PANAMJAS
Pan-American Journal of Aquatic Sciences

Diversity of aquatic arthropods on *Eichhornia crassipes* (Mart.) Solms roots before and after removal of substrate in a reservoir in southern Brazil

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Abstract. The objective of this study was to determine the influence of substrate removal on the diversity, composition and trophic structure of aquatic arthropods found on *Eichhornia crassipes* roots. Because many arthropods are intimately associated with their substrate, its removal might result in increased richness and diversity for the aquatic arthropods on *E. crassipes* roots. The study was performed in the Lajeado da Cruz River in Cruz Alta-RS, where the identification of the aquatic arthropods captured during eight samplings between August 2008 and May 2011 was performed. Four samples were collected prior to removal of the substrate and four were collected afterward. A total of 8,894 exemplars and 55 families of aquatic arthropods were sampled. The families Palaemonidae and Chironomidae were the most abundant. The diversity indices indicated increases in both diversity and richness after substrate removal. Values of the water quality parameters of turbidity, color, iron and aluminum were found to be outside the norms, which indicated a need for caution with regard to water quality. The removal of the substrate triggered changes in the community and its trophic structure as well as an increase in the diversity of arthropods on the water hyacinth roots.

Key words: water hyacinth, Palaemonidae, Chironomidae, water quality parameters

Resumo. Diversidade de artrópodes aquáticos em raízes de *Eichhornia crassipes* (Mart.) Solms antes e depois de remoção de substrato em um reservatório no sul do Brasil. O objetivo deste estudo foi determinar a influência da remoção de substrato sobre diversidade, composição e estrutura trófica de artrópodes aquáticos associados a raízes de *Eichhornia crassipes*. Uma vez que muitos artrópodes são intimamente associados com o substrato, a remoção deste poderia resultar em aumento de riqueza e diversidade de artrópodes aquáticos em raízes *E. crassipes*. O estudo foi realizado no rio Lajeado da Cruz em Cruz Alta-RS, onde foram identificados artrópodes aquáticos capturados em oito coletas entre agosto de 2008 e maio de 2011. Foram realizadas quatro coletas antes e quatro após a remoção do substrato. Um total de 8.894 exemplares e 55 famílias foram amostradas. Palaemonidae e Chironomidae foram as famílias mais abundantes. Índices de diversidade mostraram aumento de diversidade e riqueza depois da remoção do substrato. Valores de parâmetros de qualidade da água para turbidez, cor, ferro e alumínio encontraram-se fora dos padrões e indicam precaução com a qualidade de água. A remoção de substrato ocasionou alterações da comunidade, resultando em aumento de diversidade de artrópodes aquáticos associados a raízes de aguapé.

Palavras chave: aguapé, Palaemonidae, Chironomidae, qualidade da água

Introduction

The management of dams can cause reservoirs to vary widely in hydrological conditions; consequently, changes in inflow, outflow, water level and retention time can directly affect limnological features. Factors such as the lack of riparian vegetation, urbanization, the dumping of domestic sewage and agricultural chemicals leaching from nearby farms tend to intensify existing environmental stresses (Moore & Palmer 2005, Copatti *et al.* 2009, Copatti & Copatti 2011, Park *et al.* 2011). The fluvial zone receives a high input of nutrients, but primary production is reduced by the scarcity of light just under the surface due to the large concentration of macrophytes. The lentic zone is characterized by nutrient limitation and reduced phytoplankton biomass (Thornton 1990, Soares *et al.* 2012). Influenced by these factors, aquatic arthropods may switch their habitats between plants and water in the lentic zone. Difonzo & Campbell (1988) found that the relative abundance and composition of invertebrates varied depending on the type of microhabitat (e.g., plant species, benthic substrate or water column) and that invertebrates can move between microhabitats.

Originally from South America, the water hyacinth *Eichhornia crassipes* (Mart.) Solms is one of the world's most prevalent invasive aquatic plants. It possesses physiological characteristics and reproductive strategies that enable rapid growth and expansion in several types of aquatic ecosystems in both tropical and subtropical regions (Bartodziej & Leslie 1998), and the reestablishment of native vegetation in areas previously altered by an invasive plant can result in the rapid recovery of the native arthropod assemblages associated with the restored habitat (Gratton & Danno 2005). Invasive species can result in either lower (Wu *et al.* 2009) or higher (Pearson 2009) aquatic arthropod diversity and richness.

Water hyacinth has invaded freshwater systems in over 50 countries on five continents and, according to climate change models, its distribution may expand into higher latitudes as temperatures rise (Rodríguez-Gallego *et al.* 2004, Hellmann *et al.* 2008, Rahel & Olden 2008).Water hyacinth absorbs heavy metals (Tiwari *et al.* 2007), organic contaminants (Zimmels *et al.* 2007) and nutrients from the water column (Palma-Silva *et al.* 2012). Water hyacinth roots accumulate substrates with high concentrations of organic matter from the rivers where they originate (Poi de Neiff & Carignan 1997), and they exhibit great potential for use in recovery strategies for eutrophic lakes in subtropical regions (Palma-Silva *et al.* 2012). However, high densities of water hyacinth also reduce photosynthetic rates and dissolved oxygen concentrations in the water column, and both of these factors create physiological problems for invertebrates (Bechara & Andreani 1989).

Substrate removal is a common technique in the restoration management of standing water bodies around the world (Sychra & Adámek 2011). It is especially used in lakes and ponds with considerable substrate accumulation (especially in areas of soil and nutrient runoff from in appropriate agricultural land use) to reduce internal nutrient loading and for the general restoration of aquatic ecosystems (Moss *et al.*1996, Clemente *et al.* 2005, Ayala *et al.* 2007). Substrate removal influences both the environment of the water body and its communities of aquatic organisms (Sychra & Adámek 2011).This study examined how aquatic arthropod assemblages associated with *E. crassipes* roots changed with the removal of their substrate. Because many arthropods are intimately associated with their substrate, decreases in the substrate can change the habitat characteristics and chemical water quality and incorporate a portion of this fauna into the macrophytes. This would result in increased richness and diversity of the aquatic arthropods in the roots of *E. crassipes*. For example, aquatic plants provide ideal habitat for colonization by macroinvertebrates (Masifwa *et al.* 2001), which are generally more abundant in association with aquatic macrophytes than in open water (Olson *et al.* 1994). Water hyacinths also serve as substrata for periphyton and as sites of abundant food production for many aquatic animals (Zimmer *et al.* 2000), and they also contribute as locations for the emergence of aquatic and semi-aquatic insects (Pelli & Barbosa 1998).

There have been several publications discussing invertebrate assemblages on water hyacinth root masses, focusing on the specific composition of the invertebrate assemblages, the species-environment relationships, the identification of functional groups and the relationships between plant decomposition and invertebrate colonization (Bartodziej 1992, Bailey & Litterick 1993, Bartodziej & Leslie 1998, Masifwa *et al.* 2001, Montoya 2003, Rocha-Ramirez *et al*. 2007, Kouamé *et al.* 2010, Oke 2011). Other studies have been devoted to analyzing the effects of substrate removal on aquatic invertebrate assemblages (Brown *et al.* 1997, Friberg *et al.* 1998, Sychra & Adámek 2011). However, data are lacking on how the diversity, richness, abundance and trophic structure of aquatic arthropods on *E. crassipes* roots are influenced by substrate removal. The goal of this study was to provide such information.

Materials and Methods

Study sites

Field investigations were undertaken in the Lajeado da Cruz River (LCR) (Fig. 1), a 2nd order river, in the Jacuí Basin of the Atlantic Forest Biome (28º41'41.22" S, 53º32'53.82" W, 379 m altitude), which serves as a reservoir for the water capitation station for the water supply for Cruz Alta-RS, southern Brazil, in the subtropical region. The LCR, in the region investigated, is covered extensively by water hyacinths. A 1,000 m stretch was considered, which is mostly characterized as lentic, with the presence of some lotic spans. It exhibits an average width of 15 m and a depth of 30-300 cm. The river bottom is mostly sandy-muddy. The property belongs to CORSAN (Companhia Riograndense de Saneamento) and is part of an environmental preservation area.

Figure 1. Location of LCR, Cruz Alta, RS, Brazil. Fonte: Abreu 2006, Google Earth 2012 (map adapted).

The water surface is covered almost entirely by exemplars of non-indigenous *E. crassipes*. Other aquatic macrophytes observed in the LCR include water lettuce (*Pistia stratiotes*) and *Salvinia* sp. Riparian vegetation is almost non-existent, with native and exotic vegetation along the shorelines and several sites where it is totally absent from both banks. Furthermore, the area is surrounded by roads, wetlands and agricultural planting areas alternating with pastures.

Aquatic arthropods

Aquatic arthropods were sampled between August 2008 (Winter) and May 2011 (Autumn). In August 2009, the substrate was removed by CORSAN. The principal component of the substrate was dead water hyacinths. Samples were taken before substrate removal, in August and November 2008 and in February and May 2009, as well as after substrate removal, in August and November 2010 and in February and May 2011. The substrate was removed mechanically from the study area.

Samples were taken manually from margins of the river, resulting in a total of 30 *E. crassipes* adult specimens of similar size with an average weight of 700g *in situ* for each sampling month. Water hyacinths were stored in individual plastic packages. Afterward, they were taken to the laboratory, where they were stored in a refrigerator below 4º C.

Subsequently, the root masses were manually separated from the other parts of the plant and preserved in a 10% formaldehyde solution in plastic containers for further analysis. In the laboratory, all aquatic arthropods were separated from the collected root mass by washing each root sample in a tank to concentrate the organisms. The specimens (family level) and their functional feeding groups were later identified using Merritt & Cummins (1996), Domínguez & Fernández (2001) and Costa *et al.* (2006) as references. The material identified was preserved in 80% ethanol.

Environmental variables

We analyzed the following physiochemical parameters of the water: turbidity (NTU), color ($mg.L^{-1}Pt$), alkalinity ($mg.L^{-1}$ $CaCO_3$), organic matter ($mg.L^{-1}$ O_2 consumed in an acid medium), dissolved oxygen ($mg.L^{-1}$), hardness ($mg.L^{-1}$ $CaCO_3$), bicarbonates ($mg.L^{-1}$), chlorides ($mg.L^{-1}$), magnesium ($mg.L^{-1}$), total solids ($mg.L^{-1}$) and pH.

The following metals ($mg.L^{-1}$) were also analyzed using atomic absorption spectrometry: aluminum, iron, manganese, arsenic, barium, lead, copper, chromium, cadmium, mercury, nickel, selenium and zinc, and hexavalent chromium was analyzed using molecular absorption spectrometry. The following agrochemicals ($\mu g.L^{-1}$) were also screened for: hexachlorobenzene, Simazine, Atrazine, Lindane (Y-BHC), Propanil, heptachloroepoxide, Aldrin/Dieldrin, Endosulfan, Endrin, DDT, Methoxichlor, Chlordane, Molinate, Alachlor, Metalachlor, Pendimetaline, Permetrine, benzopyrene, 2,4,6-trichlorophenol, 2,4d-pentachlorophenol, Bentazone and Trifluraline using gas chromatography, and Glyphosate + AMPA using ionic chromatography.

Analyses were made weekly based on Ordinance N°518/04 of the Brazilian Ministry of Health (Brasil 2004) and according to Eaton *et al.* (2005) at CORSAN's water laboratory.

Data analysis

The sampling months represented the repetitions and the water hyacinth represented the pseudo-replications. The dates when aquatic arthropods were found in the water hyacinths were grouped within the months of their collection. Shannon's diversity index (H'), Pielou's evenness index (J') and rarefaction richness (S') were calculated for the families utilizing Biodiversity Pro (McAleece *et al.* 1997). The homogeneity of the variances among the different groups (before and after substrate removal) was tested using Levene's test. Comparisons of differences in diversity H, evenness J", richness, rarefaction and abundance between collections made before and after substrate removal were performed using a one-way analysis of variance (ANOVA) and Tukey's test with the software package Statistica (version 7.1) ($P < 0.05$). The relationships between diversity with richness (with or without rarefaction) and abundance by correlation were determined using Sigma Plot 11.0 software.

Results

In total, 8,894 individuals and 55 families were sampled (Table I). Four families represented 77.87% of the faunal abundance: Palaemonidae, Chironomidae, Coenagrionidae and Leptohyphidae, in descending order, with 4,707; 1,232; 532 and 455 individuals, respectively. The Palaemonidae family was the most abundant taxon in the samples, except in May 2009, when the Chironomidae dominated, with 36.57%. In contrast, several families (such as Calopterygidae, Gelastocoridae, Perlidae and Philopotomidae) were found at low frequencies; hence, it is not possible to state whether they are typical or casual groups in these locations. In total, 26 predator, 12 collector-gatherer, 10 shredder, 7 scraper and 4 collector-filterer taxa (Table I) were recorded, and the Chironomidae, due to the complexity of the group, were considered to belong to all of the functional feeding groups.

Table I. Relative abundance of aquatic arthropods on *Eichhornia crassipes* roots in the LCR. FFG = Functional Feeding Groups. Cg = Collector-gatherer. Cf = Collector-filterer. Sh = Shredder. Sc = Scraper. Pr = Predator.

Taxa	2008-2009				2010-2011					
	Aug	**Nov**	**Feb**	**May**	**Aug**	**Nov**	**Feb**	**May**	**Total**	**FFG**
CHELICERATA										
Aranae										
Lycosidae	0.20	0.18	0.55	1.06	0.49	1.04	0.64	0.10	0.57	Pr
Pisauridae	0.20	0.09	0.22	0.24	0.12	0.42	0.14	0.10	0.20	Pr
Acari										
Hydrachnellidae	-	-	-	-	-	0.07	0.07	0.31	0.06	Pr
CRUSTACEA										
Decapoda										
Aeglidae	0.20	0.27	0.44	2.84	0.49	0.49	3.46	0.73	1.15	Sh
Palaemonidae	42.28	79.24	70.25	28.88	34.48	47.95	52.90	39.33	52.92	Sh
HEXAPODA										
COLLEMBOLA										
Entomobryidae	-	-	0.05	-	-	-	-	0.73	0.09	Cg
Isotomidae	-	-	-	0.36	-	0.14	0.28	0.31	0.13	Cg
INSECTA										
Ephemeroptera										
Baetidae	0.41	-	1.64	0.36	0.86	0.07	2.48	-	0.88	Cg
Caenidae	0.41	-	0.82	0.24	-	4.04	0.21	0.42	0.94	Cg
Leptohyphidae	13.21	2.89	1.42	3.67	14.81	5.84	1.41	8.32	5.12	Cg
Leptophlebiidae	0.81	-	0.27	4.14	0.49	0.63	0.21	0.83	0.76	Cg
Odonata										
Aeshnidae	0.20	0.45	-	0.36	0.37	-	0.21	-	0.17	Pr

Calopterygidae	-	-	-	-	0.24	-	-	-	0.02	Pr
Coenagrionidae	3.86	4.33	4.33	9.35	5.54	4.80	7.00	9.78	5.98	Pr
Corduliidae	-	-	3.56	-	1.10	0.14	0.50	1.98	1.15	Pr
Gomphidae	0.41	-	-	0.59	0.12	0.07	-	0.31	0.13	Pr
Lestidae	4.47	0.99	1.53	3.08	-	-	-	-	0.98	Pr
Libellulidae	2.24	1.81	0.16	0.71	0.86	1.60	1.13	1.87	1.17	Pr
Orthoptera										
Gryllidae	-	-	-	0.12	-	-	-	0.21	0.03	Sh
Gryllotalpidae	0.20	-	-	0.36	-	-	-	-	0.04	Sh
Tettigoniidae	0.20	-	0.16	-	-	-	-	-	0.04	Sh
Plecoptera										
Gripopterygidae	-	0.09	-	-	11.82	5.15	-	3.43	2.29	Sh
Perlidae	0.20	-	-	-	-	-	-	-	0.01	Pr
Megaloptera										
Corydalidae	-	-	0.44	-	-	-	-	0.10	0.10	Pr
Hemiptera										
Aphididae	-	-	-	-	0.25	0.07	-	-	0.03	Pr
Belostomatidae	0.20	0.63	0.99	0.95	0.37	0.70	1.63	0.21	0.81	Pr
Corixidae	-	-	-	-	-	0.07	-	-	0.01	Sc
Gelastocoridae	-	-	-	-	-	0.07	-	-	0.01	Pr
Gerridae	0.20	0.09	-	-	-	-	-	-	0.02	Pr
Hebridae	-	-	0.05	0.12	-	-	0.28	2.29	0.31	Pr
Veliidae	-	0.09	1.10	0.48	3.44	3.90	2.40	4.27	2.02	Pr
Trichoptera										
Helicopsychidae	-	-	-	-	-	0.42	-	-	0.07	Sc
Hydrobiosidae	-	-	0.49	0.12	0.37	0.14	-	-	0.17	Pr
Hydropsychidae	0.41	-	0.88	0.95	-	-	0.28	-	0.34	Cf
Hydroptilidae	-	-	0.33	0.12	-	0.49	-	0.21	0.18	Cg
Leptoceridae	-	-	-	-	0.49	0.56	0.92	0.94	0.38	Sh
Philopotomidae	-	-	-	-	0.12	-	-	-	0.01	Cf
Lepidoptera										
Crambidae	0.41	0.36	0.33	0.12	0.49	0.07	0.21	0.42	0.28	Sc
Noctuidae	-	0.09	-	-	0.24	0.42	0.71	1.25	0.35	Sc
Pyralidae	0.81	-	-	-	-	-	-	-	0.04	Sc
Diptera										
Chaoboridae	0.20	-	-	-	0.12	-	0.07	0.21	0.06	Pr
Chironomidae	23.37	2.62	6.19	36.57	16.26	16.98	11.53	13.32	13.36	All
Culicidae	1.01	-	-	0.36	0.24	-	1.06	-	0.28	Cg
Dixidae	-	0.27	-	-	0.12	-	-	0.21	0.07	Cg
Simuliidae	0.20	0.27	-	0.12	0.49	0.14	-	-	0.12	Cf
Tipulidae	-	0.09	-	-	0.12	-	-	-	0.02	Pr
Coleoptera										
Curculionidae	0.41	0.27	0.33	0.36	0.49	0.21	1.56	1.25	0.62	Sh
Dryopidae	-	0.36	0.05	-	1.10	1.25	1.06	0.31	0.56	Sc
Dytiscidae	-	-	-	-	0.12	-	2.12	1.25	0.48	Pr
Elmidae	0.20	2.89	0.16	1.89	0.74	1.46	2.26	1.04	1.36	Cg
Gyrinidae	0.81	-	-	-	0.24	0.07	-	0.73	0.16	Pr
Haliplidae	-	-	-	-	0.24	-	0.14	-	0.04	Sh
Hydrophilidae	1.63	0.45	2.19	0.36	1.48	0.56	2.48	0.62	1.32	Pr
Noteridae	-	0.72	0.77	0.83	0.74	-	-	0.10	0.40	Pr
Scirtidae	0.61	0.45	0.27	0.36	0.24	-	0.64	2.50	0.57	Cg
Total individuals	492	1108	1825	845	812	1437	1414	961	**8894**	

The samplings recorded 4,270 and 4,604 individuals, respectively, before and after substrate removal, and there were no significant differences between the measurements. Lestidae, which are predators, were found before substrate removal (104 individuals) but not after. Other taxa present only before substrate removal were Pyralidae, Gerridae, Perlidae, Tettigoniidae and Gryllotalpidae. Despite the Lestidae not having been found again, other predator groups were present only after substrate removal: Hydrachnellidae, Calopterygidae, Corixidae, Aphididae and Gelastocoridae. Other groups found only after substrate removal were Corixidae, Helicopsychidae, Leptoceridae, Philopotomidae and Haliplidae.

The Shannon's diversity (H'), Pielou's evenness (J'), richness (S) and rarefaction richness(S') indices for aquatic arthropods on *E. Crassipes* roots in the LCR were significantly higher ($p< 0.01$) after substrate removal. Rarefaction richness (S') was calculated for 492 individuals (total abundance in August 2008) and showed an expected richness of between 20.29 and 30.00 before substrate removal and from 25.27 to 32.80 after substrate removal (Fig. 2). Diversity was significantly correlated with family richness with regards to rarefaction ($r^2 = 0.81$; $p< 0.01$) or no rarefaction ($r^2 = 0.79$; $p< 0.01$), although there was no relationship between diversity and individual abundance ($r^2 = 0.13$; $p > 0.05$).

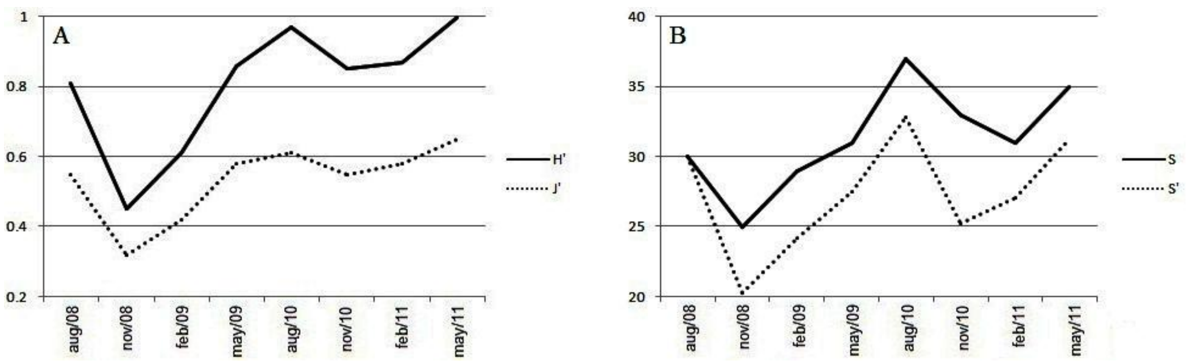

Figure 2. Diversity H' and evenness J' (A), and richness S and rarefaction richness S' (B) indices of aquatic arthropods on *Eichhornia crassips* roots in the LCR.

The abiotic parameters of water quality were measured and are presented in Table II. Values for arsenic, barium, lead, copper, chromium, cadmium, mercury, nickel, selenium, zinc and hexavalent chromium were not detectable. Moreover, all tests for agrochemicals measured undetectable levels. Values for turbidity and color suggested caution according to Ordinance N°518/04 of the Brazilian Ministry of Health (Brasil 2004) with regard to water quality, but the iron and aluminum concentrations are more disturbing due to their being heavy metals. These water quality parameters were of more concern after substrate removal.

Table II. Average values and standard errors of abiotic parameters measured in the LCR. Maximum Value Permitted = MVP (Brasil 2004). Value Not Available = VNA.

Parameter	MVP	2008-09	2010-11
Turbidity	5.00	11.9 ± 0.97	21.02 ± 3.02
pH	6.00-9.50	6.87 ± 0.01	6.49 ± 0.03
Color	15.00	45.80 ± 2.80	80.64 ± 14.26
Alkalinity	250.00	25.96 ± 0.52	18.87 ± 0.76
Organic matter	5.00	2.70 ± 0.12	3.20 ± 0.28
DO	10.00	7.10 ± 0.17	8.67 ± 0.38
Hardness	500.00	18.00 ± 0.63	15.33 ± 0.51
Bicarbonates	-	VNA	34.00 ± 8.00
Chlorides	250.00	VNA	0.58 ± 0.58
Magnesium	-	VNA	3.00 ± 1.00
Total solids	1000.00	VNA	49.50 ± 4.50
Manganese	0.10	0.03 ± 0.01	0.06 ± 0.01
Iron	0.30	0.38 ± 0.04	0.50 ± 0.07
Aluminum	0.20	VNA	0.54 ± 0.14

Discussion

Few surveys of aquatic arthropods associated with water hyacinth roots have been conducted in Brazil, so we supply new information concerning this topic. Water hyacinth roots in the LCR are colonized by an important assemblage of aquatic arthropods. We consider that *E. Crassipes* provided excellent microhabitats with special characteristics that enhanced establishment and colonization for many invertebrates. It has been suggested that the greater niche diversity provided by plant biomass, periphyton, detritus and the silt collected by root mats, especially floating root mats, together supports a more complex and richer food-web structure than bare substrate (Hargeby 1990, Brown & Lodge 1993, Masifwa *et al.* 2001). Only a minimum fraction of the invertebrates found in root mats actually feed on the plants, although Palaemonidae taxon has been reported to consume water hyacinth roots (Montoya 2003).

Danell & Sjöberg (1982) noticed, in a man-made lake (northern Sweden) with a high number of macrophytic species, that Chironomidae, Coleoptera and Hemiptera were relatively early colonizers, while Odonata, Ephemeroptera and Trichoptera became abundant later. In this study, Odonata and Ephemeroptera were more abundant than Coleoptera and Hemiptera (Table I), indicating that the study area was not in an early stage of succession and that the patterns found had been influenced by the existence or removal of water hyacinths in the substrate. Among insects, Chironomidae was the most abundant taxon in this study. Chironomidae are common inhabitants of most aquatic habitats and often dominate aquatic insect communities in both abundance and species richness, consisting of individuals that are resistant to disturbances in the water (Ferrington Jr. 2008, Raunio *et al*. 2011).The same has been reported in other water hyacinth studies, with the dominance of Chironomidae sometimes reaching over 90% (Trivinho-Strixino & Strixino 1993, Correia & Trivinho-Strixino 1998, Peiró & Alves 2006).

In the present study, Palaemonidae and Chironomidae were the dominant taxa (Table I) and can be an important food resource for the maintenance of predators. “Predator” was the functional group with the highest richness in our study. Kouamé *et al.* (2010) also reported predators to be the trophic category most represented in their study, and their numbers may increase when more prey are present.

The decomposition of the water hyacinths also strongly influences colonization by benthic macroinvertebrates, mainly the collector-gatherers (Mormul *et al.* 2006). Collector-gatherers collect detritus provided by aquatic plants (Moretti *et al.* 2003). We found 342 (8.01%) and 582 (12.64%) collector-gatherers, respectively, before and after substrate removal (Table I). Biomass removal could be related to the large number of collector-gatherers found on water hyacinths after the removal process (such as Scirtidae, Elmidae, Leptohyphidae, Caenidae and Culicidae). In this study, after removal of the biomass, this functional group may have migrated to live on the water hyacinth roots to satisfy their demand for food and, once there, have also influenced the appearance of predators, which could find prey in the water hyacinth roots more easily than in open water. Other functional feeding groups did not seem to have been affected by the removal of the substrate.

In general, functional and taxonomic shifts in the macroinvertebrate assemblage were connected to changes in the substrate. In our study, the diversity was influenced by richness, as verified in the correlation (r^2 = 0.81 and 0.79 for richness with and without rarefaction, respectively). The rarefaction calculations demonstrated, on the whole, an increase in the richness of aquatic arthropods on water hyacinth roots (Fig. 2b), which was most likely a consequence of the substrate removal. Richness and evenness are key elements in the evaluation of diversity and, given equivalent levels of richness, communities in which there are no dominant species have greater diversities (Siegloch *et al.* 2008). In this study, the highly dominant *taxa* Palaemonidae and Chironomidae influenced minor diversity in the samples and influenced the absence of a correlation between diversity and abundance (r^2 = 0.13), although the minor dominance of the Palaemonidae after substrate removal (45.50%)compared with their dominance before the removal (61.17%) (Table I) contributed to the increases in diversity H’ and evenness J’ (Fig. 2a).

The abundance and diversity of aquatic arthropods generally increase in response to increases in habitat heterogeneity and structural complexity provided by water hyacinths. These can enhance macroinvertebrate abundance and richness through the provision of additional, and in some cases novel, habitats (Villamagna & Murphy 2010). However, in our study, the removal of the substrate was more important for the increases in diversity and richness in the *E. crassipes* roots (Fig. 2). Aquatic invertebrates are often removed at the same time as the substrate by heavy machinery, and a portion of the fauna disappears without having had a chance to migrate to the water hyacinth roots. A significant loss of aquatic invertebrates in the benthic region of the reservoir must have occurred, but this was not observed in the water hyacinth roots.

Rocha-Ramirez *et al.* (2007) suggested that community composition was affected not only by the presence of water hyacinths but also by physiochemical conditions such as dissolved oxygen and turbidity. In our study, special attention was dedicated to turbidity, color, iron and aluminum concentrations, which might have been affected by the substrate removal (Table II) that provided soil particles affecting the turbidity and color and the levels of iron and aluminum retained in the substrate. Aquatic arthropods can respond strongly to abiotic parameters in water. The values of turbidity and color in our study can decrease the penetration of light to aquatic arthropods, and iron and aluminum are important heavy metals that act to reduce water quality. However, aluminum is toxic only at extreme pH (Wauer & Teien 2010), and the effects of iron, turbidity and color on aquatic arthropods need to be further investigated. Analyses for other heavy metals and agrotoxins did not detect them above the MVP (Table II).

Water hyacinth mats decrease dissolved oxygen concentrations beneath the mats by preventing the transfer of oxygen from the air to the water's surface (Hunt & Christiansen 2000) and by blocking light used for photosynthesis by phytoplankton and submerged vegetation (Uwadiae *et al.* 2011). Unlike phytoplankton and submerged vegetation, water hyacinths do not release oxygen into the water column (Meerhoff *et al.* 2003). However, well-oxygenated water with water hyacinths present still supports diverse and abundant invertebrate communities (Masifwa *et al.* 2001). In our study, the concentration of dissolved oxygen in the water was within the range required for these species, and they were most likely not affected by the presence of the water hyacinths. However, there might have been a methodological error, where the dissolved oxygen was measured near the surface or in a place where mechanical agitation for water capitation was occurring. Nevertheless, the removal of the substrate may have contributed to the increased oxygen, which ranged from 7.10 to 8.67 $mg.L^{-1}$ O_2 (Table II).

In addition, Clemente *et al.* (2005) suggested that in hypertrophic lakes, the effects of organic matter enrichment in the sediment might be even more relevant than fish predation in shaping the zoobenthos. Therefore, the low organic matter values found (Table II) contributed to arthropod colonization. Substrate removal changes both the physical and chemical characteristics of the bottom soil (Yuvanatemiya & Boyd 2006), and in this study, it influenced changes in water quality.

Conclusions

The substrate removal caused changes in both the community and trophic structure, resulting in an increase in the diversity of aquatic arthropods on *E. crassipes* roots. Most likely, aquatic arthropods whose niches disappeared with the removal of the substrate came to occupy the living water hyacinths. This may have also benefited the populations of collector-gatherers and predators. Thus, water hyacinths can function as an important niche for aquatic arthropods, especially in the absence of other niches that provide their necessary resources.

Acknowledgments

We are grateful to CORSAN – Companhia Riograndense de Saneamento and Vilson Alexandre Gayger Vaz for providing the water analysis. Laidines S. Fagundes received a PIBIC/CNPq/UNICRUZ fellowship.

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Received December 2012
Accepted August 2013
Published online December 2013