Primary Productivity and Chlorophyll *a* of Selected Northern Indiana Lakes

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Introduction

The State of Indiana was required by Section 314 (a) of the Federal Water Pollution Control Act Amendments of 1972 to identify and classify all publicly owned fresh water lakes according to their trophic status. Initially a preliminary limnological survey of all public lakes in the state was undertaken. Subsequent classification using Bon Homme's index (2) placed these lakes into a trophic state ranking. From this information, more intensive studies were implemented on selected "key" or "problem" lakes. Special attention was given those bodies of water where a high degree of cultural eutrophy or a rapid change in the quality of the lake existed.

As part of the intensive survey program, eight lakes in northern Indiana were sampled in the summer of 1976. The study was designed to determine: 1) the rate at which new organic matter is formed and accumulated within the lake under study (primary productivity), 2) the concentration of photosynthetic pigment for estimation of plankton biomass (chlorophyll *a*), and 3) how the previous classification using BonHomme's index (2) compares with the 1976 findings and other classification schemes.

Study Areas

A total of eight lakes was studied in Kosciusko, LaGrange, Noble and Steuben Counties. They range in size from 10 ha. to 325 ha., and represent a wide range of trophic states. Crooked, Webster, Hamilton, and Sylvan are large lakes that are heavily developed and highly recreational. Palestine, Long and Waubee are somewhat smaller but are also developed along a significant portion of their shore line. While only a small portion of Martin Lake is populated, it is being developed at a fast rate. Table I presents a more complete morphometric description of the lakes.

Table 1. *Morphometric characteristics of the eight lakes studied in northern Indiana, 1976.*

Lake	County	Area (ha.)	Volume ($m^3 x 10^6$)	Max Depth (m)	Mean Depth (m)
Crooked	Steuben	325	12.4	23.5	3.8
Webster	Kosciusko	237	8.8	13.7	3.7
Hamilton	Steuben	325	20.5	21.3	6.3
Martin	LaGrange	10	1.1	17.1	11.0
Waubee	Kosciusko	76	5.9	15.5	7.8
Long	Steuben	37	1.9	9.7	5.1
Sylvan	Noble	255	7.6	11.0	3.0
Palestine	Kosciusko	94	1.1	9.0	1.2

Methods

Algal primary productivity was measured *in situ* using carbon-14 methodology. Modification of the procedures outlined by Slack (4), Strickland and Parsons (5), and Vollenweider (13) were utilized. The procedures outlined in this study incorporated suggestions proposed by the Biology Section, Central Regional Lab of Region V, U.S. Environmental Protection Agency.

Samples for determination of primary productivity were collected at depth intervals which varied from 0.25 to 1.0 m (dependent upon the depth of the eupthotic zone) with either an opaque plastic Van Dorn or Kemmer-type sampler. Surfactant washed (Contrad 70), acid washed, and thoroughly rinsed 300 ml BOD bottles were filled from the sampler through a length of rubber tubing. One dark and two light bottles were filled for each depth sampled. The contents of a sterile glass ampoule containing 2.0 ml of C-14 as sodium bicarbonate of known activity (approximately 1 μCi/ml) was injected into the BOD bottle with a 2 ml B-D Cornwall syringe fitted with a 4-inch canula. While adding the C-14, the bottles were either kept in subdued light or enclosed within a black plastic bag. All bottles were placed in light-tight plywood boxes from the time of sample collection until placement in the water column. When all samples at a station had been inoculated, the bottles were suspended at the depth from which the samples had been collected and incubated *in situ* for four hours (generally, between 10:00 a.m. and 2:00 p.m.). Following incubation, 1 ml of formalin was added to each bottle to arrest photosynthesis. Samples were immediately transported to the field laboratory and processed within two to three hours.

In the laboratory a measured aliquot (usually 50 ml) was filtered through a 47 mm, 0.45 μm membrane filter (Millipore-HAW PO4 4700). Vacuum was maintained at less than 200 mm of mercury. A rinse of approximately 10 ml of distilled water was applied and the filter vacuum dried. Each filter was immediately placed in a scintillation vial containing 20 ml of Beckman Filter-Solv liquid scintillation cocktail and stored until counted.

Background samples were prepared by filtering 50 ml of distilled water through a membrane filter and placing the filter in 20 ml of cocktail. Background samples were prepared in triplicate at least once each week throughout the study. Productivity and background samples were counted twice in series for 20 minutes or 10,000 counts and the results averaged.

Counting efficiency was determined by the external standard ratio method. A quench series was prepared using nitromethane as the quenching agent and Beckman Filter-Solv as the cocktail. Primary productivity in mg carbon per cubic meter per hour (mgC/m^3/hr) was calculated using the equation of Saunders (3). The values from the entire eupthotic zone were integrated using the method of Slack (4) and expressed as mgC/m^2/hr.

Samples for analysis of chlorophyll *a* were collected with an opaque plastic sampler. Lake water was transferred to plastic containers and stored in a cooler until processed. Samples were kept in subdued light with the time between collection and processing rarely exceeding two hours.

At the field laboratory, the sample was thoroughly shaken and 200 ml were filtered through a glass fiber filter (Gelman-type AE). When the filter was almost clear, approximately 1 ml of saturated magnesium carbonate suspension was added to the filter followed by a distilled water rinse. The filter was folded with forceps, algae side inward, and wrapped in aluminun foil. The foil packets were placed in labeled 48 x 5 mm plastic petri dishes and immediately frozen. Samples were kept frozen until the chlorophyll was extracted. Replicate samples were run for quality control and consisted of 200 ml aliquots from the same sample container.

The extraction and measurement of chlorophyll *a* in the samples was performed by the Biology Section, Central Regional Laboratory of Region V, U.S. Environmental Protection Agency, according to the fluorometric method of Strickland and Parsons (5). Chlorophyll *a* concentrations were corrected for phaeophytin.

The eight study lakes were ranked and classified based on primary productivity and chlorophyll *a* values. Where the exact trophic status was not delineated by these two parameters, subjective judgments were based on the supplemental data collected. These other data included total phosphorus, nitrate-nitrogen, ammonia, total kjeldahl nitrogen, alkalinity, pH, temperature, dissolved oxygen, Secchi disc readings and light transmittance levels. Secchi disc, total phosphorus and chlorophyll *a* were used to calculate Carlson's Trophic State Index (TSI) (1).

Results

Primary productivity and chlorophyll *a* data for the eight study lakes are summarized in Table 2. Palestine Lake showed the highest primary productivity at 430 $mgC/m^2/hr$ in June. The value dropped somewhat in July and declined further in August. During July, 85 percent of the production in Palestine Lake was restricted to the first meter. In August, when the Secchi disc reading was 0.25 m and the one percent light transmittance level was less than one meter, 100 percent of the primary productivity was found in the first meter. These productivity values did not include that contributed by the extensive macrophyte growth (primarily spatterdock and duckweed) which covered over 40 percent of the lake surface. Although macrophytes were evident in other lakes studied, none approached the dense growth found at Palestine. The chlorophyll *a* values were twice that of any other study lake in July and August, ranging up to 87.8 mg/m^3.

Algal production at Sylvan Lake increased as the summer progressed. Eighty-five percent of the primary productivity within the euphotic zone was confined to the first meter in August. Unlike Palestine Lake, the density of macrophytes was small, contributing little to the total productivity of the lake. The rapid extinction of light in the water column (one percent light transmittance level at 2.5, 1.75, and 1.75 m in June, July and August, respectively) from the biogenic turbidity effectively limited macrophyte growth. This observation was also noted by Wetzel (14).

Long Lake has a history of severe algal problems according to Indiana State Board of Health records (ISBH unpublished) and (5). The findings of this

TABLE 2. *Primary productivity (mg C/m²/hr) and mean chlorophyll **a** (mg/m³) values of the eight study lakes.*

Lake	June			July			August		
	Primary Prod.	Clorophyll *a*		Primary Prod.	Clorophyll *a*		Primary Prod.	Chlorophyll *a*	
		Mean	Std. Dev.		Mean	Std. Dev.		Mean	Std. Dev.
Crooked	54	6.3	1.6	120	4.2	1.4	130	5.2	1.7
Webster	56	4.7**	—	120	5.5**	—	160	7.5	3.9
Hamilton	78	3.4	1.0	240	11.2	3.5	90	6.5	2.9
Martin	58	8.4	0.5	25	6.0	2.5	150	14.1	11.4
Waubee	120	5.7**	—	180	17.1**	—	290	41.7	8.9
Long	90	13.7	4.9	240	26.0	3.0	200	36.5	3.9
Sylvan	200	13.6	2.2	230	18.4	6.2	380	31.1	2.6
Palestine	430	12.4*	—	400	65.4	21.2	320	87.8	3.8

* Single value only

** Only two values used to calculate the mean study indicated it to be a highly productive lake (240 mgC/m^2/hr in August). The chlorophyll *a* values were high in all months sampled, indicating no decline from the National Eutrophication Survey (NES) findings of 1973 (8).

Primary productivity in Waubee Lake reached 290 mgC/m^2/hr in August. The high chlorophyll *a* values, also found this month, indicated the fertile nature of this lake. Only Palestine and Sylvan indicated higher productivity during the study, while only Palestine had higher chlorophyll *a* concentrations.

In Martin Lake, primary productivity in June and August were comparable to the values found at Webster, Crooked and Hamilton Lakes. However, productivity in July was much lower than during the same sampling period at the above-mentioned lakes.

Hamilton Lake experienced a large increase in productivity in July. Algal clumping was apparent in some areas of the lake, while Secchi disc readings and light transmittance levels indicated the increase in biogenic turbidity. Chlorophyll *a* values in July were also the highest found at this lake. Both the June and August samples indicated a lowered rate of production and chlorophyll *a*.

In both Webster and Crooked Lakes primary productivity values were low initially and increased as the summer progressed. Both also displayed low chlorophyll *a* values ranging from 4.2 to 7.5 mg/m^3.

Discussion

Rankings and classifications from this study and other methods are shown in Table 3. Crooked, Hamilton and Webster Lakes exhibited similar trophic characteristics. This study classified Crooked Lake eutrophic, not meso-eutrophic as indicated by both NES (6) and ISBH (unpublished). However, by all classification methods it was considered the least eutrophic. We based our ranking on the low productivities and chlorophyll *a* values found. In addition, the distribution of productivity in the water column was indicative of a eutrophic lake (15) during July and August. Productivity and chlorophyll *a* values were similar in Webster and Crooked Lakes but the values for Webster were slightly higher (except for the June chlorophyll *a* value). The large increase in productivity and chlorophyll *a* values in Hamilton Lake during July were responsible for ranking this lake more eutrophic than Webster Lake. These July figures may indicate that this lake is more susceptible to algal blooms. This ranking corresponds with the NES results (6, 7, 12). However, both earlier ISBH data (unpublished) and TSI (1) show Hamilton Lake to be less eutrophic than Webster Lake. Thus, the importance placed on different parameters may influence the ranking of these two lakes.

The relatively low ranking assigned Martin Lake was not expected since the other two lakes in the chain (Oliver and Olin) were considered to be mesotrophic by NES (9, 10) and the earlier ISBH survey (ISBH, unpublished). Impact from non-point source runoff in recent years has been decisive in changing the trophic status of this lake. Heavy rain in the watershed the day before the July sampling brought in an excessive amount of sediment from a soybean field approximately one-half mile away. This inorganic turbidity restricted the euphotic zone to the

TABLE 3. *Ranking of eight study lakes by different classification systems.*

Lake	ISBH '76	Trophic State Index (1)	Indiana Lake Class System (2)	NES-1973 (6, 7, 8, 11, 12)
Crooked	1	1	1	1
Webster	2	3	4	2
Hamilton	3	2	2	3
Martin	4	4	3	—
Waubee	5	5	6	—
Long	6	6	5	5
Sylvan	7	7	7	4
Palestine	8	8	8	—

upper 1.5 m. In addition, overcast weather conditions reduced incident solar radiation, further limiting the energy available for algal photosynthesis. These conditions were probably responsible for the low productivity found in July, and it is the opinion of these investigators that this measurement is not indicative of the true trophic status of Martin Lake.

Waubee, Long and Sylvan Lakes appear to be similar when viewing productivity and chlorophyll *a* data. The ranking of Waubee Lake as less eutrophic reflects the chlorophyll *a* and productivity found in June and July. Although Long Lake showed chlorophyll *a* values in excess of Sylvan Lake in all months, the productivity depth profile (ISBH, unpublished) in August showed Sylvan Lake to be in a more advanced eutrophic state.

Palestine Lake was found to be highly eutrophic, much more so than the other lakes in the study. Based on ISBH surveys (ISBH, unpublished), this lake has a history of problems related to its highly eutrophic state and these problems were evident at the time of sampling.

Conclusions

1. Crooked Lake was considered the least eutrophic of the study lakes.
2. Hamilton and Webster Lakes generally exhibit characteristics of moderate eutrophy, but are subject to algal blooms which are indicative of their trophic variability.
3. Accelerated eutrophication might be expected in Martin Lake due to the impact of heavy non-point source runoff. If not controlled, this trend may spread to the other lakes in the chain.
4. Sylvan, Long and Waubee Lakes appear to be in an advanced eutrophic state.
5. Based on the consistently high productivity and chlorophyll *a* values, Palestine Lake was considered the most eutrophic of the eight lakes studied.
6. Various lake classification schemes may produce different results. Differences between the classification scheme developed in this study and those developed from earlier studies may reflect actual changes in trophic state. However, differences in techniques, parameters, sampling dates and subjective observations may explain some of the differences.

Disclaimer

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