Diversity and Spatiotemporal Distribution of Larval Odonate Assemblages in Temperate Neotropical Farm Ponds

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ABSTRACT. Farm ponds help maintain diversity in altered landscapes. However, studies on the features that drive this type of property in the Neotropics are still lacking, especially for the insect fauna. We analyzed the spatial and temporal distribution of odonate larval assemblages in farm ponds. Odonates were sampled monthly at four farm ponds from March 2008 to February 2009 in a temperate montane region of southern Brazil. A small number of genera were frequent and accounted for most of the dominant fauna. The persistence of dominant genera and the sparse occurrence of many taxa over time probably led to a lack in a seasonal pattern in assemblage richness.

Key Words: dragonfly, reservoir, aquatic insect, spatial distribution, seasonality

Artificial ponds have recently been recognized as biodiversity hosts in freshwater environments (Ruggiero et al. 2008, Williams et al. 2008, Chester and Robson 2013). These systems not only fulfill their primary role in agriculture but they also serve as refuge for threatened species and maintain regional diversity in altered landscapes (Williams et al. 2008). The importance of farm ponds for benthic macroinvertebrate diversity has already been studied (Della-Bella et al. 2005, Davies et al. 2008, Ruggiero et al. 2008). However, features that improve and maintain diversity in these habitats are still poorly understood (Williams et al. 2008).

In general, macroinvertebrate assemblages in natural ponds are influenced by factors such as area, hydroperiod, and vegetation structure (Heino 2000, Oertli et al. 2002, Della-Bella et al. 2005). Environmental factors that affect freshwater assemblages are subject to changes across time and space (Spencer et al. 2002). For instance, photoperiod, and air and water temperatures (WTs) are highly seasonal in temperate areas (e.g., Corbet et al. 2006). Thus, knowing how much temporal features contribute to local environmental factors that affect macroinvertebrate assemblages is indispensable for interpreting these assemblages (Borcard et al. 1992, Hutchinson 1998).

Odonate larvae are common members of macroinvertebrate assemblages in many lentic environments such as wetlands, lakes, and ponds (Schindler et al. 2003, Niba and Samways 2006, Suhling et al. 2006). The size and age of an area, aquatic and riparian vegetation structure, and water chemistry (e.g., dissolved oxygen and nitrogen levels) are important drivers of odonate assemblages in these environments (Oertli et al. 2002, Kadoya et al. 2004, Carchini et al. 2007, Dibble and Thomaz 2009, Rensburg and Turner 2009). These factors affect both adult oviposition and larval survival rates. However, studies approaching simultaneously temporal and spatial features at natural ponds and wetlands (Ellenrieder 2000, 2009; Maltchik et al. 2010), and especially at water bodies on farms (Hamasaki et al. 2009) are lacking. Consequently, how time and space influence odonate larval assemblages is also poorly understood (McCauley 2006, Hamasaki et al. 2009).

Farm ponds are common features of the landscape throughout southern Brazil. Land in Rio Grande do Sul state (RS) has traditionally been used for cattle raising and agriculture, which requires the construction of artificial reservoirs (regionally named “acãudes”). Thus, small reservoirs are widespread, especially in small properties, where they provide water supply services. Information about odonate diversity in Brazilian farm ponds and other reservoirs is restricted to few larval inventories conducted in small reservoirs (De Marco et al. 1999, Fonseca et al. 2004, Pires et al. 2013) and generally conducted in warmer climate (tropical–subtropical) regions of the country. Additionally, ecological studies concerning the spatial and temporal structure of these assemblages remains largely unknown. Thus, this study aims to analyze both the spatial and temporal drivers of odonate larval assemblages in small farm ponds, in a temperate region in the Neotropics.

Materials and Methods

Study Area. The study area is located in central RS (Fig. 1), between the plateau (~500 m in height) and the central depression (~50 m in height), in a mountainous region, the Northeastern Lower Slope (Pereira et al. 1989). This area is occupied by the middle course of the Jacuí River, which lies within a deep and narrow valley, and exhibits numerous rivers and streams with predominantly gravel beds (boulders and cobbles). Lentic environments such as marshes and lakes are absent, macrophytes are scarce, and few backwaters are found only downstream, near the lowlands of the lower course of the river (Pires et al. 2013). The middle course of the Jacuí River is dammed at its downstream end by a hydroelectric station (UHDF: Usina Hidrelétrica Dona Francisca; Dona Francisca Power Station (Agudo and Nova Palma municipalities, Rio Grande do Sul State, Brazil); Fig. 1).

Small fragments of Seasonal Deciduous Forests remain in the region, and second-growth and riparian forests are also present and distributed sparsely along rivers and on mountain slopes. The region is unfavorable for large agricultural areas, and land use consists mainly of
small farms used for livestock, some fruits and vegetables, and maize and tobacco crops (Marchiori et al. 1982). Thus, small reservoirs and artificial farm ponds are common and constitute the lentic freshwater environments of the area. The climate of the region is Cfa, humid subtropical, according to the Köppen classification system (Maluf 2000). The mean annual temperature ranges from 18 to 22°C (Maluf 2000), and the rainfall is distributed evenly throughout the year, with the total annual precipitation ranging from 1,500 to 1,750 mm (Pereira et al. 1989). Recently, some authors have considered the climate of the region as temperate because the mean temperature can near 13°C during the coldest period of the year (IBGE 1986, Maluf 2000).

**Site Characterization and Sampling Methods.** Sampling was conducted monthly at four farm ponds, from March 2008 to February 2009 (Fig. 1). These sites are described in Table 1. All ponds have a muddy bottom and are used for watering cattle, and casually, for domestic purposes (Pond 2). Except for occasional events (see Results), pond depth showed little variation during most part of the year (~1 m), because they are connected to different water supplies.

Samples were taken with hand sieves (mesh = 1 mm), with a sampling effort of 1 h by one person. The specimens collected were fixed and preserved in 70% ethyl alcohol. Larvae were identified to genus level using a specialized key (Costa et al. 2004) and the help of specialists (see Acknowledgments). Voucher specimens are deposited in the Coleção de Invertebrados, Departamento de Biologia, Universidade Federal de Santa Maria (UFSM), RS, Brazil.

**Local Environmental Factors.** The following abiotic factors were measured at each sampling site: WT (alcohol 0–50°C thermometer), dissolved oxygen (DO; mg/liter oxymeter), and pH (pH meter). Regional values for monthly rainfall data (Prec) and mean monthly temperature (MMT) for the study area were obtained at the Plant Science Department (Departamento de Fitotecnia), UFSM. Pond age and surface area were obtained by means of interviews with local dwellers and examination of satellite images, respectively. Percentage of marginal vegetation cover of each pond was visually determined, and structure of dominant vegetation and macrophyte richness at each pond were also measured (Table 1).

**Data Analysis.** A two-way analysis of variance was used to compare the abiotic factors among ponds and months. This analysis was complemented by a Tukey’s test. All statistical tests followed the significance level of 5% (Zar 1999).

Rarefaction curves were constructed to compare genera richness among the farm ponds studied. Through this method, the estimated richness is compared at the largest comparable abundance level among the assemblages (Gotelli and Colwell 2001). The mean rarefaction curves were estimated based on 1,000 iterations, using the program EcoSim version 7.72 (Gotelli and Entsminger 2006).

Similarity among farm pond assemblages was calculated with a Bray–Curtis similarity index, posteriorly ordinated through nonmetric multidimensional scaling (NMDS). The quality of the representation of the ordination was measured by the stress value, usually <0.2 (Clarke and Warwick 2001). These analyses were carried out in the software PrimerE version 6.0 (Clarke and Gorley 2006).
Circular statistics (Zar 1999) was used to verify the occurrence of seasonality in abundance and richness of odonates, using the program ORIANA 3.21 (Kovach 2010). The vector length is given by the abundance and richness values recorded in each month throughout the study. The average vector $r$ measures data concentration around the mean. Rayleigh’s uniformity test (Zar 1999) was performed to test whether the data were distributed uniformly along the sampled months.

Results

Local Environmental Factors. No significant variation in pH and DO was detected either among ponds or among months ($P > 0.05$). WT varied among ponds ($F_{3,33} = 4.49; P < 0.05$; Pond 2 differed from Pond 4) but not through time ($P > 0.05$). MMT values were higher in spring and summer months, and lower in autumn and winter months (Table 2). Rainfall was similar throughout the study period (~100–150 mm), except for October 2008, when extreme high values were recorded (>250 mm) (Table 2). Thus, variations in pond depth were recorded for Pond 1, after a flooding event in October 2008, and for Pond 4, which completely dried in January 2009, due to higher temperature.

Macrophyte richness differed among ponds (Table 1), and percentage of marginal vegetation coverage remained stable along all the study period. However, the dominant vegetation structure differed among ponds (Table 1). Emergent macrophyte species dominated Ponds 3 and 4 (mainly Rhynchospora aurea Vahl [Cyperaceae]) and Juncus densiflorus Kunth [Juncaceae]), whereas Pond 2 had showed both floating and emergent macrophytes (mainly Hydrocharite L. sp. [Araliaceae] and R. aurea Vahl [Cyperaceae], respectively). Pond 1 had no macrophytes.

Composition and Assemblages’ Spatial Structure. In total, 2,574 larvae distributed among 20 genera, and five families were recorded in the four farm ponds (Table 3). Acanthagrion Selys, 1876 (30%), Lestes Leach, 1815 (24.7%), Erythrodiplax Brauer, 1868 (15.5%), and Oxyagrion Selys, 1876 (12.4%) were the dominant genera. Eight genera were rare and represented by no more than five individuals (Table 3). Acanthagrion was the dominant genera at Pond 1, Acanthagrion and Oxyagrion dominated Pond 2, and Erythrodiplax and Lestes predominated in Pond 3, whereas Lestes and Acanthagrion dominated Pond 4 (Table 3).

Richness and abundance varied among farm ponds. Richness was similar among Ponds 1, 3, and 4 (Table 3). Pond 2 had the lowest richness (8). Abundance in Pond 4 was more than twice the abundance of Pond 1 (Table 3). The estimated richness comparing the four ponds, for a sample of 389 individuals, confirmed the highest and similar richness of Ponds 4, 3, and 1, which was evidenced by the overlapping of their confidence intervals (Fig. 2). Pond 2 had the lowest estimated richness (7.63). The NMDS diagram showed that pond samples were spatially structured in two groups, which were formed by the segregation of samples of Ponds 3 and 4 from samples of Ponds 1 and 2 (stress value $2D = 0.14$) (Fig. 3).

Temporal Structure. Richness data did not appear to be strongly concentrated around the mean (low Z values), except for Pond 4 ($P > 0.05$; Fig. 4; Table 4). On the other hand, abundance distribution was significantly seasonal (high Z values; $P < 0.01$), and peaks of abundance occurred in spring months at all farm ponds (Fig. 5; Table 4).

Table 1. Location and characterization of the sampling sites of the odonate larval assemblages (MC% = % of marginal vegetation cover at each pond; MR = macrophyte richness; DV = dominant vegetation structure)

| Site | Coordinates | MCA | MR | Area (m²) | Age (yr) | Origin | Hydroperiod | DV |
|------|-------------|-----|----|-----------|----------|--------|-------------|----|
| Pond 1 | 29° 27’30” S 53° 17’30” W | — | 0 | 50 | — | Natural | Permanent | — |
| Pond 2 | 29° 29’41” S 53° 16’54” W | 50 | 10 | 230 | 6 | Artificial | Permanent | Emergent |
| Pond 3 | 29° 28’5” S 53° 13’23” W | 100 | 1 | 560 | 10 | Artificial | Permanent | Emergent |
| Pond 4 | 29° 25’27” S 53° 09’01” W | 100 | 10 | 600 | 12 | Artificial | Nonpermanent | Emergent |

Table 2. Regional values of monthly accumulated rainfall and mean monthly air temperature (MMT) during the study period (March 2008 to February 2009) in the study area

| Season | Month | Rainfall (mm) | MMT (°C) |
|--------|-------|---------------|----------|
| Summer | Mar.  | 106           | 22.9     |
| Autumn | April | 131.9         | 18.4     |
| Autumn | May   | 131.7         | 15.9     |
| Autumn | June  | 157.7         | 11.9     |
| Winter | July  | 176.8         | 15.9     |
| Winter | Aug.  | 99.8          | 14.3     |
| Winter | Sept. | 120.8         | 15.1     |
| Spring | Oct.  | 255.3         | 19.1     |
| Spring | Nov.  | 143.1         | 22.6     |
| Spring | Dec.  | 147.9         | 23.7     |
| Summer | Jan.  | 162.1         | 23.5     |
| Summer | Feb.  | 131.7         | 22.7     |

Table 3. Composition, number of individuals (N) and richness (S) of larval odonate genera at each farm pond studied

| Sites | Pond 1 | Pond 2 | Pond 3 | Pond 4 | Total |
|-------|--------|--------|--------|--------|-------|
| Coenagrionidae | | | | | |
| Acanthagrion Selys, 1876 | 312 | 285 | 52 | 144 | 793 |
| Ischnura Charpentier, 1840 | 2 | 7 | 7 | 10 | 26 |
| Oxyagrion Selys, 1876 | 7 | 159 | 108 | 47 | 321 |
| Telebasis Selys, 1865 | 0 | 0 | 0 | 0 | 1 |
| Lestidae | | | | | |
| Lestes Leach, 1815 | 45 | 20 | 25 | 60 | 126 |
| Aeshnidae | | | | | |
| Anax Leach 1815 | 0 | 1 | 1 | 3 | 5 |
| Cnapheoschisma Williamson, 1903 | 0 | 14 | 0 | 4 | 18 |
| Rhionaescha Förster, 1909 | 0 | 3 | 11 | 14 | 36 |
| Gomphidae | | | | | |
| Aphylla Selys, 1854 | 0 | 0 | 1 | 1 | 2 |
| Libellulidae | | | | | |
| Elystanthemis Westfall, 1888 | 1 | 0 | 0 | 0 | 1 |
| Erythemi Hagen, 1861 | 0 | 2 | 0 | 0 | 2 |
| Erythrodiplax Brauer, 1868 | 37 | 104 | 218 | 41 | 400 |
| Gynothemis Calvert in Ris, 1909 | 5 | 0 | 0 | 0 | 5 |
| Microthyrn Kirby, 1889 | 0 | 15 | 4 | 3 | 22 |
| Oligocladus Korsch, 1890 | 2 | 0 | 0 | 0 | 2 |
| Orthemis Hagen, 1861 | 1 | 0 | 1 | 33 | 35 |
| Pantala Hagen, 1861 | 0 | 0 | 3 | 11 | 14 |
| Perithemis Hagen, 1861 | 0 | 0 | 0 | 4 | 4 |
| Tauriphila Kirby, 1889 | 1 | 0 | 0 | 0 | 1 |
| Tramea Hagen, 1861 | 5 | 0 | 138 | 8 | 151 |
| N | 388 | 597 | 750 | 839 | 2,574 |
| S | 13 | 8 | 13 | 14 | 20 |
Discussion

Composition and Assemblages’ Spatial Structure. In general, the dominant genera were coenagrionids, libellulids (Acanthagrion and Oxyagrion, and Erythrodiplax, respectively), and lestids (Lestes). The dominance of these families in farm ponds was expected because both groups have been documented in artificial and lentic water bodies from tropical areas of the Neotropics (De Marco et al. 1999, Fonseca et al. 2004). The overall richness recorded in the study area was lower than that of some natural lentic systems of tropical South America (Ferreira-Perquetti and Gessner 2001) but also higher than others (De Marco and Latini 1998, De Marco et al. 1999, Franco and Takeda 2002, Fonseca et al. 2004). Also, about 50% of the genera found in this study have already been recorded in natural lentic systems of southern Brazil (Maltchik et al. 2010). Thus, artificial ponds show significant potential for hosting a large portion of odonate biodiversity.

Differences among local environmental factors of the ponds studied accounted for most of the results concerning the composition of dominant genera and the spatial distribution and structure of the assemblages. Additionally, the overall dominance of zygopteran genera (Coenagrionidae and Lestidae) was related to the dominant vegetation structure in each farm pond. Although Pond 2 had higher macrophyte richness, Ponds 3 and 4 were fully covered by marginal vegetation and were dominated by more complex macrophyte species (emergent; according to classification of macrophyte types [Cronk and Fennessey 2001]; Table 1). Vegetation diversity and density can favor both the endophytic oviposition by adult zygopterans and the climbing habit of their larvae (Carvalho and Nessimian 1998, De Marco et al. 1999, Gibbons et al. 2002, Kadoya et al. 2004). The fully marginal vegetation cover of the shoreline in Pond 3 accounted for the dominance of Erythrodiplax and Lestes larvae because they are well adapted to vegetated substrates (Carvalho and Nessimian 1998, De Marco et al. 1999, Maltchik et al. 2010).

The dominance of Acanthagrion at Ponds 1 and 2 determined the high similarity between the assemblages of these sites. Acanthagrion larvae are known to be successful in many freshwater environments, including natural and artificial lentic ones (De Marco et al. 1999, Maltchik et al. 2010). Pond 2 also had the lowest odonate richness, even though the macrophyte richness was high. The low area, the less complex vegetation structure, and scarce marginal vegetation at this site negatively influenced the assemblage diversity. Furthermore, Pond 2 differed from other ponds in local abiotic factors. For instance, Pond 2 is the site most affected by anthropogenic disturbance because it is used for domestic sewage, grazing, and pasture, which could lead to artificial eutrophication. All these features likely contributed to the lower odonate larvae richness recorded. Lower odonate richness has also been reported in highland areas subject to anthropogenic pollution (Carchini et al. 2007).

The higher estimated richness and higher abundance values of the odonate assemblages of Ponds 3 and 4 were responsible for the higher similarity between these assemblages. This result is probably related to pond size and vegetation structure. Ponds 3 and 4 had larger surface areas, fully covered shorelines, and emergent dominant vegetation. Larger areas tend to have higher habitat diversity in permanent environments than smaller ones (Oertli et al. 2002, Williams et al. 2008). Additionally, the vegetation structure of each of these sites is probably...
related to pond age. Older ponds tend to have more developed marginal vegetation, which influences odonate communities (Kadoya et al. 2004). Thus, the effects of vegetation on the fauna may be linked to pond age too. On the other hand, the environmental heterogeneity yielded by more complex vegetation structure influences food availability and provides odonate larvae with protection against predators, which leads to assemblages with higher richness and abundance (Oertli et al. 2002, Ruggiero et al. 2008, Dibble and Thomaz 2009, Remsburg and Turner 2009). The dominance of *Lestes* in Pond 4 may be related to the pond’s nonpermanent hydroperiod. Previous studies (Ellenrieder 2000, Schindler et al. 2003) observed *Lestes* larvae living in intermittent settings because its eggs are resistant to drought (Corbet 1980).

It is important to discuss the differences between Pond 1 and the other ponds, because it is the only natural water body in the study. Pond 1 is the only site without marginal vegetation cover and has the smallest size. Its odonate assemblage is more similar to that of Farm Pond 2 (NMDS, Fig. 4), but its estimated richness is higher. The higher richness is probably due to its permanent contact with the large and main course of the Jacui River, which provides its permanent hydroperiod and prevents strong variations in abiotic factors and casual colonization events (Juen et al. 2007). In fact, the dominant genus in this site (**Acanthagrion**) is successful in both lentic and lotic water bodies. Thus, although the absence of macrophyte hinders the occurrence of higher richness, such as those of Ponds 3 and 4, the connectivity and cleaner waters of Pond 1 constitute important environmental features for maintaining diversity of odonate assemblages in farm ponds.

**Temporal Distribution.** The temporal structure of the assemblages studied showed no seasonal peak in richness. Few genera predominated

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**Table 4. Circular Analysis of the abundance (A) and richness (R) of odonate larval assemblages in farm ponds studied.**

| Site     | Pond 1 | Pond 2 | Pond 3 | Pond 4 |
|----------|--------|--------|--------|--------|
|          | A      | R      | A      | R      | A      | R      | A      | R      |
| Mean vector angle (µ) | 302.95° | 139.55° | 233.85° | 230.51° | 244.46° | 276.99° | 248.70° | 218.49° |
| Mean vector length (r) | 0.27   | 0.06   | 0.18   | 0.12   | 0.28   | 0.14   | 0.52   | 0.2    |
| Circular SD*       | 92.71° | 133.66° | 105.13° | 116.12° | 91.17° | 112.51° | 64.74° | 101.91° |
| Rayleigh’s test (Z) | <0.01  | 0.16   | 20.55   | 0.85   | 59.62  | 1.34   | 233.75 | 3.42   |
| Rayleigh’s test (P) | <0.01  | <0.01  | <0.01   | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  |

*Circular SD: circular standard deviation.

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![Fig. 4. Temporal distribution of odonate larval assemblage richness in the farm ponds studied.](image-url)
in each pond throughout the study period (Table 4), and most of the assemblies were composed of accidental and low frequent genera. For instance, *Acanthagrion*, *Erythrodiplax*, *Lestes*, and *Oxyagrion* were collected almost every month of the study period. Pond permanence and water level fluctuation are likely related to these results, because there tends to be less drastic changes in the community richness of permanent sites, which stabilizes their composition (Shurin 2007). One pond (Pond 4) had a nonpermanent hydroperiod, and its importance in driving odonate assemblies is discussed below. Water level in Pond 1 is highly influenced by the water level of the Jacuí River, which frequently oscillates due to the functioning of the UHDF (<2 km upstream). Variability of water permanence in lentic habitats has been shown to affect odonate richness in ponds and wetlands in other areas (Ellenrieder 2000, Della-Bella et al. 2005, Whiles and Goldowitz 2005).

On the other hand, there were seasonal peaks in the odonate assemblies in each pond, and these peaks were concentrated in the spring months. This seasonal pattern is probably related to the life cycle of the dominant genera cited above. Larval abundance peaks during the spring have been recorded in subtropical region ponds (Shieh and Chi 2010). This pattern contrasts with odonate assemble seasonality in tropical areas (de Marmels 1998, Delgado 2002, Franco and Takeda 2002, Fulan and Henry 2007), which is related to rainfall cycles. In RS, rainfall has historically been distributed regularly throughout the year due to the humid temperate climate of the region (IBGE 1986, Maluf 2000) and therefore does not influence odonate assemblies. Most temperate odonate species tend to have only one generation per year, which differs from tropical species and reveals a latitudinal gradient in voltinism (Corbet 1980, 1999; Corbet et al. 2006). Therefore, the pattern here observed reflects the role of temperature in influencing the seasonal regulation of life cycles of odonates from temperate Neotropical regions.

The slight displacement of the abundance vector from Pond 1 in November is related to the absence of larvae in October 2008. There was an intense environmental disturbance during this month, particularly in Pond 1. Intense and sudden flood pulses caused by heavy rain affected the Jacuí River and the backwater forming Pond 1 a few days before sampling. Some studies have already shown the negative role that these environmental events cause on diversity and the structuring of benthic macroinvertebrate freshwater assemblies (Flecker and Feifarek 1994, Ward 1998). The absence of specimens in Pond 4 during the summer months (March 2008 and January 2009) is explained by the complete drought that occurred at the site.

**Final Remarks.** Small farm ponds can sustain a diverse odonate larval assemblage if they possess specific environmental conditions. As in natural areas, factors such as area, hydroperiod, and vegetation structure drive the spatial distribution and structure of the assemblages, and the dominance of certain genera. Some human activities can also play an important role and concur to avoid the occurrence of richer assemblies, even in vegetated ponds. Seasons also play an important role because temperature and precipitation can modulate important drivers, such as hydroperiod, which affect seasonal patterns in assemblages. However, extreme oscillations in hydroperiod may affect odonate assemblage structure, suggesting that climatic changes altering rainfall distribution in southern Brazil (Junk 2013) could have negative influence on ponds’ odonate diversity of the region.

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