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Short Research Note

Biomass-dependent effects of common carp on water quality in shallow ponds

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Abstract

We examined the biomass-dependent effects of common carp (*Cyprinus carpio*) on water quality in 10 ponds at the Eagle Mountain Fish Hatchery, Fort Worth, Texas, USA. Ponds contained 0–465 kg ha^{-1} of common carp. We measured limnological variables at weekly intervals for four weeks in early summer, after which ponds were drained and the biomass of fish and macrophytes was determined. Common carp biomass was significantly positively correlated with chlorophyll *a*, total phosphorus, total nitrogen, and *Keratella* spp. density and negatively correlated to bushy pondweed (*Najas guadalupensis*) biomass. In addition, we combined our data with data from comparable studies to develop more robust regression models that predict the biomass-dependent effects of common carp on water quality variables across a wide range of systems.

Introduction

Common carp (*Cyprinus carpio*) are benthivorous fish that have negative effects on water quality and have been introduced worldwide into freshwater ecosystems. Common carp reduce water quality through their feeding activities by physically disturbing sediments and recycling nutrients. These activities can result in an increase in chlorophyll *a* (chlorophyll), water column nutrient concentrations and turbidity, and a decrease in macrophytes (e.g. Zambrano et al., 1999; Williams et al., 2002; Parkos III et al., 2003).

In general, the effects of fish are biomass dependent (Drenner & Smith, 1991; Lazzaro et al., 1992; Drenner et al., 1996). Despite the large number of studies on the community and ecosystem level effects of common carp (reviewed in Chumchal & Drenner, 2004), relatively few studies have examined the effects of common carp as a function of their biomass (e.g. Lougheed et al., 1998; Sidorkewicj et al., 1998; Parkos III et al., 2003). Therefore, predictive models describing the biomass-dependent effects of common carp are needed to understand the biomass at which common carp affect water quality and to enable targeted management of high biomass populations of common carp. The purpose of this study is to examine the biomass-dependent effects of common carp on water quality, zooplankton, and macrophytes.

Materials and methods

The study was conducted in 10 ponds at the Eagle Mountain Fish Hatchery, Fort Worth, Texas, USA. The ponds have earthen bottoms composed of a clay loam. Ponds are rectangular ovals and have a surface area of 0.36 ± 0.13 ha (mean ± S.D.) and a maximum depth of 1.2 m. All ponds were filled with water from nearby eutrophic Eagle Mountain Lake one year before fish were stocked. Organic matter accumulated in the ponds and invertebrates and macrophytes colonized the ponds.

In September 1997, ponds were stocked with adult common carp from other ponds at the facility at estimated biomasses of 0–100 kg ha^{-1}. In previous experiments ponds were stocked with largemouth bass (*Micropterus salmoides*) and bluegill sunfish (*Lepomis macrochirus*). In addition, three ponds contained various combinations of gizzard shad (*Dorosoma cepedianum*), triploid grass carp (*Ctenopharyngodon idella*), and channel catfish (*Ictalurus punctatus*) remaining from previous studies. Common carp were stocked into ponds that contained other fish species because reservoirs where common carp are present contain relatively diverse fish communities (Miranda, 1983) and the effects of an individual fish species is dependent upon the presence of other fish species in the community (Nowlin & Drenner, 2000). Fish in the ponds were not given supplemental food.

From 11 May to 1 June 1998 water quality and zooplankton samples were collected at weekly intervals for four weeks. Ponds were sampled between 0900 and 1200 h. The deepest area of each pond was sampled from the shore. Integrated water column samples for phytoplankton, nutrients, and turbidity were sampled at a depth of 0.5 m with a PVC tube sampler (4 cm internal diameter). Chlorophyll was used as a proxy for phytoplankton biomass. Water samples were filtered through a 0.45 μm HAWP Millipore filter and chlorophyll was extracted from filters in 2:1 chloroform:methanol in the dark for a minimum of 4 h. Absorbance at 665 nm was determined with a spectrophotometer (Wood, 1985). Samples for total phosphorus (TP) were digested with potassium persulfate (Menzel & Corwin, 1965) and analyzed using the malachite green method (van Veldhoven & Mannaerts, 1987). Samples for total nitrogen (TN) were digested with alkaline potassium persulfate (D'Elia et al., 1977) and analyzed by UV estimation at 220 nm (APHA, 1985). Turbidity was measured with a model 2100A Hach turbidimeter. Zooplankton were sampled with a vertical tow of an 80-μm mesh Wisconsin plankton net and preserved in 10% sugar-formalin. Zooplankton were identified to genera (except for adult copepods which were identified to suborder) and enumerated.

Ponds were drained during June and July 1998 to determine fish and macrophyte biomass. All fish were collected, weighed, and measured. On the same day a pond was drained and fish were removed, we estimated macrophyte biomass by taking 10 samples along a transect that intersected the deepest point of the pond. The first sample was collected 0.5 m offshore, and the other nine samples were collected at random points along the transect. At each sample site, all vegetation above the sediment within a 0.25 m^2 quadrat was collected. Macrophyte samples from each pond were pooled and frozen before they were sorted to species or genera, dried in an incubator, and weighed.

The four-week mean of each response variable was regressed against common carp biomass using simple linear least-squares regression with SYSTAT 8.0 (Wilkinson, 1998). Due to the small sample size ($N = 10$), we set α at 0.10 to reduce the probability of making a type II error (accepting a false null hypothesis). An α-level of 0.10 is commonly used in ecological studies when variability is high and sample size is low (e.g. Drenner et al., 1998).

To explore the generality of the relationships found between the biomass of common carp and water-quality variables and to develop a more robust and less site-specific model to predict common carp effects, we searched the ecological literature for comparable studies. Comparable studies were those conducted in ponds, lakes, or enclosures that reported the biomass of common carp. Studies that used juvenile common carp or did not allow common carp access to sediments were omitted. We used data from comparable studies to examine the relationship between the biomass of common carp and chlorophyll, TP, turbidity, and macrophyte biomass. We log-transformed ($\log_{10}[x+1]$) response variables prior to regression analysis in order to meet the assumption of homogeneity of variance.

Results and discussion

In our pond experiment, common carp biomass ranged from 0–465 kg ha^{-1}. Common carp are found in U.S. reservoirs at a mean biomass of 25.4 kg ha^{-1} (Jenkins, 1975) and can naturally occur at high biomasses of 670 to 1160 kg ha^{-1} (Threinen, 1949; Robel, 1961; Fletcher et al., 1985).

Several water quality variables were affected by common carp biomass. Chlorophyll, TP, and TN increased with common carp biomass (Fig. 1). Turbidity was also positively correlated with common carp biomass although the relationship was not statistically significant (R^2 = 0.24, p = 0.15).

In general, common carp biomass had less of an effect on zooplankton densities than on water quality variables. Cladoceran (primarily *Bosmina* spp.), copepod (primarily calanoids), and copepod nauplii density were not significantly related to the biomass of common carp (R^2 = 0.17, p = 0.24; R^2 = 0.11, p = 0.35; R^2 = 0.12, p = 0.33

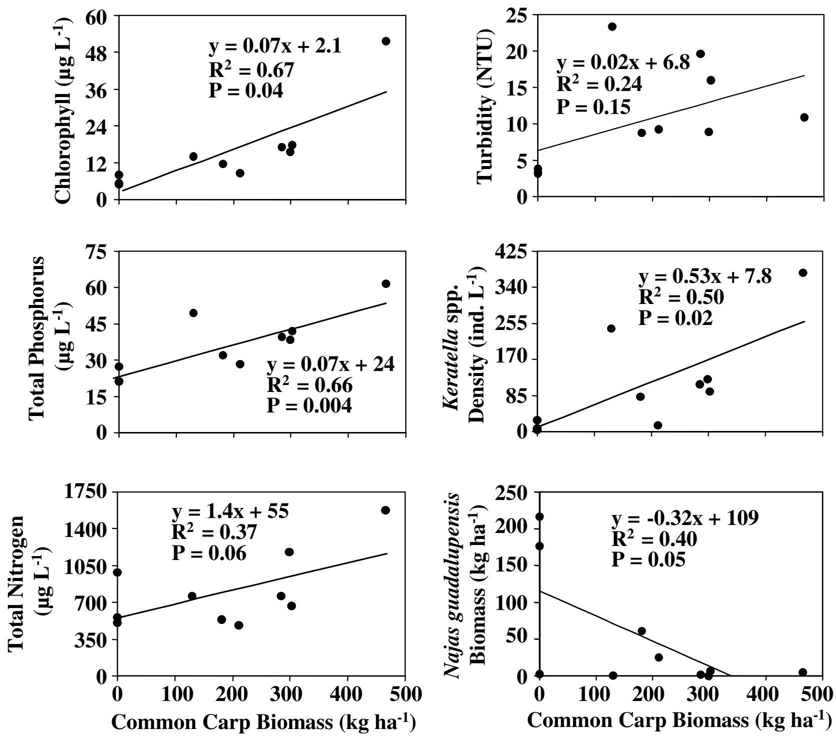

Figure 1. Relationship between common carp biomass and water quality variables in ponds at the Eagle Mountain Fish Hatchery.

Table 1. Biomass (kg ha^{-1}) of fish recovered at the conclusion of the experiment from each pond at the Eagle Mountain Fish Hatchery

Species	Fish Biomass (kg ha^{-1})									
	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6	Pond 7	Pond 8	Pond 9	Pond 10
Common Carp	302	0	0	211	181	0	298	465	285	130
Largemouth Bass	57	46	55	29	37	32	36	14	17	29
Bluegill	88	87	80	41	126	101	132	65	70	57
Gizzard Shad	0	0	0	11	0	0	35	0	1	0
Channel Catfish	0	0	0	10	0	0	52	0	0	0
Triploid Grass Carp	0	0	0	34	0	0	0	0	0	0

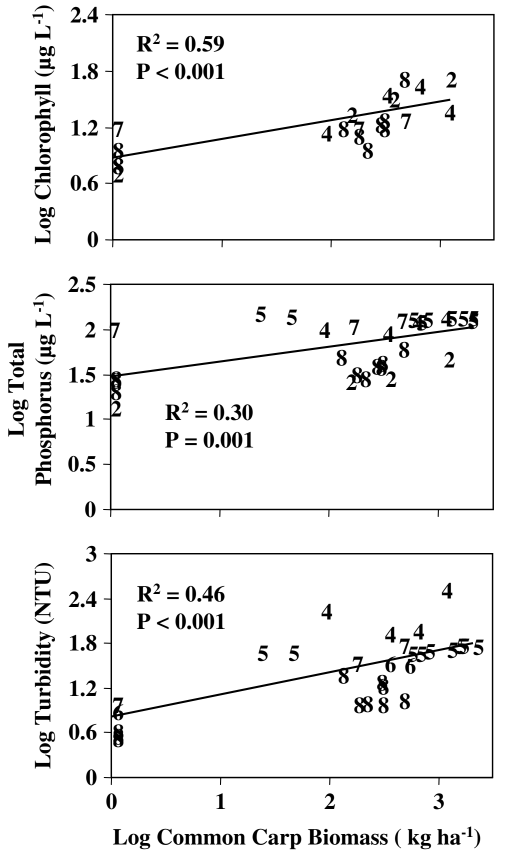

Figure 2. Relationship between log-transformed (log[$x+1$]) common carp biomass and log-transformed (log[$x+1$]) water quality variables. Numbered points correspond to studies in Table 2.

respectively). However, *Keratella* spp. (the dominant rotifer genera) had a significant, positive relationship with common carp biomass (Fig. 1).

Ponds contained from three to nine macrophyte species including bushy pondweed (*Najas guadalupensis*), musk grass (*Chara* spp.), pondweeds (*Potamogeton pusilis* and *P. nodosus*), American lotus (*Nelumbo lutea*), Eurasian watermilfoil (*Myriophyllum spicatum*), and coontail (*Ceratophyllum demersum*). Bushy pondweed was the only macrophyte species whose biomass decreased significantly with the biomass of common carp (Fig. 1). Total macrophyte biomass was not affected by common carp biomass ($R^2 = 0.008$, $p = 0.8$).

At the end of the experiment, all ponds contained largemouth bass and bluegill, two ponds contained gizzard shad and channel catfish and one pond contained triploid grass carp (Table 1). We conducted a step-wise regression to determine if the biomass of the other individual fish species in the ponds explained a significant amount of variance in response variables after the effect of common carp biomass was removed. The biomass of other fish species did not explain a significant amount of the variation in any response variable after the effect of common carp was removed. Further, we conducted a stepwise regression to determine if total fish biomass or common carp biomass was a better predictor of response variables. For each variable common carp biomass was the better predictor.

During our literature search we identified seven comparable studies that could be used to explore the generality of the relationships found between the biomass of common carp and water-quality variables. These studies were conducted in ponds, lakes, or enclosures that had sediment bottoms and all reported the biomass of common carp (Table 2). We did not include 12 studies from the literature because they used juvenile common carp, were conducted in sediment-free systems, or did not report the biomass of common carp (Grygierek et al., 1966; Forester & Lawrence, 1978; Fletcher et al., 1985; Meijer et al., 1990; Qin & Threlkeld, 1990; Richardson et al., 1990; Cline *et al.,* 1994; Roberts et al., 1995; Tatrai et al., 1997; Drenner et al., 1998; Zambrano et al., 1999; Williams et al., 2002).

Data from comparable studies combined with the results from our study indicate that there is a general relationship between common carp biomass and several water quality variables across a wide diversity of systems. Specifically, we found a significant positive relationship between the biomass of common carp and chlorophyll, TP, and turbidity (Fig. 2). We did not find a significant relationship between the biomass of common carp and macrophyte biomass ($R^2 = 0.02$, $p = 0.45$), but we were only able to include data from two studies in this analysis (Table 2). We were unable to quantify the relationship between the biomass of common carp and TN because we could not find any published studies that met our criteria and reported TN concentrations (Table 2).

In addition to biomass, the effects of common carp are dependent upon the size of the individual

Table 2. Studies examining the effects of common carp on chlorophyll *a* (Chl), total phosphorus (TP), total nitrogen (TN), turbidity (Turb) and macrophytes (Macro)

Study	#	Experimental Conditions							Carp Effects				
		Experimental system	N	Ind fish size (cm)	Fish community	Amb TP ($\mu g\ l^{-1}$)	Amb macro	Amb benth ($g\ m^2$)	Chl	TP	TN	Turb	Macro
Robel, 1961	1	enclosures	16	NR	Absent	NR	Present	NR	NR	NR	NR	0	–*
Lamara, 1975 (Kuska pond)	2	enclosures	4	NR	Absent	10	NR	NR	+*	+*	NR	NR	NR
Crivelli, 1983	3	enclosures	6	NR	Absent	NR	Present	NR	NR	NR	NR	0	–
King *et al.*, 1997	4	billabongs	4	31– > 70	Present	91	Sparse	NR	+*	+*	NR	+*	NR
Lougheed *et al.*, 1998	5	enclosures	9	9.7–59.3	Absent	NR	Absent	NR	0	+*	NR	+*	NR
Sidorkewicj *et al.*, 1998 (Experiment Two)	6	enclosures	3	39	NR	NR	Present	NR	NR	NR	NR	+*	–
Parkos III *et al.*, 2003	7	enclosures	3	NR	Absent	108	Present	1.7	+*	+*	NR	+*	–
This study	8	ponds	10	> 30	Present	23	Present	NR	+*	+*	+	0*	0*

The table presents the experimental system, the number of data points (*N*), sizes of individual common carp (Ind Fish Size), if other fish species were present (Fish Community), ambient TP (Amb TP), ambient macrophyte conditions (Amb Macro), and ambient benthos biomass (Amb Beth). The direction of the response of Chl, TP, TN, Turb, and macrophyes to common carp is reported for each study. NR = not reported. + = enhanced by common carp. – = reduced or depressed by common carp. * = data included in analysis.

(Sidorkewicj et al., 1998; Williams et al., 2002), the species composition of fish communities (Qin & Threlkeld 1990; Richardson et al., 1990), trophic state (Drenner et al., 1998; Chumchal & Drenner, 2004), and benthos abundance (Zambrano et al., 2001). Each of these parameters differed between studies or was not reported by the authors (Table 2). Due to the limited number of studies and a lack of uniformity in variables analyzed, we were not able determine how these factors affected the relationship between common carp biomass and water quality variables.

Here, we have developed the first robust model describing the biomass dependent effects of common carp on water quality. The model would be more useful as a predictive tool if data on the other factors known to affect the impact of common carp on water quality could be included and these variables should be collected in future studies.

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