

Effects of a vertebrate predator (*Poecillia reticulata*) presence on *Ceriodaphnia cornuta* (Cladocera: Crustacea) in laboratory conditions

Efeitos da presença de predador vertebrado (*Poecillia reticulata*) sobre *Ceriodaphnia cornuta* (Cladocera: Crustacea) em condições de laboratório

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Abstract: Aim: To detect the induction of morphological and populational alterations on *Ceriodaphnia cornuta* concerning cyclomorphosis and population dynamic parameters as densities, fecundity rates, juveniles percentage, males presence and ephippia presence in the presence of predators; **Methods:** Two experiments were performed: Experiments with fishes fed on *Ceriodaphnia cornuta* – Experiment 1 – and “Fish Water” Experiment – Experiment 2; **Results:** Main results observed include decrease in primiparous length and increase in *Ceriodaphnia cornuta* fecundity; **Conclusions:** The presence of vertebrate predators (*Poecilia reticulata*) influenced the *Ceriodaphnia cornuta* population dynamics at fecundity levels and primiparous; Due to the short duration of repetitions, it was possible to observe morphological changes and the production of ephippia; *Ceriodaphnia cornuta* is susceptible to the presence of vertebrate predators at the population dynamics level and not at the morphological plasticity; The changes occur in *Ceriodaphnia cornuta*, in the presence of vertebrate predators especially in population dynamics; Possibly *C. cornuta* presents different response behaviors for each kind of predator.

Keywords: *Ceriodaphnia cornuta*, kairomones, in vitro tests, predation effects, vertebrate predator.

Resumo: Objetivo: Detectar alterações morfológicas e em parâmetros da dinâmica populacional, tais como densidades, taxas de fecundação porcentagem de juvenis, presença de machos e presença de efípias da espécie *Ceriodaphnia cornuta* na presença de predadores; **Métodos:** Dois experimentos foram realizados: Experimento com peixes alimentados com *Ceriodaphnia cornuta* – Experimento 1 – e Experimento “Água de peixe” – Experimento 2; **Resultados:** Os principais resultados observados incluem diminuição no comprimento das primíparas e aumento da fecundidade em *Ceriodaphnia cornuta*; **Conclusões:** A presença do predador vertebrado (*Poecilia reticulata*) influenciou a dinâmica populacional de *Ceriodaphnia cornuta* aos níveis de fecundidade e comprimento das primíparas; Devido à curta duração das repetições realizadas, não foi possível observar alterações morfológicas, assim como produção de efípias; *Ceriodaphnia cornuta* é suscetível à presença de predadores vertebrados ao nível de sua dinâmica populacional e não na plasticidade morfológica. A presença de predadores vertebrados causa alterações em *Ceriodaphnia cornuta*, principalmente na dinâmica populacional; É possível que *C. cornuta* apresente comportamentos de resposta distintos para cada tipo de predador

Palavras-chave: *Ceriodaphnia cornuta*, efeitos da predação, predador vertebrado, queromônios, testes in vitro.

1. Introduction

Cladocerans are one of the most important groups in continental aquatic environments concerning transference of energy along the trophic web (Villalobos and Gonzalez, 2006). Excepting for some few species with raptorial habits, cladocerans are generally algae consumers or detritivorous and because their continuous feeding, they present a great importance in abundance and diversity control of freshwater phytoplankton (Sarma et al., 2003). At the same time, they are the favorite preys among vertebrate and invertebrate predators (De Bernardi and Peters, 1987). Vertebrate and invertebrate predation is among the most important biotic interactions and is fundamental for structure and densities in zooplankton communities. Effects of predation by fishes

or invertebrates on zooplanktonic community may manifest under several forms in the aquatic environment: alterations in the pH, oxygen concentration, and inorganic nutrients; phytoplankton biomass and composition, diversity and density of species which compose the zooplankton, for instance (Esteves, 1988). Invertebrate predation favors the presence of far-reaching species and the large individuals in zooplanktonic populations, while vertebrate predation causes the inverse effect, keeping the small individuals in the populations, once the large ones are preferably preyed by visual predators (Crispim, 1997).

This kind of predation is common in several environments. Thus, organisms have to perform a balance between

the two strategies. However, some authors (Cerný and Bytel, 1991; Reede, 1995) report the presence of small or large individuals in the populations as a consequence of predation, and others (Hardy, 1992), for instance, demonstrate that cladocerans early reach the primiparous stage in the presence of predators, which may be a flight strategy from predation.

In order to avoid predation, other strategies, such as spines development and helmet increase are developed (Pijanowska, 1992). *Ceriodaphnia cornuta* may generate a series of responses as defense mechanisms front of predation: polymorphism, changes in some life history parameters and vertical migration (Villalobos and Gonzalez, 2006). Despite all the preys strategies to avoid their predators, predation is still happening in the environments, possibly being an important force in the planktonic community (Zaret, 1980) considering the high mortality rates imposed to these preys (Cassano et al., 2002). Extinction or absence of cladocerans in lakes may be, in some cases, influenced by invertebrates (Threlkeld et al., 1980; Arcifa et al., 1992; Castilho-Noll and Arcifa, 2007).

Further, daphnids are known by reacting to predation pressure using chemical substances secreted by their predators (also named kairomones or infochemicals) as information source on their presence. Kairomones may not only induce changes in the life cycle characteristics (Coors et al., 2004), as regulation on the synchronism of sexual reproduction (formation of males and production of ephippial or resistance eggs) to protect the genome during periods of high predation risk (Van Donk, 2007).

Better knowledge about these interactions makes easier to comprehend seasonal fluctuations common to planktonic species, attributing or not these alterations occurring in the nature to biotic interactions, both in the presence or absence of species or by the densities observed.

Few studies have been developed on *Ceriodaphnia cornuta* (Sars 1886) in the sense of knowing morphological alterations which may be induced in response to the presence of predators once the model organism used among cladocerans in biological studies is the genus *Daphnia* (De Bernardi and Peters 1987). However, *Daphnia* is frequently found in aquatic bodies of temperate regions and rarely occurs in tropical regions (Fernando et al., 1987).

Thus, it is difficult to compare results observed in tropical aquatic environments to studies on *Daphnia*. *Ceriodaphnia cornuta* is considered one of the three cladocerans of widest distribution and abundance in the tropical freshwater (Fernando, 1980; 1984), being the only species belonging to the family Daphniidae. *Bosmina* is another well studied cladoceran genus, whose species present morphological alterations in the presence of invertebrate predators (Black, 1980; Kerfoot, 1987; Chang and Hanazato, 2003).

The ability of escaping predation is one of the factors related to the species success in the environment (Freitas,

2005). Therefore, studies on interactions between preys and predators are extremely important to understand the mechanisms by which predators influence the preys community structure as well as the behavior and morphology of individual species (Roche, 1990; Tollrian and Jeschke, 2000).

In order to improve the knowledge on this biotic interaction process, this work proposed to carry out in vitro experiments to identify responses of *Ceriodaphnia cornuta* to predation. This kind of information is relevant when intending to know the functioning of aquatic environments, which suffers constant antropic impacts, and where knowledge is still insipient. Understanding the ecosystem dynamics makes possible to infer the consequences of any management or impact action.

Furthermore, important morphological modifications may be observed in *Ceriodaphnia cornuta* which become difficult its identification. Thus, to know these cyclomorphosis is an important contribution to the systematic study of these zooplanktons.

The main objective of this work was to detect the induction of morphological and populational alterations concerning cyclomorphosis and populational dynamics in the presence of *Ceriodaphnia cornuta* vertebrate predator.

2. Materials and Methods

Specimens of *Ceriodaphnia cornuta* (Sars 1889) were collected in aquatic environments from the paraibano semi-arid (07° 10' 91" S and 36° 50' 08" W) using 45 µm plankton net. Subsequently, the companion fauna was separated and transported to the Conservation Biology Laboratory from the Universidade Federal de Pernambuco.

In the laboratory, organisms were transferred to 1.3 L glass containers and maintained at climatized environment (22 °C) 24 hours a day. Studies performed on the cladoceran *Daphnia magna* showed that when these organisms are maintained at lower temperatures they tend to decrease their densities (Ricklefs, 1996).

Feeding of *Ceriodaphnia cornuta* specimens from the cultures was performed using water from natural environment collected at the dependencies of the university (Universidade Federal de Pernambuco – UFPE). This water was filtered through 45 µm mesh and conditioned at a 30 L aquarium illuminated with incandescent lamp at photoperiod 10:00 AM to 14:00 PM light/dark, in a 25 °C temperature. This photoperiod was chosen by biosecurity reasons. As in the natural environment, a mixed number of phytoplanktonic species was observed in the aquarium.

Food was offered as follows: individuals of *Ceriodaphnia cornuta* were taken from the cultures at each three days using a 45 µm sieve; the water from the aquarium was filtered again through 45 µm net and placed in the bottles to replace the water in the recipients. Afterwards, cladocerans were returned to the culture bottles.

2.1. Experiments with vertebrates

Six mini limnocurrals, 0.10 m diameter and 0.08 m height were used for predation experiments. They were made of PVC and the bottom composed by 45 µm plankton net, facilitating exchanges with the environment but avoiding the entrance of organisms. Polystyrene floaters were adapted in the limn-enclosures (Figure 1).

Two aquariums (170 L approximately) divided into three equal parts were used. One of them was used as control and the other as treatment.

Water from natural environment filtered through 45 µm net was inserted in these aquariums and two days-aired in order to evaporate the substances contained. The limnocurrals were placed in these aquariums receiving the *Ceriodaphnia cornuta* specimens.

Treatments were defined as follows:

- Treatment with vertebrate fed on zooplankton (Experiment 1) – Three limnocurrals with ten 24 hours-life neonates of *Ceriodaphnia cornuta* each

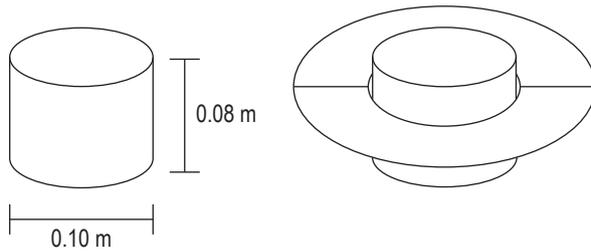


Figure 1. a) Scheme of the mini limn-enclosures with bottom composed of 45 µm aperture mesh plankton net; b) Mini limn-enclosures with adapted floaters.

one were put in aquariums which beyond the mini limnocurrals received ten planktivorous fishes from the species *Poecilia reticulata* (Pisces, Poeciliidae, Peters 1859) fed on *Ceriodaphnia cornuta* once a day. Fishes were acquired at a specialized business.

- Control – Three limnocurrals with ten 24 hours-life neonates of *Ceriodaphnia cornuta* each one were put in aquariums without fish.

From four to five aquatic macrophyte vegetative rami from the species *Pistia stratiotes* L. (Araceae) were placed in each aquarium in order to function as a natural filter and simulate a natural environment.

- Treatment “Fish Water” (Experiment 2, Figure 2) – this experiment was performed as follows: three *Poecilia reticulata* specimens were separated and placed at a 1.3 L bottle containing the same water used for *Ceriodaphnia cornuta* feeding. Fishes stood 48 hours without food (Zooplankton or fish food) and immediately after that they were returned to their respective aquariums. This “Fish Water” was placed in three 0.30 L bottles and ten *Ceriodaphnia cornuta* neonate individuals were also placed in each one.
- Control – controls were conducted in the same way, however using only water from the feeding aquarium without fishes.

All experiments were performed in three repetitions to detect possible changes. The repetitions were performed in distinct temperature and light conditions because the repetitions were analyzed in different periods.

Analyzes on number of individuals/density, fecundity rates, juveniles percentage, presence or absence of cyclo-

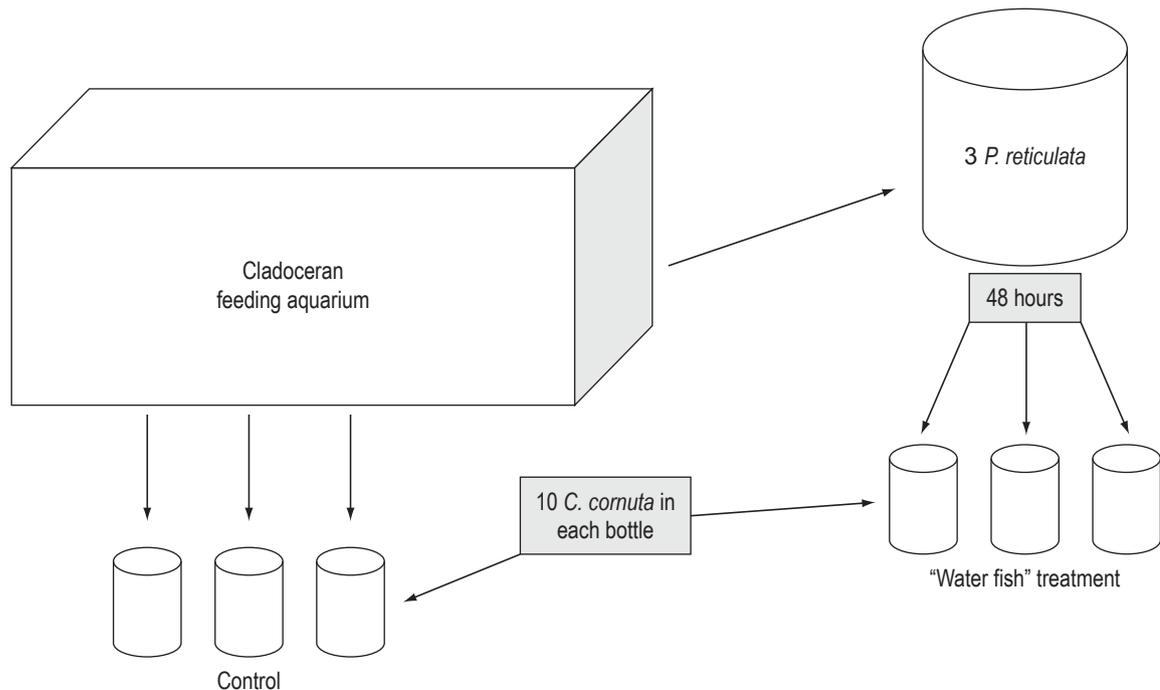


Figure 2. Experiment 2 Scheme.

morphosis (presence of head or caudal spines), presence or absence of ephippias and primiparous lengths in alive organisms were performed at each three days. This experiment was performed as follows: 50 individuals were randomly chosen, with 25 adults and 25 juveniles to carry out the analysis with living organisms, and after, returned to their limnocurrais. These organisms were measured with a micrometrical ocular, previously calibrated. Subsequently to analyzes, about 7.0×10^3 cel.ml⁻¹ of phytoplankton (most Chlorophytes: *Chlorella* sp. and *Scenedesmus* sp.) taken from the algae aquarium were added to the limnocurrail in order to feed individuals on its interior. These algae were counted using a Fuchs-Rosenthal counting chamber and quantified through the formula: Cells number per mL = $(n1 + n2)/2 \times 10^3 \times d$, where: n1 = number of cells counted in the superior counting chamber; n2 = number of cells counted in the inferior counting chamber and d = Dilution factor (once there was no dilution, d = 1).

Ceriodaphnia cornuta fecundity rates were calculated in the four treatments using the Equation 1:

$$F = (\text{eggs average number or embryos} \times \text{ovigerous females}) / \text{Total adult females} \quad (1)$$

Instantaneous growth rate was also calculated through the formula described by Krebs (1985) (Equation 2):

$$r = (\ln N1 - \ln N0) / T \quad (2)$$

where: N1 = individuals number in the date analyzed; N0 = individuals number in the previous date and T = Passed time between N1 and N0.

2.2. Statistical treatment

Data on number of individuals, length average, fecundity, instantaneous growth rate and primiparous length were compared through ANOVAs to verify the significant differences between the treatments and repetitions. Data on juveniles percentage were analysed through the Chi-square test (χ^2), comparing the values from the last day of observation, using $\alpha = 0.05$

3. Results

3.1. Experiment 1

3.1.1. Individuals quantity

Individuals average number was higher in the treatments than in the control (Figure 3). In the first repetition it was 58.3 against 30.4 in the controls; treatments presented 18.7 individuals average while the controls only 6.8 in the third repetition; however, controls and treatments presented almost equal averages in the second repetition (11.1 and 11.7, respectively). Even with few variations on the averages among experiments, the ANOVA test discriminated significant difference concerning quantity of individuals between

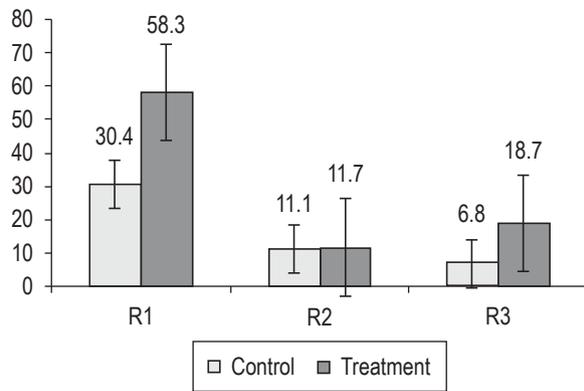


Figure 3. *Ceriodaphnia cornuta* individuals number averages in the Experiment 1. The bars show the Standart Error.

controls and treatments ($F_{(1,40)} = 23.42$; $p < 0.001$); the latter presenting the highest individuals quantity average.

3.1.2. Length averages

Although in the third repetition the length values had reached a highest level in the treatments, considering the general average, cladocerans lengths were highest in the treatments in the first and third repetitions with 386.4 and 381.1 μm , respectively; while the controls reached 384.4 μm in the first repetition and 377.5 μm in the third one. In the second repetition *Ceriodaphnia cornuta* length was higher in the controls (382.6 μm) than in the treatments (371.4 μm) (Figure 4).

Significant differences occurred among repetitions along time, with great variations on individuals length when clustering Control and Treatment. Specially in the first repetition where a brusque increase on *Ceriodaphnia cornuta* size occurred followed by a great decrease in these values. In the other repetitions such fact did not occur, being length variations more gradual and homogeneous.

3.1.3. Fecundity

It could be observe that fecunditie average was higher in treatments than in controls varying between 1.76 and 3.03 eggs or embryos per individual while in the controls values varied between 1.01 and 2.91 eggs/embryos per individual (Figure 5).

This difference showed to be significant in the ANOVA test, in which fecundities were higher in the treatments than in controls ($F_{(1,40)} = 10.04$; $p < 0.0029$). When fecundities were analyzed considering the study period, they were clearly higher in the treatments during the whole experiment. Also, fecundities oscillation was lower in the treatments, between 2.1 and 2.6 eggs/embryos per individual, there being more variation in the control, from 1.1 to 2.3 eggs/embryos per individual, although the results were not significant.

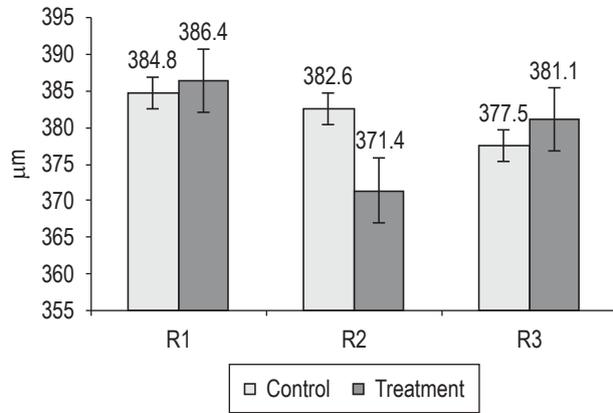


Figure 4. *Ceriodaphnia cornuta* length averages during the study period in the Experiment 1. The bars show the Standart Error.

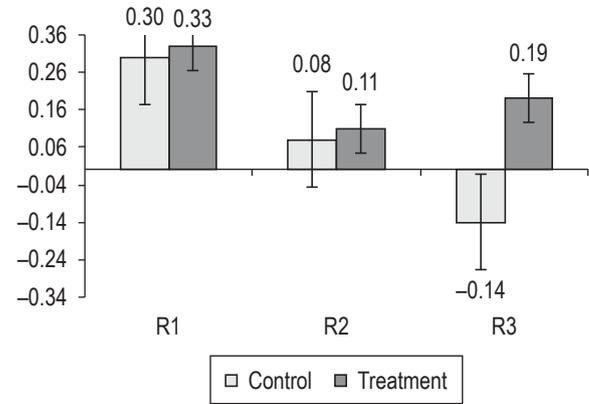


Figure 6. *Ceriodaphnia cornuta* grow rates averages during the study period in Experiment 1. The bars show the Standart Error.

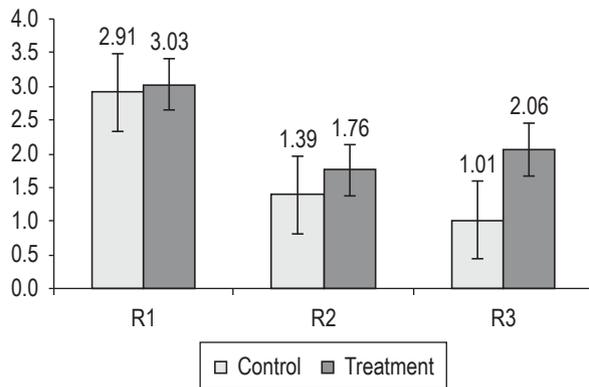


Figure 5. *Ceriodaphnia cornuta* fecundity averages observed during the study period in the Experiment 1. The bars show the Standart Error.

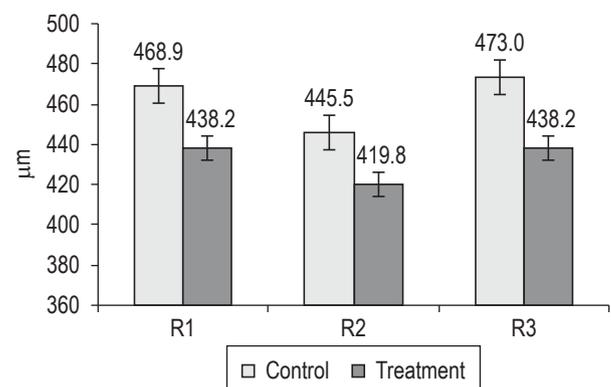


Figure 7. *Ceriodaphnia cornuta* primiparous sizes averages during the study period in Experiment 1. The bars show the Standart Error.

3.1.4. Growth rate

Growth rates averages were higher in the treatments in the three repetitions performed varying between +0.11 and +0.33, while in controls variation was between -0.14 and +0.30. However, even with higher averages in the treatments, this difference was not significant in the ANOVA test.

Concerning repetitions along the study period, rates presented few variations, with exception of the first repetition when a great increment occurred in the second day. There were few variations on growth rates in the other repetitions. Once repetitions were performed in distinct periods, it could explain why these values were so different among them ($F_{(2,40)} = 15.08$; $p < 0.001$) (Figure 6).

3.1.5. Primiparous length

Primiparous length averages were also lower in the treatments in all repetitions, being the higher difference in the third one with 438.2 µm in the treatments and 473 µm in the controls. According to the ANOVA test, primiparous length was significant lower in the treatments ($F_{(1,40)} = 39.56$; $p < 0.000$) (Figure 7).

3.1.6. Ceriodaphnia cornuta - individuals length

Juveniles length average was also lower in the treatments if compared to controls: 309.65 µm and 315.16 ± 82.0 µm, respectively. Adults length average was higher in the controls (474.82 ± 82.0µm) than in the treatments (463.78 ± 77.0 µm).

Smaller individuals were also observed in the treatments. Among juveniles, variation was between 242 ± 95.0 µm and 407 ± 97.0 µm; however, adults presented the smallest and biggest individuals, with 396µm, and 616 µm. In the controls, juveniles varied between 242 ± 94.0 µm and 484 ± 98.0 µm while adults from 418 ± 97.0 µm to 605 ± 93.0 µm (Figura 8).

3.1.7. Juveniles percentage in the Ceriodaphnia cornuta population, males presence and ehippia production

Concerning juveniles percentage, there was no significant difference between quantity of juveniles and adults in the population at any replications performed. The appearance of caudal or cephalic spines was not observed in any *Ceriodaphnia cornuta* individual in this experiment.

Besides, there was neither appearance of males nor presence of ephippias or ephippiated females.

3.2. Experiment 2

3.2.1. Individuals quantity

Individuals number averages were also higher in the treatments in the three repetitions performed, except in the first one, where controls presented 45.4 individuals against 33.9 in the treatments. Treatments presented higher average than the control in the second repetition (86.4 and 81.9, respectively) and in the third one (51.2 and 42.07 individuals, respectively) (Figure 9).

Although treatments present higher averages no significant differences were observed in the individuals number among experiments (Controls and treatments). There was a significant difference between the number of individuals both in the controls and treatments considering the study period, where a slight increase can be observed in the last day of observation ($F_{(3,48)} = 4.28$; $p < 0.0094$).

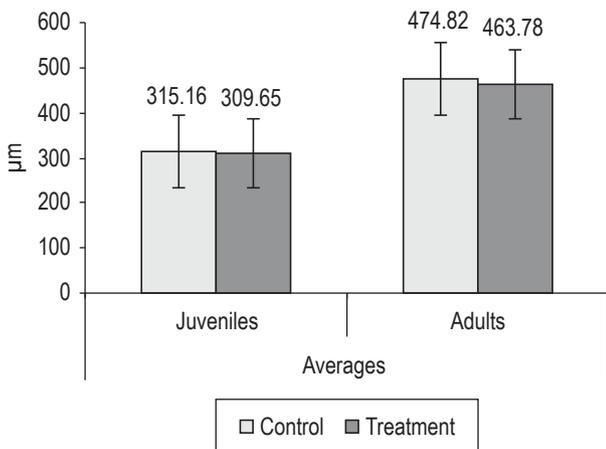


Figure 8. *Ceriodaphnia cornuta* individuals length averages during the study period in Experiment 1. The bars show the Standard Error.

A significant difference was also observed concerning the number of individuals when comparing the study period and repetitions performed ($F_{(6,48)} = 10.90$; $p < 0.001$). Populational increase was higher in the second repetition if compared to the others; such difference may be attributed to these repetitions had been performed in distinct periods, that is to say, under different climatic and experimental conditions.

3.2.2. Length average

Size averages per repetition performed were also lower in the treatments in all repetitions. Lowest value (365.3 µm) occurred in the first repetition while the highest one (385.5 µm) was observed in the second repetition. In the third repetition the average 382.0 µm was observed in the control, while the other averages were 390.6 and 394.8 µm in the first and second repetitions, respectively (Figure 10).

According to the ANOVA test, there was significant difference among length averages, being it lower in the treatments than in control ($F_{(1,60)} = 9.45$; $p < 0.0032$). This difference shows the *Ceriodaphnia cornuta* response to the vertebrate predator presence (Figure 11).

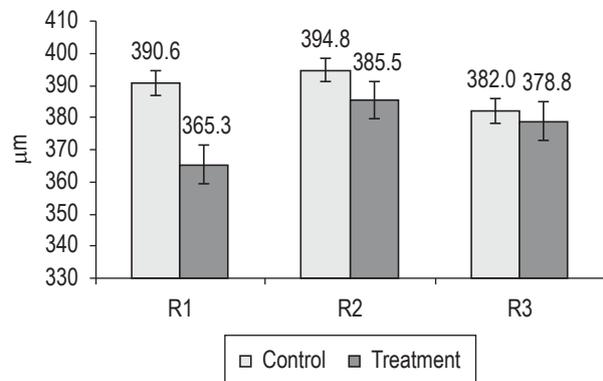


Figure 10. *Ceriodaphnia cornuta* length averages during the study period in the Experiment 2. The bars show the Standard Error.

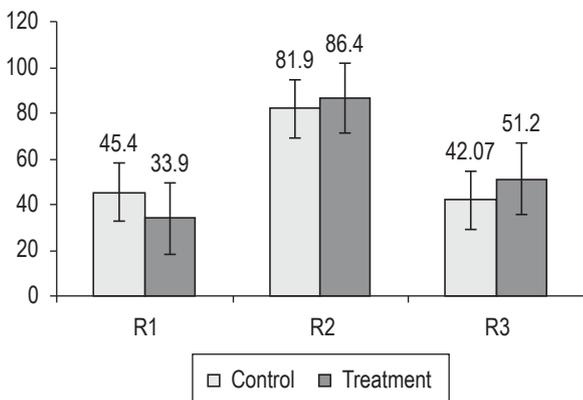


Figure 9. *Ceriodaphnia cornuta* individuals number averages during the study period in Experiment 2. The bars show the Standard Error.

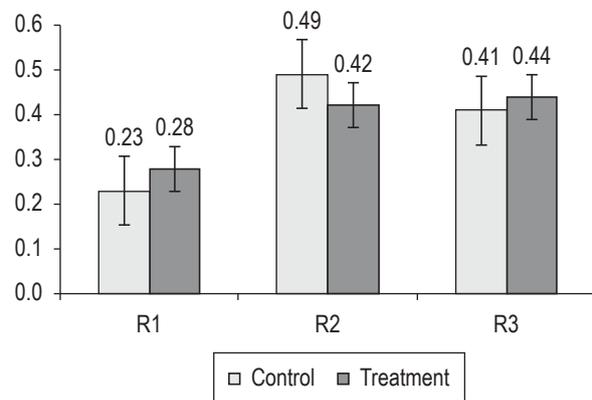


Figure 11. *Ceriodaphnia cornuta* grow rates averages during the study period in Experiment 2. The bars show the Standard Error.

3.2.3. Fecundity

Fecundity was higher in the controls reaching 6.0 eggs/embryos per individual in the third repetition, while in the treatments maximum value was 5.12 eggs/embryos per individual (observed in the first repetition).

There was a fecundity peak in the third day of observation in all repetitions in both experiments, except in the treatment of first repetition when this peak occurred in the fourth day.

With exception of the second repetition, where fecundity averages were higher in the control (3.15 against 2.67 eggs/embryos per individual), treatments presented the highest fecundity averages. In the first repetition values reached 1.84 in the treatment against 1.76 in the control; while in the third repetition values observed for treatment and control were 30.7 and 2.97, respectively (Figura 12).

Although results show higher fecundity in the treatments, no significant differences were discriminated by the ANOVA test among experiments.

There was significant difference in the experiments during the study period but there was a fecundity peak in the treatments in the third day while in the control it occurred in the fourth day. In both experiments these values tended to decrease in the last day of observation ($F_{(4,48)} = 6.06$; $p < 0.0001$).

3.2.4. Growth rates

Averages growth rates were higher in the treatments in the three repetitions performed, varying from +0.28 and +0.52, while in the controls variation was between +0.23 and +0.49. However, even with higher averages in the treatments, no significant difference was detected by the ANOVA test.

Concerning the study period, rates were higher in the controls during the whole experiment; with exception of the last day when treatments presented slight decrease promot-

ing the higher final values in the treatments ($F_{(3,46)} = 13.17$; $p < 0.0001$).

3.2.5. Primiparous length

Primiparous length averages were also lower in the treatments in all repetitions, being the highest difference between treatments and controls in the first repetition: 430.8 and 467.5 μm respectively.

According to the ANOVA test, differences in primiparous length were significant lower in the controls ($F_{(1,48)} = 60.66$; $p < 0.0001$).

Considering the study period, significant differences were observed, being primiparous smaller in the whole experiment. However, both experiments presented higher primiparous length in the second day, period when organisms are still adapting to experimental conditions ($F_{(3,48)} = 23.34$; $p < 0.001$).

3.2.6. *Ceriodaphnia cornuta* individuals length

Juveniles length was also lower in the treatments than in controls: $321.88 \pm 71.0 \mu\text{m}$ and $330.82 \pm 68.0 \mu\text{m}$. Average adults length was higher in the controls ($528.07 \pm 71.0 \mu\text{m}$) than in the treatments ($505.00 \pm 68.0 \mu\text{m}$).

Smaller individuals were also observed in the treatments: both among juveniles – which varied from $242 \pm 75.0 \mu\text{m}$ to $429 \pm 75.0 \mu\text{m}$ – and adults (from $396 \pm 75.0 \mu\text{m}$ to $660 \pm 75.0 \mu\text{m}$). In the controls juveniles varied from $242 \pm 81.0 \mu\text{m}$ to $462 \pm 81.0 \mu\text{m}$ while adults varied between $418 \pm 81.0 \mu\text{m}$ and $682 \pm 81.0 \mu\text{m}$ (Figure 13).

3.2.7. Juveniles percentage in the *Ceriodaphnia cornuta* population, males presence and ehippia production

Significant differences were only observed in the third repetition, presenting Chi-square (χ^2) value equal to 19.94, which is much superior to the critical χ^2 : 3.84, indicating significant difference between quantities of juveniles and adults in the population. However, we cannot affirm sig-

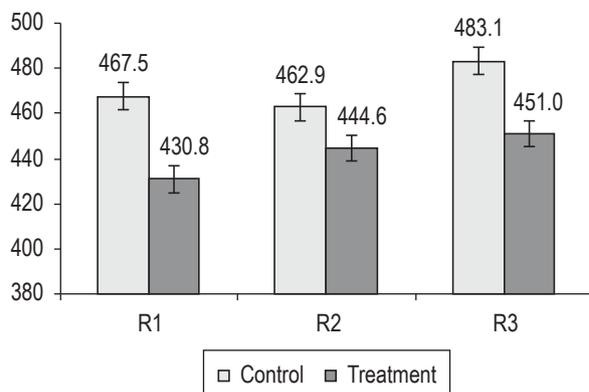


Figure 12. *Ceriodaphnia cornuta* primiparous sizes averages during the study period in Experiment 2. The bars show the Standart Error.

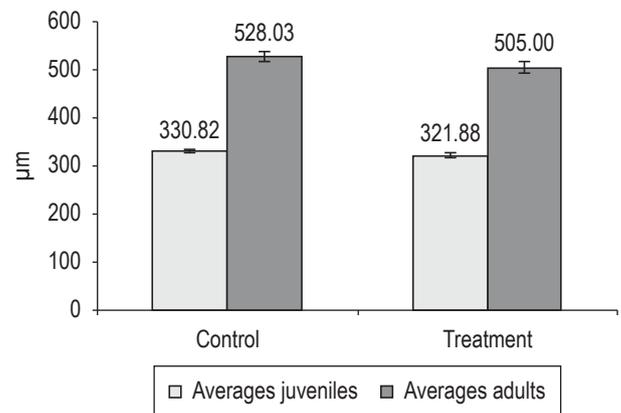


Figure 13. *Ceriodaphnia cornuta* individuals length during the study period in Experiment 2. The bars show the Standart Error.

nificant differences between percentage of juveniles and adults once this difference occurred only in one repetition and several factors may be influenced such change once repetitions were performed in distinct periods.

No appearance of caudal and cephalic spines was observed in *Ceriodaphnia cornuta*, and also there was neither presence of males nor ephippias or ephippiated females.

4. Discussion

Increase in quantity of individuals in *Ceriodaphnia cornuta* populations only occurred in the experiments which cladocerans were exposed to fish, indicating that such increase may be occurred due to water eutrophication.

Phytoplanktonic densities tend to increase due to excrete released in the water by fishes. Once *C. cornuta* is a filter organism, its populational growth increases more rapidly if compared to the controls due to higher food availability in the environment. In the experiment "Fish Water", there was no contact with nutrients released by fishes, thus this difference in quantity of individuals among experiments was not observed.

The unique experiment in which there was difference in the *C. cornuta* length averages was the "Fish Water", as cladocerans in presence of predators that select preys of greater size (visual predators) tend to reduce life time and body size as also related by Gabriel and Taylor (1991) and Taylor and Gabriel (1992).

In laboratorial conditions, predatory pressure is transferred for environment through chemical signs launched by predator (Larsson and Dodson, 1993; Dodson et al., 1994).

In the experiment with fishes fed on cladocerans, size reduction in *C. cornuta* was observed though not significant, if compared to the control.

Planktonic preys suffer damages by vertebrate or invertebrate predators before being ingested (Kerfoot, 1978). These body parts damaged or partially digested and excreted in the predator faeces (Pijanowska and Kowalczewski, 1997) may launch signs for the environment. Further, presence of fishes indirectly guarantees proliferation of small body size cladocerans which are protected against predation by these vertebrate due to their reduced sizes serving as refuge to overcome predation risk (Lemma et al., 2001).

In the experiment with fishes fed on cladocerans, *C. cornuta* from the treatments present fecundity increase compared to individuals in the controls. Crispim and Boavida (2001) compared cladocerans fecundities inside and out of the limnocrurals placed at reservoirs in Portugal and observed more elevated fecundity in limnocrurals interior. Some authors reported that *Daphnia* exposed to fishes' kairomones reduce brood's size (Fecundity) and increase offsprings' size (Machacek, 1993; Stibor, 1992; Weider and Pijanowska, 1993; Hanazato, 1995). However, Hanazato et al (2001) observed that fecundity increase in

Daphnia was probably due to limitation on food availability. As in this experiment food availability was enough to maintenance of specimens studied, probably the predator presence was responsible for such more elevated fecundities in cladocerans sharing the same environment with fishes, since exposition to predator kairomones may induce life cycle alterations in daphnids (Coors et al., 2004); fecundity increase for instance.

Lowest values observed in the ANOVA test were those related to primiparous length which presented smaller size if compared to control in both experiments. This reduction on primiparous size may be considered as a feasible strategy to escape predation (Hardy, 1992). Mikulski (2000) used *Daphnia* at culture middles presenting fishes' purified kairomones (denominated "extratum"). The author observed that females' size in the first reproduction (Primiparous) was significantly smaller than those not placed at this middle (denominated "Control"). Gliwicz and Boavida (1996) observed that primiparous size was significantly smaller in lakes with presence of fishes than in lakes without them.

In shallow lakes, presence of fishes induce to changes in the daphnids life cycle, such as reduction in the first reproduction size (primiparous) (Hülsmann, 2001). Smaller primiparous may promote the daphnid to reproduce before being ingested by fish as smaller daphnid is less visible to that fish searching for its prey (Vos et al., 2006). Considering the high predation risk, the possibility of brood's launching in the second reproduction or subsequent reproductions is very low (Lampert, 1991). As the first reproduction may be the unique, this reproduction optimization seems to be evident (Mikulski, 2000).

This difference in primiparous length may have occurred due to the utilization of neonate individuals of *Ceriodaphnia cornuta*. When juvenile cladocerans in the two first instars are exposed to chemical substances exudated by fishes, more accelerated maturation of gonads occurs and animals early reproduce with smaller size, also producing smaller eggs (Macháček, 1995).

In these experiments using predators, maximum size observed for *C. cornuta* was 660 µm, except for the experiment in which fishes were fed on *C. cornuta* when this value was 649 µm. However, the biggest individuals were observed in the control of the "Fish Water" experiment reaching the maximum value of 682 µm.

None experiment presented significant differences on juveniles percentage or growth rates. These results may have not been observed due to the experiments short duration. Maybe with longer study period *C. cornuta* could have responded to predators concerning these parameters, though some works consulted did not report alterations on cladocerans growth rates, more specifically daphnids, when exposed to vertebrate or invertebrate predators (Jack and Thorp 2002; Richardson and Barsch, 1997). Hanazato and Dodson (1995) observed no significant differences in the

growth rates between small and big neonates of *Daphnia pulex* when exposed to high O₂ concentration but without presence of kairomones. However, growth rates were significantly lower on smaller neonates than in the bigger ones under the same O₂ conditions but with the presence of kairomones.

It was not possible to observe any morphological alteration on cladocerans, even with traces that there was response to predator presence, such as primiparous reduction, for instance. This fact may also have not been observed due to short time experiment. According to Freitas (2005) who studied morphological alterations on *C. cornuta* in the presence of predators, spines formation on the head is strongly associated to more advanced life stages of this cladoceran. Other fact that influences on the cyclomorphosis magnitude is food quantity (Dodson, 1988). As cladocerans in these experiments presented available food in satisfactory amounts, it was not probably necessary that *Ceriodaphnia cornuta* expended energy for producing some morphological alteration such as cephalic and/or caudal spines. Predators' presence may induce ephippias production in cladocerans, more specifically in *Daphnia* (Slusarczyk, 1995), but during the whole experiment this egg type was not observed in *C. cornuta*.

It was possible to observe that cladocerans exposed to fishes presented higher fecundity and also reduced primiparous length. Cladocerans in contact to predators may alter their populational dynamics by reducing age and primiparous length, reducing the neonates' length and increasing eggs number in the first brood (Cerný and Bytel, 1991; Reede, 1995) reaching the primiparous stage earlier (Hardy, 1992).

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References

- BERNARDI, R. and PETERS, V. Why *Daphnia*? In PETERS, R. and BERNARDI, R. (Eds.). *Daphnia. Mem. Ist. Ital. Hidrobiol.*, 1987, vol. 45, p. 1-9.
- BLACK, RW. The nature and causes of cyclomorphosis in a species of the *Bosmina longirostris* complex. *Ecology*, 1980, vol. 61, p. 122-132.
- CASSANO, CR., CASTILHO-NOLL, MSM. and ARCIFA, MS. Water mite predation on zooplankton of a tropical lake. *Braz. Jour. Biol.*, 2002, vol. 62, no. 4A, p. 565-571.
- CERNÝ, M. and BYTEL, J. 1991. Density and size distribution of *Daphnia* populations at different fish predation levels. *Hydrobiologia*, 1991, vol. 225, p. 199-208.
- CHANG, KH. and HANAZATO, T. Seasonal and reciprocal successions and cyclomorphosis of two *Bosmina* species (Cladocera, Crustacea) co-existing in a lake: their relationships with invertebrate predators. *Jour. Plank. Res.*, 2003, vol. 25, no. 2, p. 141-150.
- COORS, A., HAMMERS-WIRTZ, M. and RATTE, HT. Adaptation to environmental stress in *Daphnia magna* simultaneously exposed to a xenobiotic. *Chemosphere*, 2004, vol. 54, p. 395-404.
- CRISPIM, MC. *Empty impact study of Maranhão Reservoir under zooplanktonic community: main biotic relations to affect the Cladocerans*. Lisboa: Lisboa University 1997. 183 p. [Tese de Doutorado].
- CRISPIM, MC. and BOAVIDA, MJ. Impacto da predação por peixes e copépodes na comunidade zooplanctônica do reservatório do Maranhão (Portugal). *Rev. Nord. Biol.*, 2001, vol. 15, p. 49-67.
- DODSON, SI. Cyclomorphosis in *Daphnia galeata mendotae birge* and *D. retrocurva* Forbes as predator-induced response. *Fresh. Biol.*, 1988, vol. 19, p. 109-114.
- DODSON, SI, CROWL, TA., PECKARSKY, BL., KATS, LB., COVICH, AP. and CULP, JM. Non-visual communication in freshwater benthos: an overview. *J. N. Am. Benthol. Soc.*, 1994, vol. 13, no. 2, p. 268-282.
- Van DONK, E. Chemical information transfer in freshwater plankton. *Ecol. Inform.*, 2007, vol. 2, no. 2, p. 112-120.
- ESTEVEES, FA. *Fundamentos de Limnologia*. Rio de Janeiro: Interciência; Finep, 1988.
- FERNANDO, C. 1984. Reservoirs and lakes of southeast Asia (oriental region). In TAUB, F. (Ed.). *Ecosystem of the world 23, lakes and reservoirs*. New York: Elsevier, 1987. p. 411-446.
- FERNANDO, C., PAGGI, J. and RAJAPAKSA, R. *Daphnia* in tropical lowlands. In PETERS, R. and BERNARDI, R. (Eds.). *Daphnia. Mem. Ist. Ital. Hidrobiol.*, 1987, vol. 45, p. 107-141.
- FREITAS, GTP. *Influence of Biomanipulation Technics in the Zooplanktonic Community Structure in a Brazilian Northeast Semi-Arid Dam*. João Pessoa: Universidade Federal da Paraíba, 2005. 67 p. [Dissertação de Mestrado].
- GABRIEL, W. and TAYLOR, B. Optimal resource allocation in cladocerans. *Verh. Int. Ver. Limnol.*, 1991, vol. 24, p. 2784-2787.
- GLIWICZ, ZM. and BOAVIDA, MJ. Clutch size and body size at first reproduction in *Daphnia pulicaria* at different levels of food and predation. *Jour. Plank. Res.*, 1996, vol. 18, no. 6, p. 863-880.
- HANAZATO, T. Life history responses of two *Daphnia* species of different sizes against a fish kairomone. *Japan Jour. Limnol.*, 1995, vol. 56, no. 1, p. 27-32.
- HANAZATO, T. and DODSON, SI. Synergistic effects of low oxygen concentration, predator, kairomone, and a pesticide on the cladoceran *Daphnia pulex*. *Limnol. Ocean.*, 1995, vol. 40, no. 4, p. 700-709.
- HANAZATO, T., FUEKI, K. and YOSHIMOTO, M. Fish-induced life-history shifts in the cladocerans *Daphnia* and *Simocephalus*: are they positive or negative responses? *Jour. Plank. Res.*, 2001, vol. 23, no. 9, p. 945-951.

- HARDY, ER. 1992. Changes in species composition of Cladocera and food availability in a floodplain lake, lago Jacaretinga, central Amazon. *Amazoniana*, 1992, vol. 12, p. 155-168.
- HÜLSMANN, S. *Population dynamics of Daphnia galeata in the biomanipulated Bautzen Reservoir: life history strategies against food deficiency and predation*. Dresden, Germany: Technische Universität Dresden, 2001. [Tese de Doutorado].
- JACK, JD. and THORP, JH. Impacts of Fish Predation on an Ohio River Zooplankton Community. *Jour. Plank. Res.*, 2002, vol. 24, no. 2, p. 119-127.
- KERFOOT, WC. Combat between predatory copepods and their prey: *Cyclops*, *Epischura* and *Bosmina*. *Limnol. Ocean.*, 1978, vol. 23, no. 6, p. 1089-1102.
- KERFOOT, WC. Translocation experiments: *Bosmina* responses to copepod predation. *Ecology*, 1987, vol. 68, no. 3, p. 596-610.
- KREBS, CJ. *Ecology: the experimental analysis of distribution and abundance*. 3 ed. New York: Harper & Row, 1985.
- LAMPERT, W. The Dynamics of *Daphnia magna* in a shallow lake. *Verh. Int. Verein. Limnol.*, 1991, vol. 24, no. 2, p. 795-798.
- LARSSON, P. and DODSON, S. Chemical communication in aquatic animals. *Arch. Hydrobiol.*, 1993. vol. 129, p. 129-155.
- LEMMA, B., BENNDORF, J. and KOSCHEL, R. Fish predation pressure on and interactions between Cladocerans: observations using enclosures in Three Temperate Lakes (Germany) and One Tropical Lake (Ethiopia). *Limnologica*, 2001, vol. 31, no. 3, p. 209-220.
- MACHÁČEK, J. Comparison of the response of *Daphnia galeata* and *Daphnia obtuse* to fish-produced chemical substance. *Limnol. Ocean.*, 1993, vol. 38, p. 1544-1550.
- MACHÁČEK, J. Inducibility of life history changes by fish kairomone in various developmental stages of *Daphnia*. *Jour. Plank. Res.*, 1995, vol. 17, p. 1513-1520.
- MIKULSKI, A. Does *Daphnia* really minimize its size at first reproduction in the presence of fish? *Verh. Int. Verein. Limnol.*, 2000, vol. 27, p. 2888-2891.
- PIJANOWSKA, J. Anti-predator defense in three *Daphnia* species. *Int. Rev. Ges. Hydrobiol.*, 1992, vol. 77, no. 11, p. 153-163.
- PIJANOWSKA, J. and KOWALCZEWSKI, A. Cues from injured *Daphnia* and from cyclopoids feeding on *Daphnia* can modify life histories of conspecifics. *Hydrobiologia*, 1997, vol. 350, p. 99-103.
- REEDE, T. Life story shifts in response to different levels of fish kairomones in *Daphnia*. *Jour. Plank. Res.*, 1995, vol. 17, no. 8, p. 1661-1667.
- RICHARDSON, WB. and BARSCH, LA. Effects of zebra mussels on food webs: interactions with juvenile bluegill and water residence time. *Hydrobiologia*, 1997, vol. 354, no.1, p. 141-150.
- RICKLEFS, RER. *Ecology*. 3 ed. New York: WH. Freeman, 1996.
- ROCHE, K. Some aspects of vulnerability to cyclopoid predation of zooplankton prey individuals. *Hydrobiologia*, 1990, vol. 198, no. 1, p. 153-162.
- SARMA, SSS., MANGAS-RAMÍREZ, E. and NANDINI, S. Effect of ammonia toxicity on the competition among three species of cladocerans (Crustacea: Cladocera). *Ecotoxicol. Environ. Saf.*, 2003, vol. 55, p. 227-235.
- SLURSARCZYK, M. Predator-induced diapause in *Daphnia*. *Ecology*, 1995, vol. 76, p. 1008-1013.
- STIBOR, H. Predator induced life-history shifts in a freshwater cladoceran. *Oecologia*, 1992, vol. 92, no. 2, p. 162-165.
- TAYLOR, B. and GABRIEL, W. To grow or not to grow: optimal resource allocation for *Daphnia*. *Amer. Natur.*, 1992, vol. 139, no. 2, p. 258-266.
- THRELKELD, ST., RYBOCK, JT., MORGAN, MD., FOLT, CL. and GOLDMAN, CR. The effects of an introduced predator and food resource variation on zooplankton dynamics in an ultraoligotrophic lake. In KERFOOT, WC. (Ed.). *Evolution and ecology of zooplankton communities*. New England: The University Press of New England, 1980. p. 555-568.
- TOLLRIAN, R. and JESCHKE, JM. Density-dependent effects of prey defenses. *Oecologia*, 2000, vol. 123, no. 3, p. 391-396.
- VILLALOBOS, MJ. and GONZALEZ, EJ. Studies on the biology and ecology of *Ceriodaphnia cornuta* Sars: a review. *Interciencia*, 2006, vol. 31, no. 5, p. 351-357.
- VOS, M., VET, LEM., WÄCKERS, FL., MIDDLEBURG, JJ., PUTTEN, WH. Van der, MOOIJ, WM., HEIP, CHR. And Van DONK, E. Infochemicals structure marine, terrestrial and freshwater food webs: Implications for ecological informatics. *Ecol. Infor.*, 2006, vol. 1, no. 1, p. 23-32.
- WEIDER, LJ. and PIJANOWSKA, J. Plasticity of *Daphnia* life history in response to chemical cues from predators. *Oikos*, 1993, vol. 67, p. 385-392.
- ZARET, T. *Predation in freshwater communities*. Ann Arbor: Edwards Brother Inc., 1980.

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