

Effects of daily changes in environmental factors on the abundance and richness of Odonata

Efeitos das mudanças diárias dos fatores ambientais
sobre a abundância e a riqueza de Odonata

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Abstract: Aim: The aim of this work was to investigate the effects of daily changes in surface water abiotic factors on the abundance of Odonata larvae and the genus richness in a lateral lake isolated from a tropical river during the nycthemeral cycle in dry and wet seasons; **Methods:** Macrophytes were sampled on a single day at 6-hours intervals for 24 hours (at 12:00 AM, 6:00 AM, 12:00 PM and 6:00 PM) in dry and wet periods. At each site, abiotic factors were measured as follows: air temperature, surface water temperature, dissolved oxygen, pH, and electric conductivity. Canonical correspondence analysis (CCA) of abiotic and biological data and sampling periods was made using CANOCO program; **Results:** A total of 249 and 265 Odonata larvae from six genera (*Acanthagrion*, *Cyanallagma*, *Telebasis*, *Erythemis*, *Erythrodiplax* and *Tauriphila*) were sampled in association with macrophytes in wet and dry seasons, respectively. *Telebasis* presented the highest frequency of occurrence and was collected in all nycthemeral cycle sampling periods in both seasons. The highest abundance of dragonflies was recorded at 6:00 AM and 12:00 AM in wet and dry seasons, respectively. Anoxia was detected in wet season during the entire nycthemeral cycle, while in the dry season, the highest variability in oxygen content was observed during sunlight. Canonical correspondence analysis showed that the abundances of *Telebasis* and *Erythemis* were positively related to water electrical conductivity, temperature, and depth, while for *Acanthagrion* and *Tauriphila*, abundance showed a positive relationship to water oxygen and pH. The variability of the abundance of Odonata due to surface water temperature, dissolved oxygen, electrical conductivity, pH, and depth during the daily cycle was therefore evidenced; **Conclusions:** We suggested that the better sampling period Odonata larvae must to be carried in the morning, since that we recorded the highest densities of both wet and dry stations at that hour. We point out that our data must to be examined with caution because the low sampling effort and the reduced taxonomic resolution.

Keywords: tropical lake, nycthemeral variation, Odonata, temperature, dissolved oxygen.

Resumo: Objetivo: O objetivo deste trabalho foi investigar os efeitos da variação diária de oxigênio e da temperatura de superfície da água e outros fatores abióticos sobre a abundância e a riqueza de larvas de Odonata em uma lagoa isolada de um rio tropical durante o ciclo nictemeral nas estações seca e chuvosa; **Métodos:** As macrófitas foram amostradas em um único dia por 24 horas em intervalos de 6 horas (00:00, 6:00, 12:00 e 18:00) nos períodos seco e chuvoso. Em cada sítio de amostragem foram medidos a temperatura do ar, temperatura de superfície da água, oxigênio dissolvido, pH e condutividade. Uma análise de correspondência canônica (ACC) foi realizada no programa Canoco com os dados abióticos, biológicos e períodos de amostragem; **Resultados:** Um total de 249 e 265 larvas de Odonata de seis gêneros (*Acanthagrion*, *Cyanallagma*, *Telebasis*, *Erythemis*, *Erythrodiplax* and *Tauriphila*) foram amostradas junto à macrófita nas estações seca e chuvosa, respectivamente. *Telebasis* apresentou a maior frequência de ocorrência e foi amostrado em todo ciclo nictemeral em ambas estações. A maior abundância de Odonata foi registrada às 6:00 e 12:00 nas estações chuvosa e seca, respectivamente. Um período anóxico foi detectado durante toda a estação chuvosa, enquanto que no

período seco a maior variabilidade de oxigênio foi observada durante o dia. A Análise de Correspondência Canônica mostrou que as abundâncias de *Telebasis* e *Erythemis* foram positivamente correlacionadas com a condutividade elétrica, temperatura e profundidade, enquanto que *Acanthagrion* e *Tauriphila* mostraram correlação positiva com o oxigênio e com o pH. Portanto, foi observada uma variância na abundância de Odonata com temperatura, oxigênio, condutividade, pH e profundidade durante o período de 24 horas; **Conclusões:** Nós sugerimos que o melhor período de amostragem de larvas de Odonata deve ser pela manhã, pois neste período registramos as maiores densidades nas estações seca e chuvosa. Destacamos que os resultados deste trabalho devem ser interpretados com cautela devido ao baixo esforço amostral e reduzida resolução taxonômica.

Palavras-chave: lagoa tropical, variação nictemeral, Odonata, temperatura, oxigênio.

1. Introduction

Nycthemeral studies in tropical lakes are extremely important due to the high variability of chemical and physical characteristics of water, such as dissolved oxygen and temperature (Esteves et al., 1988). Both water dissolved oxygen concentration and temperature directly affect the abundance of Odonata larvae. The amount of dissolved oxygen in water affects the behavior, metabolism, and survival of Odonata larvae (Corbet, 1999; Hofmann and Mason, 2005). Variations in oxygen availability in lacustrine (low oxygenation) and lotic (high oxygenation) environments determine the diversity of Odonata species (Voshell and Simmons, 1978; Corbet, 1999; Fulan et al., 2008). Water temperature also has an effect on the abundance and development of Odonata larvae (Lutz, 1974; Ward, 1992; Corbet, 1999). Sites with high temperatures, such as thermal springs, tend to present low abundance and diversity of Odonata species (Corbet, 1999). However, when considering aquatic insects, Odonata are characterized by a high tolerance to changes of surface water temperature (Kondratieff and Pyott, 1987; Cobert, 1999). The importance of abiotic factors like water dissolved oxygen and temperature for the presence of Odonata larvae near macrophytes was also shown for a lake lateral to Paranapanema River, Brazil (Fulan and Henry, 2006). According to the authors, *Enallagma*, *Homeura* and *Telebasis* were highly sensitive to variations in dissolved water oxygen concentration and temperature during the year. Besides environmental variables, biotic factors such as predation risk can also affect macroinvertebrate distribution during the 24-hours period. Flecker (1992) recorded that Ephemeroptera larvae presented nocturnal habits to avoid predators such as fish, which are usually more active during the day. Odonata larvae are top predators and can feed on a great diversity of macroinvertebrates (Corbet, 1999). Nevertheless, Odonata larvae are also preyed

on by fish and can present different behaviors. Despite the significant effect of predation on Odonata larvae, the current investigation has been limited to the effects of seasonal and nycthemeral variations in the abiotic factors on aquatic insects.

According to Corbet (1999), environmental variables and biotic factors, as predation, had an important effect on Odonata larvae density. As indicated before, a daily modification on environmental factors can occur in distinct stations of the year. Thus, it should be expected that Odonata larvae presented a response to environmental variables as it was mentioned in literature. So, our paper intends to respond to the following question: Can environmental factors, as oxygen and temperature, explain nictemeral variation in Odonata larvae abundance in a tropical lake?

2. Material and Methods

2.1. The study area

Cavalos Lake, 23° 29' S and 48° 37' W, is located at the mouth zone of the Paranapanema River. It flows into the Jurumirim Reservoir, located in São Paulo State, Brazil (Figure 1). It is lateral and superficially isolated from the Paranapanema River, but it may be affected by the river by underground water exchange. In a 16-month study, Carmo (2007) showed that underground water flowed in the river-lake direction during 64% of the time and otherwise in the remaining period.

2.2. Macrophyte and Odonata larva sampling

Three great stands were selected in dry and wet seasons, according to the arrangement shown in Figure 1 (P1, P2, and P3). In each stand, only one macrophyte sampling was carried out; thus totaling three samples each for the wet and dry seasons. Macrophytes were sampled on a single day

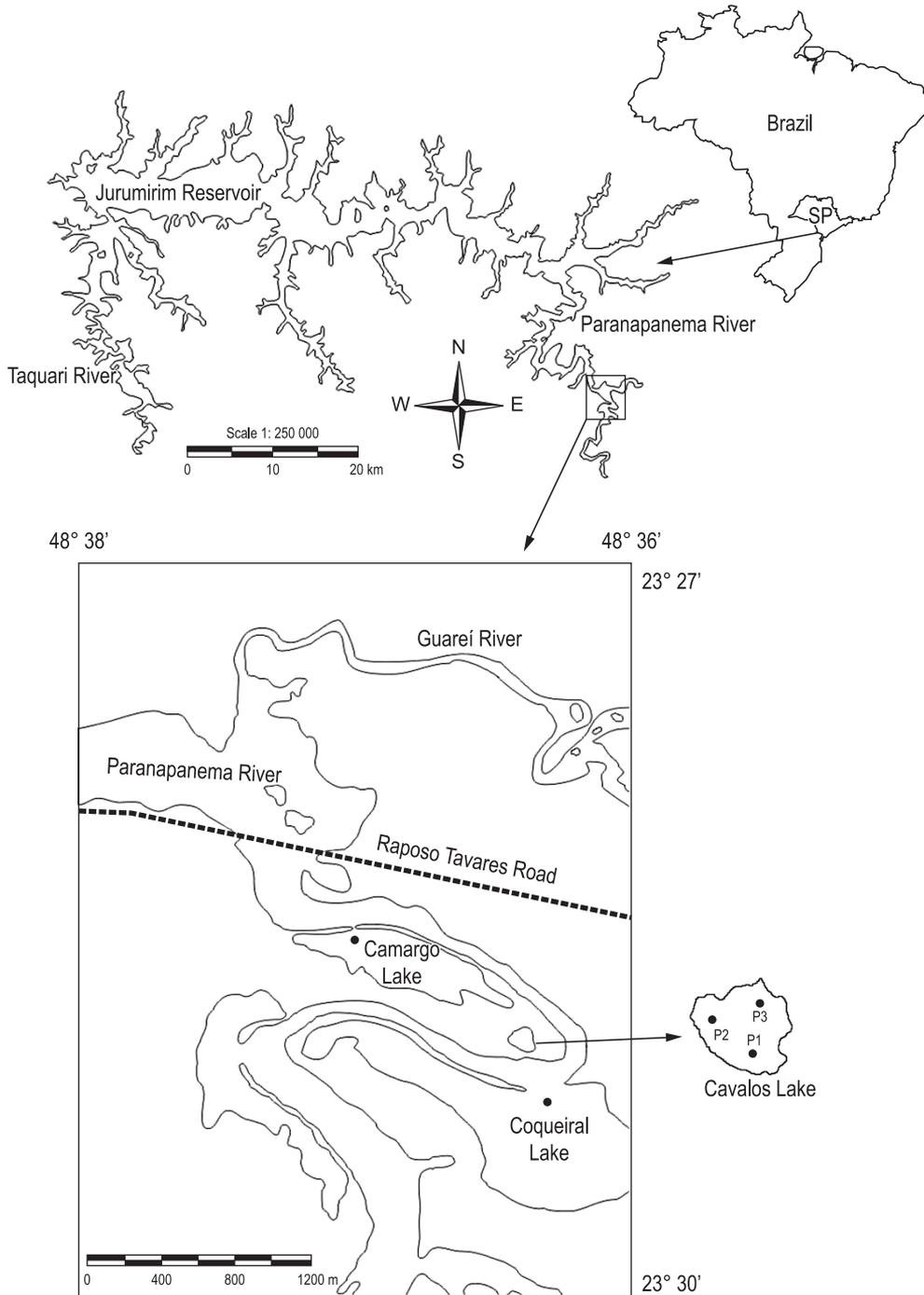


Figure 1. Study area - the mouth zone of the Paranapanema River into Jurumirim Reservoir (São Paulo, Brazil) and Cavalos Lake (Odonata larvae and surface water were sampled at sites P1, P2, and P3).

at 6-hours intervals for 24 hours (at 12:00 AM, 6:00 AM, 12:00 PM and 6:00 PM) in dry and wet periods. The 6-hours interval corresponds to the minimum time necessary to wash the plants and carry out physical and chemical analyses in laboratory. Aquatic plants were sampled with a 0.25-mm mesh net mounted on a 0.07-m² square metal frame. The sampling equipment was carefully

inserted below *S. auriculata* in the selected sites and the plants with Odonata larvae were transferred to plastic bags. In the laboratory, Odonata larvae were carefully removed by moving the plants in circular movements in three buckets containing 8 and 4% formaldehyde, and water, respectively (Fulan and Henry, 2006). The content of each bucket was filtered with a 0.25-mm mesh net sieve. Odonata

larvae retained on the sieve were preserved in 70% alcohol and identified using an identification key (Costa et al., 2004).

2.3. Abiotic factors

At each site, abiotic factors were measured as follows: air temperature by alcohol thermometer, surface water temperature by Toho Dentam thermistor, dissolved oxygen by Golterman et al. (1978), pH by Micronal B-380 pHmeter, and electric conductivity corrected to 25 °C by Golterman et al. (1978).

2.4. Data analysis

Canonical correspondence analysis (CCA) of abiotic and biological data and sampling periods was made using CANOCO program (Ter Braak and Smilauer, 2002). The significance level of the first two canonical axes was tested with the Monte Carlo test (499 permutations, $p < 0.05$) and the probability of hazard distribution of data was determined. CCA data were $\log(y + 1)$ transformed for performing CANOCO.

3. Results

Odonata larvae from six genera (*Acanthagrion*, *Cyanallagma*, *Telebasis*, *Erythemis*, *Erythrodiplax* and

Tauriphila) were sampled in wet (249 larvae) and dry (265 larvae) seasons. The highest abundances were observed at 6:00 AM in wet season and at 12:00 AM in dry season. *Telebasis* presented the highest frequency of occurrence, being observed in all sampling periods during the nycthemeral cycle and in both wet and dry seasons (Table 1). In Table 2, we can observe that the surface water dissolved oxygen concentration was zero in all periods (except at 6:00 PM) of the wet season, while in the dry season, the highest dissolved oxygen concentration (3.74 mg.L⁻¹) was found at 12:00 PM. The values of surface water temperature, electric conductivity, and depth were higher in wet season.

The CCA Monte Carlo test revealed that the first axis ($F = 4.829$, $p < 0.02$) and all the canonical axes together ($F = 4.132$, $p < 0.02$) were significant and represented relationships between abiotic and biological variables. The first and second axes explained together 70.3% of the data variability (auto-values 0.579 and 0.124 for axes 1 and 2, respectively).

Telebasis, *Erythemis* and *Acanthagrion* presented significant correlations with axis 1, while *Tauriphila* did with axes 1 and 2 (Table 3). Water dissolved oxygen, temperature, electrical conductivity,

Table 1. Abundance and richness of Odonata genera sampled within macrophyte *Salvinia auriculata* in Cavalos Lake at different hours of nycthemeral cycle during rainy and dry seasons.

| Genera | Rainy season | | | | Dry season | | | |
|---|--------------|---------|----------|---------|------------|---------|----------|---------|
| | 12:00 AM | 6:00 AM | 12:00 PM | 6:00 PM | 12:00 AM | 6:00 AM | 12:00 PM | 6:00 PM |
| <i>Acanthagrion (Aca)</i> , (Selys, 1876) | 5 | 0 | 0 | 0 | 90 | 90 | 0 | 0 |
| <i>Cyanallagma (Aca)</i> , (Kennedy, 1920) | 0 | 90 | 0 | 0 | 967 | 290 | 171 | 114 |
| <i>Telebasis (Tel)</i> , (Selys, 1875) | 162 | 319 | 200 | 186 | 214 | 38 | 52 | 14 |
| <i>Erythemis (Ery)</i> , (Hagen, 1861) | 43 | 43 | 62 | 43 | 19 | 0 | 14 | 0 |
| <i>Erythrodiplax (Erd)</i> , (Brauer, 1968) | 0 | 0 | 14 | 5 | 14 | 0 | 0 | 10 |
| <i>Tauriphila (Tau)</i> , (Kirby, 1889) | 0 | 5 | 0 | 10 | 124 | 419 | 238 | 138 |
| Genus richness | 3 | 4 | 3 | 4 | 6 | 4 | 4 | 4 |
| TOTAL | 210 | 457 | 276 | 244 | 1428 | 837 | 475 | 276 |

Table 2. Abiotic factors measured on *Salvinia auriculata* stands in Cavalos Lake in different hours of the nycthemeral cycle during rainy and dry seasons (DO – dissolved oxygen; K₂₅ – electrical conductivity corrected to 25 °C; T – surface water temperature).

| Variables/ Hour | Rainy season | | | | Dry season | | | |
|--|--------------|---------|----------|---------|------------|---------|----------|---------|
| | 12:00 AM | 6:00 AM | 12:00 PM | 6:00 PM | 12:00 AM | 6:00 AM | 12:00 PM | 6:00 PM |
| DO (mg.L ⁻¹) | 0.00 | 0.00 | 0.00 | 0.22 | 3.20 | 1.74 | 3.74 | 3.57 |
| pH | 5.48 | 5.68 | 5.98 | 5.95 | 6.37 | 6.40 | 6.42 | 6.50 |
| K ₂₅ (µS.cm ⁻¹) | 104.13 | 109.80 | 102.00 | 102.47 | 47.60 | 54.77 | 68.40 | 46.70 |
| T(°C) | 22.97 | 22.10 | 23.27 | 23.10 | 16.67 | 16.00 | 21.17 | 19.13 |
| Depth (m) | 1.77 | 1.60 | 1.70 | 1.77 | 1.57 | 1.57 | 1.28 | 1.24 |

and depth presented a correlation with axis 1 in sampling periods 6:00 AM, 12:00 PM and 6:00 PM as well (Tables 4 and 5).

The abundances of *Telebasis* and *Erythemis* were positively affected by water electrical conductivity, temperature, and depth, while the abundances of *Acanthagrion* and *Tauriphila* showed a positive correlation with water dissolved oxygen and pH (Figure 2).

4. Discussion

Daily changes on environmental variables affect the distribution of aquatic insects. In this paper, more evidences were added showing the effects of environmental variables during the diurnal cycle on Odonata larvae.

In aquatic ecosystems, oxygen availability is one of the limiting factors of the survival of insect larvae, such as Odonata (Gaufin et al., 1974; Corbet, 1999; Hoback and Stanley, 2001; Apodaca and Chapman, 2004). In the dry season, CCA showed

that the oxygen concentration affected *Telebasis* and *Erythemis* negatively and *Acanthagrion* and *Tauriphila* positively during the nycthemeral cycle. An annual study of Odonata larvae conducted in a lake lateral to the Paranapanema River showed a different result as compared with those of the present investigation. *Acanthagrion*, *Erythemis* and *Tauriphila* did not exhibit any correlation with

Table 3. Correlations between abundance of Odonata and the first two CCA axes.

| Genera | Abbreviation | Axis 1 | Axis 2 |
|----------------------|--------------|---------|---------|
| <i>Acanthagrion</i> | Aca | -0.568* | -0.301 |
| <i>Cyanallagma</i> | Cya | -0.480 | 0.335 |
| <i>Erythemis</i> | Ery | 0.998* | -0.098 |
| <i>Erythrodiplax</i> | Erd | 0.428 | -0.220 |
| <i>Tauriphila</i> | Tau | -0.656* | -0.581* |
| <i>Telebasis</i> | Tel | 0.998* | -0.023 |

*P < 0.05

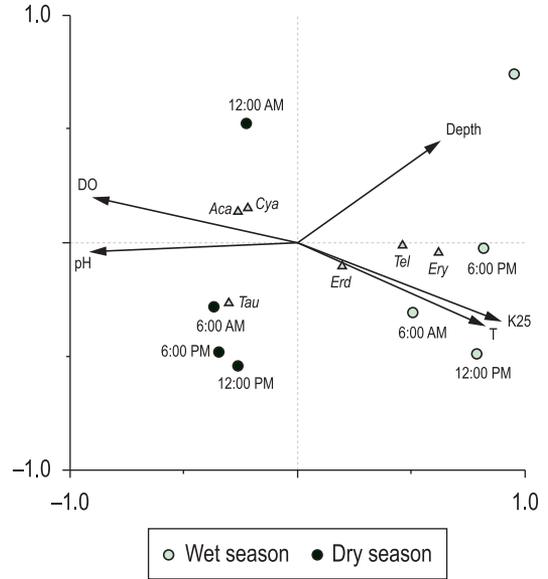


Figure 2. CCA ordination (axes 1 and 2) among abundance of Odonata larvae, abiotic variables, and sampling hours (6:00 AM, 12:00 PM, 6:00 PM, and 12:00 AM) during rainy and dry seasons. (Abbreviations, see Tables 2 and 3).

Table 4. Canonical coefficients and intra-set correlations of abiotic variables with the first two CCA axes.

| Environmental variables | Abbreviation | Canonical coefficients | | Intra-set correlation | |
|---------------------------|-----------------|------------------------|--------|-----------------------|--------|
| | | Axis 1 | Axis 2 | Axis 1 | Axis 2 |
| Dissolved oxygen | DO | -0.897* | 0.199 | -0.893* | 0.166 |
| Conductivity | K ₂₅ | 0.896* | -0.348 | 0.892* | -0.291 |
| Surface water temperature | T | 0.823* | -0.371 | 0.819* | -0.311 |
| Depth | Depth | 0.629* | 0.445 | 0.625* | 0.372 |
| pH | pH | -0.915* | -0.041 | -0.911* | -0.034 |

* P < 0.05

Table 5. Correlations between abundance of Odonata and sampling hours during the rainy and dry seasons and the first two CCA axes.

| Hour | Abbreviation | Rainy season | | Dry season | |
|----------|--------------|--------------|--------|------------|--------|
| | | Axis 1 | Axis 2 | Axis 1 | Axis 2 |
| 12:00 AM | 12:00 AM | -0.426 | 0.414 | 0.407 | -0.252 |
| 6:00 AM | 6:00 AM | *-0.882 | -0.318 | *0.576 | 0.272 |
| 12:00 PM | 12:00 PM | *-0.609 | -0.411 | 0.244 | -0.407 |
| 6:00 PM | 6:00 PM | *-0.795 | -0.024 | 0.443 | -0.414 |

*P < 0.05

dissolved oxygen concentration, and *Telebasis* was positively influenced by dissolved oxygen (Fulan and Henry, 2006). Apparently, *Acanthagrion*, *Erythemis*, *Tauriphila*, and *Telebasis* are thus more susceptible to changes of oxygen availability during the daily cycle rather than during the annual cycle. Although the changes of oxygen availability affected four of the six Odonata genera observed in this study, *Cyanallagma* and *Erythrodiplax* were tolerant enough of environmental variations, including of oxygen availability. Morphological, physiological, and behavioral adaptations in low water oxygenation conditions had already been observed for macro-invertebrates (Hoback and Stanley, 2001; Apodaca and Chapman, 2004).

Besides oxygen, the surface water temperature also influenced the distribution of Odonata larvae. Only four orders of aquatic insects (Odonata, Hemiptera, Diptera, and Coleoptera) are resistant to significant changes in water temperature (Corbet, 1999). Odonata larvae tolerate changes in water temperature through an enzymatic mechanism that promotes a fast physiological response (Schott and Brusven, 1980). In the present study, only *Cyanallagma* and *Erythrodiplax* tolerated variations in surface water temperature. Temperature changes positively affected *Telebasis* and *Erythemis* and negatively affected *Acanthagrion* and *Tauriphila*. Some Anisoptera and Zygoptera families are sensitive to variations in water temperature, as was reported for *Acanthagrion*, *Erythemis*, *Telebasis* and *Tauriphila*. (Corbet, 1999; Fulan and Henry, 2006).

In addition to the water dissolved oxygen concentration and surface temperature, other environmental factors, such as electrical conductivity, pH, and depth also had an effect on the abundance of Odonata larvae. CCA showed positive effects of electrical conductivity and depth on the abundance of *Telebasis* and *Erythemis* and of pH on the abundances of *Acanthagrion* and *Tauriphila*. *Erythemis* also showed a positive relationship with electrical conductivity in a lake lateral to the Paranapanema River, Brazil (Fulan and Henry, 2006). Differently from what was observed in the present work, *Telebasis* and *Erythemis* exhibited a negative correlation with depth (Corbet, 1999). High pressure in sites with high depth directly affects the larvae tracheal system, reducing gas exchange (Corbet, 1999). Although depth can affect Odonata larvae negatively during the daily cycle, we recorded a positive effect on *Telebasis* and *Erythemis*. Water pH, as well as depth, showed a positive effect on the abundances of *Acanthagrion* and *Tauriphila*. Zygoptera larvae, such as *Acanthagrion*., are actually

highly tolerant to pH variation when compared with Anisoptera, such as *Tauriphila* (Corbet, 1999). However, both *Acanthagrion* and *Tauriphila* are little tolerant to water pH variation during the nycthemeral cycle.

None of the measured environmental variables completely explains the Odonata distribution in the 24-hours period. Predation risk of Odonata larvae by fish must also be considered, since it directly affects the larval behavior. Carvalho et al. (2005) studied the monthly variation of fish composition and distribution in Cavalos Lake from July, 1998 to June, 1999. According to the authors, 5481 individuals of four orders, Characiformes, Siluriformes, Gymnoformes, and Perciformes, were captured in the lake. Despite Cavalos Lake being a small and isolated lake, a significant density of fish that inhabit this environment may prey on Odonata larvae. Flecker (1992) observed in an experiment that Ephemeroptera larvae are conditioned to search refuge, including in the absence of predators. Also, Bass (2004) recorded that in natural conditions, the number of invertebrates recorded during the nocturnal period was approximately four times higher than in the diurnal period, due to a lower predation risk at night. Similar to Bass' (2004) observations, we found the highest number of larvae at 12:00 AM (nocturnal period) in the dry season. This observation shows that predation can be a determinant of Odonata distribution. However, during the wet season, we recorded a very low number of larvae. In this period, the abiotic factors may have important effects on the Odonata larvae distribution. In the wet season, we recorded anoxia on the water surface in all sampling periods and also an increase of more than 100% in water conductivity as compared with the dry season.

All the six Odonata genera (*Acanthagrion*, *Cyanallagma*, *Erythemis*, *Erythrodiplax*, *Tauriphila* and *Telebasis*) described in this work had already been reported near macrophytes (Carvalho and Nessimian, 1998; Fulan and Henry, 2006). However, despite sharing the same habitat, Odonata were diversely affected by abiotic factors, the most important ones being water dissolved oxygen and temperature. As their affects on the abundance of aquatic insects during the daily cycle is highly relevant, the sampling period of Odonata must be reported. In future works, involving environmental monitoring of Odonata larvae, we suggested that the better sampling period must to be carried in the morning, since that we recorded the highest densities of both wet and dry stations at that hour. We point out that our data must to be examined

with caution because the low sampling effort and the reduced taxonomic resolution.

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