-	1430



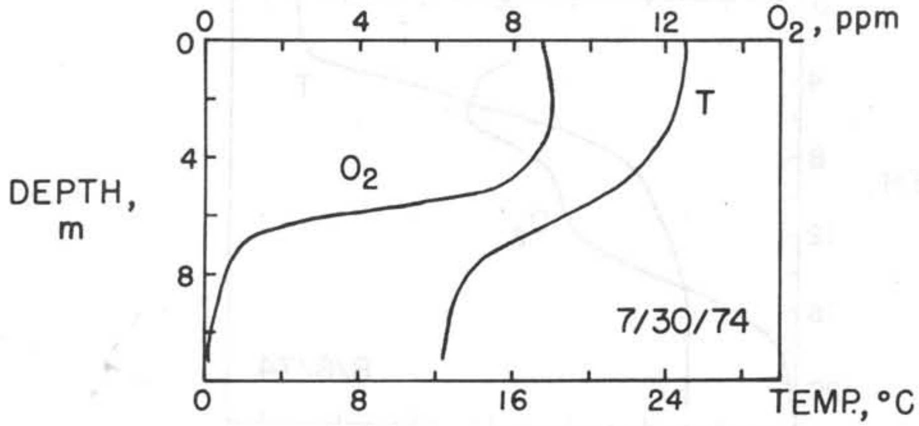
LONG POND
(Ledyard, North Stonington, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m		meq/l	ppb						
11/20/73	3.2	.2	.21	-	5	14	20	60	260	330
		5	-	-	6	16	10	40	140	250
		10	-	-	6	14	10	160	280	350
		15	-	-	4	14	40	80	280	400
		19	-	-	9	14	40	30	170	200
4/10/74	3.2	.2	.15	-	4	11	10	160	280	300
		5	-	-	3	13	30	220	310	360
		10	-	-	3	11	10	150	220	270
		15	-	-	5	8	30	160	260	300
		19	-	-	8	9	30	140	190	260
8/6/74	4.8	0-3	.20	2.8	4	13	40	110	420	640
		5	-	-	5	11	10	80	200	330
		10	-	-	3	9	10	90	180	250
		15	-	-	3	9	30	180	200	300
		19	-	-	-	10	40	170	-	300



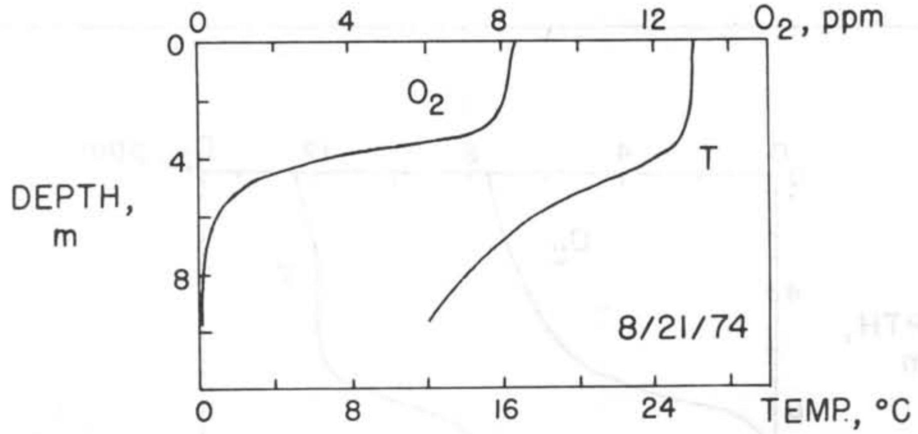
MUDGE POND
(Sharon, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/7/73	2.5	.2	3.11	-	11	33	210	60	590	720
		4	-	-	12	35	220	50	450	720
		8	-	-	11	30	200	60	570	680
4/30/74	2.5	.2	3.02	-	1	23	40	140	330	520
		4	-	-	1	27	40	150	330	550
		8	-	-	1	33	40	210	440	620
7/11/74	4.5	0-3	2.66	2.0	5	17	20	40	330	460
		4	-	-	1	12	20	80	320	390
		9	-	-	-	32	180	60	-	500
7/30/74	3.8	0-3	2.62	4.2	5	17	0	40	160	400
8/28/74	4.0	0-3	1.74	5.6	10	22	50	10	430	590
		5	-	-	7	18	50	0	260	480
		9	-	-	-	64	150	60	-	700



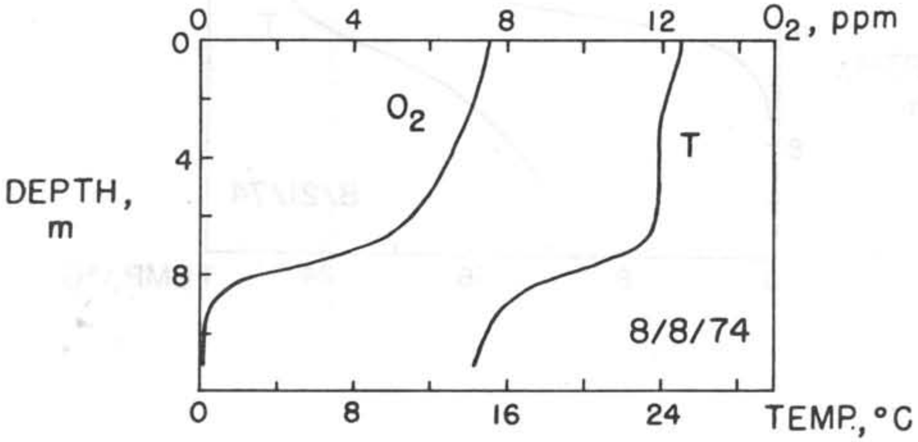
PATAGANSET LAKE
(East Lyme, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/13/73	3.0	.2	.17	-	4	13	80	50	300	370
		5	-	-	4	11	60	50	310	390
		9	-	-	3	14	80	50	280	380
4/10/74	3.0	.2	.06	-	5	15	10	180	270	460
		5	-	-	8	14	30	100	190	320
		9	-	-	8	16	40	90	180	310
7/1/74	2.5	.2	.34	14.3	3	15	0	40	400	760
		5	-	-	3	12	0	40	360	470
		9	-	-	-	15	190	150	-	860
8/21/74	3.0	0-3	.19	13.8	3	15	0	40	390	600
		5	-	-	3	17	0	40	340	570
		9	-	-	-	15	30	270	-	830



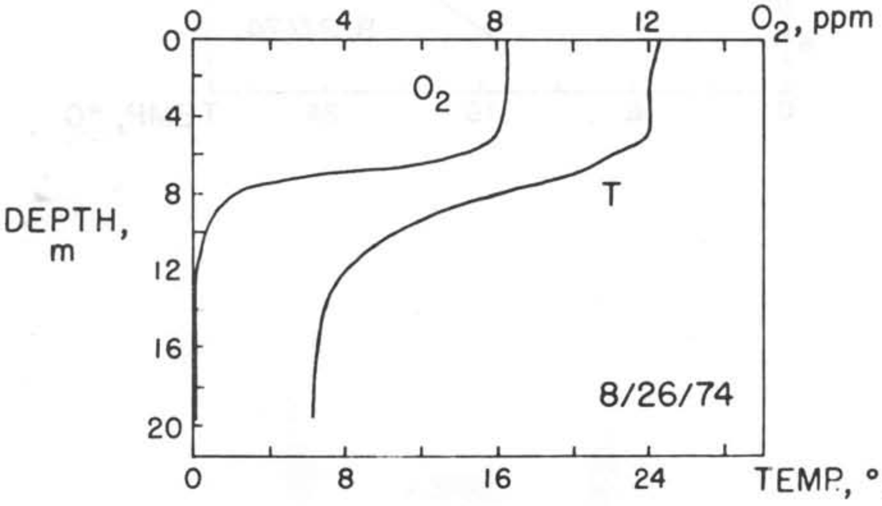
LAKE POCOTOPAUG
(East Hampton, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/15/73	4.5	.2	.12	-	8	16	70	50	310	320
		4	-	-	7	18	40	30	260	300
		8	-	-	7	17	50	30	250	330
4/15/74	2.5	.2	.10	-	6	16	40	220	440	520
		4	-	-	5	19	50	190	390	500
		8	-	-	4	18	40	240	440	500
7/9/74	4.5	0-3	.16	1.7	5	19	30	60	310	370
		4	-	-	9	15	20	110	300	360
		7	-	-	4	15	20	70	260	280
		9	-	-	-	25	90	30	-	340
8/8/74	4.3	0-3	.16	3.2	7	19	60	20	380	430
9/5/74	2.0	0-3	.17	15.5	14	36	50	10	200	460
		4	-	-	12	34	100	10	250	440
		7	-	-	12	35	130	10	260	350
		9	-	-	21	42	390	50	470	750



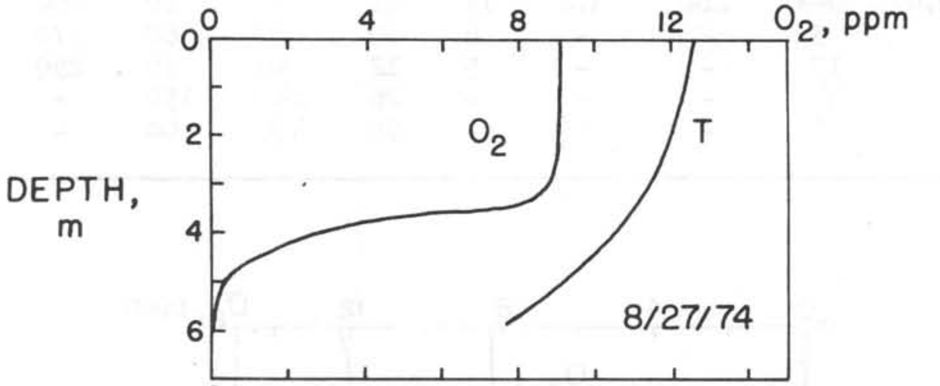
QUASSAPAUG LAKE
(Middlebury, Woodbury, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/5/73	2.2	.2	.15	-	6	19	40	90	320	410
		5	-	-	6	17	40	90	320	440
		10	-	-	6	18	60	50	270	360
		15	-	-	5	20	130	50	360	430
4/22/74	2.5	.2	.10	-	3	16	10	60	260	390
		5	-	-	4	15	20	110	310	440
		10	-	-	3	16	0	80	290	410
		15	-	-	3	15	40	160	300	500
6/27/74	6.8	0-3	.15	3.2	6	9	30	50	250	480
		5	-	-	5	13	20	50	260	310
		10	-	-	2	14	90	110	350	570
		15	-	-	4	21	270	130	550	650
		19	-	-	-	41	460	210	-	970
7/23/74	7.5	0-3	.13	2.3	5	12	50	30	350	470
8/26/74	6.0	0-3	.14	3.2	14	21	30	20	290	430
		5	-	-	6	19	20	60	270	380
		10	-	-	5	12	40	70	250	340
		14	-	-	-	26	240	150	-	660
		18	-	-	-	50	430	100	-	820



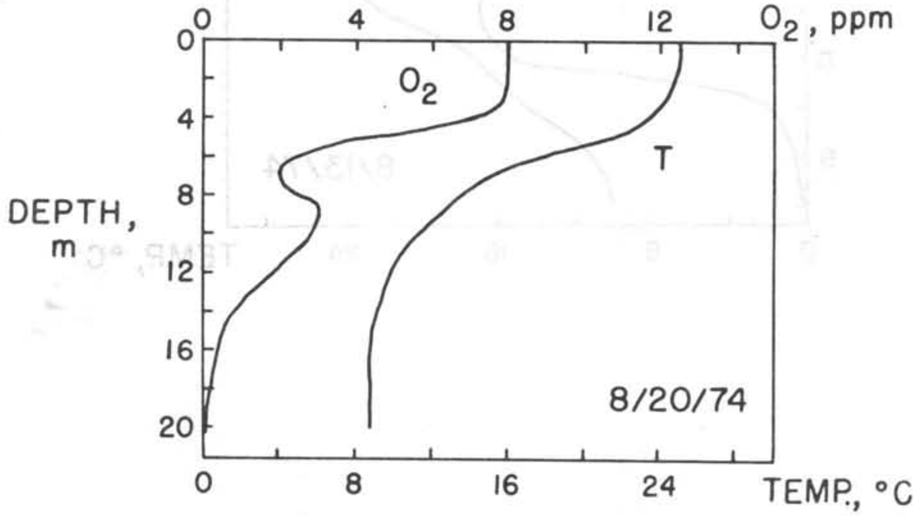
ROSELAND LAKE
(Woodstock, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	—— m	——	meq/l	——			ppb			——
10/23/73	-	.2	.48	-	15	24	90	390	760	900
		3	-	-	14	31	80	330	720	880
		5	-	-	12	37	120	380	720	970
5/2/74	2.0	.2	.30	-	9	30	0	500	810	950
		3	-	-	10	34	30	500	750	930
		5	-	-	10	38	30	500	800	980
7/17/74	2.5	0-2	.48	31	18	47	110	260	890	1220
		3	-	-	21	48	180	290	920	1140
		5	-	-	92	125	800	130	980	1520
8/27/74	3.0	0-3	.53	9.9	12	29	40	30	410	650
		5	-	-	-	114	320	230	-	1390



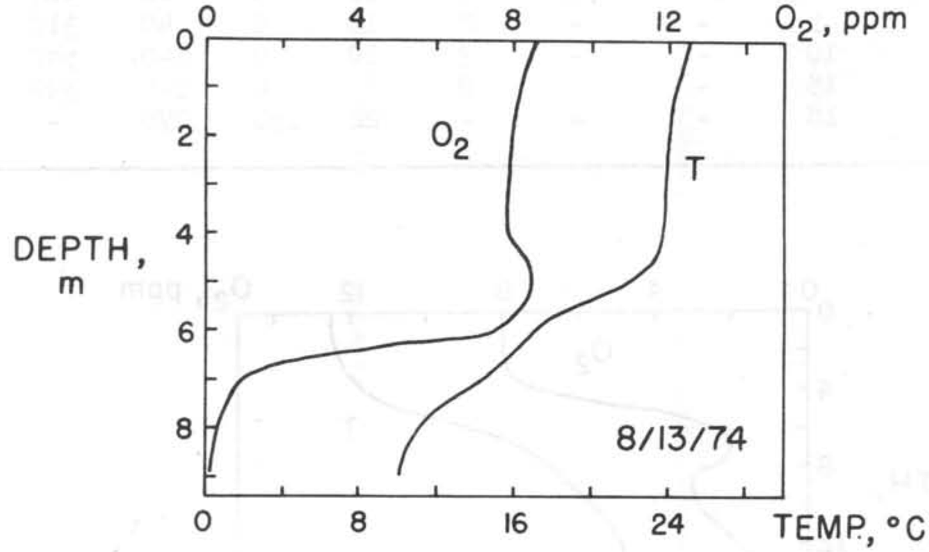
SHENIPSIT LAKE
(Ellington, Tolland, Vernon, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
10/25/73	2.5	.2	.15	-	7	11	40	40	200	350
		5	-	-	5	9	50	40	160	320
		10	-	-	10	10	70	40	190	490
		15	-	-	15	923	350	60	57	680
4/22/74	3.0	.2	.09	-	12	18	40	190	380	410
		5	-	-	10	18	10	240	400	480
		10	-	-	9	17	40	190	410	420
		15	-	-	10	21	80	190	380	450
6/28/74	4.5	.2	.24	5.9	5	11	20	170	350	430
		5	-	-	5	16	40	130	300	360
		10	-	-	5	11	80	260	460	500
		15	-	-	7	15	120	270	610	610
8/20/74	3.5	0-3	.16	5.3	3	10	0	40	400	560
		5	-	-	2	10	0	40	310	410
		10	-	-	3	10	0	240	540	540
		15	-	-	2	10	0	140	390	490
		18	-	-	-	22	150	270	-	870



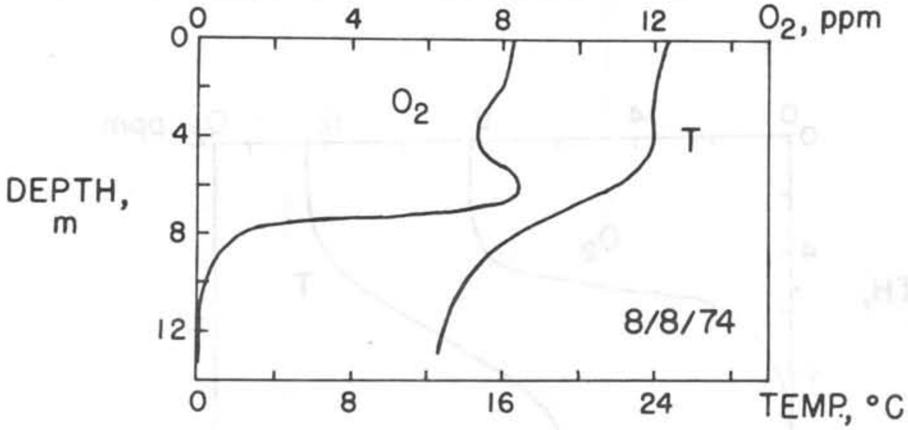
TAUNTON POND
(Newtown, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/2/73	4.5	.2	.49	-	55	77	260	90	540	570
		4	-	-	63	84	260	90	530	610
		8	-	-	62	84	280	40	470	530
4/29/74	3.5	.2	.42	-	8	21	50	10	210	350
		4	-	-	7	24	50	10	270	420
		8	-	-	4	27	40	10	300	360
8/13/74	3.3	0-3	.45	5.5	6	22	40	0	410	690
		4	-	-	7	18	10	0	270	360
		8	-	-	19	151	50	0	690	870



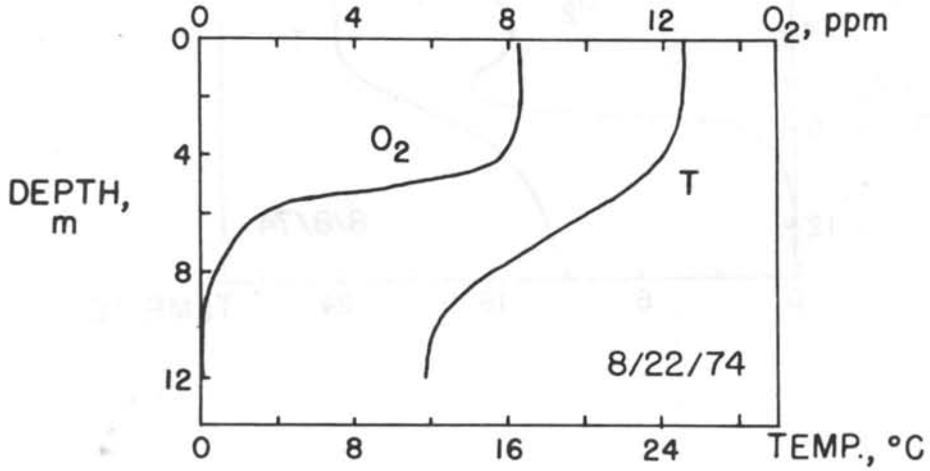
TERRAMUGGUS LAKE
(Marlborough, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/15/73	5.5	.2	.23	-	8	14	30	50	270	310
		4	-	-	8	15	20	40	260	300
		8	-	-	6	12	10	40	260	260
		10	-	-	8	12	10	40	230	310
4/15/74	4.4	.2	.19	-	2	22	40	170	430	490
		4	-	-	4	22	20	180	370	420
		8	-	-	4	21	30	170	330	410
8/8/74	6.0	0-3	.26	2.4	3	14	60	110	470	590
		4	-	-	2	10	10	80	200	330
		8	-	-	4	25	10	60	260	390



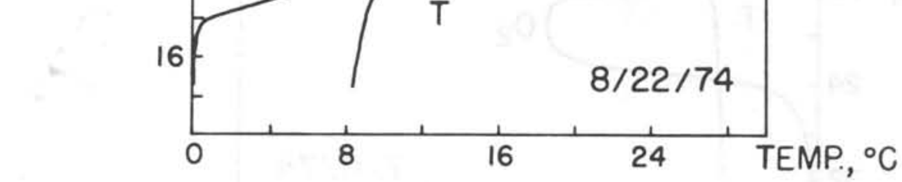
WARAMAUG LAKE
(Warren, Washington, Kent, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m	m	meq/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb
11/5/73	2.0	.2	.41	-	10	53	40	50	300	550
		4	-	-	7	59	20	50	230	510
		8	-	-	9	62	10	30	240	520
4/30/74	2.0	.2	.34	-	2	25	50	80	220	470
		4	-	-	3	28	40	80	220	460
		8	-	-	2	28	90	80	270	490
7/2/74	2.3	.2	.38	13.1	7	24	0	70	370	600
		4	-	-	9	36	0	20	370	510
		8	-	-	-	115	310	150	-	840
8/22/74	3.2	0-3	.43	9.0	12	24	40	70	410	670
		4	-	-	10	21	30	30	260	430
		8	-	-	-	57	240	180	-	980



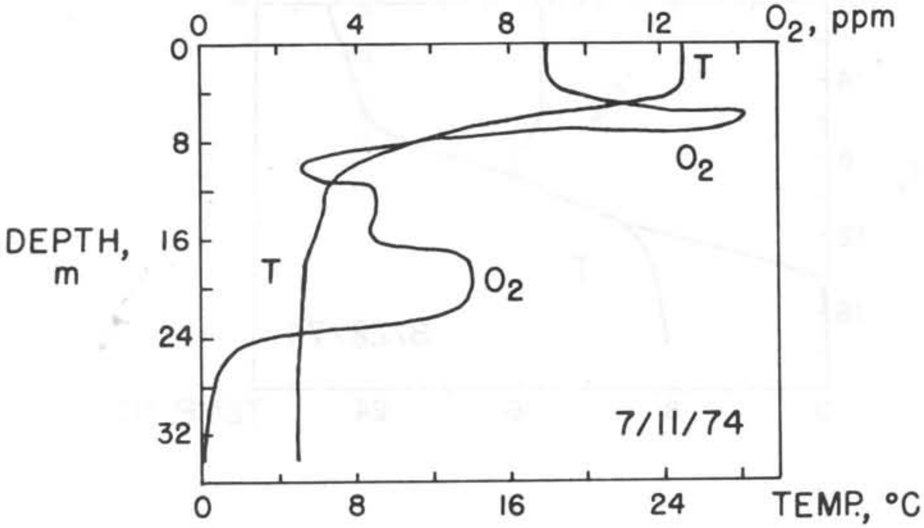
WEST HILL POND
(New Hartford, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m		meq/l	ppb						
9/26/73	-	.2	-	-	7	9	40	30	230	280
		10	-	-	4	10	40	20	240	300
		14	-	-	4	10	200	70	420	420
4/23/74	5.5	.2	.13	-	3	9	30	70	190	260
		5	-	-	3	8	30	60	270	270
		10	-	-	4	10	20	20	220	210
		14	-	-	4	7	0	20	160	310
7/2/74	6.8	.2	.16	1.8	5	8	20	30	180	190
		5	-	-	3	8	20	30	160	200
		10	-	-	3	9	0	50	190	240
		15	-	-	3	14	20	50	240	310
8/22/74	7.2	0-3	.13	1.2	6	6	30	70	250	300
		5	-	-	3	9	40	30	210	280
		10	-	-	4	14	60	30	170	280
		14	-	-	-	16	50	50	-	370



WONONSCOPOMUC LAKE
(Salisbury, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m		meq/l	ppb						
10/17/73	4.3	.2	2.00	-	7	22	10	30	320	360
		5	-	-	8	18	10	10	330	400
		10	-	-	8	107	30	10	290	780
		15	-	-	12	30	50	10	330	390
		25	-	-	350	355	1450	60	1610	1810
5/7/74	1.0	.2	2.50	-	5	50	30	50	310	740
		5	-	-	3	52	10	40	330	810
		10	-	-	4	44	30	40	240	740
		15	-	-	7	40	20	40	300	600
		25	-	-	7	29	30	40	390	520
7/11/74	7.3	0-3	2.18	0.7	2	12	20	40	360	400
		5	-	-	1	13	20	40	380	460
		10	-	-	5	123	0	30	190	1160
		15	-	-	4	31	10	40	400	560
		20	-	-	10	18	130	40	400	490
		25	-	-	-	192	530	50	-	990
9/4/74	8.2	0-3	2.07	2.4	7	16	40	10	270	620
		5	-	-	26	54	240	10	490	700
		10	-	14.6	5	159	0	10	350	1400
		15	-	-	5	25	0	10	240	300
		20	-	-	62	74	390	10	640	610
		25	-	-	276	296	870	0	1260	1380



LAKE ZOAR
(Oxford, Monroe, Newtown, Southbury, CT)

Date	Transparency	Sample depth	Alkalinity	Chlorophyll-a	Soluble P	Total P	NH_4-N	NO_3-N	Soluble N	Total N
	m		meq/l	ppb						
10/4/73	1.5	.2	2.02	-	33	102	20	420	-	1420
		5	-	-	34	52	110	430	-	950
		9	-	-	47	62	120	-	-	-
		15	-	-	44	62	100	530	-	950
5/31/74	2.2	.2	1.53	-	32	65	160	310	700	810
		5	-	-	35	63	160	240	590	690
		10	-	-	36	80	170	230	600	700
		15	-	-	40	68	160	210	590	650
7/3/74	1.0	.2	1.67	103	12	77	40	50	240	1090
		3	-	-	23	62	170	190	460	740
		5	-	-	18	49	160	190	510	680
		10	-	-	19	37	160	290	670	680
		15	-	-	32	58	210	390	740	810
		20	-	-	-	84	800	100	-	1140
7/31/74	2.5	0-3	1.81	25	24	60	0	320	680	960
8/29/74	2.1	0-3	1.80	35*	10	62	40	60	400	670
		5	-	-	34	85	180	120	420	680
		10	-	-	75	138	370	230	790	970
		15	-	-	-	207	590	110	-	900
		20	-	-	-	351	1150	110	-	1650

* Treated with $CuSO_4$ on 8/10/74. No suppression of algae apparent on 8/29/74.