



Interactions of common carp (*Cyprinus carpio*) with benthic crayfish decapods in shallow ponds

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Abstract

Introduction of common carp (*Cyprinus carpio*) for aquaculture increased in recent decades. This fish is now established in many new water systems creating interactions with native species. Some of these interactions have been partly understood, but most of them remain unknown. For instance, in shallow ponds of central Mexico, populations of crayfish (*Cambarellus montezumae*) are reduced with high carp densities, but little is known about the mechanisms that lead to this depletion. Gut analysis showed that carp ate mostly detritus, small invertebrates, plant tissues and seeds, reducing the possibility of predation as a main cause of crayfish population reduction. Field and experimental data suggest that the effect of carp on crayfish is associated with habitat depletion. Submerged macrophyte *Potamogeton pectinatus* and the algae *Cladophora glomerata* are important components in crayfish habitat, and their coverage in the water system is affected by carp presence. A second effect of carp on crayfish populations is associated with the alteration of crayfish behaviour. Crayfish displacement speed increased significantly in the presence of carp.

Introduction

Introduction of common carp (*C. carpio*) for aquaculture in tropical and subtropical lakes has dramatically increased in recent years (Fernando, 1991). For example, in Mexico, it has been promoted for 35 years as a source of protein, partly because of its capacity to survive and grow in poor quality waters (Maitland & Campbell, 1992). Carp is now present in 95% of natural and semi natural systems across this country, and its introduction in most water bodies has been done without any control (Mujica, 1987; Hernández et al., 1995).

Introduction of carp normally results in a loss of native diversity through changes in water quality and disturbance or depletion of shared resources in

both temperate (Richardson et al., 1995) and subtropical systems (Brumley, 1991). Carp abundance is inversely related to macrophyte cover and macroinvertebrate abundance, especially gastropods (Stein & Kitchell, 1975; Zambrano et al., 1999). As a generalist predator, carp can affect benthic organisms such as chironomids and tubificids and submerged plants like *Potamogeton pectinatus* and *Sagittaria mexicana* (Zambrano & Hinojosa, 1999). Indirectly, carp may decrease the abundance of submerged macrophytes by increasing turbidity in the water through bioturbation (Tatrai & Istvanovics, 1991; Breukelaar et al., 1994; Cline, 1994; Carvalho & Moss, 1995; Zambrano and Hinojosa, 1999).

Carp also affects benthic macroinvertebrates such as crayfish. The mechanism by which carp introduc-

tion contributes to the depletion of these species is poorly understood. On one hand, it is possible that carp depletes crayfish populations by predation. As benthivorous, carp search for food at the bottom of the ponds, where crayfish normally are. But on the other hand, it is possible that the effect of carp on crayfish populations could also be related to a depletion of its resources (i.e. macrophytes coverage). Significant reduction in macrophyte cover (particularly submerged) has been related to carp introduction to shallow systems (Fletcher et al., 1985; Crowder & Painter, 1991; Engel & Nichols, 1994). Macrophytes are an important source of food and shelter, providing refuges for crayfish larvae recruitment (Lodge, 1991; Newman, 1991). Therefore, changes in macrophyte community by carp may promote reduction in crayfish abundance. The scope of this study was to understand the interaction between introduced common carp (*C. carpio*) and a native crayfish *C. montezumae* in shallow ponds. A first goal was to assess crayfish abundance in natural and experimental ponds containing different carp densities. A second aim was to explore the pathways by which carp could have an effect on crayfish. Evidence of predation was examined using carp diet analysis. Crayfish preferences for different type of macrophytes in the field and in experimental tanks was also explored, along with modifications of these preferences in the presence of carp. The third aim was to explore experimentally variation in crayfish behaviour (variation of speed displacement as an index of stress) in relation to carp presence.

Study sites and methods

The project was divided in three steps: (a) gathering data from the field in shallow ponds in Acambay valley where crayfish is native and carp has been introduced, (b) experiments in controlled shallow ponds at 'El Cerrillo' research station and (c) laboratory experiments in tanks.

Acambay valley and the El Cerrillo research station are both located in El Estado de Mexico (19° 20' W and 99° 40' N), 169 km northwest of Mexico City. Altitude exceeds 2200 m, mean annual temperature is 13 °C, and mean annual precipitation in the region is 768.5 mm. In Acambay, ponds are used to provide irrigation for crops (mainly maize and wheat). In some of these ponds juvenile carp are constantly stocked by local aquaculture promoters above governmental recommended levels (>2 ind. m^{-2}).

Although these ponds are closely related to human activities, they have a high conservation value because they host endemic species of the region such as axolotl (*Ambystoma* sp), crayfish (*C. montezumae*) and the live-bearing fish (*Girardinichthys multiradiatus*) (Zambrano et al., 1999).

Ponds samples

(a) Field ponds samples

In Acambay, sampling was carried out in March 1998 and in March 1999 in the driest season when water of ponds was at the lowest level. We used eight shallow ponds (0.84 ± 0.21 m deep and 0.8–8 ha size) that had different carp densities. Crayfish abundance (ind. m^{-2}) was estimated along transects using a beam net (2×3 m) (Renfro, 1962). In order to elucidate macrophyte-crayfish preferences, transects were placed in zones that differed in macrophyte type (submerged, emergent and flat-floating). Transect length and depth varied from 45 to 90 m and 0.1 to 1 m respectively. Transects number varied in each sampling occasion based on macrophyte coverage. The minimum number of transects were three and the maximum five. Crayfish abundance on each macrophyte type (submerged, emergent and flat-floating) was estimated as the mean number of all transects in each pond. Macrophyte abundance was estimated at all sites with a 40 cm diameter circular frame (Neechi et al., 1995) at 5 sample points along each of twelve 10 m transects (60 samples per pond in total).

Carp was collected with a gill net and its gut contents were sampled using a syringe connected to a 20 cm long and 3 mm diameter hose placed into the fish stomach. Samples were extracted and mixed with distilled water (7 ml) and preserved in 70% ethanol for later laboratory analysis. Gut elements were separated and wet weight determined. In total, 100 carp of different size and age were analysed (60 carp from Acambay valley ponds and 40 carp from El Cerrillo experimental ponds).

(b) Experimental ponds samples

Five experimental ponds (area $500 m^{-2}$) in El Cerrillo research station were filled with water to a depth of 1 m. In four of the ponds juvenile carp (mean total length = 5.3 cm) were stocked at different densities: $A = 0.3$, $B = 0.5$, $C = 1.7$, $D = 3.8$ ind. m^{-2} ; whereas none were introduced in the fifth pond *E* (control). To ensure crayfish presence, 70 crayfish were stocked in each pond. Ponds were re-

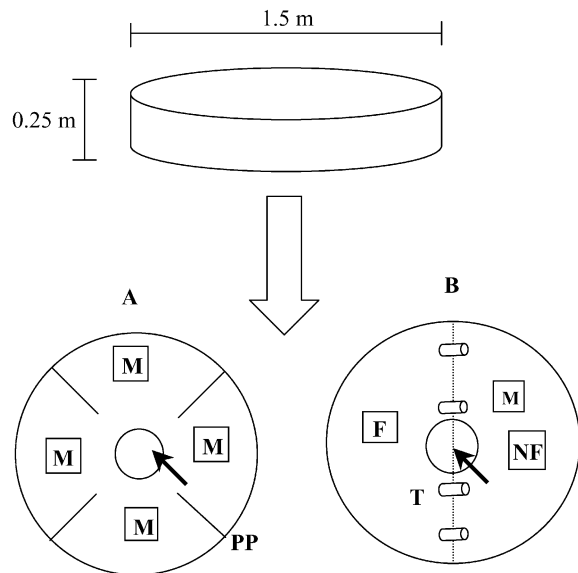


Figure 1. Experimental tanks design to test (A) crayfish distribution in relation to different type of macrophyte and (B) to explore the effect of carp on the macrophyte-crayfish association. M = macrophyte, F = fish section, NF = no fish section, T = tubes, PP = plastic panels. The dot line represents the nylon mesh used to divide the tank in two sections. The arrows indicate the area in which crayfish were released into the tank.

filled every two months in order to prevent a decrease in water level due to evaporation. Crayfish abundance (ind. m^{-2}) was estimated along transects using the same beam net described (Renfro, 1962).

Laboratory experiments

(a) Crayfish-macrophyte relationship

Experiments were carried out in a circular plastic tank (1.5 m diameter and 0.25 m high) that was filled with water from the ponds where crayfish and carp were collected. The tank was divided into four sections using rectangular (0.4 × 0.25 m) plastic panels (Fig. 1A). Before the experiments, crayfish distribution was tested in all the sections without plants; no significant difference in the crayfish distribution between sections was found. For the experiments, each section contained 350 g wet weight of one of the following species: *Elatine americana*, *Hydrocotyle verticillata*, *Nuphar advena*, and *Potamogeton pectinatus*. Forty crayfish were taken randomly from a pool of 80 and released in the centre of the tank, where they were able to move freely across all sections over a period of two hours. After this time, crayfish were collected from each section using a pond net (50 × 20 cm) and counted. Crayfish were placed in a bucket for 30

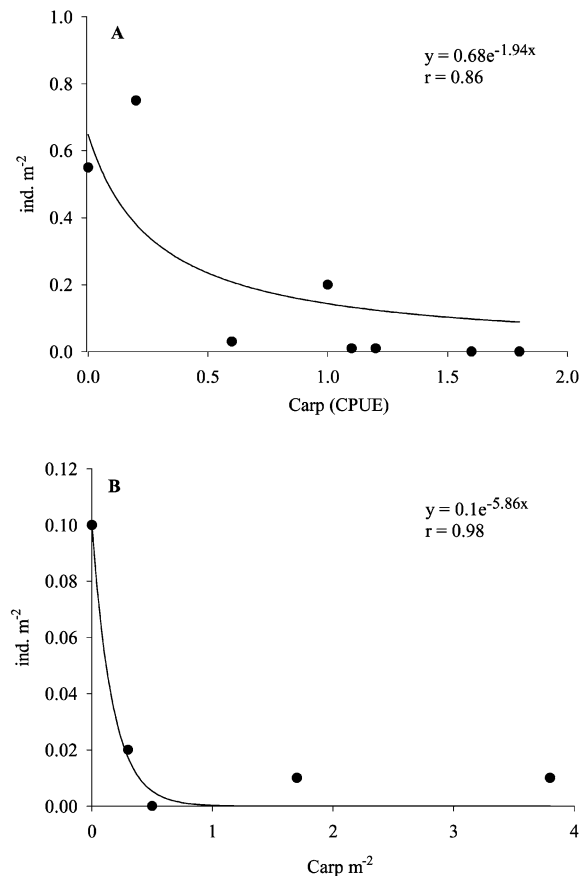


Figure 2. Non-linear regression analysis for crayfish abundance in relation to different carp abundance in (A) Acambay valley ponds and (B) El Cerrillo experimental ponds.

minutes and reintroduced in the centre of the tank repeating the procedure three times within the same day. At the end of the day, all crayfish were returned to the aquarium for next day experiments. Crayfish abundance in each section was estimated as the mean of the three experiments within the day. The experiment was repeated over five days ($n = 5$).

(b) Carp-crayfish interaction

A second experiment was carried out using the same type of tank divided into two segments using nylon mesh (Fig. 1B). In one of the sections one carp (10 cm total length) was added. All the treatments were repeated with a bigger carp (35 cm total length). 350 g wet weight of *P. pectinatus* was added to one of the sections. At the same time, 23 crayfish of different sizes were introduced in the tank and were able to move freely between both sections through five plastic tubes (5 cm diameter).

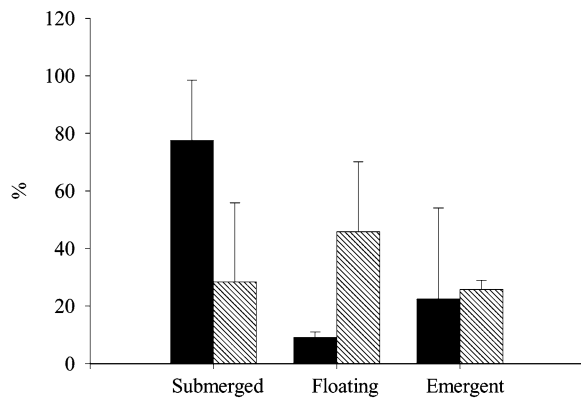


Figure 3. Crayfish mean density (expressed as percentage, \pm SD) in relation to macrophytes coverage (submerged, emergent and flat-floating) in Acambay valley ponds. Full colour bars represent crayfish density and dash bars macrophyte coverage.

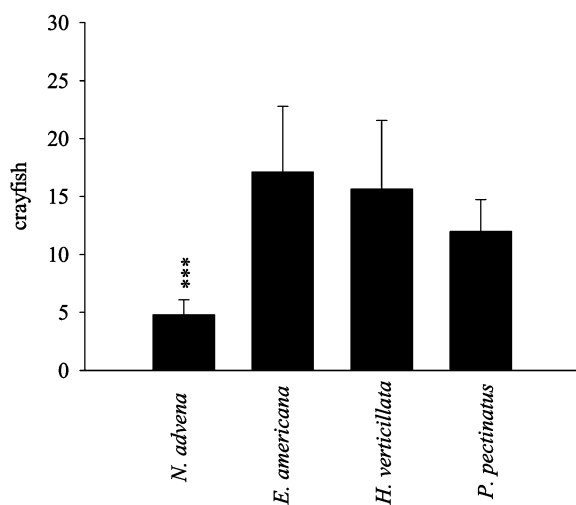


Figure 4. Crayfish–macrophyte interaction experiment. Crayfish mean number (\pm SD, $n = 5$) on plants with different grow forms (submerged, emergent, and flat-floating) in experimental tanks. Tukey test significance at $p < 0.001$ ***.

In order to compare crayfish number and distribution within each section four different treatments were tested: (a) control treatment (no carp at both sections, a section with plants and the other without plants) (b) no-plants treatment (a section with carp and the other without carp); (c) plants in both sections treatment (a section with carp and the other without carp) and (d) plants and carp together in one section and nothing in the other. Crayfish abundance in each section was estimated in the same way as was described in the previous section, and each treatment was repeated for three days.

(c) Crayfish movement speed

To explore changes in crayfish behaviour, crayfish movement speed (cm seg^{-1}) was estimated during the experiments of the carp–crayfish interactions. To measure the crayfish speed an 8 mm video camera and a grid at the bottom of the tank were used. Records of the speed were taken every two hours during daylight over three days. The number of displacements differed between days in both sections. However, in the end 29 displacements were obtained from each section.

Data analysis

Data were transformed ($\ln(x + 1)$) to get normal distribution. The relationship between crayfish and carp abundance was analysed using regression analysis. One-way ANOVA was used to explore crayfish habitat preference followed by post-hoc Tukey test in significant cases. Student's t test was used to explore the interaction of crayfish with carp. In addition, Mann–Whitney test was used to compare crayfish displacement speed across experimental tanks in the presence of carp.

Results

There was a non-linear relationship between crayfish and carp abundance (Fig. 2a, b). The trend seems to be quite similar for ponds in Acambay and experimental ponds in El Cerrillo. In general, in ponds with carp abundance > 0.4 ind. CPUE and 0.4 ind. m^{-2} crayfish abundance was significantly reduced.

As reported in previous works (Chapman & Fernando, 1994) carp gut contents in these systems included invertebrates (chironomids and oligochaeta), plant tissues, seeds and detritus. This suggests that carp can adjust their diet depending on their age and food resources. In Acambay valley and El Cerrillo ponds, small and medium carp presented a higher diversity of food sources than adult carp. Elements like detritus contribute to more than 50% of the diet of small and medium carp. In addition, filamentous algae and plant tissues were the second most abundant elements in this fish size category (Table 1). In contrast, adult carp were more selective, consuming seeds and plant tissue rather than filamentous algae (Table 1). Of all carp guts analysed in Acambay valley and El Cerrillo ponds, crayfish larvae were only found in the gut

Table 1. Gut contents mean wet weight from 100 carp that differed in sizes and age. Carp were taken randomly from ponds placed in Acambay ($n = 60$) and in El Cerrillo station ($n = 40$)

| Size | Filamentous algae | Seeds | Plant tissues | Detritus | Invertebrates |
|-----------------|-------------------|---------|---------------|----------|---------------|
| 9–14 cm | 1.208 g | 0.222 g | 0.216 g | 2.207 g | 0.145 g |
| Sd | 0.68 | 0.15 | 0.32 | 0.85 | 0.09 |
| Total % | 30.3 | 5.5 | 5.4 | 55.2 | 3.6 |
| $n = 29$ | | | | | |
| 18–23 cm | 0.219 g | 0.442 g | 1.128 g | 3.188 g | 0.054 g |
| Sd | 0.23 | 0.11 | 0.18 | 0.73 | 0.02 |
| Total % | 4.13 | 8.4 | 22.4 | 63.3 | 1.6 |
| $n = 34$ | | | | | |
| 25–30 cm | 0.542 g | 2.980 g | 1.234 g | 0.333 g | 0 g |
| Sd | 0.12 | 0.71 | 0.68 | 0.15 | 0 |
| Total % | 10.6 | 58.7 | 24.2 | 6.5 | 0 |
| $n = 37$ | | | | | |

of a young carp present in a pond with a carp density of 0.8 ind. CPUE ha⁻¹.

Most of the crayfish collected in the transects were associated with submerged macrophytes (Fig. 3). Also, in ponds with low macrophyte coverage (those with high carp abundances), transects along the few areas of submerged macrophytes had the highest crayfish abundance. Depth did not change significantly in all sites ($50.2 \pm \text{SD } 30.36$ cm in the low carp ponds, and $47.0 \pm \text{SD } 35.05$ in all other ponds) suggesting that depth does not influence crayfish distribution.

Crayfish preference for submerged macrophyte was maintained in the crayfish-macrophytes relation experiment. Crayfish abundance was significantly higher in sections containing submerged and rooted macrophytes than those containing flat-floating plants ($F_{3,19} = 18.77$, $p < 0.001$) (Fig. 4). This preference for plants was maintained in the crayfish-carp experiment (Fig. 5A). In addition, crayfish abundance was higher in all sections without carp. The same tendency was found when carp was present in treatments without plants (Fig. 5B), as well as in treatments with plants in both sections (Fig. 5C). Even in treatments where plants and carp were together, crayfish preferred the other section (Fig. 5D).

Crayfish speed displacement was significantly higher in the presence of carp ($1.8 \pm \text{SD } 0.95$ cm s⁻¹) than in the section free of carp ($1.1 \pm \text{SD } 1.01$ cm s⁻¹) ($t = 623$, $p < 0.001$, $df = 56$).

Discussion

Our findings suggest that carp have a negative effect on benthic crayfish population in shallow subtropical ponds. This crayfish population depletion can be produced by predation, competition or reducing crayfish habitat (macrophytes coverage). Carp gut content analysis indicates a potential predation on crayfish. A larva of this invertebrate was found in the gut of one young carp. Because of its size, the larva could be already dead or in ecdysis, making it more susceptible to consumption.

However, predation seems to be the smallest part of the effect of carp on crayfish. Results suggest that carp are able to predate only crayfish larvae. Small elements such as detritus, plant tissue and filamentous algae were found in all carp sizes but bigger elements such as benthic invertebrates like chironomids and oligochaeta were only present in the gut of small and medium carp. Carp normally eat invertebrates smaller than their mouth size (Dabrowki et al., 1983; Dabrowki, 1984; Hasan & Macintosh, 1992). Crayfish juveniles and adults size ranges between 3–7 cm (Villalobos, 1983), making them not accessible for mouth sizes of big carp. The fact that there was no trace of crayfish in adult carp guts, and the lack of attempt from carp to eat or chase crayfish in the experiments support this idea. Therefore, predation seems to only occur in small carp and is limited to the youngest stages of crayfish, the same stages with the highest

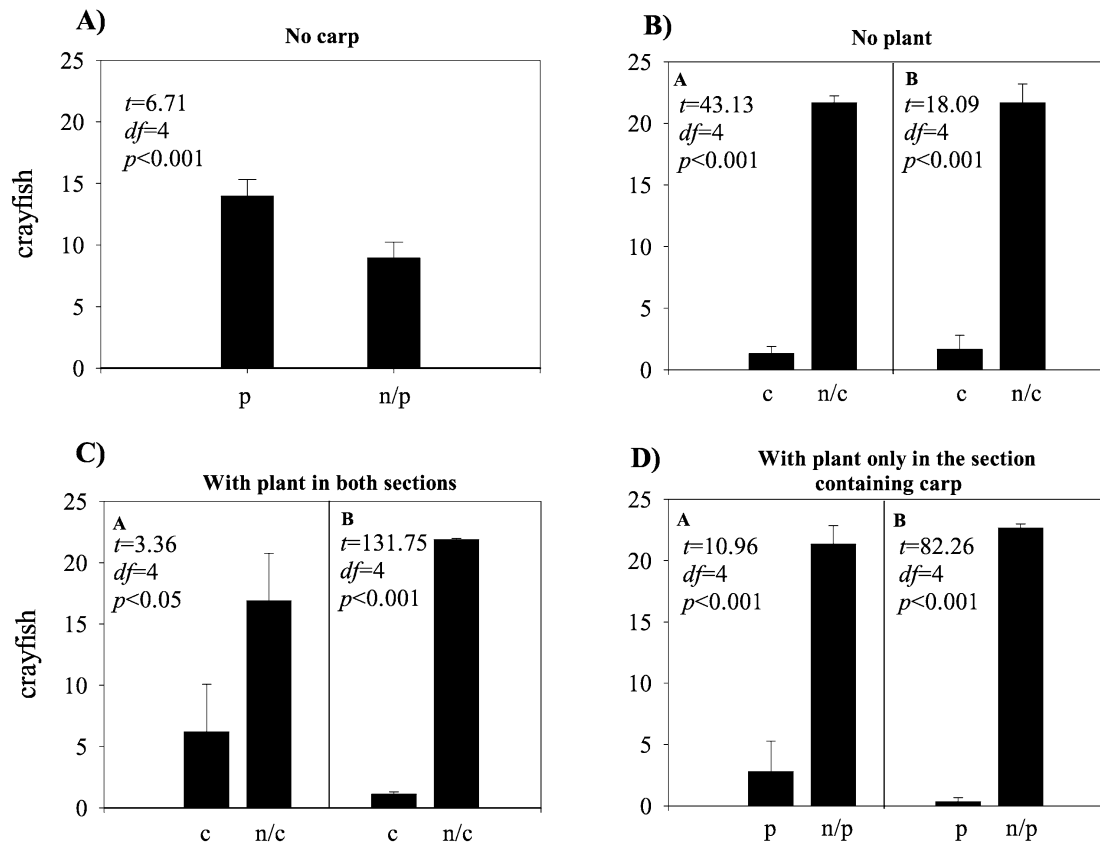


Figure 5. Crayfish–carp interaction experiment. Crayfish mean number (\pm SD, $n = 3$) in relation to: A) crayfish distribution in relation to plant presence and absence (without carp), B) crayfish distribution in relation to carp presence and absence (without plants), C) crayfish distribution with plant in both sections and presence and absence of carp D) crayfish distribution in sections with plant only in the section containing carp. (p) Plant, (n/p) no plant, (c) carp and (n/c) no carp.

mortality rate for causes different to carp predation (Villalobos, 1983). Also, we found crayfish larvae in only one (1%) of the total gut contents analysis. This finding can be supported by the total lack of crayfish larvae in the preliminary carp gut contents results in a study nearby Mexico city (where high densities of carp live with a big populations of crayfish) (Zambrano personal communication). Thus, crayfish seem to be a non-essential component in the diet of young carp, and carp predation on crayfish larvae appears to be based more on randomness than in an active search for the prey. This evidence suggests that this interaction should not be the strongest reason of crayfish population depletion.

Carp effects on crayfish populations seem to be linked to macrophyte cover. In these ponds carp density was negatively related with submerged macrophyte coverage (Zambrano et al., 1999; Zambrano & Hinojosa, 1999). The effect of carp on macrophytes has

been related to its high capacity to increase turbidity via the re-suspension of sediments (Breukelaar et al., 1994; Cline et al., 1994; Tatrai et al., 1994; Carvalho & Moss, 1995). A small increase in turbidity could produce a decrease in macrophytes cover (Spence, 1982; Fletcher et al., 1985; Crowder & Painter, 1991; Engel & Nichols, 1994). Macrophytes that suffer most from a decrease in light are those closely related with crayfish (submerged plants and filamentous algae), suggesting that high carp abundance interfere with the crayfish-macrophyte association.

In the studied ponds (with small densities of carp), macrophyte community structure was dominated by the submerged macrophyte *P. pectinatus* and the filamentous algae *C. glomerata*. Conversely, in ponds with high carp densities macrophyte community was dominated by floating plants (*N. advena*). In these ponds, macrophyte community structure remained stable during all the season (Tapia & Zambrano,

2003). Higher abundances of crayfish on the submerged plants suggest that they are used as a resource for this invertebrate. Structurally, substratum such as filaments and dissected branches provides a wide range of habitats and refuges for crayfish development (Lodge & Lorman, 1987; Lodge, 1991; Newman, 1991). In addition, generalist crayfish prefer to consume submerged macrophytes because they are more susceptible to handling and shredding (Cronin, 1992). Furthermore, previous studies have been reported that crayfish include vast amounts of macrophytes in their diet (Nystrom & Strand, 1996; Nystrom et al., 1996; Schofield et al., 2001). This behaviour is similar for most of omnivorous crayfish species as result of their food preferences (Lodge & Lorman, 1987; Hobbs, 1989; Lodge, 1991; Creed, 1994). Thus, apart from providing refuges, macrophytes may have an important role as a source of food for crayfish in these systems.

On the other hand, floating plants with broad flat leaves do not provide good refuges for crayfish. Also, these plants are inadequate sources of food because they contain a higher concentration of secondary metabolites than submerged or emerged macrophyte, making them less attractive for herbivores (Cronin, 1998).

Experimental results show another potential carp interaction with crayfish. This invertebrate prefers places with macrophytes, avoiding places with carp. But the avoidance of carp is higher than the affinity of crayfish for plants in experimental conditions. This suggests that crayfish prefer to be far away from carp scarifying the potential benefits that macrophytes can provide. In other words, crayfish behaviour seems to be modified by carp presence. Videos showed that crayfish move significantly faster in the presence of carp. As a result, crayfish could spend more energy searching for refuges or food, which would normally be assigned to reproduction and/or development (Hobbs, 1989). However, the impact on the entire crayfish population is not well known and further research is necessary.

The current work has provided a baseline of the potential for trophic interactions and some insight to ecological relations as a result of common carp introduction into subtropical ecosystems. Further experimental work is necessary in order to understand and describe potential ecological relations between native species and common carp.

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