The Odonata (Insecta) assemblage on Eichhornia azurea (Sw.) Kunth (Pontederiaceae) stands in Camargo Lake, a lateral lake on the Paranapanema River (state of São Paulo, Brazil), after an extreme inundation episode.

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ABSTRACT: The Odonata (Insecta) assemblage on Eichhornia azurea (Sw.) Kunth (Pontederiaceae) stands in Camargo Lake, a lateral lake on the Paranapanema River (state of São Paulo, Brazil), after an extreme inundation episode. A one-year study examined the variation in abundance and richness of Odonata (Insecta) genera on Eichhornia azurea (Sw.) Kunth (Pontederiaceae) stands in Camargo Lake, a lateral lake on the mouth zone of the Paranapanema River entering Jurumirim Reservoir, São Paulo, Brazil, after an extraordinary inundation episode. Also were investigated the abiotic factors correlating with Odonata presence: water transparency, surface temperature, dissolved oxygen, pH, conductivity, and suspended matter. No significant correlation was found between Acanthagrion Selys, 1876, Coryphaeschna Williamson, 1903 and Oxyagrion Selys, 1876 abundance and abiotic factors. However, Spearman analysis showed a positive correlation between Cyanallagma Kennedy, 1920, Diastatops Rambur, 1842, Enallagma Charpentier, 1840, and Micrathyria Kirby, 1889 larvae densities and suspended matter, and between Homeoura Kennedy, 1920 and Telebasis Selys, 1875 and dissolved oxygen, and a negative correlation between Enallagma, Ischnura Charpentier, 1840, and Micrathyria and transparency. The highest absolute abundances were recorded in March, August, September, and October 2004, and March 2005. Comparing genera richness, absolute density, dissolved oxygen, total E. azurea biomass, and suspended matter with data from a period prior to the perturbation, there was reduced Odonata abundance, E. azurea biomass, suspended matter, and dissolved oxygen after the inundation episode, while genera richness increased. The decrease in macrophyte biomass and suspended matter after the inundation episode promoted a reduction in larvae shelter sites and in food resource, and thus on Odonata abundance. The low post-inundation levels of oxygen in water did not affect Odonata abundance, probably due to morphological and physiological adaptations in larvae for survival under low oxygen conditions. When Coryphaeschna larvae (the longest Odonata sampled) were collected, low genera richness was recorded. Odonata presence limited to Coryphaeschna larvae probably reduced food resources for the other genera.
Key-words : Odonata, larvae, abundance, richness, lake, inundation.

RESUMO : A comunidade de Odonata (Insecta) em bancos de Eichhornia azurea (Sw.) Kunth (Pontederiaceae) na Lagoa do Camargo, uma lagoa lateral ao rio Paranapanema (Estado de São Paulo, Brasil), após um episódio de inundação extrema. Durante um ano, a variação na abundância e riqueza de gêneros de Odonata (Insecta) foi examinada em bancos de Eichhornia azurea (Sw.) Kunth (Pontederiaceae) na Lagoa do Camargo, uma lagoa lateral ao rio Paranapanema na zona de sua desembocadura na Represa de Jurumirim, São Paulo, Brasil, após um episódio de inundação extraordinário. Fatores abióticos correlatos à presença de Odonata, como transparência, temperatura da superfície, oxigênio dissolvido, pH, condutividade elétrica e material em suspensão na água, foram determinados. Nenhuma correlação significativa entre as abundâncias de Acanthagrion Selys, 1876, Coryphaeschna Williamson, 1903 e Oxyagrion Selys, 1876 e fatores abióticos foi encontrada. Entretanto, a análise de Spearman mostrou correlação positiva entre as densidades de larvas de Cyanallagma Kennedy, 1920, Diastatops Rambur, 1842, Enallagma Charpentier, 1840 e Micrathyria Kirby, 1889 com material em suspensão e, também uma relação positiva entre Homeoura Kennedy, 1920 e Telebasis Selys, 1875com oxigênio dissolvido e negativa, de Enallagma, Ischnura Charpentier, 1840 e Micrathyria com transparência. As maiores abundâncias foram obtidas em março, agosto, setembro e outubro de 2004 e em março de 2005. Comparando a

riqueza de gêneros, a densidade absoluta e parâmetros como oxigênio dissolvido, biomassa total de E. azurea e material em suspensão com dados de um período anterior a esta perturbação, uma redução na abundância de Odonata, na biomassa de E. azurea, no material em suspensão e no oxigênio dissolvido ocorreu, após o episódio de inundação, enquanto a riqueza de gêneros aumentou. A diminuição da biomassa da macrófita promoveu, após o episódio de inundação, uma redução nos locais de refugio, bem como nos recursos alimentares e, portanto na abundância de Odonata. A baixa concentração de oxigênio na água após o pulso de inundação não afetou a abundância de Odonata, provavelmente em função de adaptações morfológicas e fisiológicas das larvas para sobreviver em condições de baixa oxigenação. Quando as larvas de Coryphaeschna (larvas apresentando os maiores comprimentos totais de todas as Odonata amostradas) foram coletadas, baixa riqueza de gêneros foi encontrada. Provavelmente, as larvas de Coryphaeschna reduziram os recursos alimentares para os outros gêneros de Odonata.
Palavras-chave: Odonata, larvas, abundância, riqueza, lago, inundação.

Introduction

Inundation pulses are disturbances in aquatic ecosystems that have different effects on local biota depending on their intensity, frequency and duration (Lake, 1990). One of these effects is a decrease in aquatic insect species richness, for instance Odonata (Insecta) (Ward, 1998; Zwich, 1992), in function of the reduced availability of resources such as food. Also, these pulses can change the lakes in homogenous biotopes and in consequence increase predation from other vertebrates such as fish on the Odonata larvae causing a decrease in their abundance (Crowley & Johnson, 1992).

Inundation pulses also lead to reduced dissolved oxygen in water affecting organic matter degradation (Junk, 1997). According to Junk (1997), decreased oxygen induces a reduction in aquatic macrophyte abundance, and also the associated Odonata (Corbet, 1983; Capitulo, 1992). Franco & Takeda (2002) emphasized that oxygen is one of the more important factors affecting the Odonata abundance.

Littoral zone macrophytes play an important role in aquatic ecosystems (Junk & Howard-Williams, 1984; Lodge, 1991; Nessimian, 1997), as they are the main producers of organic matter (Esteves, 1998). Organic matter from littoral zones can be used directly as food for herbivorous organisms, or indirectly as a substratum for periphyton, and in this case are a primary energy source for scrapper organisms (Lodge, 1991; Ward, 1992). Aquatic macrophytes can also be shelter sites against predators or offspring sites for invertebrates (Callisto et al., 2002) such as Odonata (Pelli & Barbosa, 1998; Capitulo, 1992).

The Odonata assemblage has, in recent years, been used as a bioindicator of habitat quality (Osborn & Samways, 1996; Samways et al., 1996; Moulton, 1998; Von Ellenrieder, 2000; Osborn, 2005). Long immature stage duration and wide distribution in the aquatic ecosystem explain the use of Odonata in environmental biomonitoring (Corbet, 1983; Capitulo, 1992). Odonata larvae are extremely important in fauna of macrophytes, as E. azurea (Franco & Takeda, 2002; Afonso, 2002), where they are one the main predators in the littoral zone (Petr, 1968; Benke, 1976, 1978; Corbet, 1983; De Marco Jr. & Latini, 1998) and can feed on any available prey due to their adequate size (Corbet, 1983; Capitulo, 1992). Odonata larvae predation on fish larvae has been reported as causing substantial economic damage in pisciculture (Soares et al., 2003). On other hand, they can be used as food for some vertebrates such as fish, amphibians (Minter & Kenneth, 1996), and bats (Dunkle & Belwood, 1982). Despite the importance of Odonata (Ferreira-Peruquetti & Fonseca-Gessner, 2003), few studies focus on this assemblage of aquatic macrophytes (Franco, 1999; Franco & Takeda, 2002; Fulan, 2006).

The aim of this paper is to compare genera richness, Odonata abundance, and correlated abiotic factors such as dissolved oxygen, suspended matter, and Eichhornia azurea biomass after an extreme inundation episode with data from a period prior to the perturbation, in a lateral lake of a river mouth zone in a reservoir.

Material and methods

The study area

The Camargo Lake (Fig. 1) is located in the mouth zone of the Paranapanema

River entering Jurumirim Reservoir, São Paulo, Brazil. The lake is permanently connected with the Paranapanema River (Henry et al., 2005).

An extraordinary pulse in Jurumirim Reservoir increased the water level from 564.14m to 566.62m over a single month (January 01 to February 06) due to intense rains at the beginning of 2004 (Fig. 2). In a normal year, for instance March 1998 to March 1999, annual water level variation does not exceed 1.7m (Henry et al., 2005).

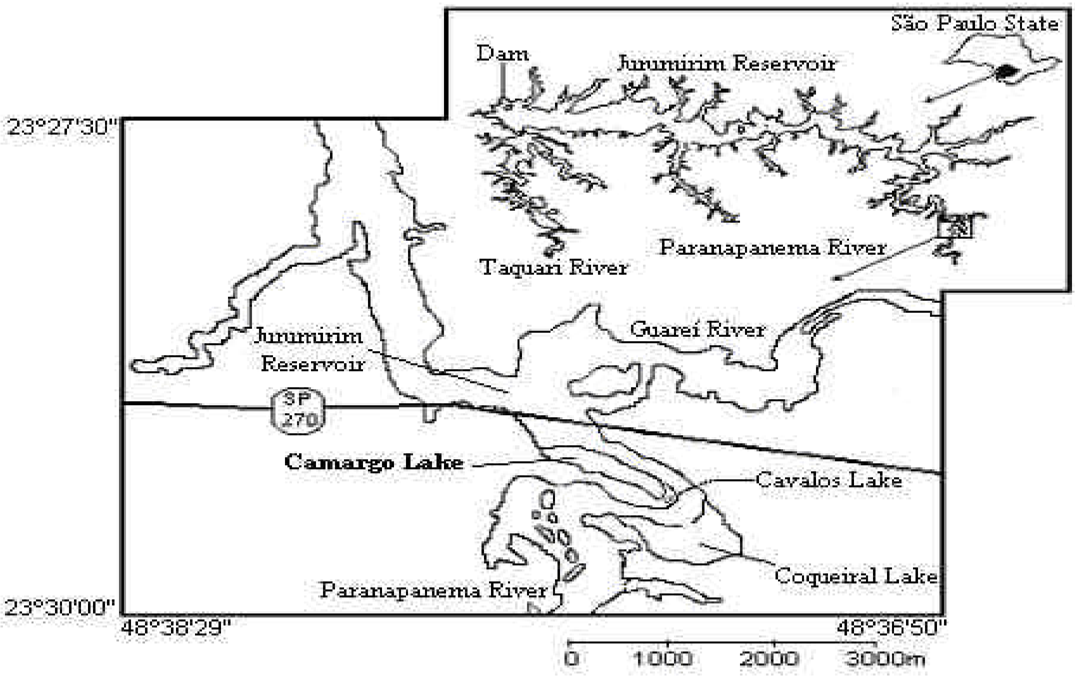

Figure 1: Camargo Lake, lateral to the mouth zone of the Paranapanema River entering Jurumirim Reservoir (São Paulo, Brazil).

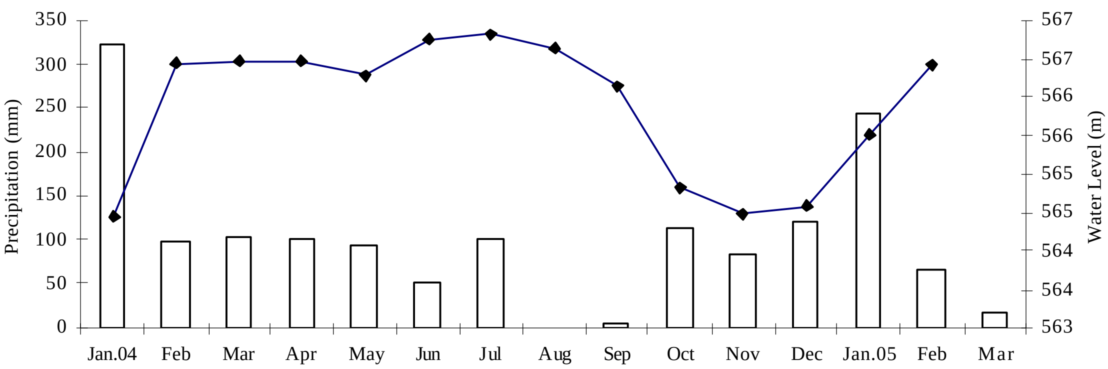

Figure 2: Monthly rainfall (data from Angatuba, São Paulo, Brazil) and mean monthly levels (data from Jurumirim Reservoir, Paranapanema River, São Paulo) from January 2004 to February 2005.

Three different stands of E. azurea were selected in the Camargo Lake as sampling sites. In each site, abiotic factors were measured: air temperature by alcohol thermometer; surface water temperature by Toho Dentam thermistor; dissolved oxygen (Golterman et al., 1978); pH (Micronal B-380 pHmeter); conductivity, corrected to 25°C (Golterman et al., 1978); and suspended matter by gravimetric method (Wetzel & Likens, 2000).

Aquatic plant sampling was by 0.5mm mesh net on a 0.16m² square metal frame. The sampling equipment was carefully inserted below E. azurea in the selected area, and the plant with fauna was transferred to a plastic bag. In the laboratory, fauna was carefully removed by circular movements of the macrophyte in three buckets containing 8% and 4% formaldehyde, and water respectively (Afonso, 2002). The content of each bucket was filtered through a 0.5mm mesh net sieve. Fauna retained in the sieve was preserved in 70% alcohol. After fauna removal, the plants were dried at ambient temperature and then in an oven (60°C, 6 days) to obtain biomass (gDW.m^{-2}). Odonata larvae were identified using an identification key (Costa et al., 2004). Total organism length of each Odonata genus was measured.

Results

Camargo Lake produced Odonata larvae from 2 suborders, 3 families and 12 genera, the largest number being from the Coenagrionidae family (Tab. I). In November 2004, sampling was impossible due to study area access conditions.

High absolute abundances were found in March, August, September, October, and December 2004 (Fig. 3). From August to October and, in December 2004, the highest richness of Odonata genera was recorded, while the lowest richness was found in May 2004 and March 2005 (Fig. 4). From all the sampled genera, Coryphaeschna Williamson, 1903 presented the highest mean total length (Fig. 5).

Table I : Total number of Odonata (Insecta) larvae sampled in Camargo Lake (Paranapanema River, São Paulo, Brazil) from March 2004 to March 2005.

Taxa	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec	Nov	Jan 05	Feb	Mar	TOTAL
Anisoptera														
Aeshnidae														
Coryphaeschna	0	0	2	0	0	0	0	0	0	-	2	0	2	**6**
Libellulidae														
Diastatops	0	0	0	0	0	0	0	0	1	-	0	0	0	**1**
Erythemis	1	1	0	0	0	0	0	2	0	-	0	0	0	**4**
Micrathyria	0	0	0	0	0	0	0	2	2	-	0	0	0	**4**
Tauriphila	0	0	0	0	0	0	2	3	1	-	0	0	0	**6**
Zygoptera														
Coenagrionidae														
Acanthagrion	3	3	0	6	0	4	3	7	4	-	1	2	0	**33**
Cyanallagma	0	0	0	0	0	5	8	18	11	-	0	0	0	**42**
Enallagma	1	0	0	0	0	0	0	1	1	-	0	0	0	**3**
Homeoura	0	0	0	0	0	1	0	0	0	-	0	0	0	**1**
Ischnura	0	0	0	0	1	0	1	0	0	-	0	0	0	**2**
Oxyagrion	9	1	0	1	4	2	4	1	4	-	1	1	0	**28**
Telebasis	0	3	5	3	2	8	4	2	0	-	0	2	0	**29**
TOTAL	**14**	**8**	**7**	**10**	**7**	**20**	**22**	**36**	**24**	**-**	**4**	**5**	**2**	**159**

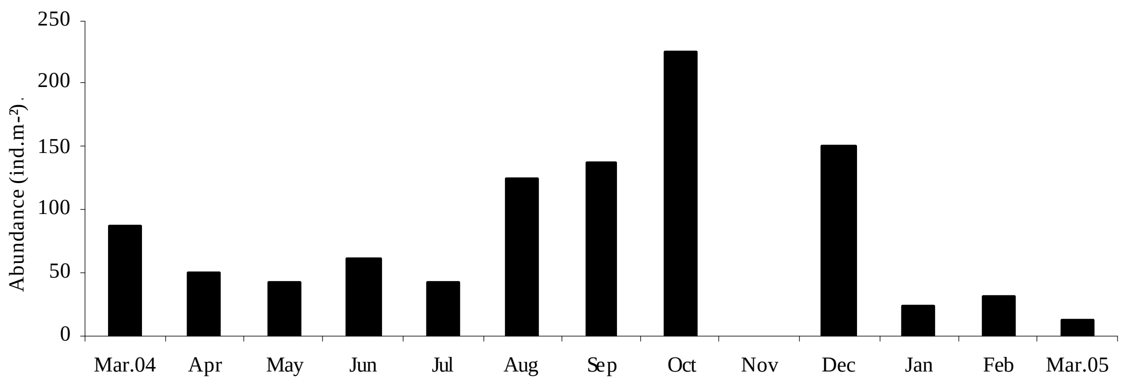

Figure 3: Mean absolute abundance (ind.m^{-2}) of Odonata (Insecta) in Camargo Lake (Paranapanema River, São Paulo, Brazil) from March 2004 to March 2005.

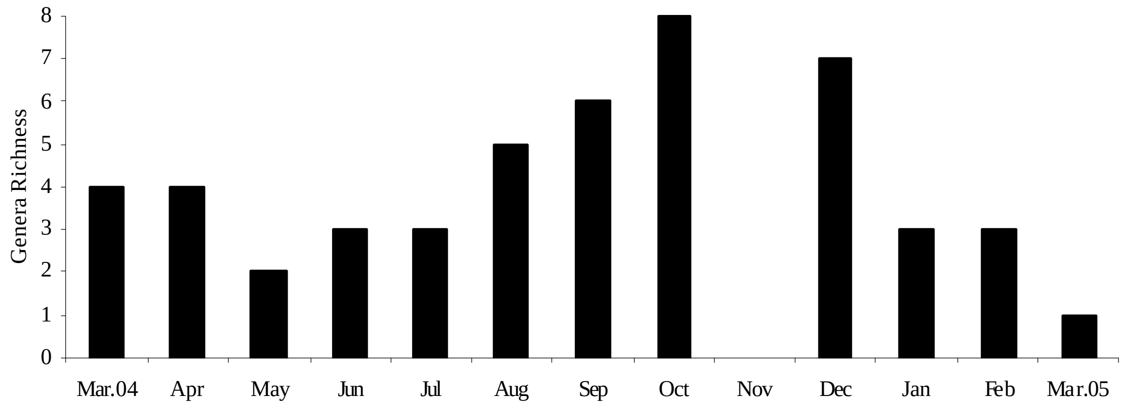

Figure 4: Mean genera richness of Odonata (Insecta) in Camargo Lake (Paranapanema River, São Paulo, Brazil) from March 2004 to March 2005.

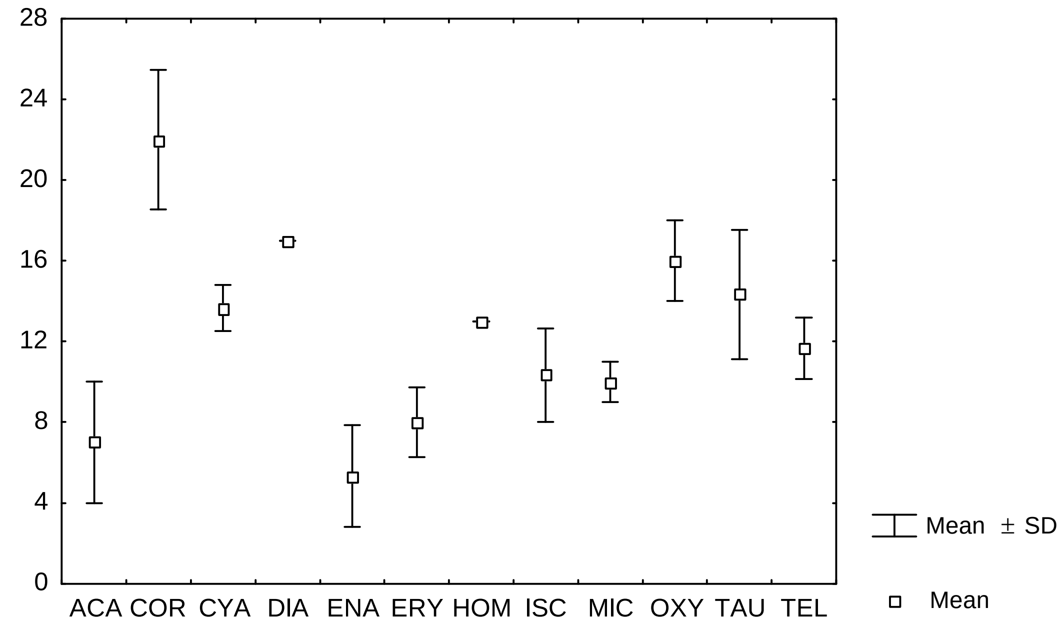

Figure 5: Mean total length (mm) of Odonata (Insecta) genera in Camargo Lake (Paranapanema River, São Paulo, Brazil) from March 2004 to March 2005. (Acanthagrion (Aca); Coryphaeschna (Cor); Cyanallagma (Cya); Diastatops (Dia); Enallagma (Ena); Erythemis (Ery); Homeoura (Hom); Ischnura (Isc); Micrathyria (Mic); Oxyagrion (Oxy); Tauriphila (Tau); Telebasis (Tel)).

The first three months (March, April, and May 2004) presented the lowest concentrations of dissolved oxygen in water (Tab. II). In December 2004, a high level of suspended matter was seen (Tab. II). Throughout the study period, little change in pH and electric conductivity were seen. The highest water transparencies were recorded in July and September 2004, and in March 2005 (Tab. II).

No significant correlation was detected between the Acanthagrion, Coryphaeschna and Oxyagrion Selys, 1876 abundance and abiotic factors or between the aquatic macrophyte biomass and the abundance of any Odonata genera (Tab. III). Enallagma Charpentier, 1840 and Micrathyria Kirby, 1889 abundance had negative correlations with depth and transparency; Cyanallagma Kennedy, 1920 and Tauriphila Kirby, 1889 abundance with depth; and Ischnura Charpentier, 1840 density with transparency. Erythemis Hagen, 1861 abundance had negative correlation with water pH, and positive correlation with conductivity (Tab. III).

Table II: Monthly means (in bold) and standard-deviations (between parentheses) of dissolved oxygen (DO), pH, electric conductivity (K_{25}),suspended matter (SM), water transparency (Z_{DS}), surface water temperature (T) and dry weight (gDW.m^{-2} ; DW) of Eichhornia azurea (Sw.) Kunth (Pontederiaceae) in Camargo Lake (Paranapanema River, São Paulo, Brazil) from March 2004 to March 2005.

Variables/ Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan 05	Feb	Mar
DO	**3,37**	**4,34**	**4,54**	**9,53**	**9,75**	**10,48**	**6,84**	**8,84**	**-**	**4,96**	**5,99**	**5,17**	**6,45**
(mg.L^{-1})	(0,82)	(0,88)	(0,65)	(0,47)	(0,20)	(0,31)	(0,56)	(0,49)	-	(0,39)	(0,17)	(0,14)	(0,39)
Ph	**6,65**	**6,70**	**6,57**	**6,73**	**6,67**	**6,72**	**6,92**	**6,42**	**-**	**6,75**	**6,83**	**6,47**	**6,90**
	(0,09)	(0,05)	(0,06)	(0,03)	(0,08)	(0,06)	(0,06)	(0,08)	-	(0,30)	(0,03)	(0,06)	(0,00)
K_{25}	**62,79**	**64,67**	**63,25**	**62,31**	**70,93**	**68,83**	**60,52**	**76,67**	**-**	**51,73**	**49,00**	**49,00**	**63,33**
(mS.cm^{-1})	(1,54)	(0,58)	(3,24)	(1,72)	(5,75)	(6,39)	(0,59)	(2,67)	-	(2,80)	(0,00)	(0,00)	(5,48)
SM	**4,7**	**3,06**	**5,54**	**3,06**	**4,82**	**13,8**	**12,74**	**6,46**	**-**	**79,92**	**8,48**	**13,56**	**9,24**
(mg.L^{-1})	(1,48)	(0,58)	(0,12)	(0,56)	(0,7)	(0,34)	(1,44)	(1,48)	-	(4,16)	(6,64)	(5,48)	(4,12)
Z_{DS}	**57,00**	**72,00**	**69,33**	**63,00**	**112,33**	**88,00**	**143,67**	**64,00**	**-**	**29,67**	**44,67**	**53,67**	**100,00**
(cm)	(5,29)	(14,73)	(4,51)	(4,00)	(2,89)	(2,00)	(1,53)	(3,61)	-	(4,04)	(0,58)	(5,13)	(17,58)
T	**25,60**	**23,33**	**20,53**	**14,63**	**18,97**	**15,20**	**20,73**	**22,23**	**-**	**25,53**	**25,50**	**22,20**	**27,23**
(^{o}C)	(0,69)	(0,57)	(0,06)	(1,33)	(0,15)	(0,20)	(0,15)	(0,29)	-	(0,23)	(0,20)	(1,06)	(0,46)
DW	**257,69**	**255,69**	**391,02**	**287,1**	**291,21**	**304,6**	**490,77**	**394,79**	**-**	**409,58**	**359,5**	**344,31**	**302,44**
(gDW.m^{2})	(15,10)	(17,84)	(23,11)	(17,88)	(21,01)	(23,26)	(39,52)	(34,69)	-	(35,38)	(29,89)	(29,17)	(14,46)

Table III: Spearman correlations ($P<0.05$; $n=36$) between abiotic factors and abundance of the main Odonata (Insecta) genera in Camargo Lake (Paranapanema River, São Paulo, Brazil) from March 2004 to March 2005. (Dissolved oxygen (DO), electric conductivity (K_{25}), suspended matter (SM), water transparency (Z_{DS}), surface water temperature (T))

Taxa	DO	pH	K_{25}	SM	T	Depth	Z_{DS}
Cyanallagma	-	-	-	0,37	-	-0,60	-
Diastatops	-	-	-	0,72	-	-	-
Enallagma	-	-	-	0,39	0,35	-0,43	-0,41
Erythemis	-	-0,48	0,48	-	-	-	-
Homeoura	0,47	-	-	-	-0,46	-	-
Ischnura	-	-	-	-	-	-	-0,70
Micrathyria	-	-	-	0,61	-	-0,71	-0,41
Tauriphila	-	-	-	-	-	-0,48	-
Telebasis	0,46	-	-	-	-0,66	-	-

Discussion

The main sources of oxygen for the aquatic ecosystems result from photosynthesis and direct diffusion from the atmosphere (Esteves, 1998). Comparing our data with that obtained in a period prior to the extreme inundation (Afonso, 2002), we noticed that the oxygen concentration was low for a period after the perturbation due to degradation of submersed organic matter. According to Junk (1997), a reduction in oxygen could decrease the abundance of local biota due to its effect on biological processes like respiration. Franco & Takeda (2002) also pointed out oxygen as one of the most important environmental variables affecting Odonata abundance. From March to May 2004, immediately after the inundation, oxygen concentrations were the lowest recorded throughout the study period, but Odonata densities were the highest. According to Corbet (1983), Odonata is extremely well adapted to oxygen deficit due to its morphology and physiology, such as being able to directly exchange respiratory gases with atmosphere through its body surface or wing-sheaths in the last instars. These adaptations can also explain the low correlation between main Odonata genera abundance and oxygen, as the organisms sampled in Camargo Lake exhibited resilience to the low water oxygenation levels after inundation.

According to Corbet (1999), oxygen is an environmental variable that greatly influences Zygoptera abundance. In June, July, and August, a period with high oxygen concentration, only genera of Acanthagrion, Cyanallagma, Homeoura, Ischnura, Oxyagrion e Telebasis from suborder Zygoptera were found, while in March 2005 when oxygen was at its lowest, no individuals from the suborder Zygoptera were recorded. The suborder Anisoptera presented a different situation, with highest levels of abundance in months with low water oxygenation (May 2004, and January and March 2005).

After the extraordinary inundation period, the abundance of Odonata assemblage reduced from 29.16 (in March 2004) to 8.33ind.m^{-2} (in January 2005). In a period prior to the inundation, abundance increased from 8.86 (March 1998) to 80ind.m^{-2} (January 1999) (Afonso, 2002). E. azurea biomass was always highest in the 1998-1999 period. According to Callisto et al. (2002), Pelli & Barbosa (1998), and Capitulo (1992), aquatic plants provide a sheltered site for invertebrate fauna against predators and a site abundant in food. Since macrophyte biomass was lower after the inundation pulse, the number of sheltered sites could have been reduced together with decreased food resources and increased larvae predation (Minter & Kenneth, 1996) thus reducing Odonata abundance. Despite the reduction in aquatic plant biomass being one of the probable causes of the decreased abundance, correlation analysis showed no direct relationship.

In some Odonata, for instance the suborder Anisoptera, vision is one of the main perception systems for prey capture (Corbet, 1983; Capitulo, 1992). Ecosystems high in suspended matter and with low transparency can reduce Anisoptera abundance due to their difficulty in perceiving prey (Corbet, 1983). After the inundation, suspended matter concentration was lower than before perturbation due to a dilution effect. Thus, Anisoptera food capture efficiency should be high promoting an increase in their density. This increase was not detected during the study period. Besides vision, other sensorial organs such as antennae can be used by Zygoptera increasing their predation efficiency (Corbet, 1983). Zygoptera was the Odonata suborder with the highest absolute abundance through the whole study period except for March 2005.

According to Ward (1998) and Zwich (1992), the richness of aquatic insects species like Odonata should be at its lowest after a perturbation such as an inundation pulse, due to reduced food availability and increased aquatic insect predators such as fish, since the environment becomes homogeneous (Crowley & Johnson, 1992). Our study showed an increase of genera richness after the extraordinary inundation compared with data from before (Afonso, (2002). Coryphaeschna genus had a higher mean length than the other genera. Odonata larvae being the longest have an advantage over the others because they can feed on larger prey, becoming asymetric interspecific competition (Blois, 1985; Dudgeon, 1989; Gribbin & Thompson, 1990; Harvey & White, 1990). In March 2004, and January and March 2005, when Coryphaeschna were recorded, genera richness was at its lowest points during the year, and in March 2005 it was found to be the unique genus. Probably, the interspecific competition for food resources favoured Coryphaeschna due to its greater length.

In summary, after the extreme inundation, absolute Odonata abundance decreased and genera richness increased in Camargo Lake, while there was a significant reduction in Eichhornia azurea biomass and suspended matter.

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