NUTRIENT-GROWTH RELATIONSHIPS FOR *POTAMOGETON PECTINATUS* AND THE RE-EVALUATION OF ESTABLISHED OPTIMAL NUTRIENT LEVELS FOR *CLADOPHORA GLOMERATA* IN SOUTHERN ONTARIO STREAMS[1]

by

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FORWARD

This report is one of a series of technical reports prepared for the Grand River Water Resource Management Study. The project described herein was undertaken by the Grand River Study Team at the request of the Grand River Implementation Committee.

The reader is cautioned that the material contained in this report is primarily technical support information and does not necessarily represent policy or management practices. Interpretation and evaluation of the data and findings, in most cases, can not be based solely on this report but should be analyzed in light of other technical reports undertaken within the comprehensive framework of the Grand River Water Resource Management Study. Questions with respect to the contents of this report should be directed to the authors or to the Grand River Implementation Committee c/o D.N. Jeffs, Water Resources Branch, Ontario Ministry of the Environment, 1 St. Clair Avenue West, 4th Floor, Toronto, Ontario.

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PREFACE

A previous report titled "Field determination of the critical nutrient concentrations for *Cladophora* in streams and their importance in waste load management" deals with the critical phosphorus levels which promote the optimal growth of *Cladophora glomerata*. This report has reevaluated the results of the above paper and in addition it deals with the species *Potamogeton pectinatus* in a similar manner. Although no critical levels were found for *P. pectinatus*, this species was observed to grow at its maximum rate wherever it was found and has not been encountered in waters with an ambient P concentration less than 35 µg/L. Future investigations may show a species shift below this concentration. This report represents the seventh in a series of reports presented by the Grand River Study Team to solve specific problems dealing with the Grand River.

INTRODUCTION

Many rivers in Southwestern Ontario are colonized by dense growths of *Cladophora glomerata* and *Potamogeton pectinatus*. The aesthetic value of the infested rivers is lessened and the metabolic activity of the plant biomass can adversely affect the dissolved oxygen regime of the river. The ultimate goal of the ongoing research is to establish criteria or guidelines for plant biomass that will ensure maintenance of desirable dissolved oxygen concentrations. It is, therefore, necessary to determine the environmental factors affecting the growth of *Cladophora* sp. and *Potamogeton* sp.

The effects of light intensity and nutrients on the growth of *C. glomerata* have been previously investigated (Wong and Clark, 1976). The technique of estimating the amount of photosynthetically available radiation at the plant depth (PARD), described by Wong and Clark (1976) allowed the first field determination of a statistically significant relationship between PARD and production.

Compensation for varying light levels in nutrient studies was therefore possible, and Wong and Clark (1976) reported that above 1.6-1.7 mg/g dry wt. cellular phosphorus concentration the daily relative production (P /Pmax) of *C. glomerata* no longer increased. This "critical" level favourably agreed with Gerloff and Krombholz's critical cellular phosphorus concentration of 1.3 mg P/g dry wt. which was derived from controlled laboratory experiments (1966).

A relationship between the cellular phosphorus content of *C. glomerata* and the total phosphorus concentration in the water was also reported by Wong and Clark (1976). The optimal concentration of phosphorus in the water that would result in a cellular phosphorus concentration of 1.6 mg/g dry wt. was reported to be approximately 60-70 µg/L. Gerloff and Krombholz's value of 1.3 mg/g dry wt. would appear as the result of an ambient total P concentration of 40 µg/L. To more accurately pinpoint the optimal nutrient concentration reducing daily relative photosynthesis of *C. glomerata*, the study was continued during the summer of 1975. This paper re-evaluates the established critical level and also discusses the effects of light and nutrients on the growth of *P. pectinatus*.

STUDY AREAS

Field studies were conducted from May to September during the summers of 1973, 74 and 75. Production studies were conducted on nine river sections (Avon, Bayfield, Conestogo, Grand, Middle Maitland, Nith, Speed, Thames and Upper Grand, Fig. 1). Selection of river sections was based on similarity of substrate, uniformity of width and depth, adequate horizontal and vertical mixing of oxygen, absence of tributaries and a range of nutrient loadings. Coarse rubble is the most common river substrate encountered in the nine river sections. The mean depth for all river sections was approximately 0.5 m ensuring reasonable light penetration to the plant depth (>20 gcal/cm ^{2} •day and <150 gcal/cm^2 • day).

The average total phosphorus concentrations for each river section are presented in Table 1 and illustrate the wide range in nutrient concentrations. *C. glomerata* grows rapidly in the spring, preferring the cooler temperatures of May (14-18°C). Usually the *C. glomerata* biomass reaches a peak density in June and the specie is then succeeded by *P. pectinatus*. A temperature of 25°C is usually considered harmful to *Cladophora* sp. (Storr and Sweeney, 1971). This temperature was usually attained by mid-June in the streams studied, except below the bottom-draw dam on the Conestogo River. *P. pectinatus* will usually replace the *C. glomerata*, presumably due to the increased temperature.

TABLE 1. Minimum, average and maximum Total P values for May-Sept. in nine rivers studied.

	Min.	Average Total P	Max.
	- - - - - - - - (µg/L) - - - - - - - -		
Upper Grand	18	39	79
Middle Maitland	28	45	64
Avon	10	64	83
Bayfield	62	69	75
Nith	69	82	99
Conestogo	28	82	99
Grand	43	103	180
Thames	34	155	210
Speed	34	208	500

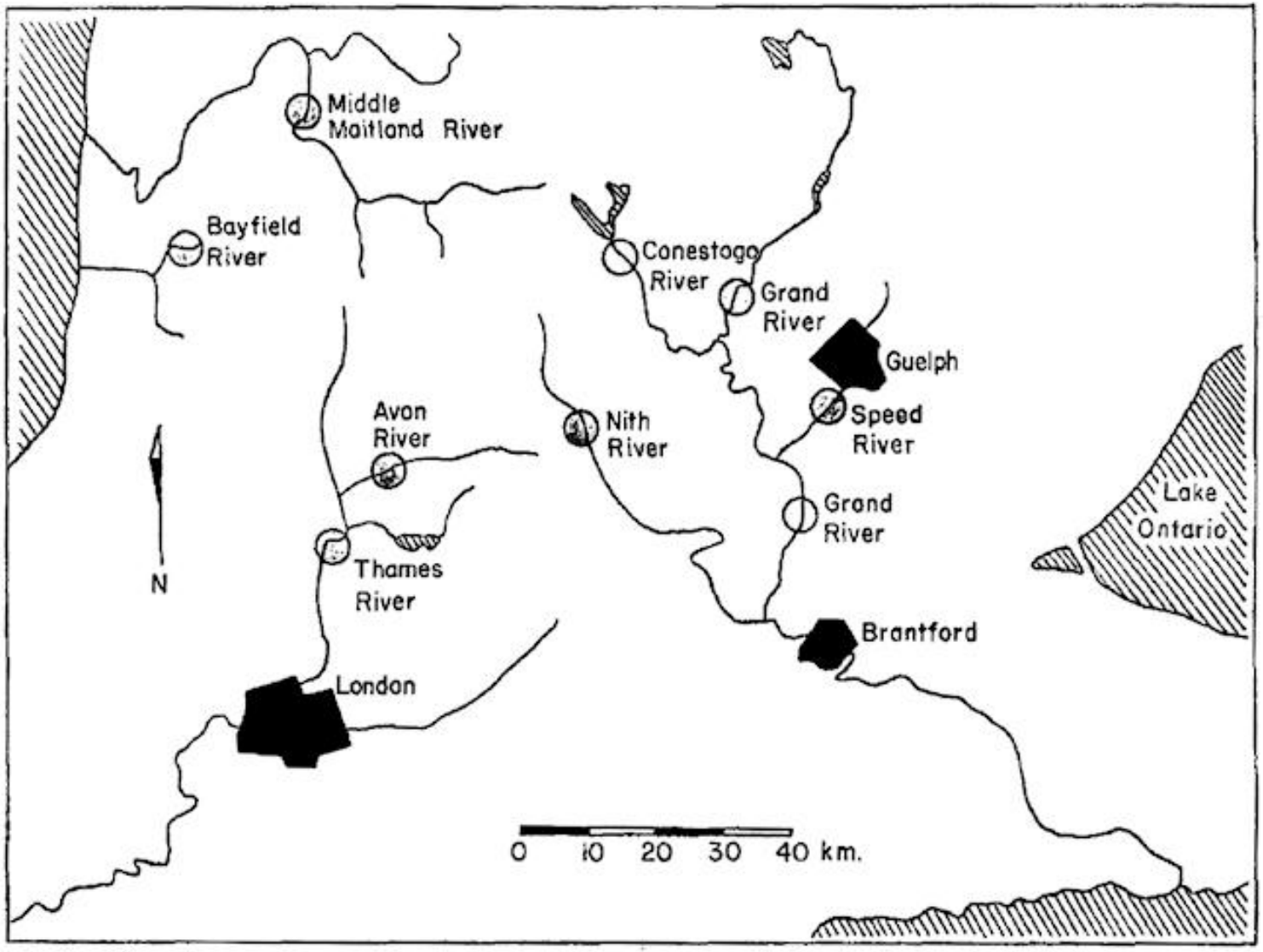

Figure 1: Location of nine river sections studied from 1973-1975 in southern Ontario. Shaded circles lie directly over river sections studied.

METHODS

Each river section was sampled at three or more stations. These were separated by at least one kilometer depending on road access and the physical characteristics of the river. Time of travel or retention time between stations was usually greater than one hour and less than four hours. Oxygen and temperature fluctuations were continually monitored over a three to four day period every two weeks using E.I.L. oxygen meters (Electronic Instruments Ltd., Richmond, Surrey, England) coupled with Rustrak recorders (Gulton Industries, Manchester, New Hampshire, U.S.A.). The daily relative gross production was expressed as P /Pmax (daily gross production divided by the maximum gross production rate).

Solar energy was measured with a Weather Measure R401 pyranometer (Weather Measure Corp., Sacramento, California) and underwater light energy was measured with a LI-COR quantum sensor model LI-185 (Lambda Instruments, Lincoln, Nebraska). The light sensor, corrected for cosine response, measures the daily photosynthetically available radiation (PAR) in the 400-700 nm range as described in Wong, Clark & Painter (1976).

Water samples for total phosphorus were collected from midstream once daily at the upstream and downstream stations. Therefore, at least twelve phosphorus measurements were averaged to obtain the average phosphorus concentration of that reach for a two week period. Fifty ml. of sample was pipetted, using acid-washed 50 ml volumetric pipettes, into 250 ml acid-washed Erlenmeyer flasks and later digested in the same flask (Dillon, 1974). Total nitrogen samples were collected in polyethylene bottles at the same time. All samples were refrigerated until analysed.

Plant samples for nutrient analysis were collected during each week of productivity studies. Three random quadrats were cropped at each station with a Surber sampler. Very little contribution from dead plant material was observed. The plant material was washed thoroughly to remove silt and attached organisms. The plant samples were quick frozen with dry ice (solid CO_2) and ground to a powder. Each quadrat was ground and the material from each was combined and analyzed for phosphorus and nitrogen content. Therefore, over a period of two weeks, six cellular phosphorus and six cellular nitrogen concentrations were measured.

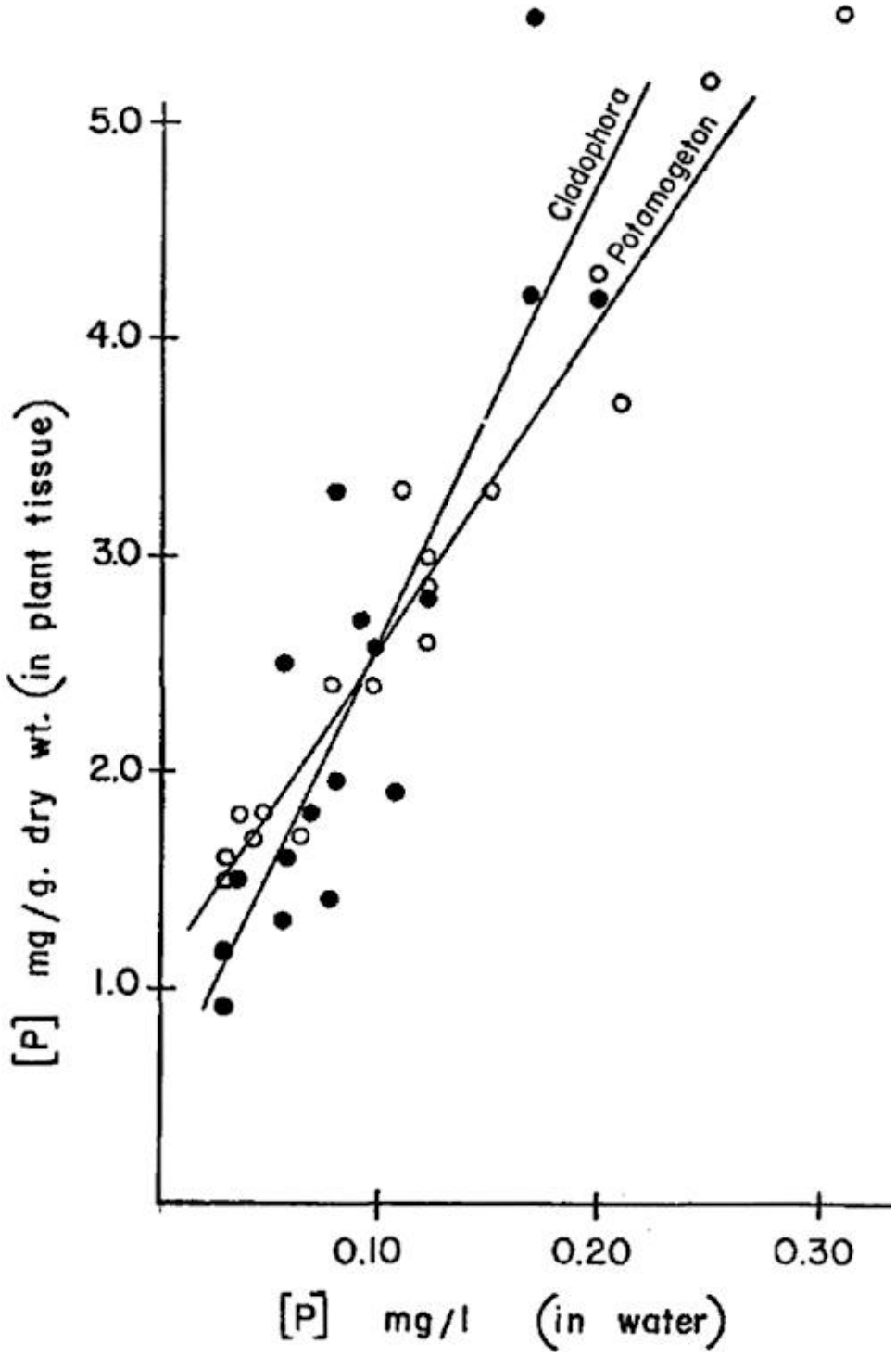

Figure 2: Relationship between phosphorus in water and phosphorus in the plant tissue for *Cladophora glomerata* (closed circles) and *Potamogeton pectinatus* (open circles).

RESULTS

Relationship between cellular nutrient concentration and nutrient concentration in the water.

The relationship between ambient P and cellular P reported by Wong & Clark (1976) has been improved with the addition of the 1975 data (fig. 2). The new regression line for *C. glomerata* is:

$$[P_c] = 0.46 + 0.022\ [P_{H2O}], \quad r = 0.89 \qquad (1)$$

where $[P_c]$ is the phosphorus concentration in the plant tissue in mg/g dry wt. and $[P_{H2O}]$ is the phosphorus concentration in the water in µg/L.

The new regression line for *P. pectinatus* is:

$$[P_p] = 1.07 + 0.015\ [P_{H2O}], \quad r = 0.97 \qquad (2)$$

When the data were pooled the regression line is:

$$[P_2] = 0.79 + 0.018\ [P_{H2O}] \quad r = 0.91 \qquad (3)$$

The slopes of the separate lines are not statistically different but variances are statistically different ($p<0.1$). This allows us to use separate relationships for each species. A prediction of the cellular phosphorus concentration would be more accurate using the two separate lines since the variance of the combined data is large. Because *C. glomerata* is an attached algae with no root system, its only supply of phosphorus is via the water. However, *P. pectinatus* is a rooted macrophyte and can potentially draw upon the sediments as a source of phosphorus. Jeschke and Simonis (1965) reported the uptake of phosphate by shoots of Elodea dense was dependent on the external concentration in the range from 0.1 µg/L to 475.0 mg/L.

The linear relationship between cellular phosphorus in *P. pectinatus* and ambient phosphorus suggests that the major source of phosphorus for *P. pectinatus* is the water. After reviewing the literature on nutrient absorption by leaves versus roots, Sculthrope (1971) came to the conclusion that if nutrients are readily available from the ambient water, then absorption of nutrients from the water through the shoot epidermis could be a faster route of supply to the metabolic centers in the mesophyll than transport along the substrate-root-stem-leaf mesophyll pathway. This implies that phosphorus uptake through

the leaves would adequately supply the plant's demand for phosphorus provided that the external concentration is sufficient. The flow rates encountered will continually replenish the supply of phosphorus to the leaf. If Gerloff and Krombholz's critical value of 1.3 mg/g dry wt. is considered valid, then the critical ambient concentration for Potamogeton pectinatus would be 15 µg/L according to the relationship in figure 2. The average summer phosphorus concentrations for the nine rivers studied were greater than 39 µg/L; therefore, it can be concluded that the external concentration is generally sufficient. The coarse rubble found in the nine study areas must be low in phosphorus content because plants analyzed from the same headwater section with ambient P being less than 20 µg/L had tissue contents of 1.6 mg P/g dry wt. when growing in rubble and 2.8 mg P/g dry wt. when growing in muddy organic substrate. The cellular P content of the plants growing in the muddy organic substrate is similar to the phosphorus contents of plants in lakes and ponds in Southern Ontario (Wile & McCombie, 1972).

Unlike phosphorus, there was no relationship between cellular nitrogen and total nitrogen in the water (fig. 3). Plant samples collected from stations above and below Guelph exhibited a five-fold increase in their phosphorus concentration while maintaining similar nitrogen concentrations, suggesting N was always available in surplus. Although the phosphorus content is related to the ambient concentration, nitrogen appears to be maintained in the plant tissue independent of the ambient concentrations.

Nitrogen/phosphorus ratios (by weight) ranged from 17.7:1 to 3.4:1. Luxury absorption and storage of phosphorus results in the low ratios. N/P ratios of 7:1 - 7.5:1 are considered normal for freshwater and marine plankton (Redfield, 1934, 1958; Cooper, 1938; Fleming, 1940; Strum and Leckie, 1971; and Serruga and Berman, 1975). Gerloff (1969) reported the critical N/P ratio for aquatic Macrophytes to be 10:1. Wong and Clark (1976) reported the critical cellular phosphorus concentration for *Cladophora* to be 1.6 mg/g dry wt. and the critical nitrogen concentration to be between 12 and 15 mg/g dry wt. This would result in a critical N/P ratio for *Cladophora* between 7.5:1 and 9.4:1. This range lies between the number of ratios for plankton and Gerloff's ratio for macrophytes. Forty-two percent of the observed N/P ratios for *C. glomerata* and *P. pectinatus* were between 7.5:1 and 9.5:1 with equal number above and below these limits. However, N/P ratios above the critical level cannot always be interpreted as limiting phosphorus conditions. For instance, Serruya and Berman (1975) observed N/P ratios as high as 20:1 for *Peridinium* with no decrease in growth. However, the cellular phosphorus concentration was 1.8 mg/g dry wt. which is

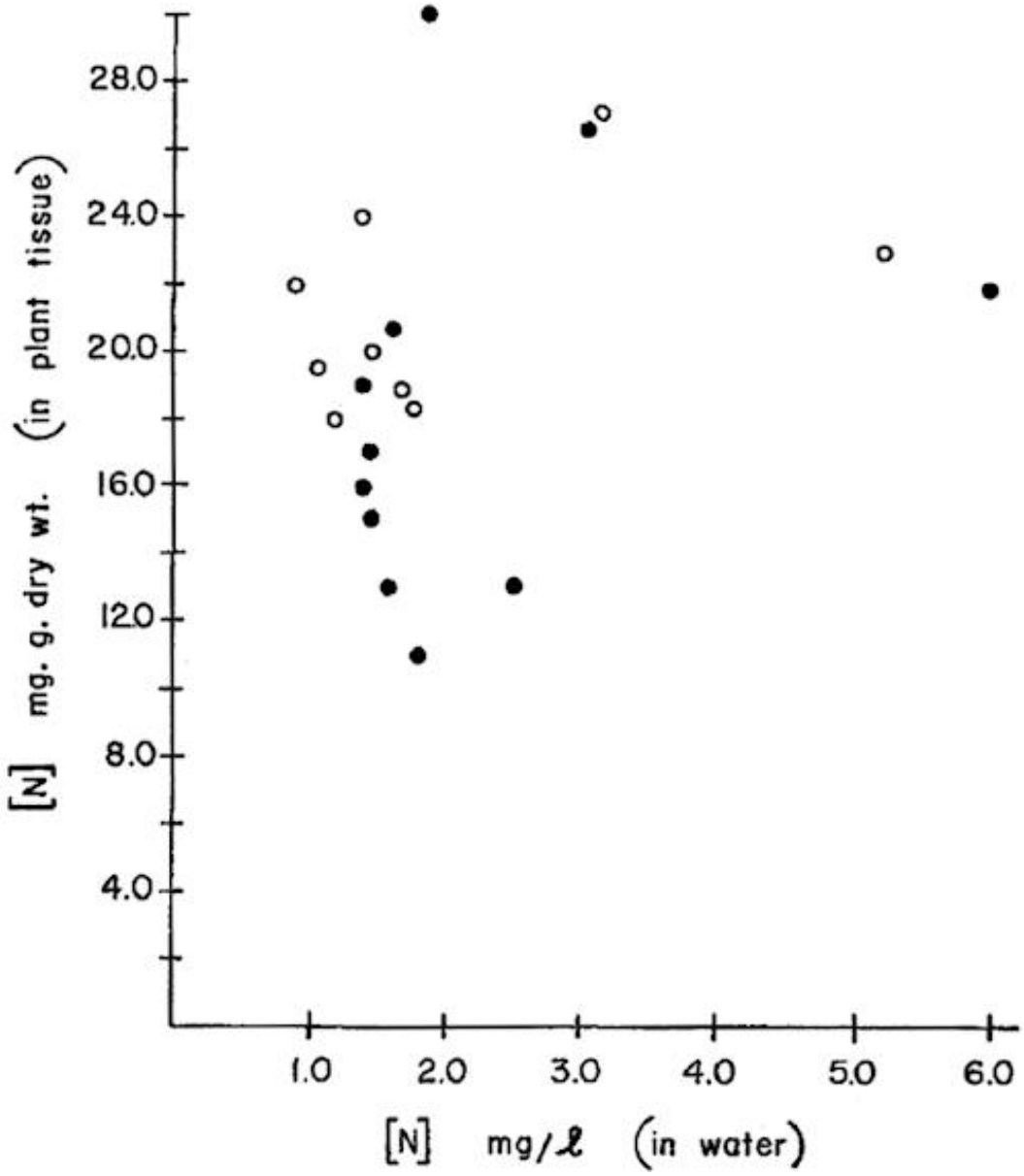

Figure 3: Relationship between Nitrogen in the water and Nitrogen in the plant tissue for *Cladophora glomerata* (closed circles) and *Potamogeton pectinatus* (open circles).

above the critical P concentrations reported by Gerloff (1969) and Wong and Clark (1976). Thus N/P ratios have little meaning if both nutrients are in excess. Conversely, reduced relative growth can occur when N/P ratios are normal because both N and P concentrations are low. For instance, reduced relative growth was observed in *C. glomerata* even though N/P ratios were 8.2, 8.8 and 9.3:1. The cellular nitrogen and phosphorus concentrations were both below the determined critical levels and both could be potentially reducing relative growth. The reduced production rates that can be attributed to phosphorus limitation alone had N/P ratios from 15 - 18:1. Thus, the N/P ratios can only indicate which nutrient could be limiting, provided it is known that the nutrient is below the critical levels to begin with.

Determination of the Critical Nutrient Concentration

Compensation for the effect of light in nutrient studies has been previously described for *C. glomerata* (Wong, Clark & Painter, 1976). A very similar relationship between daily relative photosynthesis and PAR was observed for *P. pectinatus*. Figure 4 illustrates the relationship between photosynthetically available radiation at the plant depth and daily relative photosynthesis of both *C. glomerata* and *P. pectinatus*. The equation of the curve for *C. glomerata* is P/Pmax = 0.59 + 4.26 log I (R = 0.73). The equation of the similar curve for *P. pectinatus* is P /Pmax = 1.52 + 4.30 log I (R = 0.78). The slope of the line can be used to correct a measured P /Pmax at any light intensity to a calculated P /Pmax at one light intensity. The compensation for light allowed Wong & Clark (1976) to observe the optimal cellular phosphorus concentration of 1.6 mg/g dry wt. for *C. glomerata*.

The new 1975 field data confirmed the ascending slope of the relationship between daily relative photosynthesis and cellular phosphorus. Furthermore, after investigating N:P ratios, it was apparent that several of the observed P/Pmax values could be a result of limiting levels of both phosphorus and nitrogen. Therefore, these values were discarded from the relationship which now appears as Fig. 5(a). The ascending slope has the equation P /Pmax - 6.78 + 2.41 [P_t] with a correlation coefficient (r) of 0.94 ($p < 0.01$). The horizontal line has the equation P/Pmax = 10.9.The critical phosphorus concentration for *C. glomerata* using the new data is 1.7 mg/g dry wt. which corresponds to an ambient P concentration of 57 µg/L. Thus, Wong & Clark's (1976) original critical concentration of 60 µg/L is reaffirmed with the new data.

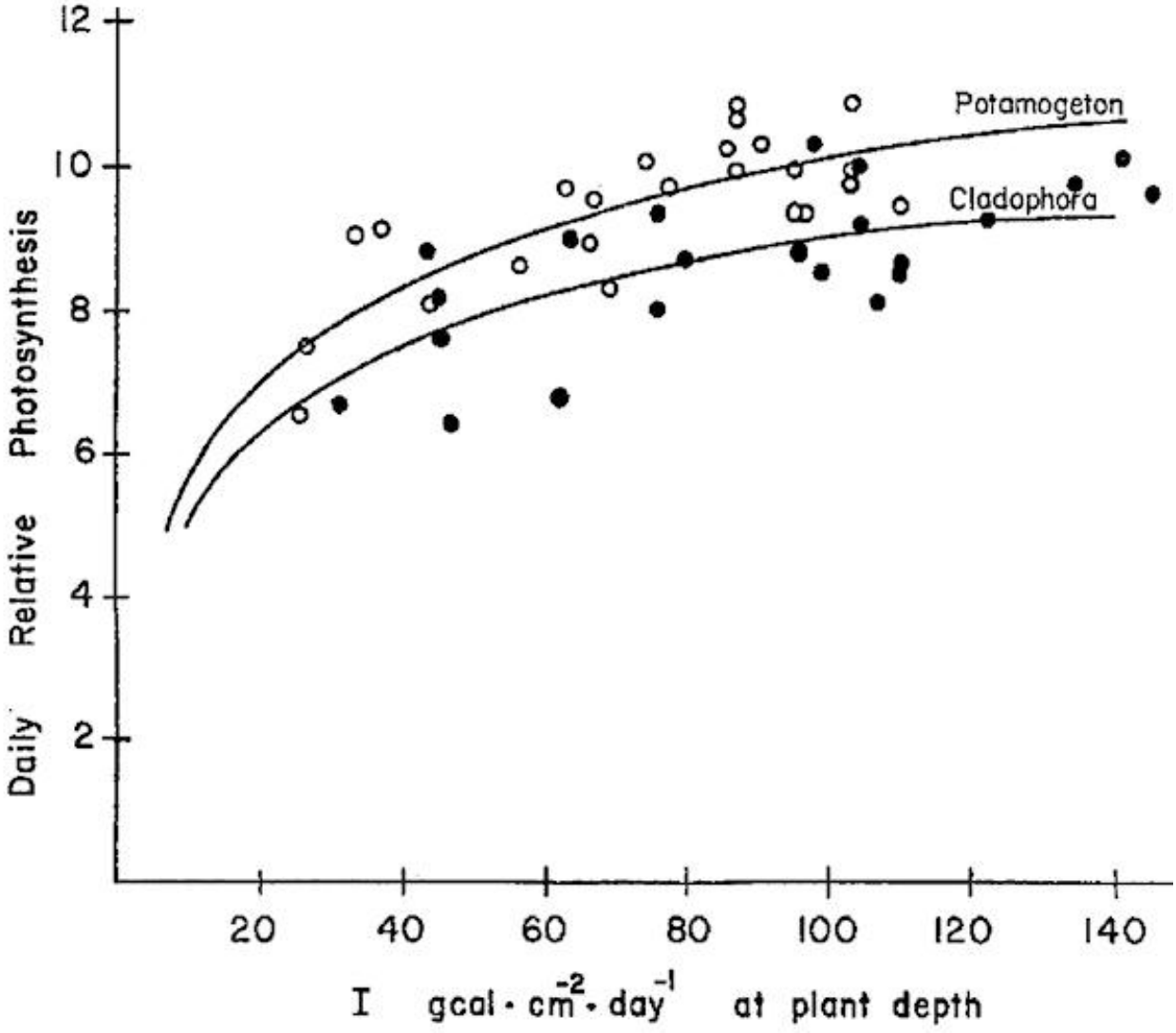

Figure 4. Relationships between PARD and the daily relative photosynthesis for *Cladophora glomerata* (closed circles) and *Potamogeton pectinatus* (open circles)

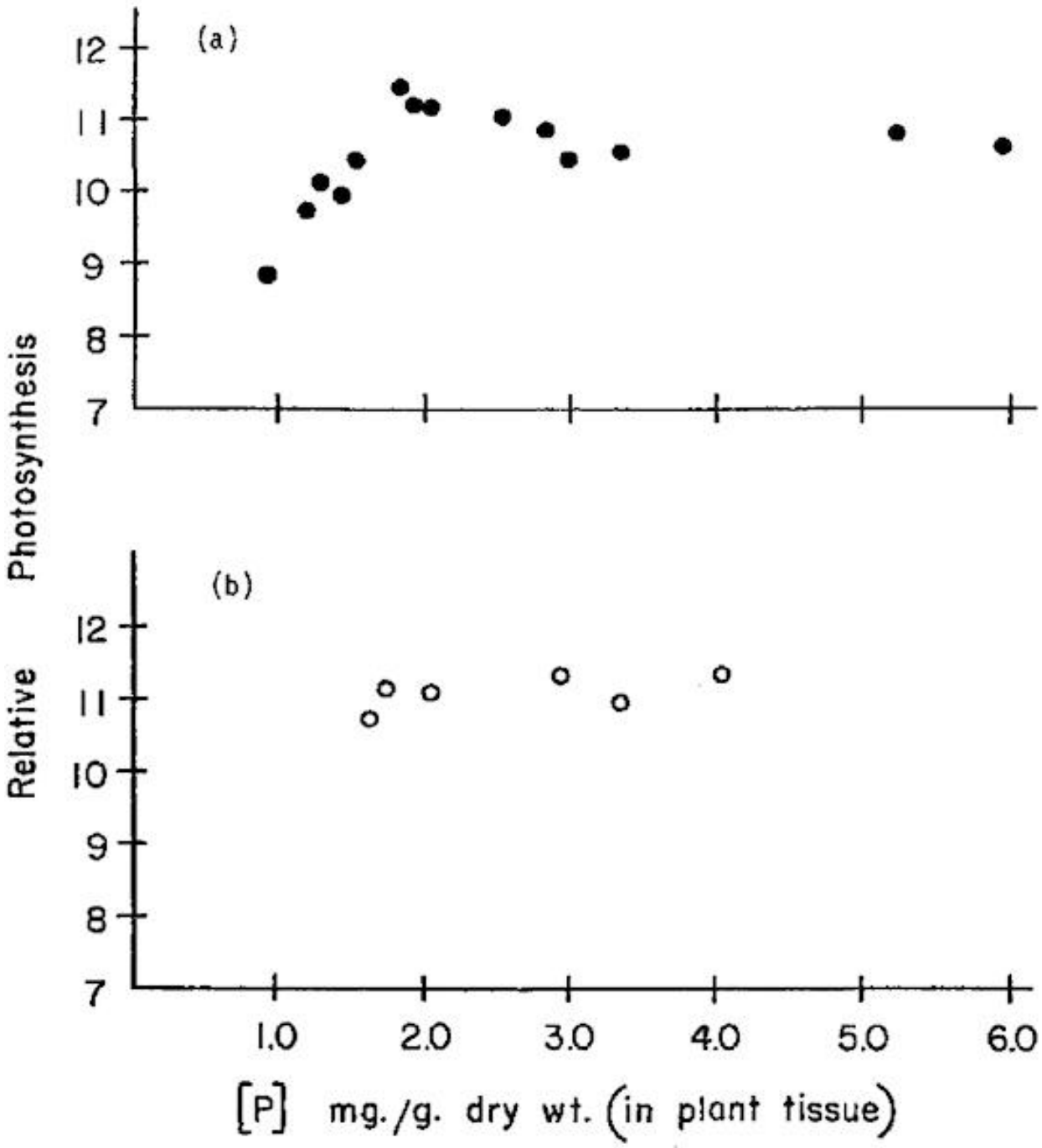

Figure 5 a and b: Relationship between phosphorus in the plant tissue and daily relative photosynthesis for *Cladophora glomerata* (a) and *Potamogeton pectinatus*.

A critical phosphorus concentration which will reduce the daily relative photosynthesis of *P. pectinatus* was not observed (Fig. 5b). The available data points fall on a horizontal line with the P/Pmax equal to 11.1. The lowest average cellular phosphorus concentration observed was 1.6 mg/g. dry wt. This corresponds to an ambient P concentration of 34 µg/L. *P. pectinatus* was not observed to inhabit headwater sections where ambient P concentrations were less than 30 µg/L. *P. amplifolius*, *P. foliosus* and *Ranunculus trichophyllus* were the typical species in these cleaner headwaters. The determination of environmental conditions that discourage the growth of *P. pectinatus* in cleaner headwaters and encourage the other three species would involve a great deal of speculation at this time. *P. pectinatus* has been observed to survive in heavily silted environments where the broad leafed *Potamogeton* sp. and dissected leafed *Ranunculus* cannot survive (Scultrope, 1971). This observation serves only as a partial explanation of why *P. pectinatus* is the dominant plant in our downstream sections. This does not explain why *P. pectinatus* is absent in the cleaner headwater sections. Westlake (1967) reported low photosynthetic rates for *P. pectinatus* compared to *R. pseudofluitans*. Perhaps the low photosynthetic capacity of *P. pectinatus* will not allow it to compete favorably with other species. Therefore, an ambient P concentration of 30 µg/L is considered to coincide with reduced *P. pectinatus* distribution possibly because of interspecific competition although nutrient limitation remains a possibility requiring further investigation.

The ultimate goal of the research is to establish the relationship(s) between biomass, dissolved oxygen concentration and nutrient loading. The level of 30 µg/L ambient total phosphorus cannot be interpreted as the level of phosphorus that results in desirable biomass or dissolved oxygen concentration. For example, our cleanest section, the Upper Grand, had an average total phosphorus concentration of 39 µg/L and a mixed plant community composed of *P. pectinatus*, *P. foliosus* and *R. trichophyllus* yet the dissolved oxygen fell below 5 mg/L on four of the five weeks that dissolved oxygen was monitored. Further research is required to determine if desirable oxygen concentrations can be attained by nutrient loading controls.

CONCLUSIONS

Wong and Clark's (1976) relationships between daily relative photosynthesis of *C. glomerata*, light intensity and nutrient concentration were confirmed with 1975 data. The critical cellular phosphorus concentration affecting daily relative photosynthesis was 1.7 mg P/g dry wt. which corresponds to an ambient total phosphorus concentration of approximately 60 µg/L. The relationship between cellular P and ambient P was separated into two lines, one for *C. glomerata* and one for *P. pectinatus*. There was no relationship between nitrogen in the water and nitrogen in the tissue. The nitrogen:phosphorus ratio for both species was observed to lie between 7.5 and 9.4. This ratio agrees favourably with reported ratios for plankton and aquatic macrophytes.

A nutrient concentration reducing daily relative photosynthesis of *P. pectinatus* was not observed. However, the distribution of *P. pectinatus* was restricted to river sections with ambient P concentrations greater than 30 µg/L. It is not certain whether the absence of *P. pectinatus* in river sections which have average ambient P concentrations less than 30 µg/L is the result of a nutrient effect alone. The measured growth rate of *P. pectinatus* in all cases remained relatively constant and showed no response to variations in the average P concentration in the water. For this reason it is likely that the most important parameter affecting the production of *P. pectinatus* is the amount of light energy available to the plant.

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