# NUTRIENT—PRIMARY PRODUCTION RELATIONSHIPS IN CENTRAL LAKE ERIE: A SIMPLE CORRELATION APPROACH[1]

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## ABSTRACT

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Correlation coefficients were determined between primary production, phytoplankton biomass as chlorophyll *a*, temperature, and forms of N, P, and Si in Lake Erie during 10 cruises between April and December, 1970. The Central Basin was emphasized due to too few stations in the Eastern and Western Basins for significant statistical analyses. Primary production was significantly affected by nutrients in the summer when concentrations in the water were quite low. Temperature appeared to be of secondary importance. Chlorophyll *a* rarely correlated with any of the measured parameters. Dissolved inorganic nitrogen ($NO_3^- + NO_2^-$) appeared to be more limiting in the summer than phosphorus. A highly significant positive relationship between particulate phosphorus and primary production was found on all cruises suggesting the use of the measurement of particulate phosphorus as a possible biomass indicator.

Lake Erie is well-known to both the layman and limnologist as a highly productive ecosystem exhibiting the symtoms of cultural eutrophication, especially in its Western Basin. Nutrient inputs, mainly from U.S. domestic and industrial sources, have been suggested as the cause of this high production (IJC, 1969). The key nutrient involved in such problems has been felt to be phosphorus (see Vollenweider *et al*, 1974), and this relationship has been the basis of phosphorus control of effluents as set forth in the Canada-U.S. agreement of 1972.

Much controversy on the role of phosphorus as a "limiting nutrient," came out in the early 1970's culminating in a special symposium entitled "Nutrients and Eutrophication: The limiting-nutrient controversy" (Likens, 1972). This paper will attempt to investigate the interrelationships between selected environmental parameters, both nutrients and temperature, and observed patterns of both algal biomass as measured by chlorophyll *a* and primary production in Lake Erie. Temporal and spatial distributions of these biological parameters have been previously discussed by Glooschenko *et al* (1974a, b) and temperature and nutrients by Gächter *et al* (1974).

It is the opinion of the author that the word "limiting factor" is a highly confused term in the literature due to arguments over whether there can be only one limiting factor in the sense of Leibig's "Law of the Minimum" (Hutchinson, 1973; O'Brien, 1972) or several simultaneous limiting factors. At a given time in Lake Erie, the phytoplankton consist of many taxa of algae, each with different physiological responses to environmental parameters such as light, temperature, individual nutrients, and potential inhibitors such as trace metals. The author, therefore, feels that in utilizing integrated terms such as biomass and production the idea of a single limiting factor is hard to apply.

## METHODS

The data used in this paper were collected during the 1970 field season on 10 cruises between April to December, 1970, from 14 stations in the Central Basin of Lake Erie (see station map in Glooschenko *et al*, (1974a). The biological parameter chosen for primary production was $^{14}C$ uptake and for biomass, chlorophyll *a* corrected for the presence of pheopigments (Glooschenko *et al*, 1974a, b). Chemical parameters of phosphorus utilized were total phosphorus (TP) (the sum of dissolved inorganic, organic and particulate inorganic plus organic phosphorus), total filtered phosphorus (TFP) (dissolved inorganic and organic phosphorus), soluble reactive phosphorus (SRP) (equivalent to dissolved inorganic

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TABLE 1

*Correlation Coefficients Between Primary Production and Biological, Chemical and Physical Parameters in Central Basin of Lake Erie*

| Parameter | 7–10 April | 6–10 May | 2–6 June | 3–7 July | 28 July–1 Aug. | 25–30 Aug. | 23–27 Sept. | 21–26 Oct. | 25–30 Nov. | 14–18 Dec. |
|---|---|---|---|---|---|---|---|---|---|---|
| Chlorophyll *a* | 0.207 | 0.285 | 0.385 | 0.764# | 0.958# | 0.872 | 0.724† | 0.134 | 0.950# | 0.090# |
| Temp. | 0.672† | 0.731† | 0.840# | 0.580* | 0.537* | 0.472 | 0.498 | −0.029 | −0.654* | −0.785# |
| TP[1] | 0.520 | 0.611* | 0.852# | 0.627* | 0.958# | 0.722† | 0.485 | 0.571* | 0.716† | 0.742† |
| PP[1] | 0.677† | 0.604* | 0.667† | 0.643* | 0.926# | 0.709† | 0.762† | 0.732† | 0.730† | 0.810# |
| TFP[1] | 0.290 | 0.485 | 0.743# | 0.562* | 0.335 | 0.644* | −0.109 | 0.321 | −0.134 | −0.340 |
| SRP[1] | 0.158 | 0.461 | 0.792# | 0.392 | 0.585* | 0.385 | 0.544* | 0.132 | −0.027 | −0.233 |
| $NO_3^-$ and $NO_2^-$ | 0.673† | 0.406 | 0.745† | 0.726† | 0.887# | 0.794# | 0.115 | 0.260 | 0.636* | 0.502 |
| $NH_4^+$ | 0.527 | 0.320 | 0.780# | 0.608* | 0.724# | 0.290 | 0.248 | −0.416 | −0.134 | 0.370 |
| $RSiO_2$[1] | 0.526 | −0.163 | 0.656* | 0.517* | 0.644* | 0.759† | −0.246 | −0.798# | −0.657* | −0.556* |

*Significant at $p<0.05$ level ($r>.532$) where r=correlation coefficient.
†Significant at $p<0.01$ level ($r>.661$).
#Significant at $p<0.001$ level ($r>.780$).
[1]TP=total phosphorus; PP=particulate phosphorus; TFP=total filtered phosphorus; SRP=soluble reactive phosphorus; $RSiO_2$=reactive silica.

phosphorus), and particulate phosphorus (PP) (the difference between TP and TFP). Nitrogen measurements were made of $NO_3^-+NO_2^-$, and $NH_4^+$, and silica was measured as reactive silicate ($RSiO_2$). Details of analytical procedures are given in Traversy (1971).

All biological and nutrient analyses were done on mixed water samples from depths of 1 and 5M, hence represent only surface conditions. In Lake Erie, however, maximum photosynthesis occurs above 5 meters (Glooschenko *et al*, 1974b), thus the author feels these sampling depths were realistic of optimal productivity in the lake. Data were subjected to a correlation analysis by basin for each sampling cruise. For statistical significance, the probability level $p = 0.05$ was chosen.

## RESULTS AND DISCUSSION

Correlation coefficients and levels of significance ($p=0.05$, 0.01 and 0.001) are presented for primary production vs chemical and physical parameters in table 1 and chlorophyll *a* as a measure of biomass in table 2.

### *Primary Production Relationships*

Primary production ($^{14}C$ uptake) is controlled by many environmental factors such as light intensity, temperature, nutrients, and species composition. In this paper, light was kept constant in the

TABLE 2

*Correlation Coefficients Between Chlorophyll a and Selected Chemical and Physical Parameters in the Central Basin of Lake Erie*

| Parameter | 7–10 April | 6–10 May | 2–6 June | 3–7 July | 28 July–1 Aug. | 25–30 Aug. | 23–27 Sept. | 21–26 Oct. | 25–30 Nov. | 14–18 Dec. |
|---|---|---|---|---|---|---|---|---|---|---|
| Temp. | 0.309 | 0.053 | 0.264 | 0.408 | 0.436 | 0.384 | 0.673† | −0.594* | −0.708† | −0.812# |
| TP[1] | 0.333 | 0.292 | 0.228 | 0.424 | 0.894# | 0.744† | 0.636* | 0.238 | 0.560* | 0.614* |
| PP[1] | 0.225 | 0.202 | 0.290 | 0.424 | 0.868# | 0.691† | 0.846# | 0.466 | 0.692† | 0.654 |
| TFP[1] | 0.387 | 0.476 | 0.111 | 0.393 | 0.299 | 0.780# | 0.029 | −0.007 | −0.408 | −0.206 |
| SRP[1] | 0.108 | 0.519 | 0.009 | 0.216 | 0.482 | 0.138 | 0.609* | −0.115 | −0.062 | −0.129 |
| $NO_3^-$ and $NO_2^-$ | 0.398 | 0.349 | 0.371 | 0.341 | 0.815# | 0.825# | 0.188 | −0.076 | 0.771† | 0.267 |
| $NH_4^+$ | 0.293 | 0.534* | 0.202 | 0.323 | 0.577* | 0.020 | −0.130 | −0.091 | −0.020 | 0.366 |
| $RSiO_2$[1] | 0.373 | −0.470 | −0.226 | 0.388 | 0.515 | 0.538* | −0.574* | 0.230 | −0.599* | −0.413 |

*Significant at $p=0.05$ ($r>.532$) where r=correlation coefficient.
†Significant at $p=0.01$ ($r>.661$).
#Significant at $p=0.001$ ($r>.780$).
[1]TP=total phosphorus; PP=particulate phosphorus; TFP=total filtered phosphorus; SRP=soluble reactive phosphorus; $RSiO_2$=reactive silica.

incubator, and species composition was neglected as many species were present in a given sample, and it was impossible to visually ascertain which species were actively photosynthesizing. Therefore, the chosen variables will be chlorophyll *a* as a measure of phytoplankton biomass, forms of N, P, and Si, and temperature.

Suprisingly, until the July cruise, there were no significant correlations found between chlorophyll *a* and production. This would imply the rate of $^{14}C$ uptake per chlorophyll *a* concentration (assimilation number) was controlled by other factors during that period of time. It is well known that assimilation number is affected by various factors such as temperature, nutrients and species composition (Eppley, 1972), but our data did not indicate temperature or nutrients influencing assimilation number except in the early June cruises when temperature, soluble reactive phosphorus, total phosphorus, and total filtered phosphorus all showed highly significant ($p<.01$) correlations with assimilation number. During the first two cruises, perhaps species composition was controlling productivity, not the physical or chemical parameters measured, but this fact is impossible to ascertain.

As for the forms of phosphorus, the two dissolved forms measured, total filtered phosphorus and soluble reactive phosphorus, essentially showed no significant correlations with primary production. This could be due to several explanations. First, if a correlation did exist, one might expect more of an inverse correlation, i.e. soluble reactive phosphorus is taken up and formed into particulate organic P compounds in the biomass. We did not observe such an inverse relationship; however, during the summer, soluble reactive phosphorus is almost depleted in the Central Basin waters with levels around 5 $\mu g\ PO_4\ l$ (Gächter *et al*, 1974), a level considered to be possibly limiting by limnologists. During this period, some significant correlations were found between $^{14}C$ uptake and soluble reactive phosphorus. A lack of correlation also occurs in the spring and fall and is probably explained by soluble reactive phosphorus concentrations being "non-limiting" for primary production, which is backed up by bioassays done by Lange (1971), and by the fact that soluble reactive phosphorus concentrations are quite high in the Central Basin during the spring and especially in the fall. Total phosphorus, the sum of dissolved inorganic P + organic P and particulate forms of P showed a fairly significant positive correlation with primary production except in April, and late September; the meaning of this high correlation is hard to ascertain since total phosphorus represents both dissolved forms of P, organic P compounds in cells and detritus, and inorganic particulates such as clay particles. If the dissolved forms of P, i.e. total filtered phosphorus is subtracted and particulate P, the sum of particulate organic and inorganic P compounds is left over. Unfortunately, one cannot separate the organic and inorganic forms from each other but the high positive correlations found on all cruises between primary production and particulate P was the most highly significant relationship found in this study. I do not believe that this necessarily implies that particulate P is biologically available to phytoplankton as a source of P to any great extent. Most likely, this relationship would indicate that particulate P basically consists of the particulate organic P compounds in the biomass itself, and since particulate phosphorus correlates much more significantly with $^{14}C$ uptake than chlorophyll *a* does, it may be a good biomass parameter, a concept that merits further consideration. It would also be beneficial to know how much of the particulate P consists of particulate inorganic P compounds. This fraction may be high nearshore due to the presence of particulate inorganic P compounds from bluff erosion, or due to resuspension of bottom sediments during storm periods.

Inorganic nitrogen was measured as $NO_3^- + NO_2^-$ and $NH_4^+$. Primary production highly correlated with $NO_3^- + NO_2^-$ between June and late August, while $NH_4^+$ correlated significantly between June and early August. This would imply a possible summer limitation of N in the Central Basin, which is also backed up by the high correlation between chlorophyll *a* and $NO_3^- + NO_2^-$ during the two August cruises (table 2). During summer, dissolved inorganic N compounds are quite low in concentration (Gächter *et al*, 1974). During this time, algal species were mainly members of the diatoms and dinoflagellates, while blue-green algae consisted of less than 10% of the biomass by volume with mainly *Anabaena spiroides* Kleb. and *Aphanizomenon flos-aquae* Cl. Ralfs. Both of these are potential nitrogen fixers, and one might speculate that if dissolved inorganic nitrogen got lower, these blue-green species might become more abundant due to their ability to fix nitrogen gas dissolved in water.

Silica, of course, would only influence the diatom assemblages of phytoplankton in the Central Basin due to their requirement for this element for their frustules and metabolism. This group of algae is fairly abundant throughout the year in the Central Basin, with a minimum occurring in early June (Vollenweider *et al*, 1974). Therefore, one might expect a relationship between primary production and reactive silica. Apparently reactive silica is non-limiting in the spring, and becomes possibly limiting in the summer through August (table 2). The negative correlation from late October to mid-December (table 2) cannot be due totally to uptake by diatoms as reactive silica levels are highest in the lake in December (Gächter *et al*, 1974). This may explain the negative correlation though that was observed in October and late November. The relationship in mid-December remains enigmatic.

The effect of temperature upon primary production was significantly positive through early August. This could imply an indirect effect however, as the warmest portions of the Central Basin also are characterized by highest nutrient levels, i.e the nearshore zone (Gächter *et al*, 1974). The lack of significance from late August to late October is most likely due to low temperature gradients in the basin, which were only approximately 1–2°C until November and December when much greater gradients occurred (Gächter *et al*, 1974). The significant negative correlations of both primary production (table 1) and chlorophyll *a* (table 2) then are explainable by the observation that lowest temperatures occurred nearshore where nutrients were highest indicating that nutrients were probably more controlling than temperature in the Central Basin.

In terms of factors influencing primary production, I feel a definite seasonal trend occurs in the Central Basin. In the summer, my data indicate that P may become limiting, but a much stronger case for N limitation is apparent. In the spring and fall, it does not appear that either N or P is limiting, but Si could become limiting for diatoms in the fall and summer. The role of Si bears further investigation based on the papers by Schelske and Stoermer (1971, 1972).

### *Biomass Relationships*

A measure of primary production is essentially a rate process based upon the amount of biomass present, in this case chlorophyll *a* and physiological processes in the algae as influenced by nutrients, light, temperature, species characteristics, etc. The amount of biomass present, however, represents a balance between the amount of primary production and losses due to advection (both horizontal and vertical), active vertical migration, zooplankton grazing and parameters affecting the biomass measure, such as diel periodicity in the case of chlorophyll (Glooschenko *et al*, 1972). Therefore, one would expect the relationship between biomass and various environmental parameters to be more tenuous in nature. My results suggest this as seen in table 2.

To late July, only one significant correlation between chlorophyll *a* and other measured parameters was found, that with $NH_4^+$ in May. Nitrogen did give indications of limiting biomass during August as previously discussed. In terms of P, the positive correlation with particulate P was significant from late July through December with exception of late October, and the same was found with total phosphorus. Perhaps an explanation is that particulate P correlated highly as a biomass parameter except in October during overturn when resuspended sediments interferred with the relationship (Glooschenko *et al*, 1974a).

The only temperature effects were in late September (+) and October through mid-December (−), again possibly due to the effect of nutrients, not temperature *per se* as previously discussed. I would, therefore, suggest that trying to relate biomass to selected environmental parameters is a difficult task.

The use of simple correlation coefficients only tells us that two factors are varying together, either positively or inversely; the idea of cause and effect is not necessarily implied, unless there is a logical scientific basis for thinking that such a relationship does exist. The study of causal relationships between abundance of certain organisms, or certain activities of organisms such as productivity and environmental parameters, has been the concern of both theoretical and applied ecologists. Recent techniques in multivariate statistical analyses, such as ordination techniques (see Gittins, 1968), may lead to a much better understanding of causal ecological relationships, especially by use of principal components analysis. The next step in this study will be to subject the data to such an analysis to attempt to confirm the speculative ideas presented in this paper.

It is apparent that the sampling network on the Western and Eastern Basins of Lake Erie was inadequate in 1970 for statistical analyses of the data. I believe that the Central Basin has more adequate coverage for a basic understanding of limnological processes there, but further studies must be done especially on the Eastern Basin for a proper understanding of its limnological behaviour.

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