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Effects of Eutrophication on *Ranunculus* and *Potamogeton*

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ABSTRACT

Water crowfoot (*Ranunculus penicillatus* subsp. *pseudofluitans* (Syme) S.Webster) plants were grown in two artificial recirculating rivers, in one of which the phosphate concentration of the input was raised from 40 μgPl^{-1} to 200 μgPl^{-1}. Fennel pondweed (*Potamogeton pectinatus* L.) plants were planted as a competitor in association with 50% of the *Ranunculus* clumps. Chemical concentrations of the major elements in the water were measured weekly. Filamentous algae grew in profusion in the channel with added phosphate (0.77 T fresh weight), compared with an immeasurably low amount in the control channel. After 100 days the plants were removed, dried and weighed and the tissue concentrations of the major elements were measured. The *Ranunculus* shoots grew less in the eutrophic channel, and its roots grew less in the presence of *Potamogeton*. The *Potamogeton* showed a greater reduction in shoot and root biomass than the *Ranunculus*. Tissue phosphate concentrations were higher in both species in the eutrophic channel. The data suggested that *P. pectinatus* is a more competitive species (*sensu* Grime) than *R. penicillatus*.

Key Words: macrophytes, algae, phosphate, river, competition.

INTRODUCTION

River plants tend to be associated with particular nutrient concentrations (Holmes and Newbold 1984). In streams where there is an inflow of polluted water (for example

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sewage effluent), species such as *Ranunculus fluitans* L. and *R. penicillatus* are often replaced by *Potamogeton pectinatus* (Butcher 1933, Harding 1979, 1980). Although the pollution is sometimes intense enough to destroy the *Ranunculus* outright (Hawkes 1978), often it appears that the change in vegetation is due to a change in the competitive balance between the plant species present. However, there is a paucity of experimental data to back up conclusions which have mostly been drawn from field observations. The aim of the experiment described here was to investigate the effects of pollution by increased phosphate concentration on *R. penicillatus* subsp. *pseudofluitans* and *Potamogeton pectinatus*.

METHODS

The experiment was carried out in two artificial recirculating rivers at the Waterston Experimental Station of the Institute of Freshwater Ecology. Each artificial river consists of a 53-m-long race-track shaped fiber-glass channel, incorporating an Archimedes screw pump to circulate the water. The water velocity was, on average, 0.25 m s^{-1}, with no significant difference between the two channels. The channels were both filled with water to a depth of 0.4 m above the gravel substratum. They have a trapezoid cross-section, and the base was filled with gravel to a depth of 0.4 m. The channels were continuously topped-up with groundwater from a borehole. The input was adjusted to 100 m^3 $week^{-1}$. The volume of water in each channel was *ca.* 50 m^3 when the gravel was installed (Fox 1987). Bullhead fish (*Cottus gobio* L.) were electro-fished from a nearby stream and placed in the channels (equal numbers in each) to prevent large fluctuations in populations of invertebrate grazers.

The water supply has a constant chemical composition which is similar to the source of many chalk streams (Marker and Casey 1982, Casey and Newton 1973, Westlake *et al.* 1972). It contained adequate concentrations of all the ions necessary for plant growth, with the exception of iron (Marker and Casey 1982), so $FeCl_3$ was added (together with EDTA) at a concentration equivalent to 1 mg l^{-1} Fe^{3+} in the borehole water.

In one channel (the control) no other additional chemicals were added. In the other, phosphate was added as H_3PO_4. The input PO_4-P concentration was increased from 40 µgP l^{-1} to 200 µgP l^{-1} (see Figure 1). Concentrations of 200 to 750 µgP l^{-1} have been measured in southern English chalk streams such as the River Itchen which has abundant *R. penicillatus* subsp. *pseudofluitans* (Spink 1992). The phosphate was continuously added by a peristaltic pump from a 60-L vat. The major chemical elements in the water were analyzed weekly (Figure 1). Soluble phosphate and nitrate were measured using flow injection analysis (Ruzicka and Hansen 1981), potassium using atomic absorbtion spectrophotometry (American Public Health Association 1980) and sulphate using an ion-exchange procedure (MacKereth 1955).

On 31 March 1990 *R. penicillatus* subsp. *pseudofluitans* and *Potamogeton pectinatus* plants were planted in the two channels. Ten groups of five pots were planted with five *Ranunculus* plants in each pot and an additional four *Potamogeton* plants in 50% of the pots. The fresh weight of all the plants was measured before planting to ensure that there was no initial difference between treatments. Before planting, water was pumped for several hours between the two channels (in both directions, consecutively) to ensure that the initial algal populations were similar for both channels.

On 12 July 1990 (after 100 days) the plants were removed from the channels, dried (95C), separated into roots and shoots, weighed, and the tissue concentrations of phosphorus, nitrogen, carbon and potassium were measured. An estimate was also made of the weight of filamentous algae (*Cladophora glomerata* (L.) Kutz) in the channels. A rigid polypropylene container (*ca.* 20 l) was carefully placed in the channel and allowed to fill with water plus algae. The container was removed from the channel, the volume of water was determined, and the weight of the algae was used to estimate the total weight in the total volume of the channel (nine replicates).

RESULTS AND DISCUSSION

The control channel had an immeasurably low amount of algae growing in it, whereas the channel with added phosphate had an estimated 770 kg fresh weight (23 kg dry weight) of filamentous algae (*Cladophera glomerata*).

The channel with added phosphate had less *Ranunculus* shoot biomass, the root-to-shoot ratio was increased and there was a greater concentration of major nutrients in the shoots. There was no effect on the root biomass, but this was decreased in the pots with *Potamogeton pectinatus* present. The *Potamogeton pectinatus* root and shoot biomass was reduced in the channel with added phosphate (though the ratio remained unaltered) and there were reduced levels of other major nutrients (see Table 1 and Figure 2).

The addition of phosphate to one channel had a major effect on filamentous algal growth in that channel. A likely result of this greatly enhanced filamentous algal biomass would be to substantially reduce the quantity of light available for submerged macrophyte photosynthesis, and so would be a significant cause of stress (Turner *et al.* 1991, Marrs *et al.* 1992).

The ten pots in each channel were not true replicates but "pseudoreplicates" as they were not statistically independent (Hurlbert 1984). As only two channels were available for this

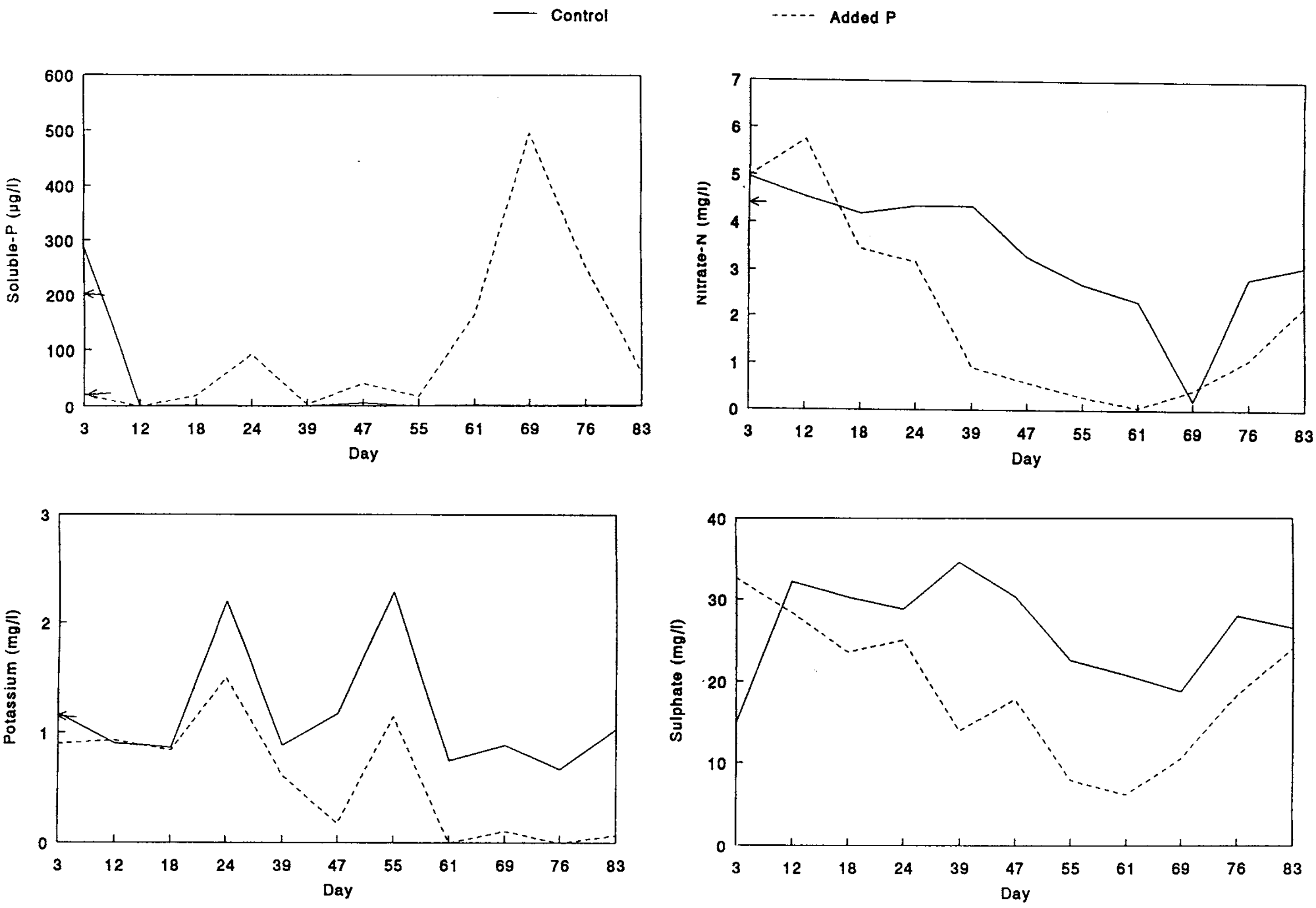

Figure 1. Chemical concentrations of soluble phosphate, nitrate, potassium and sulphate in artificial rivers. Control channel shown in solid line, channel with added phosphate in dotted line. Concentration of input shown by arrow on ordinate (not available for sulphate).

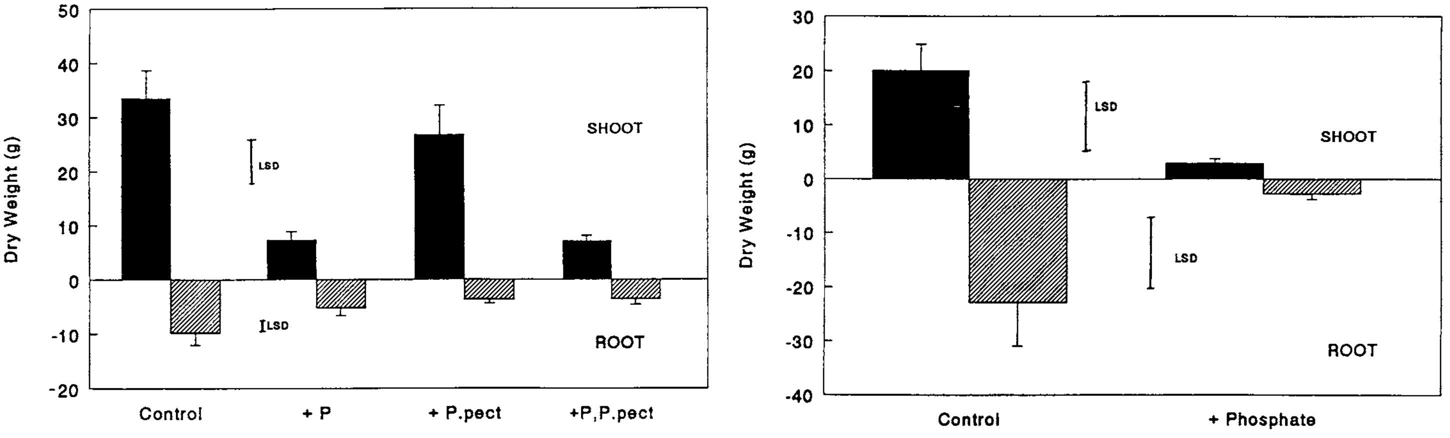

Figure 2. Effect of channel with added phosphate (+P) and presence of Potamogeton *pectinatus* (+P.pect) on *Ranunculus penicillatus* subsp. *pseudofluitans* growth (left graph), and on *P. pectinatus* growth (right graph). "Control" represents plants in channel without added phosphate, and growing without competition from *P. pectinatus*. Bars on histograms represent ± 1 standard error, separate bars represent least significant difference (LSD) ($p \leq 0.05$).

TABLE 1. SUMMARY OF ANALYSIS OF VARIANCE. "COMPETITION" INDICATES THE EFFECTS OF *POTAMOGETON PECTINATUS* PLANTS ON THE *RANUNCULUS* PLANTS, "CHANNEL" INDICATES THE DIFFERENCE BETWEEN THE CONTROL CHANNEL AND THE ONE WITH ADDED PHOSPHATE. NUTRIENT VALUES REFER TO LEVELS IN SHOOT TISSUE. IF THE VALUE IS INDICATED AS AN "INCREASE" IT IS GREATER IN THE TREATMENT THAN IN THE CONTROL. LEVELS OF SIGNIFICANCE AS FOLLOWS: n.s. = not significant, * = 95%, ** = 99%, ** = 99.9%.

Variate	Source	Significance	Direction
Ranunculus:			
Shoot dry weight	Competition	n.s	
	Channel	***	Decrease
	Interaction	n.s.	
Root dry weight	Competition	*	Decrease
	Channel	n.s.	
	Interaction	n.s	
Nitrogen	Competition	n.s.	
	Channel	***	Increase
	Interaction	n.s.	
Phosphate	Competition	n.s.	
	Channel	***	Increase
	Interaction	n.s	
Potassium	Competition	n.s.	
	Channel	***	Increase
	Interaction	n.s.	
Potamogeton:			
Shoot dry weight	Channel	**	Decrease
Root dry weight	Channel	*	Decrease
Nitrogen	Channel	**	Increase
Phosphate	Channel	***	Increase
Potassium	Channel	*	Increase

experiment it was not possible to fully replicate the treatment. The statistical comparisons are therefore comparisons between the two channels rather than between the two treatments. The question therefore arises as to whether it is a reasonable assumption that the differences observed between the channels were due to the phosphate treatment or due to another factor. The major measured differences between the channels were the relatively high phosphate concentration (Figure 1) and large algal growth in the channel with the added phosphate; both were clearly directly caused by the treatment. Conversely, the concentrations of many of the other chemical elements rose and fell in concert in each channel during the growing season (Figure 1; details in Spink 1992). This indicates that it is likely that external factors acting on the channels had similar effects on each channel. However, although it is likely that the effects on the plants observed were due to the treatment, the possibility that it was due to another factor cannot be excluded.

The data indicate that in the channel with the increased phosphate the *Ranunculus* responded with a reduction in shoot growth (but no change in the root growth). Conversely, the competition from the *Potamogeton* did not cause any reduction in shoot biomass, but it did cause a significant reduction in root growth. The reduced growth in both *Ranunculus* and *Potamogeton pectinatus* was most likely to have been caused by shading which resulted from increased filamentous algal growth. This effect is consistent with the hypothesis proposed by Phillips *et al.* (1978) to explain the disappearance of aquatic macrophytes from the Norfolk Broads.

The tissue phosphate concentrations of both the *Ranunculus* and the *Potamogeton pectinatus* were increased in the high phosphate channel. As the sediment concentrations of nitrogen and potassium were identical in both channels these data indicate that the concentration of these elements in the water is a significant factor, demonstrating that, for both *Potamogeton pectinatus* and *R. penicillatus* subsp. *pseudofluitans*, shoots as well as roots are an important pathway for nutrient (N, P and K) uptake.

A number of characteristics of the biology of *Potamogeton pectinatus* suggest that some ecotypes of this species show a strongly competitive strategy (*sensu* Grime 1979). *P. pectinatus* is frequently found in very productive eutrophic habitats and can form an extensive dense canopy (Van Wijk 1988). It shows little physiological acclimation to changes in light intensity, responding instead with changes in biomass (Hootsmans and Vermaat 1991). The species shows a strong seasonal variation in phenology and photosynthesis (Van Wijk 1988). From these characteristics it might be expected that *Potamogeton pectinatus* would be a more competitive (and so less stress-tolerant) plant than *Ranunculus penicillatus*—the data from this experiment go some way toward confirming that. A competitive plant responds to stress with relatively large changes in growth rate (Grime 1977, 1979), whereas a more stress tolerant plant will show a smaller change. The *Potamogeton* shoot biomass was seven times smaller in the added phosphate ("stress") treatment, whereas the *Ranunculus* shoot was only 4.4 times smaller (Figure 2). In addition there was a significant biomass reduction in both the shoot and root of the *Potamogeton*, whereas there was only a significant reduction in the shoot of the *Ranunculus*.

In several English chalk streams dominated by *R. penicillatus* subsp. *pseudofluitans*, the water phosphate concentrations have increased over the past few decades. For example, the River Itchen at Winchester has shown a threefold increase in phosphate concentration during the period 1979-1989 (National Rivers Authority, unpublished data). The results from this experiment indicate that, if the concentration of phosphate continues to increase, it is likely that there may be a decline in macrophytes and an increase in filamentous algae.

In the recirculating channels the algae could not get washed away downstream and so this may have led to more algal accumulation than would occur naturally in a fast-flowing river, though algal populations apparently as dense as those in this experiment have been observed in some chalk rivers (Spink 1992). In situations where algae may not grow so abundantly it would be useful to predict what changes might occur in the balance between the species making up the macrophyte community. Data from this experiment support the hypothesis that *Potamogeton pectinatus* is a more competitive taxon than *R. penicillatus* subsp. *pseudofluitans* (it showed larger morphological changes when stressed). So it is likely that if there was a situation of increased nutrient supply without the stress caused by competition from filamentous algae, the *Potamogeton* would forage nutrients more efficiently than the *Ranunculus*, show a greater plasticity in its growth response, and so outcompete the *Ranunculus*. Indeed, there is evidence (Caffrey 1990) to suggest that this has already happened in some organically polluted rivers in the British Isles.

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