A Study of the Relationship Between Phytoplankton Abundance and Trace Metal Concentrations in Eutrophic Lake Charles East, Using Correlation Techniques

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Introduction

While phytoplankton succession is familiar, determination of the specific biological and environmental factors which influence the timing of relative species abundances remains a central question for aquatic ecologists. Recently, Porter (13) has reviewed the literature on the relative importance of chemical (nutrient availability), physical (light, temperature), and biological (zooplankton grazing) factors and concluded that all three interact to determine which algal species will occur and become dominant in a lake at any given moment. However, much remains to be learned before ecologists arrive at a general model to explain the temporal changes in species composition which characterize aquatic communities. Goldman (5) suggests that this statement is especially significant with regard to the role of trace metals, which may play a dual role in phytoplankton species succession. Trace metals may function either as limiting nutrients (6), or as substances which differentially inhibit algal photosynthesis and growth (16,18,19) thereby, influencing species succession (12, 17).

Chau *et al.* (2) studied relationships between levels of Cd, Cr, Co, Cu, Fe, Pb, Mn, Mo, Ni, Sr, V, and Zn and the subsurface concentrations of chlorophyll in Lake Ontario during 1969. They reported positive correlations between chlorophyll and Zn, and combinations of Zn, Cu, and Fe. The purpose of this paper is to examine the results of a similar study using data on the phytoplankton community and physio-chemical parameters collected from Lake Charles East, Indiana. In the course of this study the levels of 10 trace metals, 8 of which were considered by Chau *et al.* (2) were measured. Additionally, measurements of the levels of arsenic and selenium were included in the present study. Comparisons between the total algal standing crop and trace metal levels, were augmented by attempts to correlate trace metal levels with the abundances of classes of algae and of individual species. Such comparisons are not possible when algal abundance is measured as chlorophyll. Therefore, this study not only contributes information on two trace metals not considered by Chau *et al.* (2), but also provides information on the interaction between trace metal levels and individual algal species abundances under field conditions.

TABLE 1. *Morphometric and geographic characters for Lake Charles East, Indiana*

Maximum length	617.2 m
Maximum width	237.7 m
Maximum depth	3.1 m
Mean depth	2.1 m
Relative depth	.9 m
Surface area	8.6 hectares
Volume	184952.5 m^3
Shore line length	1563.6 m
Shore line development	1.5
Elevation	311.0 m
Latitude	41.38 N
Longitude	85.00 W

Study Area

Lake Charles East is a small, shallow, man-made lake located approximately 7 kilometers north of Angola, in Steuben County, Indiana. Pertinent morphometric and geographic characteristics are listed in Table 1. The lake is traversed by 2 bridges which are part of U.S. Interstate Highway 69. Using the criteria of Wetzel (22) the lake may be described as hypereutrophic. During the study period the mean value for total phosphorus (particulate plus reactive) was 301 (±66.5) $\mu g/l$, and the mean total algal biomass was 160.3 (±140.1) cm^3/m^3. Additional data on the chemical and physical characteristics of Lake Charles East are given in Table 2.

TABLE 2. *Chemical, physical, and biological parameters for Lake Charles East from April—October, 1976.*

	$\bar{X}$	s
Total phosphorus	301.0	66.5 $\mu g/l$
Dissolved phosphorus	53.4	48.1 $\mu g/l$
Temperature	21.6	3.8 °C
pH	8.5	0.7
Dissolved oxygen	6.6	2.0 mg/l
Alkalinity	11.5	28.5
Ammonia-Nitrogen*	0.7	0.7
Nitrite Nitrate-Nitrogen*	0.04	0.04
Total Organic Nitrogen*	1.8	1.0
Hardness	148.3	35.6
Calcium	78.2	37.6
Sulfates	16.6	2.1
Total Algal Biomass	160.3	140.1 cm^3/m^3

*mg/l as nitrogen

Methods of Analysis

One liter samples were collected with a plastic Kemmerer water sampler from 0.5 m depth at a sampling station near the deepest part of the lake. Samples were filtered through fiber glass filters (1 μm pore size) within one-half hour or collection. One hundred milliliters were pipetted into acid-washed ground glass-stoppered bottles, preserved with 5 drops of 50% perchloric acid and transported to the laboratory for analysis. The trace metal concentrations were determined using a Perkin-Elmer model 305 atomic absorption spectrophotometer equipped with a graphite furnace and an automatic sampling device. Additional chemical parameters were determined using the techniques outlined in Standard Methods (1).

One liter phytoplankton samples were collected and fixed with Lugol's solution (20). Phytoplankton enumeration was accomplished using the stained-organism, membrane filter technique described by DeNoyelles (4). Cell counts were converted to biomass units (cubic micrometers) using species volumes given by Nauwerck (9). Climatic data were obtained from a local weather station. Data on the traffic flow across the two bridges of Interstate 69 were obtained from the Indiana Department of Highways. Statistical treatment of the data was facilitated by use of the programs in the Statistical Package for the Social Sciences (10).

TABLE 3. *Trace metal concentrations in Lake Charles East, Indiana during April to October, 1976. Values are from samples collected from 0.5 meter and are in units of ug/l.*

Date	FE	Mn	Cu	Cr	Cd	As	PbZn	Ni	Se
Apr 15	165	5	29	15	nd	x	318	365	x
May	180	13	24	18	nd	100	335	300	37
Jun 8	186	4	7	1	72	502	6539		
Jun 17	307	43	5	11	1	65	551	85	37
Jun 24	216	37	5	6	2	61	553	103	34
Jul 8	160	51	7	1	3	57	596	83	30
Jul 21	143	40	8	1	3	60	596	40	30
Jul 28	90	10	8	1	3	60	554	33	30
Aug 4	108	23	8	1	2	58	784	28	31
Aug 18	170	97	7	2	1	70	1186	56	44
Aug 25	215	158	6	3	1	84	1357	90	55
Sep 15	295	115	45	4	2	60	549	83	30
Oct 4	655	510	30	8	3	56	257	90	30
MEAN	222	88	14	6	2	67	625	109	36
S.D.	144	135	13	5	1	13	322	103	8

nd, not detected; x, not determined

Results and Discussions

Table 3 lists the measured concentrations for each of the trace metals monitored during this study. The general trends for temporal metal distributions were as follows. Arsenic, chromium, and nickel were relatively high during the spring and decreased through the summer and autumn. Arsenic exhibited a second peak in late August. Cadmium was low through the spring, peaked in midsummer, declined, and then peaked again in late autumn. Copper displayed a vernal and an autumnal peak and was relatively low through the summer. Iron, lead, manganese, and selenium exhibited general increases from spring to late autumn. Zinc displayed three peaks: spring, midsummer, and autumn.

Metal concentrations in Lake Charles are higher in every case except zinc, than those reported by Wetzel (220 for 8 lakes in northeastern Indiana. Concentrations of Pb, Ni, Fe, and Mn are higher than the average level reported by Kopp and Kroner (8) for lakes and rivers in the United States, while Zn and Cd are lower than the values given by Kopp and Kroner (8).

Figure 1 shows the relationship between Pb concentration in Lake Charles and the traffic density over the bridges of Interstate 69 which cross the lake. The functional relationship between Pb concentration and traffic density was determined using Bartlett's 3-group method for Model II regression (14,15). The regression equation is, (Pb) = -707.3 + 0.068 x Traffic density. The 95% confidence limits on the slope are lower limit = 0.053 and upper limit = 0.124.

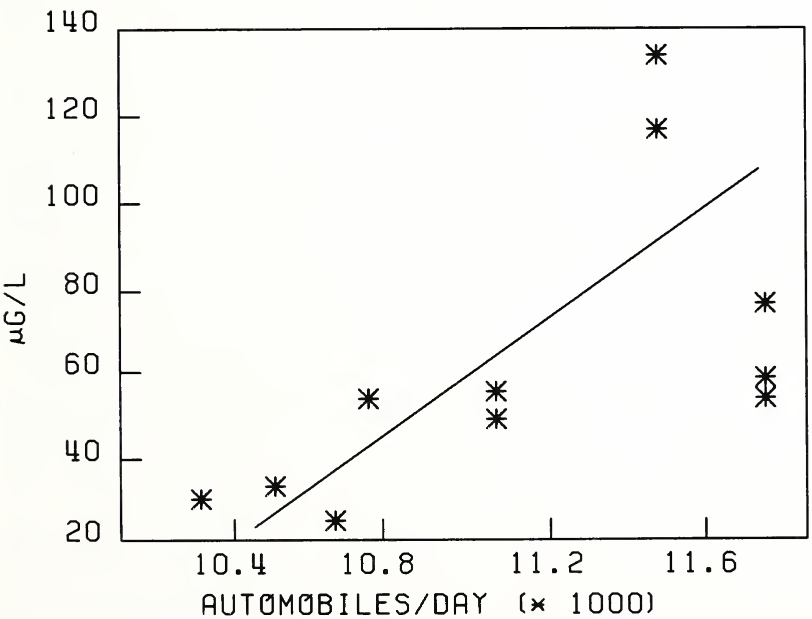

FIGURE 1. *This figure shows the relationship between lead concentration and the traffic density across the two bridges which bisect the lake. The verticle axis shows lead concentration in ug/l while, the horizontal axis refers to the mean daily number of automobiles across the bridges.*

Cowgill (3) reported that rainfall during the previous 7 days and zinc concentrations in Linseley Pond, Connecticut, were correlated, suggesting that zinc dynamics were closely related to rainfall. This does not appear to be so for Lake Charles. Neither, zinc nor any other metal measured by us showed a significant correlation with rainfall.

TABLE 4. *The phytoplankton species sampled in Lake Charles East during the study period. The values given are the mean and standard deviation of three samples taken at 5.0, 1.5, and 2.0 meters.*

Species	$\bar{X}$	S
Oscillatoria Agardhii	3147	5500
Anabaena circinalis	5223	6948
Microcystis aeruginosa	406	598
Aphanizomenon flos-aquae	26	47
Merismopedia sp.	57	80
Trachelomonas hispida	132	203
Scenedesmus dimorphus	15	31
S. quadricauda	676	1209
S. arcuatus	11	41
Ankistrodesmus falcatus	11	40
Pediastrum duplex	35	76
Cosmarium sp.	15	42
Dactylococcus sp.	68	170
Staurastrum sp.	38	78
Tetraedron sp.	750	2375
Chlamydomonas sp.	403	1038
Cyclotella bodanica	878	2730
Synedra ulna	18	36
Navicula sp.	64	97
Cryptomonas ovata	10489	21253
Gymnodinium palustre	916	1304

Phytoplankton species succession in Lake Charles East followed the typical pattern described by Hutchinson (7) for temperate eutrophic lakes. Species and their mean abundances (counts/ml) are given in Table 4. In the spring Cryptophyta, Bacillariophyceae, and Chlorophyta were dominant. Thereafter, with the exception of a diatom bloom (*Cyclotella bodanica*) in mid-June, Cyanophyta remained dominant until mid-September. During this period the dominant blue-green species shifted according to the following scheme: *Aphanizomenon flos-aquae* to *Anabaena circinalis* to *Microcystis aeruginosa.*

Other species which contributed up to 20% of the total biomass during this period were *Gymnodinium palustre, Cryptomonas ovata,* and *Scenedesmus quadricauda.* By mid-September, *Cryptomonas ovata* had become the dominant species. The general pattern is evident in Figure 2.

Using bivariate correlation analysis the matrix of algal abundances, trace metal concentrations, and physico-chemical parameters were scanned for statistically significant relationships. The null hypothesis is that there exists no relationship between trace metal concentration or physico-chemical parameter and algal abundance. Algal abundance was represented by three types of variables. They are total algal biomass, biomass of classes of algae (i.e. blue-greens, greens, diatoms, *etc.*), and biomass of individual species. Since there is *a priori* evidence to suggest that any given correlation may be positive or negative, a two-tailed test of significance was employed. A number of statistically significant correlations were found. These are listed in Table 5. The question arises as to whether or not the significant correlation observed between the abundance of species A and trace metal B is real, or whether it merely reflects the

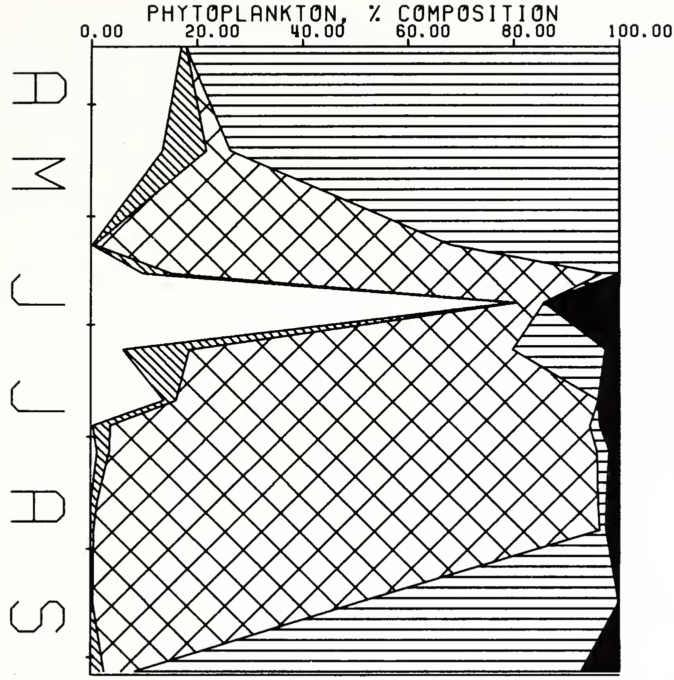

FIGURE 2. *This figure shows the percent contribution of the Chrysophyta (white), Chlorophyta (diagonal), Cyanophyta (cross-hatched), Cryptophyta (vertical), and Pyrrhophyta (solid) to the total algal biomass during the study period.*

TABLE 5. *Pearson correlation coefficients between algal variables and the physico-chemical and trace metal parameters measured in this study. Correlations are significant at the 0.05 level.*

Oscillatoria Agardhii—Pb,Se,A,H,Ca
Microcystis aeruginosa—Pb,PH,A,H,Ca
Trachelomonas hispida—Cr,Zn,A,H,Ca
Navicula sp.—Cr,Ni,T,H,Ca
Scenedesmus quadricauda—Pb,PH,A,H,Ca
Ankistrodesmus falcatus—Cr,As,Ni
Cosmarium sp.—Cu,TPO4
Cryptomonas ovata—Cu,TPO4
Aphanizomenon flos-aquae—Cr,As
S. dimorphus—Pb,Se
Dactylococcus sp.—Zn,Si,A,SO4
Merismopedia sp.—Pb,TP04,OPO4
Pediastrum duplex—Si,PH
S. arcuatus—Fe,Mn,NH3
Cyanophyta—Cr,Pb,Se,PH,A,H,Ca
Total Algal Biomass—pb,PH

A, represents alkalinity; H, represents hardness; T, represents temperature; TPO4, represents total phosphorus; OPO4, represents dissolved phosphurs; NH3, represents ammonia-nitrogen.

fact that both are correlated with a third factor, C. Partial correlation techniques provide a means of answering this question, at least in terms of the variables measured during this study. For example, in the case of the correlations observed between *T. hispida* and Cr, Zn, alkalinity, hardness, and Ca, partial correlations techniques allow calculation of the correlation between *Trachelomonas* abundance and Zn while statistically holding Cr, alkalinity hardness, and Ca constant. A resulting significant partial correlation coefficient suggests that in terms of the variables considered, the correlation between *Trachelomonas* and Zn is not a spurious one (10). Table 6 list the significant correlations between algal variables and the trace metal concentrations.

TABLE 6. *Significant partial correlation coefficients between algal variables and physico-chemical and trace metal paramets. Coefficients are significant at the 0.05 level, 'ns' indicates that no significant correlations were observed.*

Total Algal Biomass		ns
Chlorophyta		ns
Chrysophyta		ns
Pyrrhophyta		ns
Cryptophyta		ns
Cyanophyta—Se		0.83
Microcystis aeruginosa—Pb		0.84
Scenedesmus quadricauda—Pb		0.67
Trachelomonas hispida—Car		0.77
Aphanizomenon flos-aquae—Cr		0.51
Navicula sp.—Ni		0.75
S. arcuatus—Mn		0.77
T. hispida—Zn	-0.68	

Chau *et al.* (2) reported positive correlations between subsurface chlorophyll concentrations for Zn and combinations of Zn and Cu and Zn and Fe. Lake Charles total algal biomass was not correlated with these or any other trace metal considered here. However, total blue-green algal biomass was significantly correlated with Se concentration. Selenium was not reported by Chau *et al.* (2). The significant species abundance—trace metal correlations involve 3 species of green algae, 2 of blue-green, and 1 diatom species. The trace metals include 2 which are known to be required micronutrients, Zn and Mn (11), while the role of Pb, Cr, Ni, and Se in natural waters still needs to be established. The observed correlations are all positive except for the one between Zn and *T. hispida.*

Care must be used in ascribing ecological meaning to these correlation coefficients. A significant correlation coefficient implies that the two variables covary in a manner that does not seem likely to be due to chance alone (15). With this caution, we suggest that the positive correlations between species abundance and trace metal concentration reported here may be interpreted as meaning that a given species may be more tolerant of higher levels of the trace metal it is correlated with, than another noncorrelated species. A second interpretation may be that a nutrient limitation is involved (5). Controlled bioassy experiments presently underway should provide a clearer indication as to which interpretation is more appropriate for the cases reported above.

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