Structure of invertebrates community associated with *Eichhornia crassipes* Mart. (Solms-Laubach) after the introduction of *Limnoperna fortunei* (Dunker, 1857) (Bivalvia, Mytilidae) in the Upper Paraguay River, MT, Brazil

Estrutura da comunidade de invertebrados associados à *Eichhornia crassipes* Mart. (Solms-Laubach) após a introdução de *Limnoperna fortunei* (Dunker, 1857) (Bivalvia, Mytilidae) no Alto Rio Paraguai, MT, Brasil

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Abstract: This work was based on the assumption that the structure of the invertebrates' community associated with *Eichhornia crassipes* is influenced by the water's physicochemical conditions and the abundance of *Limnoperna fortunei* on the roots of this plant. In the dry season, 0.1875 m^2 of *E. crassipes* were collected for a study of the associated invertebrates, including the exotic bivalve species *L. fortunei* from 15 lakes along the banks of the Paraguay River. A total of 86,943 invertebrates were collected and the predominant taxa found in the roots were Hydrobiidae, Ostracoda, Hydracarina, and *Eupera* sp. The ordination showed that conductivity, transparency and dissolved oxygen were the variables that best represented limnological characteristics of the lake waters, but this set of physicochemical parameters did not present a relation with the structure of the invertebrate community summarized by means of a PCoA. However, Trichoptera, Odonata and Conchostraca showed a negative correlation to dissolved oxygen and depth, probably because these factors directly influenced the state of decay of the *E. crassipes* and consequently the density of these invertebrates. The absence of significant relation between the invertebrates' community and *L. fortunei* abundance can be associated with low densities, meaning that the environment is resilient to the aggressive growth of this population in the Pantanal.

Keywords: community structure, associated fauna, exotic specie, wetlands, Pantanal.

Resumo: Esse trabalho partiu do pressuposto que a estrutura da comunidade de invertebrados associados à *Eichhornia crassipes* é influenciada pelas condições físico-químicas da água e abundância de *Limnoperna fortunei* nas raízes dessa planta. No período de seca, 0.1875 m^2 de *E. crassipes* foram coletados, para estudo dos invertebrados associados, incluindo o bivalve exótico *L. fortunei* em 15 lagoas marginais do rio Paraguai. Um total de 86.943 invertebrados foram coletados e os taxa predominantes nas raízes foram Hydrobiidae, Ostracoda, Hydracarina e *Eupera* sp. A ordenação demonstrou que a condutividade elétrica, transparência e o oxigênio dissolvido foram as variáveis que melhor representaram as características limnológicas da água das lagoas, mas este conjunto de parâmetros físico-químicos não apresentou relação com a estrutura da comunidade de invertebrados resumida por meio de uma PCoA. No entanto, Trichoptera, Odonata e Conchostraca apresentaram-se negativamente correlacionados ao oxigênio dissolvido e profundidade, provavelmente porque tais fatores influenciam diretamente o estado de decomposição de *E. crassipes* e conseqüentemente a densidade desses invertebrados. A ausência de relação significativa entre a comunidade de invertebrados e a abundância de *L. fortunei* pode estar associada com a baixa densidade, indicando que o ambiente está sendo resiliente ao crescimento agressivo desta população no Pantanal.

Palavras-chave: estrutura da comunidade, fauna associada, espécie exótica, áreas úmidas, Pantanal.

1. Introduction

Biological communities are subject to natural disturbances that act upon their dynamic and local diversity (Worm and Duffy, 2003). In recent years, in addition to natural disturbances, biological communities have been modified directly or indirectly by human intervention in the environment, altering the natural process of dispersion of species (MacIsaac et al., 2001; Boltovskoy et al., 2006).

One of the most recent invasions in the freshwater environment is that of the golden mussel, *Limnoperna fortunei* (Dunker, 1857) (Bivalvia, Mytilidae), that appeared in the La Plata River in Buenos Aires in 1991 (Darrigran and Pastorino, 1993), probably carried by ballast water from ships sailing from Asia (Pastorino et al., 1993). The colonization of *L. fortunei* along South American watercourses is advancing and increasing continually (Boltovskoy et al., 2006). The introduction of this bivalve in the Paraguay River occurred in 1999, through fluvial navigation which acts as the main means of dispersion of the planktonic larvae to the rivers and lakes of the Pantanal (Mansur et al., 2004; Oliveira et al., 2006). The concerns about the growing population of this bivalve are due to the occurrence of high densities, derived from high reproductive rates and aggregate behavior, which may cause a reduction in the fauna of the native invertebrates (Brugnoli et al., 2005) or in accordance with Beekey et al. (2004) favor species through direct, indirect or commensal relations.

In the floodplain of the Pantanal, as well as in other wet areas of the planet, the coastal region of the lakes concentrates a high density and richness of organisms (Douglas and O'Connor, 2003; Cronin et al., 2006), mainly due to the presence of macrophytes (Taniguchi et al., 2003; Thomaz et al., 2008). This vegetation affects the distribution and abundance of animals (invertebrate, fish) (Cronin et al., 2006) because it can provide habitats, refuges and works as direct (herbivorous) and/or indirect (periphyton, debris) food resources for the aquatic trophic net (Newman, 1991; Takeda et al., 2003). The lakes in this floodplain, usually, present a high density of the aquatic macrophytes (Pott and Pott, 2000), among which the floating *Eichhornia crassipes* Mart. (Solms-Laubach) stands out for its abundance in flooding systems (Wantzen et al., 2005; Milne et al., 2006). The microcosm formed on the roots of floating plants is named pleuston by Esteves (1998) and its architecture allows a greater growth of the periphyton (Toft et al., 2003; Poi de Neiff and Neiff, 2006) and increases the physical complexity on the coastal region of the lakes, providing habitats for the invertebrate colonization (Newman, 1991; Taniguchi et al., 2003; Taniguchi and Tokeshi, 2004; Thomaz et al., 2008), and recently a substrate for the invasive species *L. fortunei* (Oliveira et al., 2006). Invertebrates, in turn, play a key role in the coastal zone of lakes, controlling the biomass of periphyton, acting in the decomposition and cycling of detritus (Stripari and Henry, 2002), and serving as a link of energy transfer between secondary producers and consumers (Weatherhead and James, 2001; Warfe and Barmuta, 2006).

In floodplains, variations in the water's physicochemical conditions, the distribution of macrophytes, and fluctuations in the abundance of invertebrates are strongly influenced by periodic flooding (Junk et al., 1989; Weatherhead and James, 2001; Marchese et al., 2005; Tarr et al., 2005). During the dry season, the low depth, favors the decomposition of macrophytes that alters the chemistry of the water (Meerhoff et al., 2003), provides a concentration of nutrients (Heckman, 1994; Carvalho et al., 2001) and can lead to a local reduction in the water oxygen, mainly under the stands of macrophytes (Hamilton et al., 1995; Masifwa et al., 2001; Marklund et al., 2001; Toft et al., 2003; Tarr et al., 2005; Marchese et al., 2005; Hummel and Findlay, 2006).

The relationship between richness and abundance of invertebrates with the chemical variables of the water in rivers has been studied, being the concentration of dissolved oxygen one of the most important predictors of the structure of the invertebrate benthic communities in the plains with short or variable hydroperiods (Poi de Neiff and Carignan, 1997; Marklund et al., 2001; Toft et al., 2003; Tarr et al., 2005; Hummel and Findlay, 2006). However, studies consider that the influence of the physicochemical conditions in the invertebrate community associated with the macrophytes is reduced in seasonally flooded lakes of the Pantanal.

Added to this, studies about exotic species are overlooked in Brazil and in relation to the bivalve invader *L. fortunei,* the investigation of its impact in the communities of invertebrates associated to the macrophyte are relevant to register the history and behavior of the invasion of this species in the Pantanal ecosystem.

The work reported here was based on the assumption that, in the dry season, the structure of the community of invertebrates associated with *E. crassipes* in lakes along the Paraguay River is influenced by the water's physiochemical conditions and by the abundance of *L. fortunei* on the roots of this macrophyte.

2. Material and Methods

2.1. Study area

This study was carried out in a longitudinal strip of land along the Upper Paraguay River, between the Pantanal National Park and a Private Reserve in the state of Mato Grosso, Brazil (Table 1, Figure 1). The Paraguay River begins in the Parecis Plateau, becoming a tributary of the Paraná River, which, in turn, empties into the La

Table 1. Average values and standard deviation of the physicochemical variables of the water and geographical coordinates of the 15 shore lakes along the Paraguay River sampled in September of 2005.

	Lakes	pH	DO ($mg.L^{-1}$)	E.C. ($\mu S.cm^{-1}$)	W.T. (° C)	Depth (cm)	Transparency (cm)	Geographical coordinates
L1	Acurizal	6.51	1.32	74.13	21.53	40.00	20.00	S 17° 49' 24.8" W 57° 33' 48.9"
		± 0.06	± 0.16	± 1.40	± 0.81	± 1.73	-	
L2	Caracará	6.51	1.26	65.17	20.13	44	13.33	S 17° 52' 50.9" W 57° 28' 24.8"
		± 0.10	± 0.06	± 0.86	± 0.93	-	± 5.77	
L3	Joãozinho	6.42	1.18	67.73	20.9	30.00	20.00	S 17° 52' 13.2" W 57° 28' 51.8"
		± 0.14	± 0.11	± 0.40	± 0.96	-	-	
L4	Comprida	6.79	1.57	83.43	19.4	41.67	10	S 17° 52' 36.9" W 57° 30' 39.3"
		± 0.30	± 0.07	-	± 1.30	± 20.21	± 0.0	
L5	Piuval	6.69	1.35	90.4	21	46.67	38.33	S 17° 53' 37.6" W 57° 29' 57.4"
		± 0.2	± 0.03	± 14.18	± 0.62	± 5.57	± 12.58	
L6	Desprezo	7.28	1.56	81.13	20.57	58.33	10	S17° 53' 53.4" W 57° 29' 00.8"
		± 0.07	± 0.28	± 7.01	± 1.31	± 20.21	± 0.0	
L7	Turco	6.39	1.57	72.23	22.27	60.00	15.00	S 17° 48' 05.9" W 57° 15' 35.9"
		± 0.07	± 0.67	± 0.85	± 2.37			
L8	Bigueirinho	6.43	1.51	71.87	25.83	46.67	11.67	S 17° 48' 07.7" W 57° 34' 05.5"
		± 0.08	± 0.10	± 4.53	± 0.38	± 22.55	± 2.89	
L9	Canafisto	6.34	1.57	68.97	25.77	90	20	S 17° 47' 33.8" W 57° 33' 18.9"
		± 0.05	± 0.06	± 0.67	± 0.32	± 0.0	± 5.0	
L10	Caracarazinho	6.3	1.73	55.6	25.23	78.33	11.67	S 17° 50' 23.2" W 57° 29' 12.1"
		± 0.02	± 0.09	± 0.72	± 0.21	± 27.54	± 2.89	
L11	Três Bocas	6.43	2.20	46.27	22.67	61.67	5.67	S 17° 51' 21.1" W 57° 28' 57°.1"
		± 0.05	± 0.27	± 5.25	± 0.23	± 10.41	± 1.15	
L12	Cláudia	6.36	1.92	68.63	23.67	68.33	18.33	S 17° 51' 20.1" W 57° 30' 11.2"
		± 0.14	± 0.22	± 4.09	± 0.25	± 7.64	± 2.89	
L13	Sandrinha	6.47	1.83	69.98	24.50	96.67	19.3	S 17° 51' 02.9" W 57° 29' 45.0"
		± 0.08	± 0.19	± 1.35	± 0.44	± 15.28	± 4.4	
L14	Inês	6.45	1.46	71.50	25.87	98.33	20	S 17° 49' 54.9" W 57° 31' 46.4"
		± 0.07	± 0.12	± 1.14	± 0.91	± 12.58	± 0.0	
L15	Figueira	6.36	1.55	55.23	26.10	56.67	15	S 17° 48' 32.5" W 57° 32' 35.3"
		± 0.19	± 0.05	± 25.59	± 0.72	±10.41	± 0.0	

L1 to L15 = Lakes, D. O. = Dissolved oxygen, E. C. = Eletrical conductivity, W. T. = Water temperature.

Plata basin that extends over an area of 3,100,000 km^2 (PCBAP, 1997). Its basin has a warm climate with an average temperature of 25 °C, humidity of about 77%, and average annual rainfall of 1,070 mm, which is more intense from November to March, considered the rising and flood period, and little rainfall from April to October, considered the ebbing and dry period (Oliveira et al., 2006). In the dry season, the flood lakes of the Paraguay River may present depths of up to 2 meters (Marchese et al., 2005) and may be connected to the principal channel permanently or only during flood peaks. These environments usually present low concentrations of dissolved oxygen, high organic matter content, and carpets of floating macrophytes in different stages of monodominance, comprising mainly *Eichhornia crassipes*, *Eichhornia azurea* (Schwartz) Kunth and *Salvinia auriculata* (Micheli) Adans (Wantzen et al., 2005).

2.2. Data collection

In a single period of sample collection in the dry season, in September 2005, samples of invertebrates associated with roots of the macrophyte *Eichhornia crassipes* and physicochemical variables were collected three times in 15 marginal lakes connected to the Paraguay River.

The variables, depth and transparency were determined using a Secchi disk and the temperature (°C) was measured with a 200 WSI thermistor, while the pH values were verified with a 100 YSI pHmeter, dissolved oxygen ($mg.L^{-1}$) with a 200 WSI oximeter and electrical conductivity ($\mu S.cm^{-1}$) with an OREON 1150A+ conductivity meter.

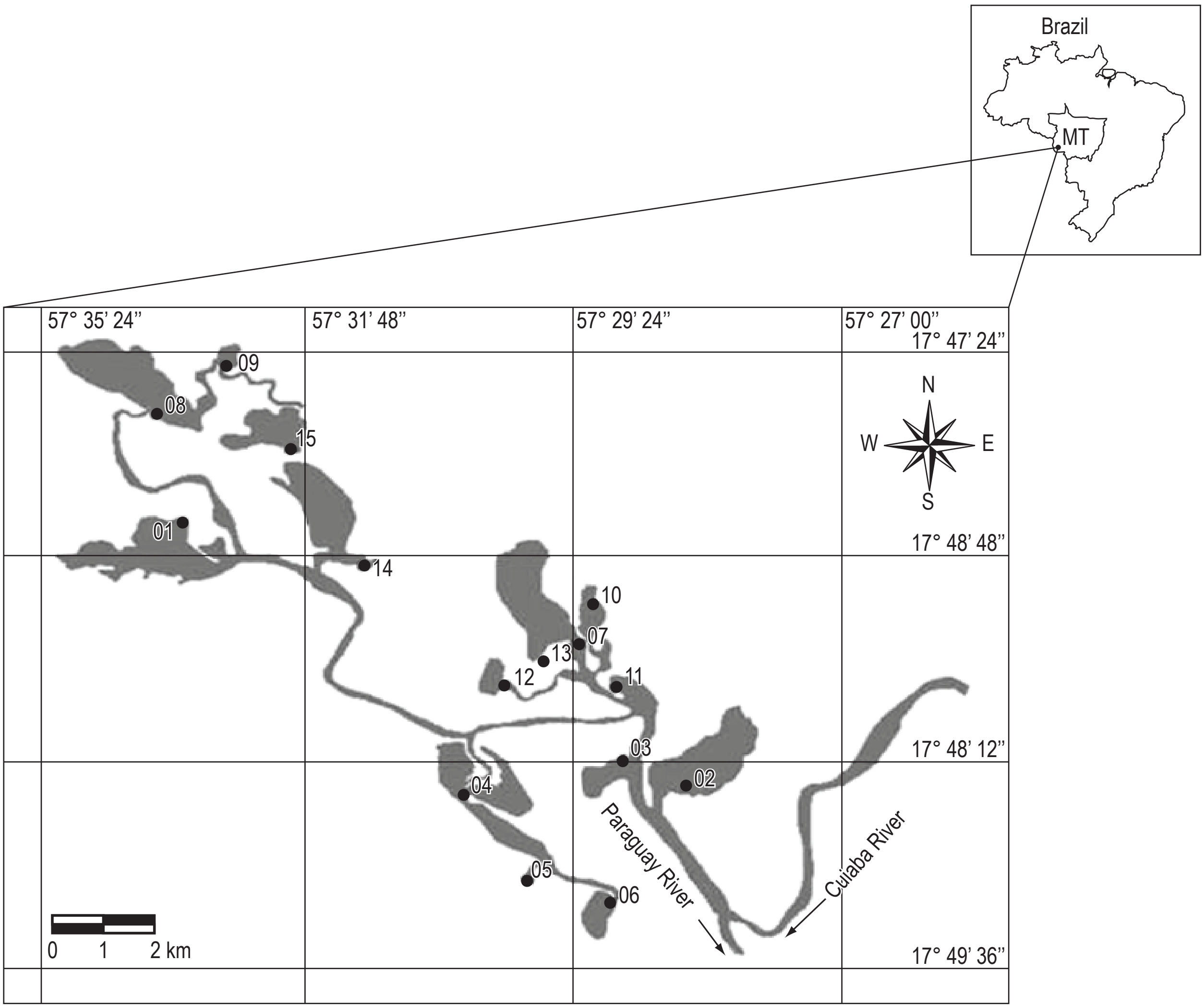

Figure 1. Localization of the 15 shore lakes along the Paraguay River, MT, Brazil sampled in September of 2005.

In each lake, three samples of the monospecific marginal stands of floating vegetation were collected from a 25 x 25 cm square using pruning shears, to study the associated invertebrates; the total area sampled was of 0.1875 m^2 per lake. The collection was carried out in three distant points and in each lake and aimed at increasing the variability of the samples in the sampling units (lakes).

To study the invertebrates, the plant's root mass was washed in 2 mm, 1 mm and 0.25 mm sieves, prescreened, and the remaining part retained in the last sieve was preserved in 70% alcohol. The invertebrates were screened and identified under a stereoscopic microscope, as described by Merritt and Cummins (1996).

2.3. Data treatment and analysis

The average of the physicochemical variables sampled under the stands of *E. crassipes* was calculated for each lake. Considering the lake as a sample unit, for the analyses, the abundance of invertebrates obtained from the triplicate was added up. In order to demonstrate the variation of the density of associated invertebrates, the mean obtained from the triplicate was expressed in number of individuals per square meter (ind.m^{-2}).

The values of the physicochemical variables obtained in the lakes were not transformed for the analysis. The temperature of the water was not inserted in the analysis because the time of collection was not standardized. A Principal Component Analysis (PCA) was used to sum up the physicochemical characteristics of the water, from the average values obtained in the 15 lakes that were sampled using the statistical program SYSTAT 10 (Wilkinson, 1990). The two first components of the PCA were used for interpretation and as predictor variables of the structure of the invertebrate community.

The relation between the abundance of invertebrate taxa with the physicochemical variables and the abundance of *L. fortunei* was established through a Spearman's correlation ($rs > 0.5$; $p < 0.05$) (SYSTAT 10).

The invertebrate community, except for *L. fortunei* values, was put in order by means of a PCoA (Principal Coordinate Analysis) with the data of composition and abundance of the taxa (quantitative), through the Bray-Curtis association index using the PATN (Belbin, 1992) program. For this purpose, the abundance data of each taxa taken from the sampled area were transformed through division by the total number of individuals obtained in the sampling units (lakes).

The relation between the invertebrate community (three PCoA axes) with the physicochemical variables (two first components of the PCA) and with the abundance of *L. fortunei* was assessed by means of a multivariate inferential analysis ($p < 0.05$) (SYSTAT 10).

3. Results

3.1. Physicochemical variables of the water

The values of pH in the coastal region of the 15 sampled lakes tended toward neutrality (6.3-7.28), along with low dissolved oxygen saturation (1.18-2.20 $mg.L^{-1}$), conductivity ranging from 46.27-90.4 $\mu S.cm^{-1}$ and water temperatures between 19.4 and 26.1 °C. The lakes showed little depth (30-98.33 cm) and changeable transparency (5.67 and 33.33 cm) (Table 1).

3.2. Composition, abundance and density of the invertebrate community

A total of 86,943 invertebrates associated with *E. crassipes* were collected from the 15 sampled lakes, distributed among phyla Nematoda, Annelida, Mollusca and Arthropoda (Table 2).

In general, the groups with the highest abundances were: the Hydrobiidae – with 17,966 individuals (21%), the Ostracoda – 17,872 (20.6%), the Hydracarina – 11,353 (13.05%) and the *Eupera* sp. (Sphaeridae) – 8,322 (9.57%) of the total number of individuals collected (Figure 2). Emphasis was also given on the Chironomidae with 6,089 individuals (7%), the Trichoptera with 4,757 (5.4%), besides the *L. fortunei* and the Planorbidae that together totalized 8.83 % of the amount of abundance.

The remaining taxa contributed with 14.8% of the abundance sampled in the 15 lakes. The Nematoda, *Pisidium sterkianum* (Pilsbry, 1897), Empididae, Dixidae, Collembola and Isopoda were the groups with the lowest occurrence in the samples, representing 0.05% of the total number of individuals collected.

The average density of invertebrates varied from 4,684 $ind.m^{-2}$ in Lake Três Bocas (L11) to 19,504 $ind.m^{-2}$ in Lake Cláudia (L12) (Figure 2). For *L. fortunei,* the density varied from 7 to 1,205 $ind.m^{-2}$ in Lakes Acurizal (L1) and Turco (L7), respectively (Table 2, Figure 3).

3.3. Relation of the structure invertebrate community with the physiochemical variables and abundance of L. fortunei

The first two axis of the PCA summed up 69.28% of the variation of the physiochemical data. The first component captured 44.11% of the original variance of the data and was related negatively to the dissolved oxygen and positively to the conductivity. The second component accounted for 25.17% of the data variation and was represented negatively by the pH and positively by the transparency of the water (Table 3).

The creation of two groups of lakes was observed due to similar values of transparency (L9, L12, L13 and L14) and dissolved oxygen (L10 and L15); and of electrical conductivity (L1, L2, L3, L7 e L8). Some lakes were different in slightly higher values of electrical conductivity and pH: Comprida (L4), Piuval (L5) and Desprezo (L6); water transparency: Piuval (L5) and oxygen: Três Bocas (L11) (Figure 4).

Some taxa were found to be negatively correlated with dissolved oxygen and depth, particularly Trichoptera, Odonata, Conchostraca and Lepidoptera. Odonata, Ephemeroptera and Culicidae were positively correlated with the conductivity; and Cladocera showed a weak correlation with *L. fortunei* (Table 4).

The invertebrate community was represented by three axis of the PCoA, which accounted for 73.92% (41.83% in the first axis, 18.11% in the second and 13.98% in the third) of the variation of the composition and abundance data.

The multivariate multiple regression demonstrated that the invertebrate community has neither a significant relationship with the abundance gradient of *L. fortunei* (Pillai Trace = 0.096; $F_{3,9} = 0.318$; $p = 0.813$), nor with the physicochemical variables represented by the first component of the PCA (Pillai Trace = 0.311; $F_{3,9} = 1.357$; $p = 0.317$) and by the second component of the PCA (Pillai Trace = 0.378; $F_{3,9} = 1.822$; $p = 0.213$).

4. Discussion

4.1. Physiochemical variables

The results showed that the electrical conductivity, transparency and the dissolved oxygen are the variables that best represent the physicochemical conditions of the lakes.

There was little variation in the conductivity (23.3-99.8 $\mu S.cm^{-1}$), a fact commonly observed in flood lakes of the Pantanal (Marchese et al., 2005). The highest values of conductivity and pH were observed in the lakes Comprida (L4), Piuval (L5) and Desprezo (L6) and the lake Piuval was the most transparent. Aburaya and Callil (2007) observed inverse values between conductivity and transparency in the Paraguay river, different from what was found in this work where the relationship is positive, namely the

Table 2. Taxonomic composition and relative density (ind.m^{-2}) of the community of invertebrates associated with *E. crassipes* in the 15 shore lakes along the Paraguay River, Mato Grosso sampled in September of 2005 (L1 to L15).

Taxa	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15
Nematoda	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-
Annelida															
Hirudinae	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Oligochaeta	2	3	3	1	2	2	2	3	3	3	1	1	1	1	-
Mollusca															
Eupera sp.	2	3	3	3	3	2	3	3	3	3	2	3	3	3	3
Pisidium sterkianum (Pilsbry, 1897)	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Limnoperna fortunei (Dunker, 1857)	1	2	3	2	2	2	3	2	3	2	3	2	3	3	3
Pomacea sp.	1	-	1	1	1	1	1	1	-	1	1	1	1	1	1
Planorbidae	3	2	3	3	3	2	2	3	2	2	1	3	3	3	3
Ancylidae	2	2	2	2	2	2	2	2	2	2	1	2	2	2	1
Hydrobiidae	3	2	3	6	3	2	3	3	3	3	-	4	3	4	3
Arthropoda															
Hydracarina	3	3	3	3	3	3	4	2	3	3	3	3	3	3	3
Crustacea															
Ostracoda	4	3	3	3	3	3	3	3	3	3	3	5	3	3	4
Cladocera	1	2	1	1	1	2	1	1	1	1	1	1	-	1	1
Conchostraca	2	3	3	2	3	2	3	1	2	2	-	1	1	1	1
Copepoda	3	3	2	2	2	3	2	2	2	2	2	2	2	2	2
Decapoda	1	1	1	1	1	1	1	1	-	1	-	1	1	1	1
Isopoda	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Insecta															
Ceratopogonidae	1	2	2	2	2	2	2	2	2	1	2	2	2	2	2
Chironomidae	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3
Culicidae	1	1	1	1	2	2	2	1	2	1	1	1	1	1	1
Dixidae	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Empididae	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Hemiptera	2	1	2	2	2	2	2	2	2	2	3	2	3	2	2
Coleoptera	2	2	2	2	2	2	2	2	2	2	1	2	2	1	2
Collembola	-	-	1	1	-	-	1	1	1	1	1	-	-	-	-
Ephemeroptera	2	1	2	2	2	2	3	2	2	1	1	2	1	2	2
Lepidoptera	1	2	1	1	2	1	2	1	1	1	1	1	1	1	1
Odonata	2	2	2	2	2	2	2	2	2	1	-	1	1	1	1
Trichoptera	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2
Total of taxa	23	22	16	16	24	23	24	23	24	24	20	23	22	23	22

Categorical values of density: 1) 1 and 100 individuals; 2) 101 and 1,000 individuals; 3) 1,001 and 10,000 individuals; 4) 10,001 and 20,000 individuals; 5) 20,001 and 30,000 individuals; 6) 30,001 and 40,000 individuals.

lake with higher conductivity is also the most transparent (L5-Piuval) and the one with lowest conductivity is the less transparent (L11-Três Bocas). This result may be linked to the fact that Lake Piuval cuts the Serra of Amolar, and it is possible that the influence of limestone in the concentration of ions and in the transparency of the water is more pronounced in this lagoon. According to Carignan and Neiff (1992) and Poi de Neiff and Carignan (1997), during the period of low waters, the nutrients diminish, the water becomes more transparent and the conductivity increases in the lakes; however, according to Carvalho et al. (2001) the electrical conductivity does not present a temporal pattern in the Brazilian lakes, with the ionic concentration differentiated in each region and influenced by the periodicity of the rain.

As it was observed in this study, the water level of the channels and lakes of the Paraguay River is low during the dry season. Due to the shallowness of the water and the decomposition of macrophytes, the saturation of oxygen in the marginal region of the lakes tends to diminish (Heckman, 1994; Hamilton et al., 1995; Poi de Neiff and Carignan 1997; Poi de Neiff, 2003; Toft et al., 2003; Marchese et al., 2005; Tarr et al., 2005).

4.2. Density of invertebrates

The density of invertebrates on the roots of *E. crassipes* was higher than that found by Poi de Neiff and Carignan

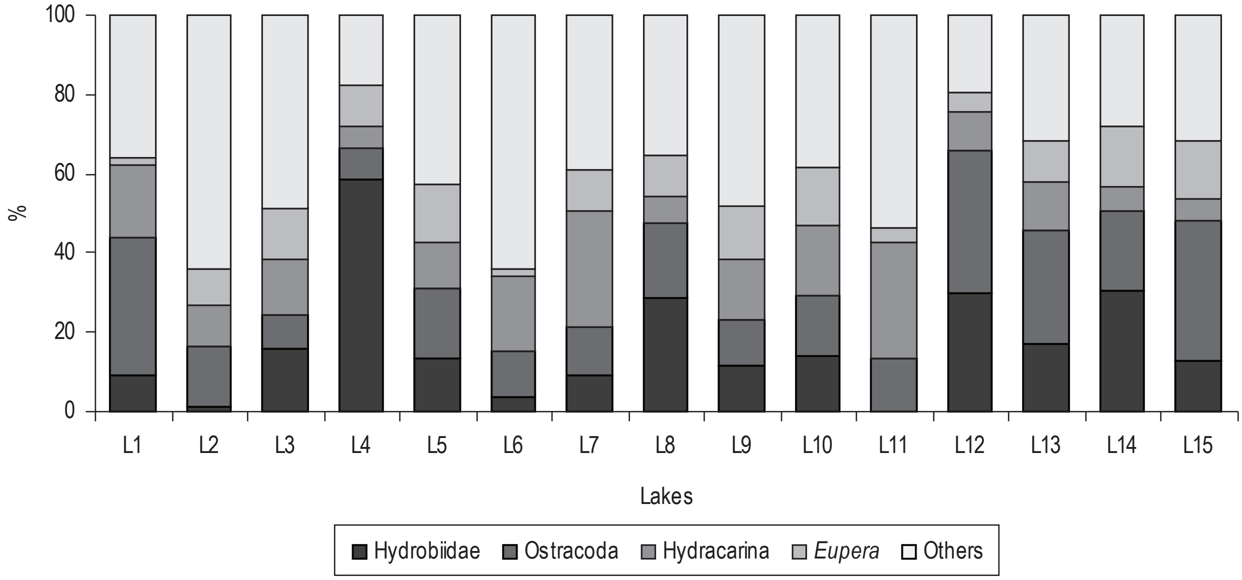

Figure 2. Relative abundance (%) of the invertebrate taxa associated with *E. crassipes* in the 15 shore lakes along the Paraguay River, Mato Grosso sampled in September of 2005 (L1 to L15).

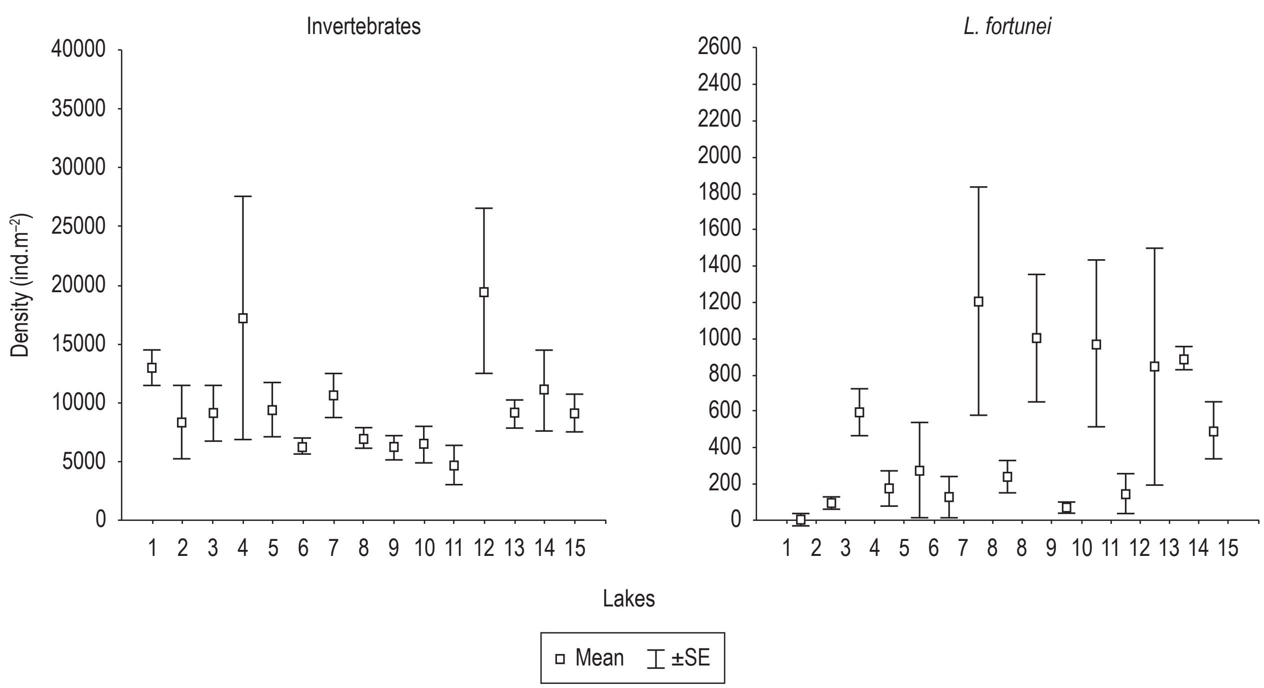

Figure 3. Average density of the invertebrates and *L. fortunei* associated with *E. crassipes* in the 15 shore lakes along the Paraguay River, Mato Grosso sampled in September of 2005. The bars shows the standard error (± SE).

(1997) in the dry season in lakes of the Paraná River. The groups of invertebrates with higher density were Hydrobiidae, Ostracoda and Acari. The same situation was observed in Argentina by Poi de Neiff and Bruquetas (1983) and Poi de Neiff and Carignan (1997), which recorded densities varying from 3,600 to 160,000 ind.m^{-2} of gastropods and mites, respectively. The bivalve *Eupera* showed a significant occurrence, such as was found by Pfeifer and Pitoni (2003), emphasizing that the sessile species as the microbivalves and gastropods, or mobile like the Ostracoda and mites, are favored by the architecture of *E. crassipes* and have their life cycle adapted to seasonal fluctuations in the level of the water (Poi de Neiff and Neiff, 2006). According to Higuti et al. (2007), the meiobenthos species

Table 3. Result of the Principal Components Analysis (PCA) for the physiochemical variables showing the variable, its loadings and the percentage of variance explained through the three first components in the 15 shore lakes along to the Paraguay River, Mato Grosso sampled in September of 2005.

Variables	Auto value		
	1	2	3
Transparency	0.588	**0.738**	0.156
Depth	–0.534	0.399	**0.667**
Conductivity	**0.862**	0.014	0.406
Dissolved oxygen	**–0.801**	–0.112	0.363
pH	0.437	**–0.736**	0.470
% of explained variance	44.11	25.17	19.73
% of accumulated variance	44.11	69.28	89.01

Values in bold: variable with loadings > 0.6.

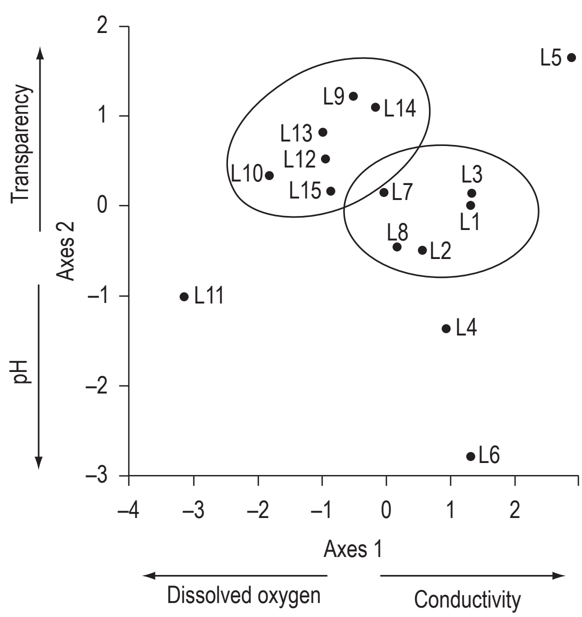

Figure 4. Ordination of scores of the first two PCA axes for the physiochemical variables in the 15 shore lakes along the Paraguay River, Mato Grosso sampled in September of 2005 (L1 to L15 = Lakes).

as non-swimming ostracods occur in floating macrophytes due to anoxia caused by the decomposition of organic matter in the sediment mainly after the flood pulse. The thin roots of *E. crassipes* gather perifiton and sediments, offering better oxygenation conditions (Takeda et al., 2003; Higuti et al., 2007), feeding in niches and refuges (Masifwa et al., 2001; Taniguchi et al., 2003) that directly favor the colonization by collector organisms - filterers (*Eupera* spp. and Ostracoda) and scrapers (Hydrobiidae), and indirectly the occurrence of predators, which enlarge the structural complexity of the community and the range of interspecific interactions (Warfe and Barmuta, 2006).

Among the taxa at the highest densities, the Ostracoda can float in the water due to the low density and the use of the root systems of floating plants as places of refuge and food. Higuti et al. (2007) suggest that the density of these microcrustaceans is seasonally adjusted by the recruitment of individuals triggered off by changes in local abiotic variables in the water (oxygen, pH and conductivity). This can explain the high density of Ostracoda obtained in this study; however, in many lakes the low depth in the stands of *E. crassipes* increased the contact of the roots with the sediment, so that the high density could also result from the contribution of the non-swimmer Ostracoda from the sediment to the pleustonic community; but, as the density of invertebrates was not measured in the sediment, nor the recruitment of individuals assessed, none of these assertions can be made.

The Acari prefer to feed mainly on algae, fungi and debris (Di Sabatino et al., 2000; Monkolski et al., 2005). Chironomidae the fifth most abundant group of this study can also be favored in *E. crassipes* because of the accumulation of residues on the roots (Takeda et al., 2003; Mormul et al., 2006). The range of feeding possibilities added to the fact that they tolerate adverse conditions, made Cranston (1982) give this dipterous the status of strategists. Though these groups are abundant and diversified in the marginal vegetation, they are hardly mentioned in the available wetlands literature, which makes it difficult to establish pertinent opinions about the determinant factors in the association of these invertebrate with the aquatic plants.

4.3. Relation of the invertebrate community with the physicochemical variables

The structure of the invertebrate community associated to *E. crassipes* did not seem to be influenced by the set of physicochemical variables of the water. However, if evaluated in an isolated way, the oxygen and the depth were important for some groups of invertebrates, showing that even if it is not captured in the multivariate regression, the relation between the abundance of invertebrates and oxygen exists. But it is not like that on the Paraná River, where the total abundance of invertebrates reduced due to oxygen depletion during the low water period (Poi de Neiff and Carignan, 1997), possibly because as was reported by Poi de Neiff (2003), the Paraguay River did not present a clear pattern of deoxygenation in the drought period due to the variation of the flow speed in different places.

Differently, we notice a negative correlation of Trichoptera, Odonata and Conchostraca with the depth and oxygen concentration dissolved in water. Our collections were concentrated in the dry season characterized by the depletion of the depth in the lakes, a fact that accelerates the decomposition process and reduces the biomass of this plant (Carignan and Neiff, 1992;

Table 4. Spearman correlation of the physicochemical variables and abundance of *L. fortunei* with the rate abundance in the 15 shore lakes along to the Paraguay River, Mato Grosso sampled in September of 2005.

	Dissolved oxygen	Conductivity	Depth	Transparency	*L. fortunei*
Nematoda				0.528*	
Pomacea sp.			–0.60***		
Cladocera					–0.566*
Conchostraca	–0.716**		–0.605**		
Odonata	–0.66**	0.567*	–0.758***		
Trichoptera	–0.746***		–0.618**		
Ephemeroptera		0.653**			
Lepidoptera	–0.523*		–0.746***		
Culicidae		0.587*			
Hemiptera	–0.57*				

*p < 0.05; **p < 0.01; ***p < 0.001.

Rocha-Ramírez et al., 2007) and interferes locally in the concentration of oxygen in the water (Poi de Neiff and Carignan, 1997; Hummel and Findlay, 2006). This process increases the density of some groups of associated invertebrates influencing directly in the diversity of the community (Stripari and Henry, 2002; Nessimian and Henriques-de Oliveira, 2005). Such information can be confirmed, since in the deeper and oxygenated lakes, we observed fewer densities of these groups of invertebrates reinforcing this correlation

In the case of Trichoptera, the negative correlation with the oxygen probably occurred because the larvae of the Leptoceridae, Polycentropodidae and Hydroptilidae families have morpho-ecological adaptations to achieve a higher respiratory efficiency and survive in lenthic environments with low concentration of oxygen (Wiggins, 2000). The inverse relation of Trichoptera and biomass of macrophytes, considering the synergism among these variables, have been described by Bruquetas de Zozaya and Neiff (1991) for the Hydroptilidae family (*Neotrichia* sp.) associated to *Typha latifolia* Cham. et Schlecht, *Polygonum acuminatum* Kunth and *Panicum elephantipes* Nees ab Esenbeck, and by Stripari and Henry (2002) for *Eichhornia azurea*.

Odonata are considered voracious predators, consequently their distribution and abundance are associated to the availability of the victim and to the factors that determine the quality of the territory (De Marco and Rezende, 2004). In this study, Odonata presented a negative correlation with depth and dissolved oxygen showing that the depth seems to be important for immature stages, as discussed before, and can interfere in the density and decomposition of the vegetation. In the marginal region of the lakes, the height of the water column and the density of the macrophyte are some of the facts linked to the selection of habitat by adult individuals that influence the composition and density of this community from the margin to the center of the lake. These factors can also increase the density of some prey and influence the occurrence of nymphs because of the depletion on oxygen and the availability of refuges against insect-eating predators (Steiner et al., 2000).

The negative correlation of Conchostraca with depth and oxygen may have occurred because these microcrustaceous present adaptations to live in temporary aquatic environments in the initial phases of succession of community, frequently associated to vegetation or in the bottom of the margins of shallow lakes (Roessler, 1995). The life cycle of this group presents a relationship with the hydroperiod, since there is a higher density of young species during the flood period (Poi de Neiff, 2003). The young species present active movement and migrate to the limnetic regions increasing the chance of being predated, while the adults have little mobility being restricted to the dense vegetation during the drought period (Roessler, 1995). Although frequent in limnic environments, the taxonomy and ecology of this group have been overlooked in Brazil.

In this study, Cladocera, Conchostraca and Copepoda, microcrustaceous typically abundant in the initial phase of macrophyte colonization (Stripari and Henry, 2002; Nessimian and Henriques-de Oliveira, 2005), presented low densities. On the other hand, high densities of Ostracoda were recorded, a common group in the senescent phase of the macrophytes (Mormul et al., 2006), indicating that *E. crassipes* samples could be on an advanced stage of decomposition which could favor also input of non swimmer Ostracoda from the sediment to the roots of *E. crassipes* (Higuti et al., 2007). Stripari and Henry (2002) and Mormul et al. (2006) suggest that the low nutritional quality and the possible presence of allelopathic substances in the early period of decomposition of the *E. azurea,* could account for the low density of microcrustaceous, such as Cladocera and Copepoda on the roots of this macrophyte, a situation similar to that attributed to the *E. crassipes* (Meerhoff et al., 2006).

When the variable conductivity was taken into consideration, we noticed that there was a weak positive correlation with Odonata, Ephemeroptera and Culicidae, unlike what was observed by Carignan and Neiff (1992) and Poi de Neiff and Carignan (1997) in lakes of the Paraná River. The Pantanal usually presents low values of conductivity (Marchese et al., 2005); however it is known that the processes of decomposition provide the dissolution of ions, and the influence of limestone in some lagoons can justify the weak correlation found.

4.4. Relation of the invertebrate community with the abundance of L. fortunei

The densities of *L. fortunei* found in the present study varied considerably (7-1,205 ind.m^{-2}), and in a large part of the lakes, they were lower than those found on rocky outcrops at the beginning of the species' colonization in the Paraguay River in 1999 (1,000 ind.m^{-2}) and in 2002 (10,000 ind.m^{-2}) (Oliveira et al., 2006). However, those densities were higher than those recorded between 2001 and 2002 by Oliveira et al. (2006) on artificial substrates of concrete (88.9 ind.m^{-2}) and wood (523.8 ind.m^{-2}), and in 2004 by Callil et al. (2007) for *Eichhornia azurea* (107.75 ind.m^{-2}), both in the Paraguay River.

The low density of the golden mussel shows that up to the moment the environment is being resilient to the population growth, typically exponential of this specie. It is possible that the instability of the *E. crassipes* as substrate and the hydrological characteristics of this ecosystem, which presents an annual flood pulse (Junk et al., 1989), act as restrictive factors of this invasive species in the Pantanal. Permanent substrates such as rocks, rock outcrops and tree trunks are exposed to desiccation during the period of low waters, and in the flooding period, the stands of *E. crassipes* can be dragged. In this period, there is also the decomposition of the organic matter carried by the flood, that when it decomposes, reduces the oxygen concentration in the water, controlling the growth of the *L. fortunei* population (Oliveira et al., 2006).

Another factor associated to the lowest densities of *L. fortunei* in the Paraguay River is the small flow of ships in this river. According to Mansur et al. (2004), the upstream dispersion of *L. fortunei* larvae occurs mainly through river traffic. However, as observed for the zebra mussel *Dreissena polymorpha* (Pallas, 1771) in the Great Lakes of North America (Diggins et al., 2004), macrophytes appear to provide an alternative substrate for the golden mussel in the Pantanal, acting in the dispersion of bivalve and larvae in the Paraguay River through drifting.

In our findings, the community of aquatic invertebrates associated with *E. crassipes* presented no relationship with *L. fortunei* and only the abundance of Cladocera – a filter-feeding microcrustacean – proved to be negatively correlated to that of *L. fortunei*. According to Ricciardi (1998), and Brugnoli et al. (2005), the activity of dense populations of *L. fortunei* reduces the phytoplankton biomass and the level of turbidity of the water, suppressing the zooplankton population and subsequently may cause modifications in the aquatic trophic network.

Studies on aquatic plants have shown that plants with greater structural complexity present a higher diversity of invertebrates, because more niches are available for colonization (Taniguchi et al, 2003; Taniguchi and Tokeshi, 2004; Warfe and Barmuta, 2006; Thomaz et al., 2008) and that disturbance in the structure of the community as pressure by fish predation can be lower in high diversity conditions since it favors an omnivorous condition (Warfe and Barmuta, 2006). It is possible that the effect of consumption in suspension (phytoplankton, zooplankton, fine particulate matter) by low dense populations of *L. fortunei* will not have a strong impact in the structure of the invertebrate community, associated to *E.crassipes* so as to create trophic cascades.

The structural complexity in the roots of *E. crassipes* may increase the diversity of invertebrates in lakes (Taniguchi et al., 2003; Thomaz et al., 2008) and increase the high efficiency in the use of available resources bringing an environmental stability (Stachowicz and Tilman, 2005) and reduce the success of the establishment of new species, such as invasive mussels. The high productivity of floodplain lakes may result from the complexity of interactions between the community of invertebrates with the abiotic environment (Newman, 1991; Taniguchi et al., 2003), largely caused by high densities of some species combined with the resilient environment due to the frequency of flooding, which makes communities adapted to the successive changes in the landscape and in the abundance of resources (Junk et al., 1989), characterizing a continuous process of secondary succession, may be acting in typically aggressive population control of *L. fortunei*.

Long-term studies focusing on the population dynamics of *L. fortunei* and on knowledge about the local aquatic fauna using words such as the richness and abundance of individuals are necessary so that in the future with further studies understand the established trophic relations, the ecological processes and the impact of this invasive species in the structure of the aquatic communities in the Pantanal.

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