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Interaction of Common Carp with Aquatic Weeds in Argentine Drainage Channels

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ABSTRACT

Two different densities (1000 and 2000 fish ha^{-1}; average weight 20 g) of common carp, *Cyprinus carpio* L., were stocked into an Argentine drainage channel, following mechanical removal of the vegetation. In a second experiment larger fish (average weight 260 g) were stocked at 500 and 1000 fish ha^{-1}. In this experiment vegetation was not removed prior to stocking. Common carp significantly reduced growth of the dominant submersed weeds present (*Chara contraria* A. Braun ex Kutz; *Ruppia maritima* L.) in both experiments, as compared with the untreated controls. Three months after the introduction of the smaller fish the reduction of plant biomass ranged from 40 to 86% of control plots. Larger fish completely destroyed all submersed weed growth within 4 months. The common carp stocking elevated water turbidity by up to 10 times that of control plots, by stirring up of sediments during their feeding activities. Direct herbivory was also observed.

Key words: Chara, turbidity, *Ruppia maritima, Potamogeton pectinatus, Cyprinus carpio,* South America.

INTRODUCTION

Growth of submersed weeds in irrigation systems is a major problem in arid and semiarid regions (Pieterse and Murphy 1993, Stocker 1993). In South America an example is the irrigation scheme of the Valle Inferior del Río Colorado (VIRC), located in the Lower Valley of the Colorado River in southern Argentina, where approximately 90,000 ha of cultivated land are under irrigation (Fernández et al. 1993).

The main effect of aquatic weed growth in the VIRC system, as elsewhere (Pieterse & Murphy 1993) is to impede the flow of water in irrigation and drainage channels. A second, indirect effect is in increasing salinity in the soil of the cultivated areas due to malfunctioning of the drainage system (Fernández et al. 1987). Mechanical methods and herbicides (acrolein) have been used to control aquatic weed growth in the VIRC system, but provide only short-term control at high cost (Fernández et al. 1993).

Submersed aquatic weed taxa recorded in VIRC drainage channels during summer 1993-94 were listed by Lamberto et al. (1997) as *Chara contraria* A. Braun ex Kütz, *Potamogeton pectinatus* L. (= *P. striatus* Ruiz et Pavon: Tur 1982), *Ruppia maritima* L., *Zannichellia palustris* L., *Potamogeton pusillus* L. (= *P. berteroanus* R. A. Phil: Tur 1982), and two filamentous algae: *Enteromorpha flexuosa* (Kützing) Bliding, and *Cladophora surera* Parodi et Cáceres. The last two sometimes form floating mats on the water surface.

Common carp (*Cyprinus carpio* L.) is an alien species in Argentina (Ringuelet et al. 1967). The date of introduction of this species in the VIRC drainage scheme is unknown, but is likely to have been during the mid-1980s, since it was not reported by Cazzaniga (1981) in a previous survey of the aquatic fauna of the system. Noticeable turbidity increases in the water of VIRC drainage channels, owing to increases in suspended sediment, were reported by water managers and farmers during the latter part of the 1980s. At the same time reductions in the biomass of submersed aquatic weeds began to be observed (Sabbatini 1989). These changes coincided with the first observations of common carp in the drainage channels.

The effects of common carp upon aquatic vegetation are produced by a combination of turbidity increase and (often) herbivory (King and Hunt 1967). In an aquarium study of their effects on *Potamogeton pectinatus,* common carp were observed to produce a substantial resuspension of sediments which shaded submersed plants, and also ate plant tissue (Sidorkewicj et al. 1996). Under field conditions the benthic-feeding behavior of the fish can affect aquatic vegetation directly by an uprooting action (Cahn 1929, Robel 1961, McCrimmon 1968, Crivelli 1983, Fletcher et al. 1985) or indirectly by stirring up sediments and increasing turbidity (Anderson 1950, Threinen & Helm 1954, Moyle and Kuehn 1964, Krull 1968).

In some parts of the world introduced common carp are considered to be a pest organism, unsuited to use as a biological control agent (Nichols 1991, Nichols and Lathrop 1994). This is usually either because of their impact on native fish species, or due to damage to banks and channel beds caused by their benthic feeding behaviour (McCrimmon 1968). In the VIRC system, common carp is now a naturalized constituent of the fish fauna of the irrigation scheme, and has not been recorded as causing problems for other fish species within the system. There is little or no use of the channel system by anglers (other than for common carp themselves, usually taken for food). VIRC management has not reported

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any significant bed or bank damage attributable to the activities of common carp.

Rather than being considered a nuisance, manipulation of common carp populations are here proposed as the basis of a biological control strategy for managing channel weed problems, at a lower cost than conventional control regimes. However, until the functional interaction between this fish and the submersed vegetation of the study area had been experimentally demonstrated and quantified, management recommendations remained uncertain.

The first objective of this research was to determine the effect, in Southern Argentine drainage channels, of different carp densities on both established submersed vegetation, and on the regrowth of submersed vegetation, following dredging of the channel. The second objective was to establish some preliminary limits to the range of fish size and stocking density within which potentially useful weed control effects might be realized.

SITES AND METHODS

Experiments were conducted in the VIRC irrigated area, a semiarid region located in the south of the Provincia de Buenos Aires, Argentina (39°10'-39°55'S; 62°55-63°05'W). Water comes from the Río Colorado (mean flow 138.8 $m^3 s^{-1}$) and is distributed for irrigation purposes by a network of 3300 km of main, secondary and subsidiary farm channels. Drainage water is collected by a network of 3500 km of drainage channels. Water remains in the drainage channels year round, while the irrigation channels are dry for 2-3 months during the winter season. The channels are low-lying, averaging some 5-20 m above sea level.

The average air temperature in the region is 1.8 C during July, and 29.6 C in summer (January). Channel water temperatures lie in the range 8.8-25.6 C. Water conductivity ranges from 1,000 to 20,000 µS cm^{-1}, the highest values being recorded in low-lying drainage channels located in former saltmarsh areas reclaimed for agriculture. Active plant growth occurs during September-March (Fernández et al. 1987).

Experiments were carried out in two drainage channels located within the experimental farm of the Universidad Nacional del Sur at San Adolfo in the VIRC area. The channels had a width between 3 to 4 m, water depth of 0.3 to 0.8 m, pH 7.0 to 9.0, with a sandy-clay-loam bottom. Preliminary surveys confirmed that no carp were present in either channel before the start of the experiments. The experimental channels were divided into 50 m sections using wooden barriers covered by waterproof plastic film and reinforced by soil banked up on one side. The height of the barriers was sufficient to prevent water from passing between sections. No fish food was added to sections during the experiments.

Two experiments were carried out in seasons 1993-94 and 1994-95. In the first year two different carp densities were tested, after mechanical removal of the vegetation at the end of December 1993. In the second, two different densities of fish were used, without prior removal of the natural vegetation growing in the experimental plots.

Fish used in both experiments were from the same reservoir stock (a nearby site in the VIRC area). After anaesthetic treatment, individual fish length and weight were determined. The animals were transported in plastic bags filled with water, with supplementary oxygen provided to minimize stress. Before fish were released into the experimental sites, an acclimatization period was provided, by putting the closed bags into the water of the enclosures for 30 min. Then the bags were opened to permit water input to equilibrate.

At intervals of approximately 2 weeks (season 1993-94) or 3 weeks (season 1994-95), dissolved oxygen (mg l^{-1}), electrical conductivity (µS cm^{-1}), water temperature (C), water turbidity (Nephelometric Turbidity Units, NTU) and water depth (m) were measured in each section. In both experiments, carp were recaptured from the sites at the end of the experimental period, using electrofishing apparatus (Electrocatch model WFC7-30/50 set for pulsed DC output at 50 Hz). At lower water conductivity the current rating was typically about 2 A at 100V; at higher water conductivity the settings used ranged from 10 A at 80 V to 18 A at 70 V. On each occasion three successive runs were performed to optimize fish recapture.

Experiment 1: season 1993-94. Two sites (A and B) with six enclosed sections each were used. Prior to dredging, all sections supported a total plant cover of approximately 100%, dominated by *C. contraria,* with occasional patches of *R. maritima, P. pectinatus, Z. palustris* and filamentous algae. Carp treatments were allocated at random to enclosures, with two replicates of each treatment per site. Fish were introduced on 12 January 1994, 2 weeks after the channels were dredged, and recaptured on 13 April 1994. The treatments were: (a) low density (**LD**): 1000 fish ha^{-1}, (b) high density (**HD**): 2000 fish. ha^{-1}, and (c) control: no fish (Table 1). Due to the different size of the channels, these represented 15 (LD) and 30 (HD) fish in site A (3 m wide), and 20 (LD) and 40 (HD) fish in site B (4 m wide). Above-ground biomass samples of submersed weeds were collected at the end of the experimental period using a 30 × 30 cm metal quadrat, located in three randomly-chosen beds of the vegetation within each treatment enclosure. In the laboratory, the samples were washed, oven-dried at 70 C for 48 h, weighed for dry weight (DW) and subsamples incinerated at 520 C over 2 h to obtain ash free dry weight (AFDW).

Experiment 2: season 1994-95. Two sites (C and D) with six enclosures each were used. Submersed vegetation was nearly continuous (approximately 100% cover) along each channel at the start of the study. *R. maritima* was dominant in site C,

TABLE 1. INITIAL AND FINAL FISH WEIGHT, TOTAL LENGTH AND BIOMASS (MEAN ± STANDARD DEVIATION). EXPERIMENT 1: LD: 1000 FISH.HA^{-1}; HD: 2000 FISH.HA^{-1}; EXPERIMENT 2: LD: 500 FISH.HA^{-1}; HD: 1000 FISH.HA^{-1}.

		Fish weight (g)	Fish total length (cm)	Fish biomass (kg ha^{-1})
Exp. 1 (1993-94)	Initial (12/1/94)	20 ± 8	11 ± 1	18 ± 6 (LD) 40 ± 4 (HD)
	Final (13/4/94)	189 ± 84	23 ± 3	163 ± 84 (LD) 210 ± 106 (HD)
Exp. 2 (1994-95)	Initial (21/11/94)	258 ± 195	25 ± 7	138 ± 88 (LD) 275 ± 98 (HD)
	Final (28/3/95)	921 ± 315	39 ± 5	342 ± 222 (LD) 535 ± 74 (HD)

and *C. contraria* in site D. Scattered patches of *Z. palustris, P. pectinatus* and filamentous algae were also present. The fish density was reduced because fish of larger size were available. The treatments were: a) **LD**: 500 fish ha^{-1}, b) **HD**: 1000 fish ha^{-1} and c) control: no fish. These represented 8 (LD) and 15 (HD) fish in site C and 10 (LD) and 20 (HD) fish in site D (Table 1). There were two randomly located replicates of each treatment in each site. Fish were introduced to the target enclosures on 21 November 1994 and recaptured by electrofishing on 28 March 1995. Above-ground plant biomass samples were collected, (as in Experiment 1) on 21 November 1994, 7 February 1995 and 28 March 1995. Three sample subplots were used on the first two dates and five in the third one. On 21 November 1994, 27 December 1995 and 28 March 1995 individual plants of *R. maritima* (site C) and *C. contraria* (site D) were collected for morphological trait measurement. Three individual ramets were collected per plot. Traits measured were total above-ground weight and length of ramet (both species), and weight of leaves, stems and fruits (*R. maritima* only). Plant processing in the laboratory was as in Experiment 1.

Statistical analysis. Each experiment was analyzed separately, using ANOVA tests for balanced data (factors: treatment and site) to assess the significance of treatments for each variable measured. The average of the three or five sample subplot values was calculated, to give a between treatment replicate value of n = 4 across the two sites in each experiment. Observed differences between mean values were subsequently determined by Dunnett and Student-Newman-Keuls (SNK) mean-separation tests.

RESULTS AND DISCUSSION

Initial data on fish weight, length and biomass are detailed in Table 1 for Experiment 1. The experiment terminated when plants and fish were harvested. Fish recapture was 80 and 92% in site A for LD and HD, and 43 and 45% for LD and HD, respectively, for site B. The weight increase of the fish during the experimental period was about 9.5 times, while their length approximately doubled (Table 1).

In Experiment 2 observed predation by birds and foxes was the likely cause of the total loss of fish from some enclosures, especially during a period of very low water level in February. This meant that, after that date, one replicate of each treatment (LD and HD) in site D and one replicate of LD treatment in site C had to be discarded for further analysis. Recapture values for the rest of the plots were satisfactory: 100% for LD and 60-80% for HD in site C, 50% for LD and 45% for HD in site D. The average increment in fish weight was 3.6 times, while the increment in total length was 1.5 times.

In Experiment 1, a uniform cover of weed regrowth had developed (following the pre-treatment dredging) in both sites by ten days after the start, with a similar species composition to that present before dredging.

Figure 1 shows the effect of fish on plant biomass (per unit of total channel area) three months after fish were introduced in Experiment 1. There were significant differences between treatments ($p < 0.01$), between sites ($p < 0.01$), and a treatment × site interaction ($p < 0.05$). The Dunnett test detected significant biomass reduction at LD (40%

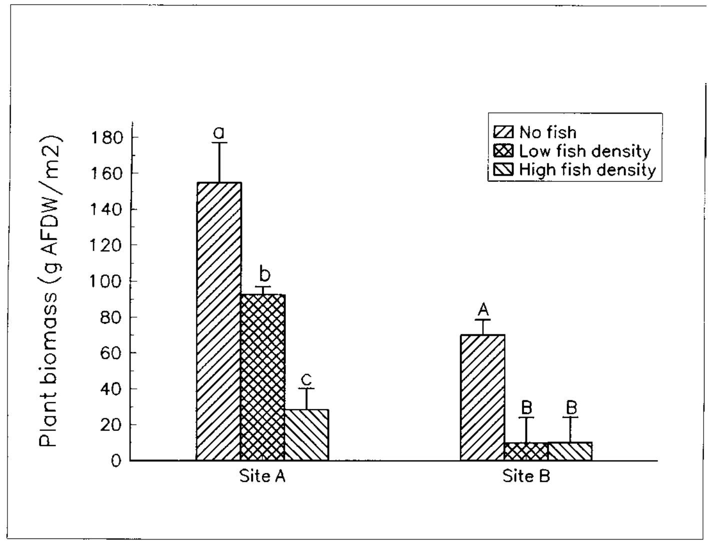


Figure 1. Above-ground biomass (ash-free dry weight) of aquatic vegetation at the end of Experiment 1 (low density: 1000 fish.ha^{-1}; high density: 2000 fish.ha^{-1}). Vertical bars represent + standard deviation. Treatments labelled with different letters for each site (a-c; A-B) are significantly different (Dunnett and SNK tests; $p < 0.05$).

in site A, 86% in site B) and at HD (82% in site A, 86% in site B) with respect to the control treatments ($p < 0.01$ in all cases). SNK test detected differences between both densities and the control ($p < 0.05$ in all cases), and also between LD and HD in site A (69% of plant biomass reduction; $p < 0.01$).

Prior to Experiment 2, average plant biomass (AFDW ± standard deviation) was 196.3 g m^{-2} (± 76.1) and 51.5 g m^{-2} (± 24.2) for sites C and D respectively. At each site, prior to starting the experiment there was no significant difference ($p > 0.05$: one way ANOVA) between enclosures for any of the submersed vegetation variables measured. Two months after fish introduction in Experiment 2, a reduction in plant biomass for both fish densities was noted in site D, compared to the control treatment (68% and 100% for LD and HD, respectively). In site C, a plant biomass reduction of 79% was found for HD. There were clear signs of grazing damage to the vegetation. The effects observed in carp-containing plots were substantial at this interim stage, but the results were not statistically significant owing to the high within-treatment variability registered. However, after four months, at the end of the experiment, there were no plants in any enclosure from which carp were recaptured, while weed growth in control plots was luxuriant: complete control of submersed weeds had been achieved by both low and high density carp treatments.

Significant reductions in total individual plant weight of *R. maritima* and *C. contraria* were recorded after 1 month in Experiment 2 (Table 2) but there were no significant treatment effects on individual plant parts, or total length. This response is of interest since it implies that the impact of common carp is on the whole (above-ground) plant, rather than being concentrated on any particular part of the plant. These results are in contrast to the effect of grass carp (*Ctenopharyngodon idella* Val.) on submersed weeds in parallel trials carried out in Southern Argentina alongside this study

TABLE 2. TRAITS MEASURED FOR INDIVIDUAL PLANTS OF *R. MARITIMA* AND *C. CONTRARIA* ON 27 DECEMBER 1994, EXPERIMENT 2. ALL MEASURES ARE IN ASH FREE DRY WEIGHT (AFDW). C: CONTROL; LD: LOW DENSITY TREATMENT (500 FISH.HA^{-1}); HD: HIGH DENSITY TREATMENT (1000 FISH.HA^{-1}). DIFFERENT LETTERS IN EACH COLUMN INDICATE SIGNIFICANT DIFFERENCES ($p \leq 0.05$) USING DUNNETT AND SNK TESTS. ABSENCE OF LETTER INDICATES THAT DIFFERENCES WERE NON-SIGNIFICANT.

	R. maritima (site C)	*C. contraria* (site D)
Individual plant weight (mg)	C: 67 ± 11 *a*	C: 67 ± 1 *A*
	LD: 43 ± 13 *b*	LD: 40 ± 7 *B*
	HD: 35 ± 0 *b*	HD: 45 ± 3 *B*
leaves weight (mg)	C: 27 ± 8	—
	LD: 17 ± 5	—
	HD: 14 ± 5	—
stems weight (mg)	C: 32 ± 7	—
	LD: 21 ± 7	—
	HD: 17 ± 5	—
fruits weight (mg)	C: 7 ± 4	—
	LD: 4 ± 1	—
	HD: 4 ± 1	—
plant length (cm)	C: 32 ± 14	C: 61 ± 2
	LD: 31 ± 5	LD: 44 ± 0
	HD: 32 ± 7	HD: 52 ± 1

(reported elsewhere: CEC. 1996). Grass carp effects were strongly concentrated on leaf tissue, leaving stem and reproductive structures largely undamaged. Common carp did not, on this evidence, appear to be selectively grazing any particular part of the plants in the way that grass carp did.

Figure 2 (a, b) shows a trend towards consistently higher turbidity values in the presence of carp during Experiment 1, but this was not usually statistically significant, except for the measurements taken on 7 April 1994 in site A, 85 days after the fish introduction. ANOVA detected no significant effect on turbidity during Experiment 2 until mid-February, except for the measurements taken on 27 December 1994 in site C, 36 days after the fish introduction, when fish treatments had significantly higher turbidity than control treatment ($p < 0.05$). Readings after February showed that data for LD and HD were higher than the control treatment at both sites (Figure 3a, b).

Environmental conditions remained throughout within the tolerance range of common carp. In the first year water depth varied from an initial value of 0.30 m to 0.65 m at the end of the period in site A. For site B the level of the water showed a constant value around 0.80 m. In site A, conductivity ranged from the maximum value of around 14,000 µS cm^{-1} in January, followed by a constant decrease as the water level increased, to a value of 6,000 µS cm^{-1} at the end of the period. For site B the value was below 2,000 µS cm^{-1}.

In Experiment 2 initial water level was over 0.60 m for both sites. A substantial decrease occurred at site C during mid-February, to <0.30 m in some enclosures. By early March the level of the water had recovered to the original values. Conductivity varied in site C between 8,000 and 19,000 µS cm^{-1}. In site D, conductivity was always below 5,000 µS cm^{-1}.

In both years, water temperature and dissolved oxygen were within the range considered adequate for the normal behaviour and growth of common carp (Sarig 1966, Opuszynski 1967). Water temperature was 23.4 ± 5.8 C in

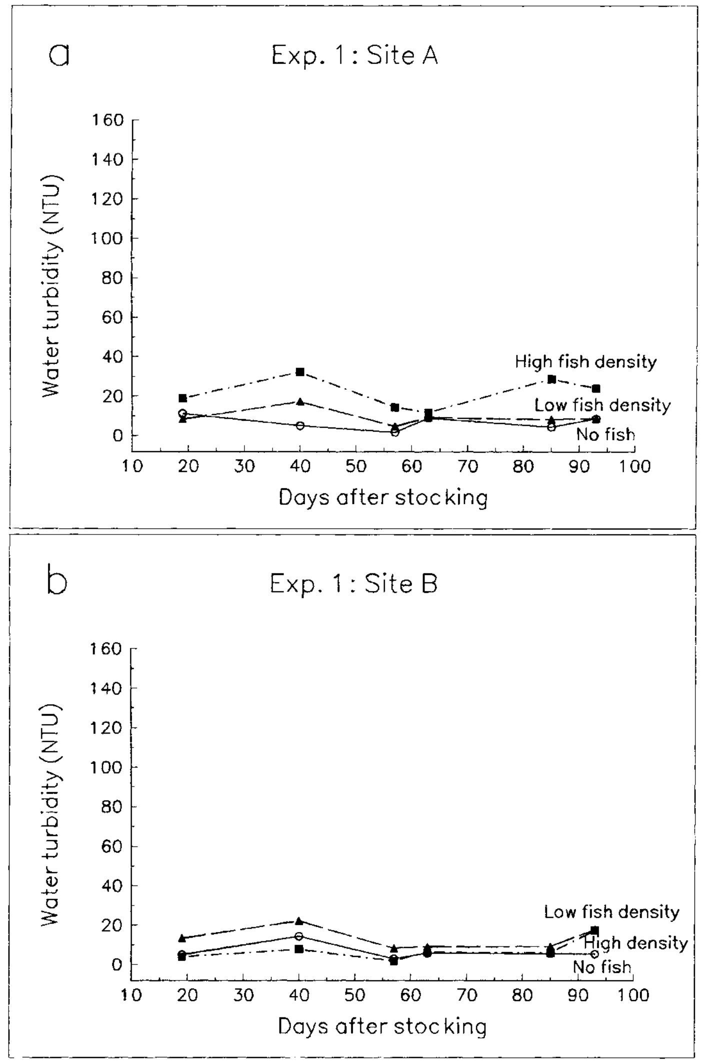
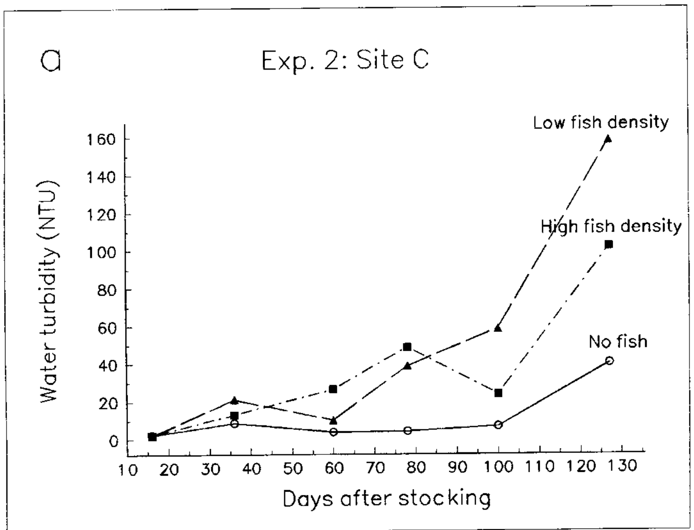


Figure 2. Mean turbidity values in Experiment 1. Low density: 1000 fish.ha^{-1}; high density: 2000 fish.ha^{-1}.

Experiment 1 and 23.8 ± 3.9 C in Experiment 2 while dissolved oxygen was 9.7 ± 2.8 mg.l^{-1} and 10.9 ± 3.1 mg.l^{-1} respectively. The results from Experiment 1 suggest that carp averaging about 20 g each, at a rate of 2000 fish ha^{-1}, could produce a significant reduction in submersed plant regrowth within three months. Results obtained with densities of 1000 fish.ha^{-1} in site A were poor in terms of plant biomass reduction. In Experiment 2, when bigger fish were used (introduced at between 150 to 370 g individual mean weight), they had a rapid effect on the growth of plants at both densities used. According to King and Hunt (1967), McCrimmon (1968), Crivelli (1983) and Fletcher et al. (1985), the destruction of submersed plants by common carp is selective, depending on plant community composition. Nevertheless, in Experiment 2, all submersed plant growth was suppressed after 4 months, by both fish densities tested.

Table 3 compares our results with data of Robel (1961) for carp in enclosures in a Utah marsh, and Crivelli (1983) in a marsh of the Camargue (Southern France). Owing to differences in ambient conditions between these studies the



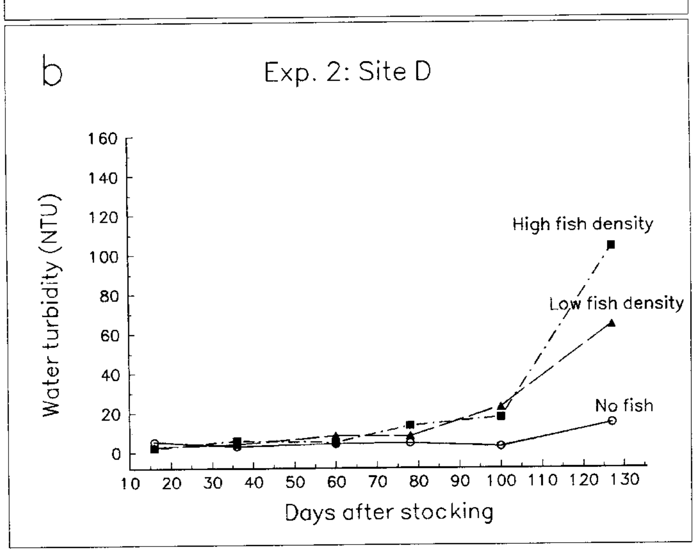


Figure 3. Mean turbidity values in Experiment 2 (low density: 500 fish.ha^{-1}; high density: 1000 fish.ha^{-1}).

results are not directly comparable, but are nevertheless of indicative interest. We observed a higher percentage destruction of aquatic vegetation than in previous studies, despite the smaller fish used. Two factors may help explain this. The effectiveness of the 20 g fish could be related to the absence of an initial dense stand of vegetation. In the second experiment carp were kept *in situ* for a longer period when compared to the earlier studies.

It is interesting to consider the relative importance of sediment resuspension as a consequence of carp feeding in producing the observed impacts on submersed plant growth. The poor correlation found in Experiment 1 between turbidity and fish (Figure 2a,b) is in accordance with the conclusions reached by Robel (1961) and Crivelli (1983) in experimental enclosures, and by Fletcher et al. (1985) under natural conditions. For Experiment 2 when larger fish and more interaction time was allowed, we found a marked increase in turbidity by the end of the experimental period in fish-containing sections (Figure 3a,b). These findings are supported by the aquarium experimental data on the interactions between common carp and *P. pectinatus,* which showed water turbidity up to 90 NTU in the presence of fish, while control turbidity was always less than 7 NTU (Sidorkewicj et al. 1996).

Carp appear to increase turbidity during feeding periods in proportion to their size, so the overall value registered for the small fish used in Experiment 1 was not much greater than in the absence of fish. Contributing factors to the variability observed in the turbidity readings could be climatic or biotic factors affecting fish activity, or variations in water depth. In turbid conditions, the reduction of light penetration plus deposition of suspended materials on the leaf surfaces, would be expected to limit submersed plant growth by increasing shade-stress.

In practical terms, where carp are likely to be used in long channel stretches (up to several kilometers long) the effects of water flow have to be considered. Each individual disturbance event caused by a fish rooting for food in the sediment will resuspend a quantity of sediment which will then move downstream with the current before the particles resettle. A sufficiently large number of such events, produced by the daytime feeding activities of a suitably large population of common carp throughout the channel, can however maintain high levels of suspended sediments over substantial stretches of slow-flowing water (typical of a drainage channel). The constant replenishment of silt particles in suspension all along the stretch should maintain the turbidity. The effect is likely to be similar to that seen in navigation canals where silt is constantly resuspended by the propeller disturbance events produced by individual boats moving along the canal. Once the frequency of boat passage attains a critical intensity, the canal water becomes turbid because sediments are constantly being stirred up, settling slowly whilst drifting downstream, only to be resuspended again by the next boat (Murphy & Eaton 1983).

Herbivory in common carp is likely when preferred food items are scarce (King and Hunt 1967, Sibbing 1988, Sarig 1966, Kantrud 1990). In our study the total eradication of the vegetation in the carp enclosures in Experiment 2, was at least in part due to carp grazing. Submersed plants did not form a canopy close to the surface in the trial sections (as would be expected if they showed a normal response to turbidity-induced high shade intensity: Barko et al. 1986). There were clear signs of direct grazing damage to many of the plants sampled.

Carp densities which are insufficiently high to suppress all growth of submersed weeds may still have a useful effect, by partially reducing the plant growth and its reproductive potential, and thus reducing the need for additional mechanical weed control treatments, or prolonging their period of effectiveness.

Our results suggest that using small fish at low stocking densities (18-40 kg ha^{-1}) is likely to produce only partial weed control. Larger fish at higher initial stocking densities (138-275 kg ha^{-1}) could produce complete suppression of submersed weed biomass within four months. These results provide a range of values within which to carry out further work aimed at manipulating common carp population density and size structure, for effective management of submersed weeds in irrigation channel systems.

TABLE 3. RESULTS OBTAINED IN THIS STUDY IN RELATION TO THOSE OF SIMILAR EXPERIMENTS CONDUCTED IN ARTIFICIAL ENCLOSURES IN UTAH, USA (ROBEL, 1961) AND THE CAMARGUE, FRANCE (CRIVELLI, 1983).

	Year	Days of experiment	Average initial fish weight (g)	Bottom	Water depth (m)	Average initial fish biomass (kg ha^{-1})	Vegetation reduction (%)
UTAH	1959	72	2400	Sandy clay	0.3	226	9
						431	32
						660	48
	1960	94	3800	Sandy clay	0.3	241	33
						433	50
						500	67
						683	78
CAMARGUE	1977	71	1600	Mud	0.43	433	25
						588	42
						647	50
						726	51
ARGENTINA	1993-1994	91	19.8	Sandy clay loam	0.3-0.8	18.3	40-86
						40.1	82-86
	1994-1995	128	258.2	Sandy clay loam	0.3-0.8	137.6	100
						275.3	100

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