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Interrelationships between phosphorus loading and common carp in the regulation of phytoplankton biomass

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With 2 figures and 2 tables

Abstract: The interrelationship between phosphorus loading and common carp in the regulation of phytoplankton biomass was examined in a four-week summer mesocosm experiment. The factorial design consisted of two levels of phosphorus loading (with/without) cross-classified with two levels of common carp (with/without). At the conclusion of the mesocosm experiment, common carp were removed from mesocosms and a nutrient excretion and defecation trial was performed. A significant interaction effect was detected between phosphorus loading and common carp for chlorophyll-a (a proxy for phytoplankton biomass), total nitrogen, and nitrogen : phosphorus. Common carp had modest effects on chlorophyll-a in mesocosms without phosphorus loading but relatively large enhancement effects on chlorophyll-a in mesocosms with phosphorus loading. Common carp increased total nitrogen in mesocosms with phosphorus loading but had no effect on total nitrogen in mesocosms without phosphorus loading. The synergistic effect of phosphorus loading and common carp on chlorophyll-a was due to nitrogen excretion and defecation by common carp and the subsequent enhancement of nitrogen in mesocosms with phosphorus loading.

Key words: mesocosm experiment, nutrients, phytoplankton production, nitrogen excretion.

Introduction

Phytoplankton biomass is enhanced by nutrients (McCauley et al. 1989) and benthivorous fish (Vanni 1995), but few studies have examined the combined effects of nutrient loading and benthivorous fish on phytoplankton biomass.

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Drenner et al. (1996, 1998) hypothesized that phosphorus loading and benthivorous fish interact synergistically to enhance phytoplankton biomass. That is, phytoplankton biomass is enhanced more in the combined presence of phosphorus loading and benthivorus fish than would be predicted by summing the individual phytoplankton enhancement effect of phosphorus loading and benthivorous fish. This study presents a mesocosm experiment examining the separate and combined effects of phosphorus loading and common carp (*Cyprinus carpio*) on chlorophyll-a (chlorophyll) (a proxy for phytoplankton biomass).

Methods

Mesocosm experiment

The mesocosm experiment was conducted at the Texas Christian University mesocosm facility Fort Worth, Texas, U. S. A. Mesocosms were white fiberglass tanks 2.2 m high and 1.8 m in diameter that held approximately 5000 L of water. Water was continually mixed within each mesocosm by an air-lift mixer system that entrained water from near the bottom of the mesocosm and ejected water across the surface of the mesocosm (Drenner et al. 1986). A 5 cm layer of washed sand was placed in each mesocosm. Tanks were filled with water and plankton from a shallow (2.5 m maximum depth), 0.7 ha pond adjacent to the mesocosm facility. When the mesocosms were filled, concentrations of total phosphorus (TP) and total nitrogen (TN) were 0.04 mg/L and 10.9 mg/L, respectively. A lake with a TP concentration of 0.04 mg/L is considered mesotrophic to eutrophic (Wetzel 2001).

A 2 × 2 factorial design that consisted of two levels of phosphorus loading (with/without), cross-classified with two levels of benthivorous fish (with/without common carp) was used to investigate the synergistic enhancement of chlorophyll by phosphorus loading and benthivorous fish. Each of the four treatment combinations was replicated three times (12 mesocosms total).

Mesocosms were filled with water and plankton on June 24, 2000 and stocked with common carp on June 25. Each mesocosm in the common carp treatment was stocked with one adult common carp weighing 167 ± 59 g (mean ± S. D.), resulting in a tank biomass of 670 ± 238 kg/ha. Common carp can naturally occur at high biomasses of 670 to 1160 kg/ha (Threinen 1949, Robel 1961, Fletcher et al. 1985).

Mesocosms in the phosphorus loading treatment received 16.7 g KH_2PO_4 (0.77 mg phosphorus/L) on June 25. Beginning June 27 all mesocosms received 6.11 g NH_4Cl (0.32 mg nitrogen/L) daily and mesocosms in the phosphorus loading treatment received 0.70 g of KH_2PO_4 (0.036 mg phosphorus/L) daily to maintain their nutrient levels.

Beginning July 1, mesocosms were sampled weekly for four weeks. Integrated water-column samples for analysis of chlorophyll, TP, TN, and turbidity were collected with a PVC tube lowered to near the bottom of the mesocosm. Samples for chlorophyll were filtered through Millipore HAWP membrane filters (0.45 µm pore size); which were wrapped in aluminum foil and frozen until extraction. Chlorophyll was extracted in 2 : 1 chloroform : methanol solution in the dark at 20–22 °C for at least four hours, and the absorbance at 665 nm was determined (Wood 1985). Samples for TP were digested with potassium persulfate (Menzel & Corwin 1965) and analyzed using a modification of the malachite green method (Van Veldhoven & Mannaerts 1987) in which 1 mL of color reagent was added to 20 mL digestions and the absorbance measured at 610 nm. Samples for TN were digested with alkaline potassium persulfate (D'Elia et al. 1977), and absorbance was measured at 220 nm (APHA 1985). Turbidity was analyzed using a Hach turbidimeter. Zooplankton were sampled with a vertical tow of an 80 µm mesh Wisconsin plankton net. Zooplankton were preserved in 10 % sugar formalin and counted under a dissecting microscope.

Nutrient excretion and defecation trials

At the end of the mesocosm experiment, a cast net was used to capture fish from the mesocosms. Each fish was dipped in de-chlorinated tap water to remove residual nutrients before being placed into an 18.9 L bucket containing de-chlorinated tap water and an air-stone. Buckets were housed in a temperature-controlled room where water temperatures were maintained at 24.5–25 °C. Water samples were taken for TP and TN analyses from buckets containing common carp and two controls without fish at 1, 6, and 18 hours after common carp were placed in the buckets. Nutrient samples were analyzed using the same techniques as in the mesocosm experiment. Upon completion of the excretion and defecation trial, all fish were weighed and measured.

Statistical analyses

Data from the mesocosm experiment were analyzed by ANOVA for cross-classified factors using SYSTAT 10.2 (Wilkinson 1998). This statistical analysis allowed us to examine main and interaction effects. Main effects reflect the separate effect of each treatment factor (phosphorus loading or common carp), while interaction effects reflect any interdependence between the effect of phosphorus loading and common carp on response variables. Simple effects, or the effects of phosphorus loading or common carp at each level of the other treatment factor, were tested for when response variables had significant interaction effects. Because of the short duration of the mesocosm experiment, time-related effects are not considered in the analyses. Chlorophyll, TN, and nitrogen : phosphorus (N : P) were log transformed to homogenize variance. These data are not presented in a log scale in Fig. 1 for ease in interpretation. Because of low replication and statistical power, a probability level of alpha < 0.10 was chosen to reduce the chance of making a type II error.

Effects of phosphorus loading on excretion and defecation of nutrients by common carp and growth rate of common carp were analyzed using a one-way ANOVA with SYSTAT 10.2 (Wilkinson 1998). Because of low replication and statistical power, a probability level of alpha < 0.10 was chosen for these analyses.

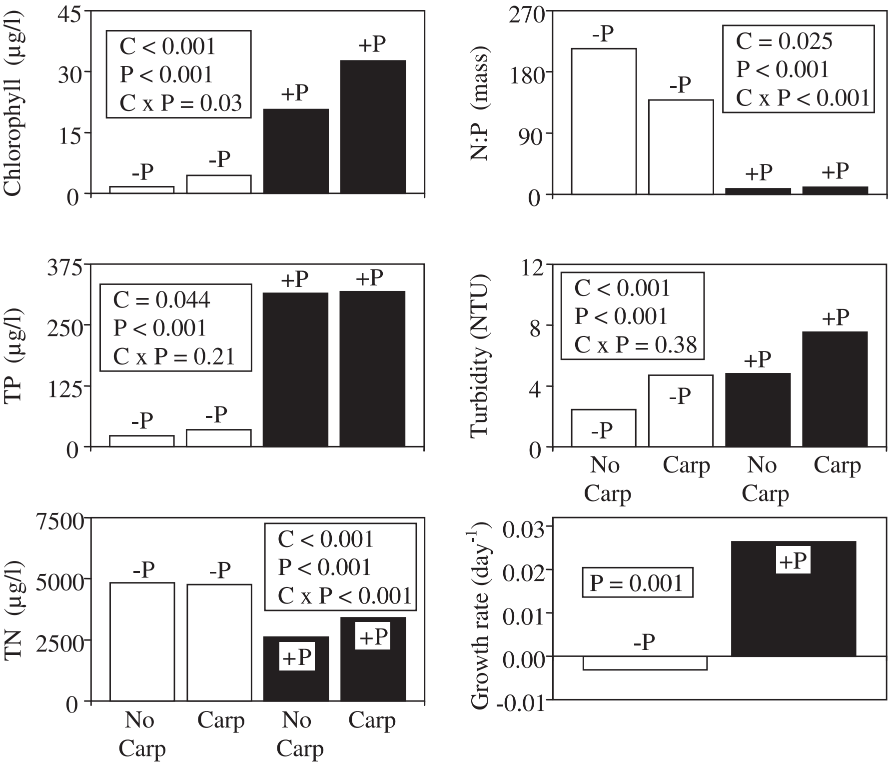

Fig. 1 a. Mean responses of limnological variables to phosphorus loading and common carp and mean growth rate of common carp in response to phosphorus loading. For limnological response variables each bar represents the mean of four sampling dates for the replicate mesocosms within each treatment combination. Probability values from ANOVA of phosphorus loading effects (P), common carp effects (C), and their interaction effects (C×P) on each limnological response variable are indicated on each graph. Probability values from one-way ANOVA of phosphorus loading effects (P) on fish growth rate are also indicated. – P = low phosphorus loading, + P = high phosphorus loading.

Results

All common carp were recovered at the end of the experiment. Common carp in the phosphorus loading treatment weighed 235 ± 34.0 g while common carp in the treatment without phosphorus loading weighed 171 ± 49.7 g.

In the mesocosm experiment, both phosphorus loading and common carp had significant effects on response variables. Phosphorus loading significantly increased chlorophyll, TP, turbidity, common carp growth rate, and the densities of *Ceriodaphnia* spp., *Pleuroxus* spp., cyclopoid copepods, copepod nauplii, and *Brachionus* spp. (Fig. 1). Phosphorus loading significantly decreased

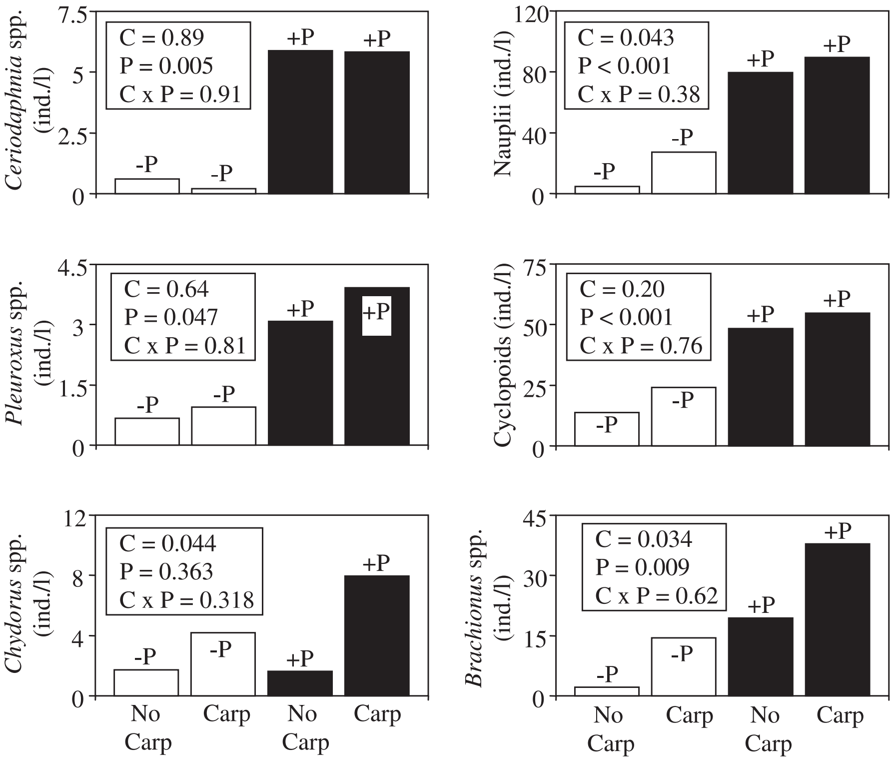

Fig. 1b. Mean responses of zooplankton to phosphorus loading and common carp.

TN and N : P. The presence of common carp significantly increased chlorophyll, TP, TN, N : P, turbidity, and the densities of *Chydorus* spp., copepod nauplii, and *Brachionus* spp. Significant phosphorus loading × common carp interaction effects were detected for chlorophyll, TN, and N : P. Analysis of simple effects showed that phosphorus loading increased chlorophyll and decreased TN and N : P in mesocosms with and without common carp (Table 1). Common carp significantly increased chlorophyll in mesocosms with and without phosphorous loading but the increase was greater in the presence of phosphorus loading. Common carp significantly increased TN in mesocosms with phosphorus loading but had no significant effect on TN in mesocosms without phosphorus loading. Common carp significantly decreased N : P in mesocosms without phosphorus loading but significantly increased N : P in mesocosms with phosphorus loading.

In nutrient excretion and defecation trials, phosphorus loading significantly increased the TP excretion and defecation rates of common carp and decreased the N : P at which common carp excreted and defecated nutrients (Fig. 2). The

Table 1. Simple effects of response variables that had significant interaction effects with common carp and phosphorus loading. Chl = chlorophyll, P = phosphorus, + = dependent variable had a significant positive response to the factor, – = dependent variable had a significant negative response to the factor, NS = P-value was not significant at an alpha level of 0.10.

Dependent Variable	Factor and Level	P-value	Direction of Effect
Chl	Carp at No P loading	<0.001	+
	Carp at P loading	0.018	+
	P loading at No Carp	<0.001	+
	P loading at Carp	<0.001	+
TN	Carp at No P loading	0.51	NS
	Carp at P loading	<0.001	+
	P loading at No Carp	<0.001	–
	P loading at Carp	<0.001	–
N : P	Carp at No P loading	<0.001	–
	Carp at P loading	0.032	+
	P loading at No Carp	<0.001	–
	P loading at Carp	<0.001	–

decline in N : P was due to an increase in phosphorus excretion and defecation with no significant change in nitrogen excretion and defecation.

Discussion

Since Cahn's (1929) pioneering study, there have been at least 38 studies of the effects of common carp on a variety of ecological variables including turbidity, phytoplankton biomass and density, phosphorus and nitrogen concentration, and the abundance and diversity of other fish species, benthic invertebrates, and aquatic macrophytes (Table 2). Only 12 of these 38 studies have examined the effects of common carp on nutrients and/or phytoplankton biomass. Several of these studies were conducted with juvenile carp and are therefore not comparable with our study. Adult common carp, like those in this study, are benthivorous and may affect nutrients and phytoplankton biomass differently than zooplanktivorous juveniles (McCrimmon 1968). The majority of studies that have examined the effects of adult common carp have found that they enhance nutrients and phytoplankton biomass (Table 2).

Only one other study has examined the effects of common carp at different nutrient concentrations. Drenner et al. (1998) used a 2 × 2 factorial design that consisted of two levels of nutrient loading (low/high), cross-classified with two levels of common carp (with/without). Their experiment was conducted in 23 experimental ponds, which were monitored for 1.5 years. In the

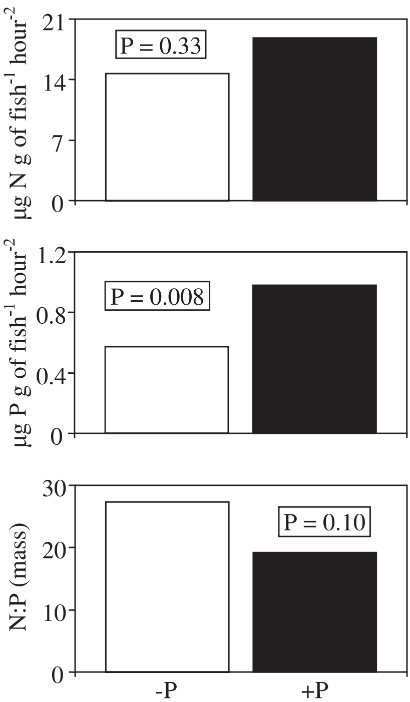

Fig. 2. Mean concentrations of nutrients and N : P excreted and defecated by common carp. Upper and middle figures represent N and P, respectively. Each bar represents the mean of three samples taken from buckets containing common carp from replicate mesocosms at 1, 6, and 18 hours. – P = low phosphorus loading, + P = high phosphorus loading.

last month of the study, Drenner et al. (1998) found that chlorophyll was enhanced more in the presence of phosphorus loading and common carp than can be explained by adding the individual effects of phosphorus loading and common carp. A similar pattern was found in this experiment, where common carp increased chlorophyll 2.8 µg/L in mesocosms without phosphorus loading but increased chlorophyll 12.0 µg/L in mesocosms with phosphorus loading.

Drenner et al. (1998) hypothesized that suppression of herbivorous zooplankton or nutrient excretion by benthivorous fish could be responsible for the synergism. In the present study no evidence was found that suppression of herbivorous zooplankton by common carp played a role in the synergism. Common carp did not suppress any zooplankton taxa but instead enhanced *Chydorus* spp., copepod nauplii, and *Brachionus* spp.

Other studies have found that common carp and other species of benthivorous fish excrete and defecate nutrients on the same scale as those found in our excretion and defecation trials (reviewed in Schaus et al. 1997). Our nutrient

Table 2. Ecological studies that have examined the community-level effects of common carp. Fish = Abundance or diversity of other fish species, Benthos = Abundance, diversity, or Index of Biotic Integrity ranking of benthic invertebrates, Turb. = Turbidity, Macro. = Abundance or diversity of aquatic macrophytes, Phyto. = Phytoplankton biomass or density, P = Phosphorus concentration, N = Nitrogen concentration, + = variable was enhanced by common carp, – = variable was depressed by common carp, 0 = variable was not affected by common carp.

Study	Year	Adult (>30 cm)	Fish	Benthos	Turb.	Macro.	Phyto.	P	N
Cahn	1929	Yes	–		+	–			
O'Donnel	1945	Yes	–						
Black	1946	Yes				–			
Threinen	1949	Yes				–			
Gerking	1950	Yes				0			
Cahoon	1953	Yes			+	–			
Threinen & Helm	1954	Yes			+	–			
Tyron	1954	Yes			0	–			
Mraz & Cooper	1957	Yes							
Jessen & Kuehn	1960	Yes				–			
Robel	1961	Yes			0	–			
Hope & Peterson	1962	Yes			+	–			
Grygierek et al.	1966	No					0		
King & Hunt	1967	Yes				–			
Lamarra	1975	Yes					+	+	
Forester & Lawrence	1978	Yes	–	–	+		+	0	+
Crivelli	1983	Yes			0	–			
Ten Winkel & Meulemans	1984	Yes				–			
Fletcher et al.	1985	Yes			0	–			
Qin & Threlkeld	1990	No			+		+	0	0
Richardson et al.	1990	No		–			+	+	+
Wilcox & Hornbach	1991	Yes		–					
Breukelaar et al. (a, b)	1994	Yes			+				
Cline et al.	1994	Yes			+			0	+
Roberts et al.	1995	No			+	–	+	0	0
Drenner et al.	1997	Yes	0		+	–			
King et al.	1997	Yes			+		+	+	
Robertson et al.	1997	Yes							
Drenner et al.	1998	Yes	–		+	–	+	+	+
Fernandez et al.	1998	Yes			+	–			
Lougheed et al.	1998	Yes			+	–	0	+	+
Sidorkewicj et al.	1998	Yes			+	–			
Zambrano & Hinojosa	1999	No		–	+	–			
Zambrano et al.	1999	No		–	+	–	0	+	0
Barton et al.	2000	Yes		–	+				
Williams et al.	2002	No			0	0	0	+	0
Parkos et al.	2003	Yes		–	+	–	+	+	

excretion and defecation trials indicate that common carp excrete and defecate a substantial amount of nitrogen and phosphorus. In the absence of phosphorus loading, common carp excretion and defecation likely contributed to the increase in water column TP. In the presence of phosphorus loading, common carp excretion and defecation contributed to the increase in water column TN, resulting in an increase in the N : P ratio.

In the mesocosms without phosphorus loading, phytoplankton were likely phosphorus limited and therefore phosphorus excretion and defecation and its subsequent enhancement of phosphorus concentration in the mesocosms had a modest enhancement effect on chlorophyll. In the mesocosms with phosphorus loading, the phytoplankton were nitrogen limited, therefore nitrogen excretion and defecation and its subsequent enhancement of nitrogen concentration in the mesocosms resulted in a relatively larger enhancement of chlorophyll. This is consistent with McCauley et al.'s (1989) hypothesis that the chlorophyll-TP relationship is best represented as a family of sigmoid curves. Each successive curve represents a higher N : P ratio, such that at any given TP concentration an increase in N : P results in movement to a higher curve and a higher chlorophyll concentration. In the absence of phosphorus loading, common carp enhanced TP (but not TN) and as predicted by the chlorophyll-TP relationship chlorophyll was enhanced. In the presence of phosphorus loading, common carp enhanced TN and thus the N : P ratio and as predicted by the chlorophyll-TP relationship this also resulted in an increase in chlorophyll. Because the chlorophyll-TP relationship is a family of curves, an increase in the N : P (movement to a higher curve) at high TP concentrations resulted in a greater increase in chlorophyll than an increase in TP at low TP concentrations.

This study indicates that populations of common carp can play an important role in the eutrophication process. Because common carp excrete and defecate both nitrogen and phosphorus, they may stimulate phytoplankton growth under nitrogen or phosphorus limiting conditions. However, populations of common carp likely have greater effects on phytoplankton biomass in high phosphorus systems relative to low phosphorus systems because their nitrogen excretion and defecation enhances water column N : P. Removal of common carp from systems with high concentrations of phosphorus may have a greater effect on water quality than removal of common carp from systems with low concentrations of phosphorus. Likewise, phosphorus abatement in systems with common carp may have a greater effect on water quality than phosphorus abatement in systems without common carp.

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