



Effects of *Cyprinus carpio* on *Potamogeton pectinatus* in experimental culture: the incidence of the periphyton

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Abstract

The effect of one-year-old common carp (*Cyprinus carpio* L.) on plants and seedlings of *Potamogeton pectinatus* L., and on periphyton development was studied in 100 l glass aquaria. Two 30-day experiments were conducted using a muddy sediment or a pebbly bottom. In both cases, three treatments based on different fish size (two fish/aquarium) were assayed. The control had no fish. In both experiments, chlorophyll content of the periphyton increased from the beginning to the end of the period, for the three fish treatments. Light attenuation by periphyton was high, with final values 12–30% higher than in the control. Periphytic communities acclimated to reduced light conditions when the bottom was muddy. It can be concluded that, in muddy conditions, small carp affected plant growth by shade stress, which is achieved by a combination of increase in turbidity and the developing of a leaf periphytic cover. Under pebbly conditions, plant damage was caused by collisions and the growth of epiphytic algae. Medium and large fish consumed plants in both experiments. Seedlings were affected by herbivory in all cases.

Introduction

Common carp, *Cyprinus carpio* L., is a benthivorous fish that has received considerable attention as a result of impacts on submerged macrophytes following its introduction to new habitats outside its native range (King & Hunt, 1967; McCrimmon, 1968; Fletcher et al., 1985; Brumley, 1991). The adverse effects of this fish upon aquatic vegetation have been historically attributed to physical disturbance, causing plant uprooting (Crivelli, 1983) and an increase in abio-genic turbidity (Sidorkewicz et al., 1996, 1998, 1999a, b; Fernández et al., 1998). More recently, bottom-up and top-down effects induced by carp have also been taken into account as mechanisms indirectly affecting the biomass of submerged macrophytes through changes in phytoplankton densities (Roberts et al., 1995; Sidorkewicz et al., 1999a, b). Less known are the effects that carp may have on vegetation through alteration in epiphytic periphyton.

Recent studies have demonstrated the importance of periphyton in terms of productivity (Lowe, 1996), as components of aquatic food webs (Otto, 1982) and as agents involved in the decline of submerged macrophytes through shading (Sand-Jensen, 1977; Phillips et al., 1978). To study the direct effects of different sizes of juvenile common carp on plants and seedlings of *Potamogeton pectinatus* L. (sago pondweed), and the indirect effects that operate through the development of epiphytic cover, two laboratory experiments with contrasting sediment conditions were performed. Acclimation of periphytic communities to decreasing light availability, caused by increasing turbidity, was also evaluated.

Materials and methods

Experimental setup

Two consecutive 30-day experiments were conducted using twenty 100-l glass aquaria (0.40 m × 0.60 m × 0.50 m height). In the first experiment (Experi-

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ment 1), muddy sediment (76% sand, 14% clay, 10% loam) was collected from a drainage channel in Argentina and distributed in the tanks in a 5 cm-thick bed. In the second experiment (Experiment 2), a 5 cm-thick layer of washed fine gravel was instead used. In both cases, the tanks were filled with tap water. In each experiment, four plants and two seedlings of *P. pectinatus*, individually contained in 200 ml pots, were introduced into each aquarium. For the epiphytic periphyton study, eight transparent plastic strips (2 × 8 cm) were suspended vertically in the water column of each aquarium 5 cm from surface. The vertical position allowed an equal colonization on both sides of the strip (Soto Perez, 1994). Nine months old common carp (age 0⁺) were weighed and added to 15 aquaria in size-matched pairs, using three size classes as treatments ($n = 5$). Mean fresh weights (\pm s.d.) were: 6.6 \pm 0.9 g (T₁), 14.0 \pm 0.7 g (T₂) and 21.0 \pm 1.3 g (T₃) for Experiment 1, and 15.2 \pm 2.7 g (T₁), 27.7 \pm 3.1 g (T₂) and 42.5 \pm 0.7 g (T₃) for Experiment 2. Values for fish total length were 79 \pm 5 mm (T₁), 101 \pm 2 mm (T₂) and 115 \pm 5 mm (T₃) in Experiment 1, and 101 \pm 7 mm (T₁), 124 \pm 4 mm (T₂) and 142 \pm 7 mm (T₃) in Experiment 2. In each case, five aquaria with no fish were used as control. Light supply was provided by fluorescent lighting (40 W; 566 $\mu\text{E m}^{-2} \text{s}^{-1}$ at water surface), with a 12 h photoperiod. Water aeration was provided by pumps. No fish food or fertiliser was added.

Sampling and analysis

At the beginning and at the end of the experiments, determinations were made of aboveground dry weight (PDW; 70 °C, 48 h) and total foliage length (TL) of plants. TL measurements were performed by adaptation of a line intersect method (Tenant, 1975), commonly used to measure root length (Sidorkewicz, 1998). Seedlings were measured in height (H). Weekly, two plastic strips were removed randomly from each aquarium; one was used for biomass and light attenuation measurements and the other was used to determine chlorophyll content. Light transmittance (PAR; LI-COR 192SB and METEX M-4650) was measured by submerging the intact strips in tap water under full sunlight. Attenuance (A) was calculated as proportional transmittance reduction relative to transmittance through a clean strip. For biomass measurements, the material attached to both sides of the strip was scraped off with a razor blade and filtered through pre-ashed and pre-weighed Whatman GF/C

filters (1.2 μm). Determinations were then made of dry weight (DW; 105 °C, 24 h), ash weight (AW; 520 °C, 2 h) and ash-free dry weight (AFDW = DW – AW). For chlorophyll analysis, the material removed from the second strip was filtered through non pre-ashed GF/C filters. Chlorophyll *a* (Chl. *a*) and *b* (Chl. *b*) contents were determined following Wintermans & De Mots (1965). As all periphyton measurements corresponded to colonization on both sides of the strips, calculations were made to refer the data to one side. Weekly, dissolved oxygen (WTW OXI 96), pH, water temperature and conductivity (WTW LF 96-A) were measured. Changes in organic and inorganic tripton, phytoplankton density, dissolved nutrients, turbidity and underwater light attenuation were also recorded (Sidorkewicz et al., 1999a).

Statistics

When residuals were not normally distributed or variances were not homogeneous, data were transformed using $\log(x)$ or $\log(x + 1)$. Differences in aboveground dry weight of plants (PDW_f - PDW_i), plant total length (TL_f - TL_i) and seedling height (H_f - H_i), based on the mean value per aquarium, were analysed by means of a one-way ANOVA ($p \leq 0.05$). The comparison among consecutive mean values was carried out by means of an *a priori*, one-tailed *t* test (LSD; $p \leq 0.05$). As was indicated above, periphyton measurements were performed weekly in independent and randomly removed plastic strips, allowing the use of a split-plot factorial design in time for DW, AW, AFDW, Chl. *a*, Chl. *b* and A ($n = 5$; $p \leq 0.05$) (Steel & Torrie, 1980). The significance of the differences between mean values was determined by SNK test ($p \leq 0.05$). Periphyton growth parameters were estimated by applying to the AFDW data the exponential growth model: $B_t = B_0 \cdot \exp^{r(t-t_0)}$, where B_0 and B_t are biomass (AFDW; mg cm^{-2}) at the beginning of the experiment and at time t (days), respectively, and r is the unrestricted growth rate (d^{-1}). Between treatment values of r were compared by analysis of covariance (ANCOVA, $p \leq 0.05$; Steel & Torrie, 1980). Rectangular hyperbolae were fitted to the attenuation-AFDW periphyton datasets: $A = (a \times B) \times [(c + B)]^{-1}$, where A is the attenuation, B is the biomass (AFDW; mg cm^{-2}), and a and c are the parameters (slope and asymptote, respectively) of the rectangular hyperbola. The fitted curves were compared between treatments by means of an *F* statistic ($p \leq 0.05$), described by Vermaat & Hootsmans (1994a).

Results

The average instantaneous growth rate of the fish used in the study (Bagenal & Tesch, 1978) was -0.30% in Experiment 1 and -0.36% in Experiment 2. Physico-chemical parameters did not exhibit differences between treatments (one-way ANOVA; $p > 0.10$). Mean (\pm s.d.) oxygen concentration, water temperature, conductivity and pH were $6.5 \pm 1.7 \text{ mg l}^{-1}$, $23.2 \pm 1.2 \text{ }^\circ\text{C}$, $1.1 \pm 0.2 \text{ mS cm}^{-1}$ and 7.9 ± 0.2 , respectively in Experiment 1, and $9.3 \pm 2.2 \text{ mg l}^{-1}$, $17.3 \pm 1.3 \text{ }^\circ\text{C}$, $0.4 \pm 0.0 \text{ mS cm}^{-1}$ and 8.6 ± 0.3 , respectively in Experiment 2. In Experiment 1, snails (*Littoridina parchappii*), which were present in the sediment, remained during all the experimental period in control tanks, but disappeared from fish aquaria within two days.

Vegetation

Initial PDW and TL (mean \pm s.d.) were $43.9 \pm 22.2 \text{ mg}$ and $3.7 \pm 1.1 \text{ m}$, respectively, in Experiment 1 and $35.3 \pm 11.3 \text{ mg}$ and $3.0 \pm 0.7 \text{ m}$, respectively, in Experiment 2. Seedlings measured $28.3 \pm 6.3 \text{ cm}$ in Experiment 1 and $17.6 \pm 3.5 \text{ cm}$ in Experiment 2. Effects of fish on vegetation for both experiments are shown in Table 1. No uprooting was noticed. The lack of significant differences between control-T₁-T₂ plants in Experiment 2 may be explained by a high within-treatment variation. Herbivory was evidenced in pebbly conditions by the appearance of green faecal pellets at the bottom of all fish aquaria.

Periphyton

Experiment 1

DW, AW and AFDW increased from the beginning to the end of the experiment (Figure 1 A–C). The three variables showed a significant interaction between treatments and time. No significant differences in estimated growth rates were detected; however, higher values were observed in the fish treatments (0.011 – 0.012 d^{-1}) than in the control (0.005 d^{-1}). Chl. *a* and Chl. *b* concentration increased from the beginning to the end of the experiment in the fish treatments (Figure 1 D, E). The interaction between treatments and time was significant for both type of chlorophyll. The chlorophyll content in the organic matter ($\mu\text{g Chl. (a + b) (mg AFDW)}^{-1}$), averaged over the whole period (\pm s.d.), was greater in the fish treatments (T₁: 12.9 ± 3.6 ; T₂: 16.7 ± 4.0 ; T₃: 12.9 ± 4.5) than in

the control (9.1 ± 4.1). Light attenuation increased through the experiment (Figure 1F), with final values 20–21% in T₁ and T₂, and 30% in T₃, higher than the control. The treatment \times time interaction was not significant. Rectangular hyperbolae fitted to the attenuation-AFDW datasets were significant only for the fish treatments, with high values of R^2 : 0.74 for T₁, 0.92 for T₂, and 0.84 for T₃. Curves were significantly different, ascending faster in direct relation to the fish size (Figure 2).

Experiment 2

DW, AW and AFDW showed growing values as fish size increased (Figure 1G–I). Only in AFDW, a significant treatment \times time interaction effect was detected. Instantaneous growth rates did not differ statistically between treatments; however, values tended to be higher according to fish size (T₁: 0.003; T₂: 0.006; T₃: 0.012 d^{-1}). The three fish treatments showed values higher than the control for both types of chlorophyll (Figure 1J, K). In Chl. *a*, a significant treatment \times time interaction was detected. The chlorophyll content in the organic matter was greater than in the previous experiment, with higher values in the fish treatments (T₁: 28.7 ± 10.7 ; T₂: 24.1 ± 5.5 ; T₃: $27.5 \pm 8.7 \mu\text{g Chl. (a + b) [mg AFDW]}^{-1}$) than in the control ($17.9 \pm 4.0 \mu\text{g Chl. (a + b) [mg AFDW]}^{-1}$). Attenuance was of the same order of magnitude than in Experiment 1 (Figure 1L). Final values were 12% in T₁ and T₂, and 22% in T₃, higher than control attenuation. The interaction between treatments and time was non significant. Attenuance-AFDW data showed high dispersion, so the adjustment of hyperbolic curves was not possible.

Discussion

Vegetation was severely affected by all fish treatments in both experiments. In Experiment 1, the main negative effect caused by small carp was probably shade stress, due to the typical growth response of *P. pectinatus* plants to reduced light conditions (Van Wijk et al., 1988). This would have resulted from the development of a dense periphytic cover and the high values of water turbidity recorded (up to 94 NTU; Sidorkewicz et al., 1999a). In Experiment 2, although some plant growth occurred, fish appeared to cause plant damage by combined collisions, as indicated by fallen leaves, and growth of epiphytic algae, which resulted in a light attenuation increase of 12%. Medium and large fish

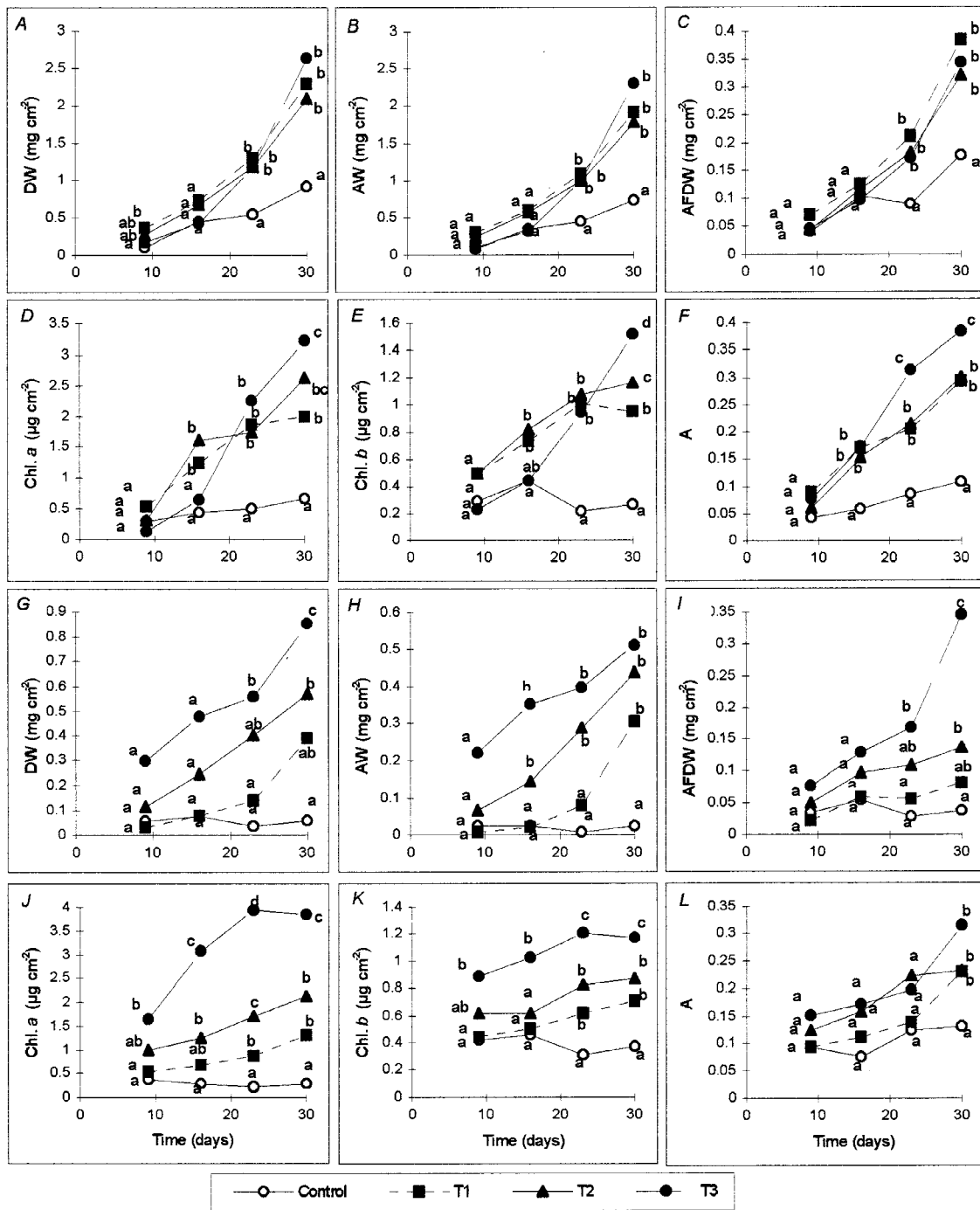


Figure 1. Mean values of periphyton biomass (dry weight: DW; ash weight: AW; ash-free dry weight: AFDW), chlorophyll *a* and *b* concentration (Chl. *a*, Chl. *b*) and light attenuation (A) in Experiment 1 (A–F) and Experiment 2 (G–L). T₁: smaller-size fish treatment; T₂: medium-size fish; T₃: largest-size fish. Different letters (a–d) indicate significant differences between treatments, at each sampling date, with SNK test ($p \leq 0.05$).

Table 1. Effects of control and fish (T₁: smaller-size; T₂: medium-size; T₃: larger-size) treatments on vegetation in Experiment 1 and Experiment 2. Plus and minus signs represent parameters increase and decrease, respectively, throughout 30 days. Different letters (a–c) indicate significant differences between treatments with LSD test ($p \leq 0.05$)

		Control	T ₁	T ₂	T ₃
Experiment 1:	Plant length:	+ 116% a (healthy; luxuriant growth; uniformly branched)	–11% b (upper canopy; basal chlorosis and necrosis)	–95% c (several plants disappeared including the root system; remaining plants: bare and browsed shoots)	–95% c
	Plant dry weight:	+ 234% a	–5% b	–57% c	–57% c
	Seedling height:	+ 47% a (healthy; uniformly branched)	–18% b (browsed)	— (disappeared)	—
Experiment 2:	Plant length:	+ 247% a (healthy)	+ 160% a (not browsed; leaves fallen at the bottom of the aquaria)	+ 170% a (browsed; few fallen leaves)	–13% b (strongly browsed; absence of fallen leaves)
	Plant dry weight:	+ 346% a	+ 166% a	+ 203% a	–76% b
	Seedling height:	+ 44% a (healthy)	–29% b (strongly browsed)	–25% b (strongly browsed)	— (disappeared)

affected plant growth mainly by herbivory in both experiments. Seedlings were affected by herbivory in all cases, indicating that carp prefer soft vegetal tissues.

In Experiment 1, the predominant fraction in the periphytic strata was from inorganic origin, as was expected from the high values of inorganic tripton concentration in the three treatments (up to 178 mg l⁻¹; Sidorkewicz et al., 1999a). A stimulus to the development of periphytic algae by fish was also observed, in spite of the high water turbidity recorded (maximum values: 94, 254 and 329 NTU in T₁, T₂ and T₃, respectively; Sidorkewicz et al., 1999a). Contrarily, Robertson et al. (1997) reported for two billabongs in Australia that carp had a negative effect on the development of the autotrophic components of the periphyton, under similar water turbidities to those recorded here. In the present study, the increased development of epiphytic algae in fish aquaria seems to be related to a top-down effect through the consumption by the fish of *L. parvichthys* (a molluscan species which selectively feeds on periphyton; Cazzaniga, 1981), and maybe other benthic organisms. Probably, an additional bottom-up effect through the enhancement of dissolved nutrient concentration by fish excretion and sediment bioturbation (Sidorkewicz et al., 1999a) was achieved. In Experiment 2, on the contrary, only a bottom-up effect through fish excretion would be re-

sponsible for the observed increase in the density of attached algae. The higher chlorophyll content in the organic matter, by comparison with the other experiment, indicates a more suitable environment in terms of light availability. In both experiments, the increase in the final chlorophyll concentration with fish size, was probably due to a higher excretion as a result of increased consumption of vegetal matter (Table 1). In addition, in Experiment 1, a higher excretion could have occurred as a consequence of an increase in the consumption of zooplankton (Sidorkewicz et al., 1999a) and zoobenthos. The body size of fish may determine not only the quantities but also the proportions of food items consumed (Lammens & Hoogenboezem, 1991), since what they are able to eat is closely related to the diameter of the chewing cavity (9% SL; Sibbing, 1988, 1991). In both experiments, a significant increase in phytoplankton biomass was also observed in all fish treatments (Sidorkewicz et al., 1999a), and this phenomenon seems not to have had negative effects on periphyton development through competition for nutrients or allelopathy.

The periphytic growth observed in the present study was exponential, contrary to the logistic fit reported elsewhere (see Rodriguez, 1987). According to the cited author, if the underlying process is logistic-like, using an exponential model will produce underes-

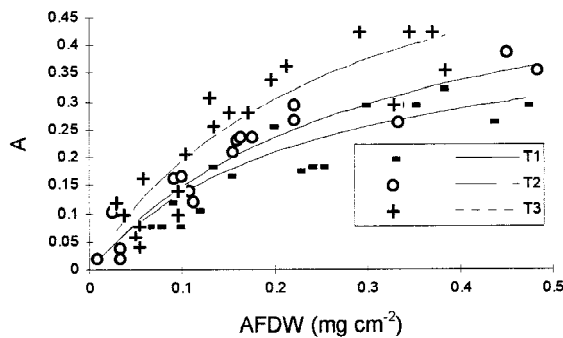


Figure 2. Attenuance-biomass datasets and fitted rectangular hyperbolae obtained in Experiment 1. Treatment abbreviations as in Figure 1.

timation of the specific growth rate. However, the error would be small if only the early phase, when growth is almost exponential, is used in the estimation. The lack of differences between growth rates agree with Vermaat & Hootsmans (1994b) who reported absence of differences between growth rates corresponding to different levels of irradiation. In the present study, differences in underwater light availability were caused by increasing turbidity values as fish size increased (Sidorkewicz et al., 1999a).

Epiphyte shading has been reported by Sand-Jensen (1977) and Phillips et al. (1978) as a main cause in the decline of submerged vegetation. The light attenuation recorded in the present study was high in both experiments (12–30%), in spite of the differences in biomass amounts reached in both cases. Differences between the attenuance-biomass curves in Experiment 1 indicated an efficient acclimation of the periphytic communities to different light conditions, in relation with the increasing turbidity levels of the three treatments. This means that, for equivalent biomass, the periphytic communities cause higher light attenuation as underwater light extinction increase, which is relevant for submerged macrophytes growing in turbid waters, typical of carp habitats. Similar results were found by Vermaat & Hootsmans (1994b) in different levels of irradiance.

The results obtained can help to acknowledge the ecological consequences of the recent introduction of *C. carpio* in the irrigation system of the Valle Inferior del Río Colorado (VIRC, Argentina), where negative effects of this fish upon submerged vegetation have been found (Fernández et al., 1998; Sidorkewicz, 1998; Sidorkewicz et al., 1998, 1999b). In this system, Drovandi (1993) and Soto Perez (1994) found

that periphyton is an agent involved in the light attenuation experienced by submerged macrophytes, but they did not establish a correlation between carp populations and epiphytic development. In the present study, a high percentage of plant destruction was due to carp herbivory. However, previous studies performed in the VIRC (Sidorkewicz, 1998; Sidorkewicz et al., 1998, 1999b) revealed that, although a certain plant consumption by fish existed, other processes such as increases in abiogenic and biogenic turbidity were involved in plant damage. In such situations, the increased light attenuation caused by periphyton enhancement could be crucial, adding a new stress factor to vegetation.

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