An Acad Bras Cienc (2025) 97(Suppl. 2): e20250159 DOI 10.1590/0001-3765202520250159
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ANIMAL SCIENCE

Effects of geographic distance and abiotic variables on larval Odonata assemblages in western Amazon savannah lakes

EMILY L. OLIVE, RENATO T. MARTINS, KARINA DIAS-SILVA, ULISSES G. NEISS & NEUSA HAMADA

Abstract: Odonata, comprising the suborders Anisoptera and Zygoptera, are important bioindicators of aquatic ecosystem health due to their sensitivity to environmental changes. We assessed the effects of environmental variables and geographic distance on larval Odonata assemblages in 25 natural lakes of the Brazilian savannah, in northern Roraima. We focused on Anisoptera, characterized by strong flight abilities and greater dispersal capacity, and Zygoptera, which are more sensitive to local environmental variation due to their limited dispersal capacity. We collected 9,578 larvae of 12 Anisoptera species and 2,884 larvae of eight Zygoptera species. Larval Odonata assemblages are influenced by abiotic variables rather than geographic distance, and richness was positively associated pH. Assemblage composition and abundance were affected by key abiotic conditions. Odonata abundance was positively correlated with oxygen and temperature, but negatively correlated with phosphate. Anisoptera abundance increased with dissolved oxygen and geographic distance, but decreased with phosphate and electrical conductivity. Meanwhile, Zygoptera abundance showed a positive correlation with conductivity and temperature but a negative relationship with geographic distance, pH, and phosphate. Additionally, pH influenced assemblage composition, positively affecting Anisoptera but negatively Zygoptera. Our results provide valuable insights into conservation planning and environmental policies aimed at preserving aquatic biodiversity in the region.

Key words: Aquatic insects, Anisoptera, Environmental variables, Geographical distance, Lentic, Zygoptera.

INTRODUCTION

Understanding species distributions and the factors shaping aquatic assemblages is essential for the conservation of these environments and their biodiversity (Basset et al. 2012, Oliveira Jr. & Juen 2019). Locally, assemblages are structured by both biotic (e.g., predation and competition) and abiotic factors (Brasil et al. 2020). In lentic environments, key abiotic drivers include connectivity, pH, temperature, and dissolved oxygen (Remsburg & Turner 2009, Pires et al. 2018, Bacca et al. 2021, Brito et al. 2021). Additionally, dispersal capacity also influences the diversity of Odonata assemblages (Melián et al. 2015). However, the interactions between these factors vary across biome, complicating predictions of assemblage structure (Gotelli et al. 2009, Legendre 1993).

Brazil's diverse ecosystems include the Atlantic and Amazonian forests and the distinctive Guiana-Venezuela savannahs, known as the non-flooded grassland savannahs (Prance 1996), which cover over 230,104 km² and are located mainly in northern and northeastern

Roraima (Miranda & Absy 2000). Its unique flora and fauna differ significantly from other Brazilian savannahs, underlining its importance for biodiversity studies (Miranda & Absy 2000, Barbosa et al. 2005). The Roraima savannah contains numerous natural lakes that support a wide variety of species, including anurans, birds, and insects (Barbosa et al. 2005, Oertli et al. 2005, 2010). These lakes are critical for aquatic biodiversity, yet research in the region is scarce. Of the 136 studies conducted in the last past 80 years, less than 15% focused on Brazilian invertebrates, mainly soil fauna (Carvalho & Mustin 2017). Thus, Savannah lakes represent a unique and understudied freshwater system within the Amazon.

Odonata have aquatic larvae and terrestrial adults, functioning as key predators in both life stages (Corbet 2004, McPeek 2004). In Brazil, the two recorded suborders, Anisoptera and Zygoptera, differ in life history, physiological traits, and responses to environmental changes (Corbet 2004, Albuquerque et al. 2024). Anisoptera adults are adapted to high metabolic demands and are characterized by robust bodies, advanced thermoregulation, and greater dispersal abilities (Oliveira Jr. et al. 2019, Brasil et al. 2020). Their larvae, which breathe through rectal tracheal gills, are less vulnerable to environmental changes (Corbet 1980, Mendes et al. 2019). In contrast, Zygoptera adults have more delicate bodies, lower thermoregulatory capacity, and reduced dispersal (Brasil et al. 2020), making them more dependent on stable local environments. Their larvae, which respire via external lamellae (Corbet 1980), are generally more sensitive to environmental changes. Consequently, the suborders respond differently to abiotic and spatial factors. Studies in Brazilian coastal lagoons suggest that Zygoptera diversity is influenced by local abiotic factors (e.g., oxygen, connectivity, and climate) and Anisoptera by geographic distance (Pires et al. 2018). Similarly, Anisoptera are more influenced by climatic factors, whereas Zygoptera are more affected by water chemistry (Bacca et al. 2021). However, it remains unclear whether these patterns hold in Amazonian savannah lakes.

Despite their importance as biodiversity hotspots, the factors influencing Odonata assemblages in these lentic environments remain poorly understood. We evaluated the influence of geographic distance and environmental variables on the abundance, richness, and composition of Odonata larvae in savannah lakes of Roraima, Brazilian Amazon. Based on the distinct traits, we hypothesize that Anisoptera, with greater dispersal capacity, are primarily influenced by geographic distance (Pires et al. 2018), whereas Zygoptera, with limited dispersal, respond more strongly to local environmental conditions (Bacca et al. 2021).

MATERIALS AND METHODS

The collections were carried out in the municipalities of Alto Alegre and Boa Vista, Roraima, Brazil (02°46’00.4’’N - 03°10’53.9’’N, 60°45’38’’W - 61°06’46.2’’W; Figure 1), at an approximate elevation of 76 meters. The region consists of flat terrain (Rio Branco-Rio Negro Pediplain) at an altitude of 85–140 m (Franco et al. 1975, Costa et al. 2005) and is dominated by savannah vegetation (Veloso et al. 1975, Miranda & Absy 1997), with grasses and Cerrado shrubs (*Curatella americana*, *Byrsonima crassifolia*).

We initially selected 50 lakes based on size and circular shape, each with a perimeter of approximately 700 m. These lakes were georeferenced using satellite imagery from Google Earth Pro (v.7.1). Based on this survey, 25 lakes were retained for sampling, selected on the basis of water retention during the dry season and a minimum distance of 1 km. The maximum

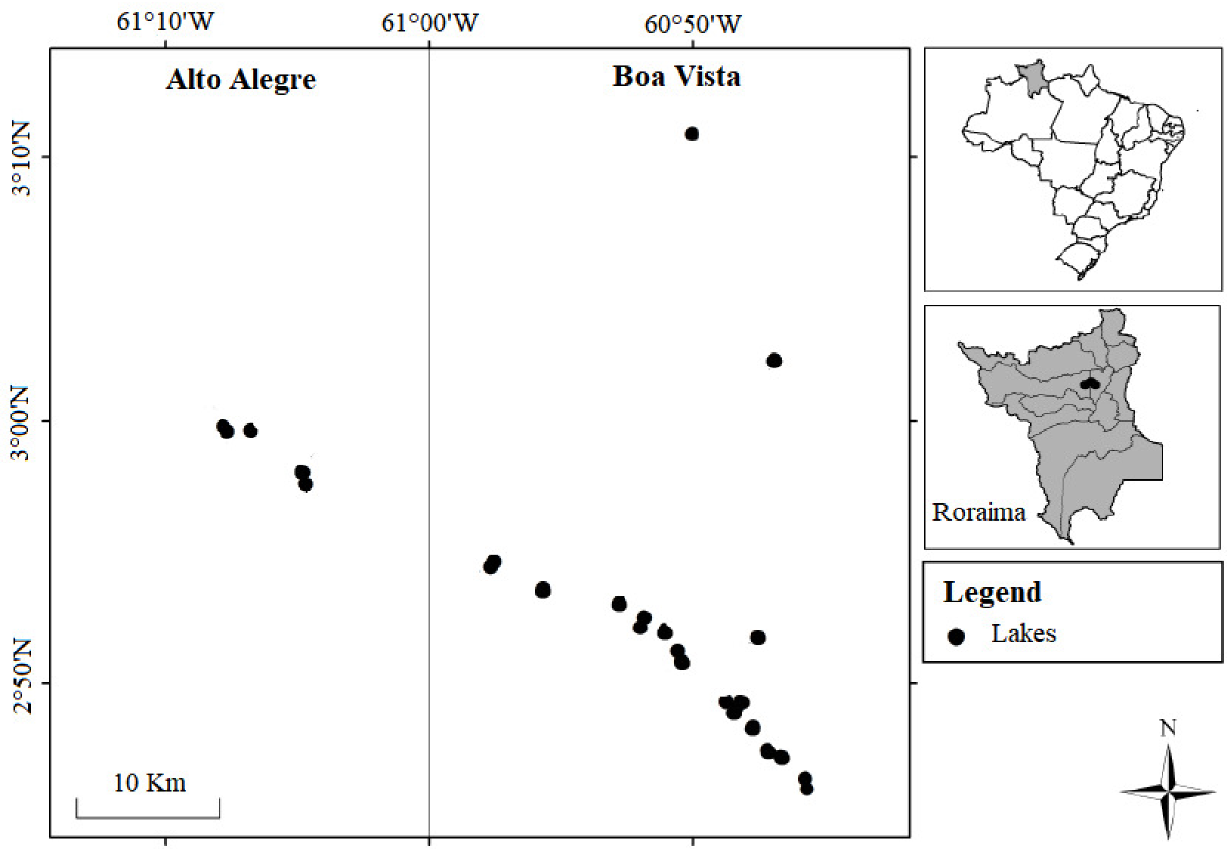

Figure 1. Distribution of the lakes (n=25) where Odonata (Insecta) larvae were sampled in August 2015, in the municipalities of Alto Alegre and Boa Vista, Roraima, Brazil.

geographical distance between the sampling units in our study is 46.1 km longitudinally and 41.6 km latitudinally. Sampling was carried out along BR-174 and RR-205 in Alto Alegre and Boa Vista, Roraima, taking into account the presence of farms, logistics and accessibility. Of the 25 lakes sampled, two were located near soybean fields and one showed signs of cattle use, while the others had no apparent anthropogenic impact. Local people estimated that this land use had been going on for 10-15 years.

We sampled Odonata larvae in August 2015, at the end of the rainy season, when aquatic assemblages are more stable and larvae are in advanced stages of development (Corbet 2004). In each lake, we collected 10 samples (30 seconds) per lake using a D-frame net to maximize substrate and area coverage in the shallow margins (Figure 2). This approach was adapted from De Marco Jr. et al. (2013), who collected 10-second samples. We examined all individuals sampled in the 250 subsamples under a stereoscopic microscope. Specimens were identified at the species level when possible, using taxonomic literature (De Marmels & Rácenis 1982, Davies & Tobin 1984, 1985, De Marmels 1988, 1989, 1992, Needham et al. 2000, von Ellenrieder & Garrison 2003, Lencioni 2005, 2006, Garrison et al. 2006, 2010). Identified specimens were preserved in 80% ethanol, with the reference material being deposited at the *Instituto Nacional de Pesquisas da Amazônia* - INPA Invertebrate Collection.

Additional collections included active searches for late-stage and penultimate larvae to raise to adulthood for taxonomic

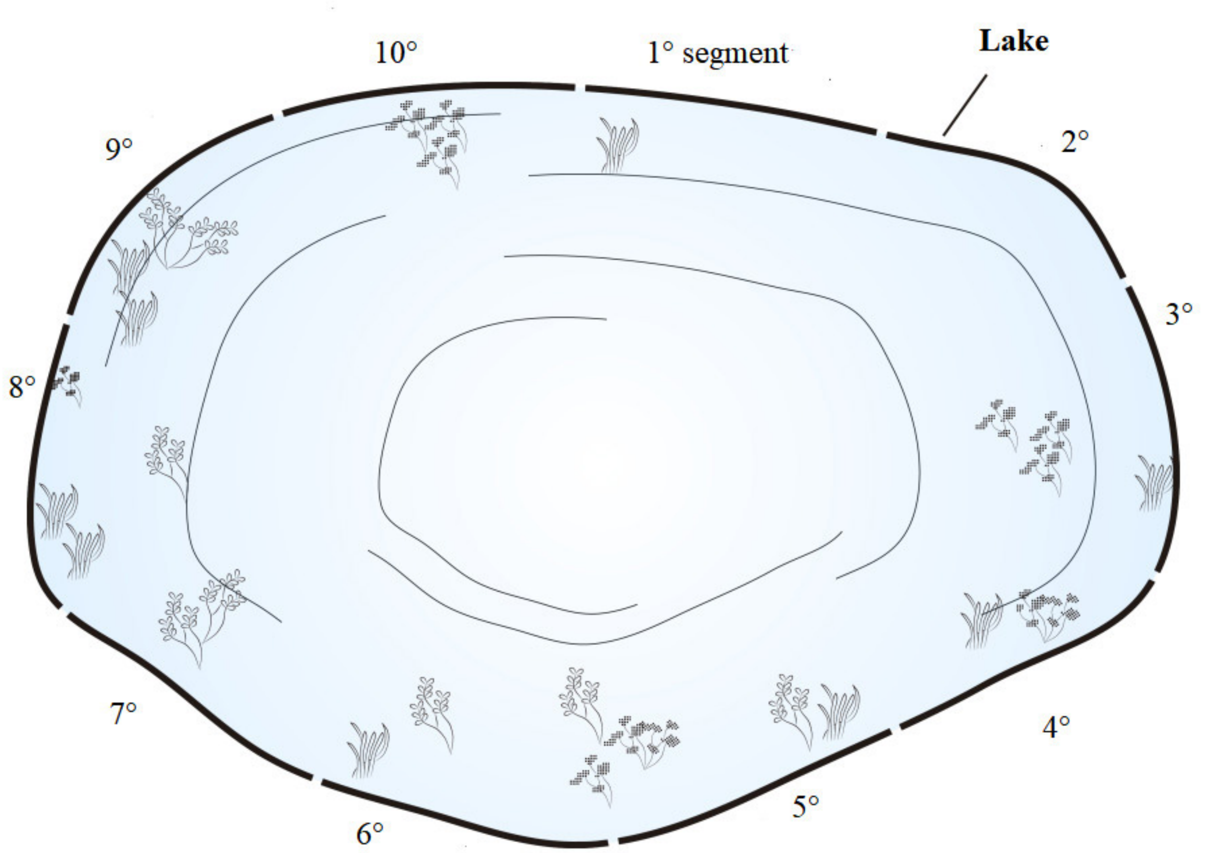

Figure 2. Schematic showing the distribution of the 10 sub-samples collected in each lake, in the municipalities of Alto Alegre and Boa Vista, Roraima, Brazil, for the study of the Odonata larvae assemblage.

identification. Since Odonata taxonomy is based on male adults, this method ensures accurate species determination. Live larvae were kept in polystyrene containers (11 × 9 × 6 cm) with water, sticks, and sediment from their habitat, and then transported to the *Laboratório de Citotaxonomia e Insetos Aquáticos* - LACIA at INPA.

In the field, the dissolved oxygen (mg/L), hydrogen ion potential (pH), temperature (°C) and electrical conductivity (µs/cm) of the water were measured using an oximeter (Oakton DO 300 Meter) and a potentiometer/conductivimeter (Oakton PC Tester 35). To determine the concentrations of phosphate, potassium, and chloride, 500 mL water samples were taken from the surface of each lake where the depth of the water column was 40 cm. Samples were kept cold in coolers during collection and transport to minimize microbial activity (Machado et al. 1995).

Statistical analysis

We considered the lake site as the sample unit. We calculated Odonata and its suborders richness (number of taxa), abundance (sum of individuals), and assemblage composition. To assess the completeness of our sampling, we performed a rarefaction analysis (*rarecurve* and *specaccum* functions, *vegan* R package) in R. Rarefaction curves were generated for each lake to visualize the relationship between sampling effort (individuals) and observed richness. Additionally, a species accumulation curve was generated to assess the overall sampling sufficiency across all sites.

To account for spatial structure in our analyses, we calculated Euclidean distances between lakes based on their geographic coordinates (latitude and longitude). We then performed a Principal Coordinates of Neighboring Matrices (PCNM) analysis, using the minimum spanning tree as the truncation criterion to define spatial connectivity between sites. Only significant spatial eigenvectors (Moran's I, $p < 0.05$; $n= 3$) were retained and subjected to Principal Component Analysis (PCA). The first PCA axis was used as a unidimensional proxy for geographic distance. This variable captured the main spatial gradient across the study area and was included in multiple regression models to evaluate its influence, along with abiotic factors, on Odonata richness, abundance, and assemblage composition. We used multiple regression to model relationships between Odonata (and suborders) richness, abundance, and assemblage composition and six explanatory variables: geographic distance and seven abiotic factors (electrical conductivity, dissolved oxygen, nitrate, pH, phosphate, potassium, and temperature). Multicollinearity was assessed through correlation analysis between the independent variables, as high correlation ($r > 0.7$) between variables, such as nitrate and phosphate, can lead to biased estimates (Zar 2010). We retained phosphate to analysis.

We used generalized linear mixed-effects models (GLMM) with Poisson distribution (glmer function, lme4 R package; Bates et al. 2015) to assess the effects of abiotic variables and geographic distance on richness and abundance of Odonata and its suborders. In these models, explanatory variables (see Supplementary Material - Table SI) were fixed effects, while sampling days were included as random effects to account for multiple lakes sampled per day and temperature or rainfall effects on activity or larval abundance. The best LME model was selected using Akaike's information criterion (AIC) and backward elimination (*dredge* function, *MuMIn* R package; Barton 2022). Model assumptions were visually assessed using the *DHARMa* package in R.

The influence of abiotic factors on Odonata assemblages was assessed using Redundancy Analysis (RDA; Legendre & Legendre 2011). The response matrix, consisting of species abundance data, was Hellinger-transformed to reduce the influence of highly abundant taxa and to allow Euclidean-based ordination (Legendre & Gallagher 2001). The explanatory matrix included environmental variables measured in each lake and a proxy for geographic distance.

To account for spatial autocorrelation, we performed Partial Redundancy Analysis (pRDA) by including spatial variables derived from a PCNM analysis, based on Euclidean distances calculated from geographic coordinates (Borcard & Legendre 2002, Dray et al. 2006). The resulting PCNM eigenvectors were used as covariates in the pRDA, allowing the partitioning of variation into pure environmental effects, pure spatial effects, their shared component, and residuals (Legendre & Legendre 2011). All analyses were performed in R (R Core Team 2024) using the *vegan* package.

RESULTS

Abiotic variables

The sampled lakes exhibited warm, acidic, and low-conductivity waters (mean temperature = 31.8°C, pH = 4.86, conductivity = 9.61 µS cm^{-1}; Table I). Dissolved oxygen averaged 4.16 mg L^{-1}. Nutrient levels were generally low, except for phosphate, which showed high variability (0.15–21.38 mg L^{-1}).

Table I. Minimum, maximum, mean and standard deviation values of the environmental variables of lake water (n=25) in savannah, Roraima, Brazil.

Variable	Minimum	Maximum	Mean	Standard Deviation
Chloride (mg L^{-1})	0.14	1.72	0.69	0.35
Electrical conductivity (μs cm^{-1})	3.32	22.50	9.61	4.92
Dissolved oxygen (mg L^{-1})	2.90	5.72	4.16	0.74
Nitrate (mg L^{-1})	0.00	0.68	0.04	0.14
pH	4.73	5.35	4.86	0.11
Phosphate (mg L^{-1})	0.15	21.38	2.33	4.52
Potassium (mg L^{-1})	0.00	0.56	0.10	0.14
Temperature (°C)	26.4	36.80	31.80	2.96

Influence of abiotic factors and geographic distance on richness and abundance

A total of 12,462 Odonata specimens were collected, comprising 9,578 Anisoptera and 2,884 Zygoptera, representing 20 taxa across 14 genera and four families (Table II; Table SI). The most abundant species, *Erythrodiplax sp.* (Anisoptera), *Tramea darwini* (Anisoptera), *Lestes forficula* (Zygoptera), and *Erythemis sp.* (Anisoptera), comprised 74% of all specimens. The average Odonata richness was 10.1 ± 2.4 taxa/lake (range: 7 to 15). Rarefaction and species accumulation analyses indicated that the sampling effort was sufficient to adequately represent the Odonata diversity within and among lakes (Figure S1). The majority of rarefaction curves approached asymptotes, indicating sufficient sampling completeness at the lake level. In a similar vein, the species accumulation curve demonstrated a plateau with narrow confidence intervals after approximately 20 lakes, suggesting that the observed richness (~20 species) captures most of the regional diversity. Odonata richness was positively associated with pH, accounting for 4% of its variability (Table II). The Odonata abundance was explained by 55% of the variation and was positively correlated with geographic distance, dissolved oxygen, and temperature, but negatively with phosphate.

Anisoptera presented an average richness of 6.2 ± 1.5 taxa/lake (range: 3 to 9). Environmental variables explained 4% of Anisoptera richness variation (Table II), with richness negatively correlated with water temperature. Anisoptera abundance was positively associated with dissolved oxygen and geographic distance, but negatively correlated with electrical conductivity and phosphate. The average Zygoptera richness was 3.9 ± 1.7 taxa/lake (range: 1 to 7). Environmental variables explained 3% of Zygoptera richness variation (Table II), with richness positively correlated with pH. Zygoptera abundance variation (72%) was driven by environmental factors, showing positive correlations with electrical conductivity and temperature but negative correlations with geographic distance, pH, and phosphate.

Table II. Influence of environmental variables and geographical distance (G) on Odonata assemblages of lakes in savannah, Roraima, Brazil. EC = Electrical conductivity; DO = Dissolved oxygen; GD = Geographical distance; PO = Phosphate; WT = Water Temperature.

Selected model	Factor	Estimate	df	logLik	AICc	Weight	delta
Richness Odonata ~ pH	intercept	-0.35	3	-58.1	123.3	0.1	1.5
Marginal r2 = 0.04	pH	0.55					
Conditional r2 = 0.04							
Richness Anisoptera ~ WT	intercept	2.67	3	-49.7	106.4	0.1	1.7
Marginal r2 = 0.04							
Conditional r2 = 0.04	WT	-0.03					
Richness Zygoptera ~ pH	intercept	-2.62	3	-48.4	103.9	0.1	1.6
Marginal r2 = 0.03	pH	0.82					
Conditional r2 = 0.03							
Abundance Odonata ~ DO +	intercept	-7.82	6	-614	1244	0.3	1.2
GD + PO + WT	DO	0.18					
Marginal r2 = 0.55	GD	0.06					
Conditional r2 = 0.99	PO	-0.13					
	WT	0.04					
Abundance Anisoptera ~ DO + EC + GD + PO	intercept	-5.84	6	-584	1185	0.3	1.8
Marginal r2 = 0.58	DO	0.11					
Conditional r2 = 0.99	EC	-0.1					
	GD	0.2					
	PO	-0.56					
Abundance Zygoptera ~ EC + GD + Ph + PO + WT	intercept	6.43	7	-460	940.1	0.5	0
Marginal r2 = 0.72	EC	0.05					
Conditional r2 = 0.99	GD	-0.34					
	pH	-3.84					
	PO	-0.12					
	WT	0.24					

Influence of abiotic factors and geographic distance on assemblage composition

Redundancy Analysis (RDA) revealed that the set of environmental variables and geographic distance significantly explained variation in Odonata larval assemblages ($F = 1.71$, $p = 0.005$). The first axis (RDA1) accounted for 8.6% of the explained variance and was statistically significant ($F = 7.22$, $p = 0.005$). In contrast, subsequent axes were not significant ($p > 0.05$). Phosphate, potassium, nitrate, and electrical conductivity exhibited a positive association with

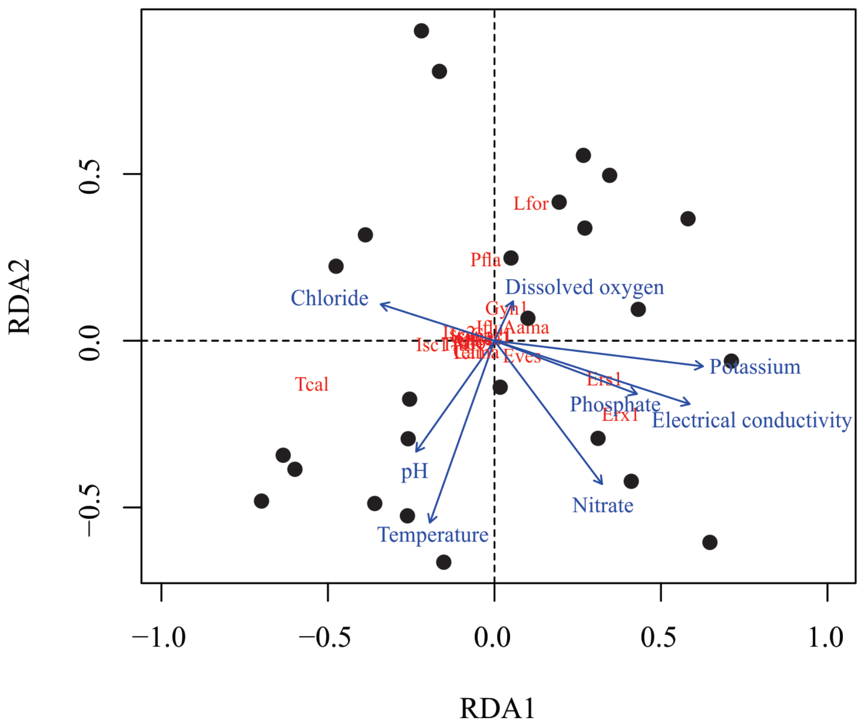

Figure 3. Redundancy Analysis (RDA) based on biotic and abiotic characteristics from savannah lakes, Roraima, Brazil.

RDA1 (Figure 3). Conversely, geographic distance, temperature, pH, and chloride demonstrated a negative association with RDA1. *Lestes forficula* and *Pantala flavescens* were strongly associated with higher concentrations of dissolved oxygen. *Erythemis* sp. and *Erythrodiplax* sp. were closely aligned with the vectors for phosphate, nitrate, potassium, and electrical conductivity. *Tramea calverti* was strongly associated with geographic distance.

In the pRDA, geographic distance and abiotic variables explained 21% of Odonata assemblage variation, with stronger effects on Anisoptera (34%) than Zygoptera (14%). Geographic distance alone had no significant impact on assemblages (p > 0.05; Figure 4), while abiotic factors significantly influenced Odonata and Anisoptera composition, but not Zygoptera (Figure 4).

DISCUSSION

We found that geographic distance between lakes only influenced the abundance of Odonata and their suborders, with no detectable effects on species richness or assemblage composition. In lentic systems, environmental variables often exert a stronger influence on aquatic insect assemblages than spatial factors, especially for species with limited dispersal ability (Heino et al. 2015, Bacca et al. 2021). This pattern is consistent with findings from Cerrado streams (Mendes et al. 2015) and Amazonian systems (Juen & De Marco Jr. 2011), where spatial effects on Odonata distributions were also minimal. In our study, local environmental filters such as pH, phosphate, and temperature likely played a dominant role in shaping community structure-especially for Zygoptera. Conversely, Anisoptera, with greater flight capacity, are less constrained by spatial barriers, which may explain the lack of spatial structure in their composition. Nevertheless, geographic distance had a positive effect on Anisoptera and total Odonata abundance, while Zygoptera showed a negative response. Interestingly, *Tramea calverti* was associated with geographic distance in the RDA,

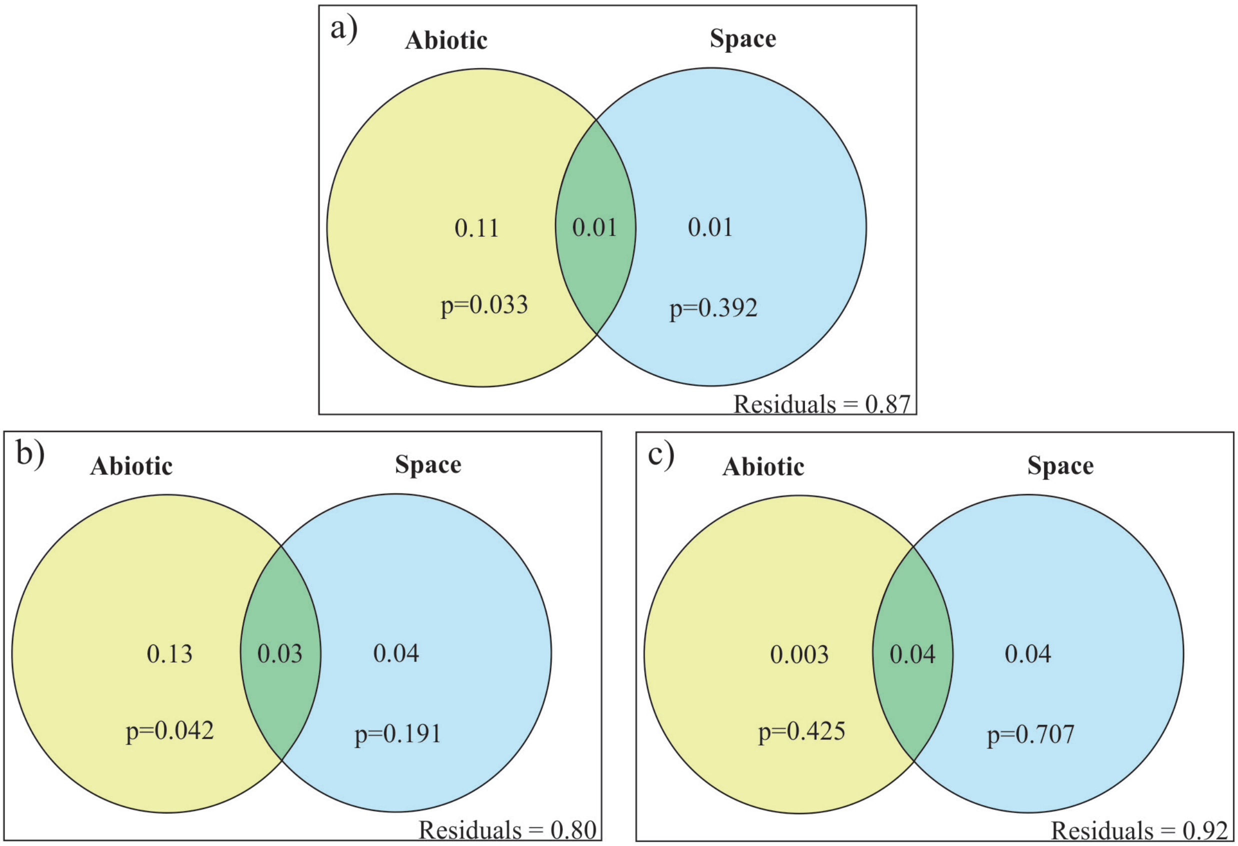

Figure 4. Partial Redundancy Analysis variance partition on the species composition of a) Odonata, b) Anisoptera, and c) Zygoptera from savannah lakes, Roraima, Brazil. The fractions represent the effect of the environment only, only the space, together environment and space and residue. The relationship between environmental variables and assemblage composition varied from 10% (Zygoptera) to 24% (Anisoptera; Table II). The selected models for Odonata and Zygoptera composition were negatively related to pH, while Anisoptera composition was positively related to pH.

suggesting that even highly mobile taxa may respond to spatial gradients in local abundance. These results highlight that spatial effects on Odonata are both scale-dependent and response-specific, affecting abundance rather than richness or taxonomic composition. The relatively small spatial scale of our study may have further limited the detection of broader spatial patterns, as larger scale studies have shown stronger spatial structuring in highly mobile species (De Bie et al. 2012). Ultimately, both species traits and spatial scale mediate the relative roles of environmental and spatial processes in structuring Odonata assemblages.

The Odonata richness observed in our study (20 species across 25 lakes) was comparable to other surveys conducted in Amazonian lentic habitats, such as artificial ponds (e.g., Santos et al. 2021), suggesting a moderate species richness. A rarefaction analysis indicates that our sampling effort captured most of the estimated richness. However, when compared to more structurally complex systems such as forested streams or macrophyte-rich lakes—the study area likely exhibits lower taxonomic richness, possibly due to its open vegetation, low macrophyte cover, and homogeneous habitat structure. Vegetation influences environmental conditions and provides key oviposition and locomotion sites for Odonata species (Carvalho & Nessimian 1998, Corbet 2004, De Marco Jr. et al. 2015). The genera collected are typical of open areas with sparse vegetation, few macrophytes, sandy soils, and high solar radiation (Carvalho & Nessimian 1998, Corbet 2004). Increased light and heat in Amazonian streams favor Anisoptera, leading to assemblage homogenization (Monteiro Jr. et al. 2015). Similarly, the low macrophyte diversity and grass dominance in savannah lakes may explain the prevalence of Anisoptera, which thrive in open environments. These findings highlight the role of habitat homogeneity in shaping Odonata assemblages in lotic and lentic systems.

The relative influence of environmental and spatial variables on Odonata assemblages varied among taxonomic groups and analytical approaches. Generalized linear mixed models (GLMMs) revealed strong relationships between environmental predictors and geographic distance on species richness. In contrast, redundancy analysis (RDA) and partial RDA (pRDA) explained less of the variation in species composition. These results demonstrate that while environmental gradients influence abundance patterns, particularly for Zygoptera, such effects are not always reflected in species composition. This discrepancy highlights the complementary nature of GLMMs and ordination-based methods such as pRDA. Abundance models tend to be more sensitive to subtle ecological responses and environmental filtering, whereas multivariate methods capture broader patterns of species turnover, which may be limited when assemblages are taxonomically similar or governed by stochastic processes (Legendre & Legendre 2011, Blanchet et al. 2008, Heino et al. 2015).

In the lakes studied, electrical conductivity negatively affected Anisoptera abundance, but positively influenced Zygoptera, reflecting their ecological differences. Anisoptera may be more sensitive to ionic fluctuations, while Zygoptera could benefit from moderate increases in electrical conductivity due to increased nutrient availability. Electrical conductivity influences Odonata assemblages by affecting larval osmoregulation (D'Amico et al. 2004) and adult oviposition, favoring species adapted to specific tolerance ranges (Cannings et al. 1980, Corbet 2004, Rychła et al. 2011). Additionally, intermediate levels of electrical conductivity may also increase nutrient availability for primary consumers, thereby increasing prey resources for Odonata (Leite et al. 2016).

Dissolved oxygen was positively correlated with the abundance of Odonata and Anisoptera. Generally, well oxygenated waters support higher abundance and diversity of aquatic organisms due to enhanced aerobic metabolism and reduced physiological stress (Baselga et al. 2007, Jacobsen & Marín 2008). Insects with active predatory habits, such as many Anisoptera larvae, are particularly sensitive to oxygen availability because they require high metabolic rates to sustain foraging and growth (Corbet 2004). The dissolved oxygen levels recorded in the studied lakes (ranging from 2.9 to 5.7 mg L^{-1}) are relatively low and may approach suboptimal thresholds for some taxa, especially under the combined effect of elevated water temperatures that reduce oxygen solubility and increase metabolic demand (Gutiérrez-Cánovas et al. 2013).

In our study, phosphate concentration, which is highly correlated with nitrate, was negatively related to the abundance of Odonata and both suborders. This suggests that elevated phosphate levels, likely associated with agricultural runoff from surrounding soybean plantations, may disrupt the ecological balance of these assemblages by altering water quality and habitat suitability. Similar negative effects of nitrate and phosphate on Odonata have been reported in urban and rural areas (Hofmann & Mason 2005, Holtmann et al. 2018, Perron et al. 2021). Interestingly, *Erythemis sp1* and *Erythrodiplax sp1* were associated with phosphate in the RDA, suggesting a possible link to nutrient-enriched conditions. Although many species within the genera *Erythemis* and *Erythrodiplax* are considered ecological generalists and can rapidly colonize and thrive in altered environments due to their short life cycles and behavioral flexibility (Villalobos-Jiménez et al. 2016, Sganzerla et al. 2021, Rocha et al. 2023).

We found that pH negatively affected Zygoptera abundance, but positively influenced Odonata and Zygoptera richness. These contrasting patterns highlight the taxon-specific and context-dependent nature of pH effects on aquatic insects. In transitional zones between the Amazon and the Cerrado, positive relationships between pH and Zygoptera richness and Anisoptera abundance were recorded (Mendes et al. 2018). Conversely, in temperate Canadian lakes, Anisoptera abundance was negatively related to pH, while Odonata richness showed a positive relationship (Bendell & McNicol 1995). Such differences may reflect regional adaptations, species turnover, and interactions with other environmental factors. Acidic conditions, particularly at pH values below 4.5, can cause physiological stress in aquatic invertebrates by disrupting ion regulation, reducing reproductive success, and narrowing ecological niches (Gorham & Vodopich 1992, Thalib et al. 2021), resulting in the presence of only adapted species.

In the studied lakes, water temperature negatively affected Anisoptera richness and Zygoptera abundance but positively influenced Odonata abundance. Temperature is strongly correlated with Odonata diversity in both lotic and lentic environments (Oliveira Jr. et al. 2019, Oliveira Jr. & Juen 2019, Barzoki et al. 2020, Ferreira Neto et al. 2021). In warmer lakes, Odonata assemblages were dominated by *Ischnura* (Zygoptera), *Telebasis* (Zygoptera), and *Tramea* (Anisoptera), which are common and abundant in lentic habitats (Franco & Takeda 2002). Odonata in open and unshaded environments with a wide temperature range tend to be tolerant generalists, characterized by traits such as high thermal tolerance, short development cycles, and broad ecological plasticity. The presence of genera like *Pantala*, *Tramea*, *Erythrodiplax*, *Erythemis*, and *Ischnura* supports this pattern, as these taxa are commonly associated with open, sunlit habitats with lower structural complexity (Sonoda 2025, Monteiro Jr. et al. 2015). These species often dominate in anthropogenically altered or naturally simplified systems, reflecting their generalist strategies in colonizing and persisting in a range of lentic environments.

In summary, our study reveals that abiotic factors play a stronger role than geographic distance in structuring larval Odonata assemblages in Amazonian savannah lakes. The abundance of Anisoptera is influenced by both environmental conditions and spatial gradients, while Zygoptera are more sensitive to local water chemistry. The substantial impact of pH, phosphate, temperature, and dissolved oxygen underscores the susceptibility of these assemblages to environmental fluctuations. These findings underscore the ecological value of savannah lakes and support the use of Odonata as bioindicators for freshwater conservation strategies in the Amazon.

Acknowledgments

RTM received visiting researcher fellowships from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (processes: 380592/2022–3 and 382557/2023-9). NH and KDS are grateful to the

Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for research productivity scholarship (308970/2019–5) and (311550/2023-1). We thank to Posgrad/Fapeam and INCT ADAPTA II, which is funded by CNPq (465540/2014-7), by Fundação de Amparo à Pesquisa do Estado do Amazonas (FAPEAM) (062.1187/2017), and by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), BIODIVERSA/FAPEAM, and by Universal/CNPq (403758/2021-1).

REFERENCES

ALBUQUERQUE AKM, VERAS DS, JUEN L & AZEVEDO CAS. 2024. Zygoptera / Anisoptera (Insecta: Odonata) ratio as a tool to assess anthropogenic changes in Brazilian Cerrado streams. Environ Monit Assess 196: 737. https://doi.org/10.1007/s10661-024-12870-1.

BACCA RC, PIRES MM, MOREIRA LFB, STENERT C & MALTCHIK L. 2021. The role of environmental and spatial factors in the assembly of aquatic insect communities in southern Brazilian temporary ponds. Austral Ecol 46: 228-238.

BARBOSA RI, NASCIMENTO SPD, AMORIM PAFD & SILVA RFD. 2005. Notas sobre a composição arbóreo-arbustiva de uma fisionomia das savanas de Roraima, Amazônia Brasileira. Acta Bot Bras 19: 323-329.

BARTON K. 2022. MuMIn: Multi-Model Inference. R package version 1.46.0. Available at: https://CRAN.R-project.org/package=MuMIn.

BARZOKI ZE, EBRAHIMI M, KIANY M & SADEGHI S. 2020. Ecological drivers of Odonata beta diversity in arid and semi-arid regions of the Central plateau of Iran. Insect Conserv Divers 14: 40-51.

BASELGA A, JIMÉNEZ-VALVERDE A & NICCOLINI G. 2007. A multiple-site similarity measure independent of richness. Biol Lett 3: 642-645.

BASSET A, BARBONE E, BORJA A, BRUCET S, PINNA M, QUINTANA XD, REIZOPOULOU S, ROSATI I & SIMBOURA N. 2012. A benthic macroinvertebrate size spectra index for implementing the Water Framework Directive in coastal lagoons in Mediterranean and Black Sea ecoregions. Ecol Indic 12: 72-83.

BATES D, MÄCHLER M, BOLKER B & WALKER S. 2015. Fitting Linear Mixed-Effects Models Using lme4. J Stat Softw 67: 1-48. https://doi.org/10.18637/jss.v067.i01.

BENDELL BE & MCNICOL DK. 1995. Lake acidity, fish predation, and the distribution and abundance of some littoral insects. Hydrobiologia 302: 133-145.

BLANCHET FG, LEGENDRE P & BORCARD D. 2008. Forward selection of explanatory variables. Ecology 89: 2623-2632.

BORCARD D & LEGENDRE P. 2002. All-scale spatial analysis of ecological data by means of principal coordinates of neighbour matrices. Ecol Model 153: 51-68.

BRASIL LS, LUIZA-ANDRADE A, CALVÃO LB, DIAS-SILVA K, FARIA APJ, SHIMANO Y, OLIVEIRA JR JMB, CARDOSO MN & JUEN L. 2020. Aquatic insects and their environmental predictors: a scientometric study focused on environmental monitoring in lotic environments. Environ Monit Assess 192: 194. doi: 10.1007/s10661-020-8147-z.

BRITO JP, CARVALHO FG & JUEN L. 2021. Response of the Zygopteran community (Odonata: Insecta) to change in environmental integrity driven by urbanization in Eastern Amazonian streams. Ecologies 2: 150-163.

CANNINGS RA, CANNINGS SG & CANNINGS RJ. 1980. The distribution of the genus *Lestes* in a saline lake series in central British Columbia, Canada (Zygoptera: Lestidae). Odonatologica 9: 19-28.

CARVALHO AL & NESSIMIAN JL. 1998. Odonata do Estado do Rio de Janeiro, Brasil: Hábitats e hábitos das larvas. Oecol Bras 5: 3-28.

CARVALHO WD & MUSTIN K. 2017. The highly threatened and little known Amazonian savannahs. Nat Ecol Evol 1: 1-3.

CORBET PS. 1980. Biology of odonata. Annu Rev Entomol 25: 189-217.

CORBET PS. 2004. Dragonflies: behaviour and ecology of Odonata. Harley Books, 829 p.

COSTA ML, CARMO MS & BEHLING H. 2005. Mineralogia e geoquímica de sedimentos lacustres com substrato laterítico na Amazônia brasileira. Rev Bras Geocienc 35: 165-176.

D'AMICO F, DARBLADE S, AVIGNON S, BLANC-MANEL S & ORMEROD SJ. 2004. Odonates as indicators of shallow lake restoration by liming: comparing adult and larval responses. Restor Ecol 12: 439-446.

DAVIES DAL & TOBIN P. 1984. The dragonflies of the world: a systematic list of the extant species of Odonata. Vol. 1. Zygoptera, Anisozygoptera. Societas Internationalis Odonatologica Rapid Comm 3: 1-127.

DAVIES DAL & TOBIN P. 1985. The dragonflies of the World: a systematic list of the extant species of Odonata. Vol. 2. Anisoptera. Societas Internationalis Odonatologica Rapid Comm 5: 1-151.

DE BIE T ET AL. 2012. Body size and dispersal mode as key traits determining metacommunity structure of aquatic organisms. Ecol Lett 15: 740-747.

DE MARCO JR P ET AL. 2013. Patterns in the organization of Cerrado pond biodiversity in Brazilian pasture landscapes. Hydrobiologia 723: 87-101.

DE MARCO JÚNIOR P, BATISTA JD & CABETTE HSR. 2015. Community assembly of adult odonates in tropical streams: an ecophysiological hypothesis. PLoS ONE 10(4): e0123023.

DE MARMELS J. 1988. *Sympetrum roraimae* spec. nov. vom venezolanischen Guayana Hochland (Odonata: Libellulidae). Opusc Zool Flum 28: 1-6.

DE MARMELS J. 1989. Odonata or dragonflies from Cerro de la Neblina and the adjacent lowland between the rio Bária, the Casiquiare and rio Negro (Venezuela). I. Adults. Bol Acad Cienc Fis Mat Nat 25: 11-78.

DE MARMELS J. 1992. Dragonflies (Odonata) from the Sierras of Tapirapeco and Unturan, in the extreme south of Venezuela. Acta Biol Venezuel 14: 57-78.

DE MARMELS J & RÁCENIS J. 1982. An analysis of the Cophysa-group of Tramea Hagen, with descriptions of two new species (Anisoptera: Libellulidae). Odonatologica 11: 109-128.

DRAY S, LEGENDRE P & PERES-NETO PR. 2006. Spatial modelling: a comprehensive framework for principal coordinate analysis of neighbour matrices (PCNM). Ecol Model 196: 483-493.

FERREIRA NETO GS, BACCARO FB, SPIRONELLO WR, BENCHIMOL M, FLEISCHER K, QUESADA CA, GONÇALVES ALS, PEQUENO PAL & BARNETT APA. 2021. Soil fertility and anthropogenic disturbances drive mammal species richness and assemblage composition on tropical fluvial islands. Austral Ecol 46: 792-801.

FRANCO EMS, DEL'ARCO JO & RIVETTI M. 1975. Geomorfologia da folha NA.20 (Boa Vista) e parte das folhas NA.21 (Tumucumaque), NB.20 (Roraima) e NB.21. In: DEPARTAMENTO NACIONAL DA PRODUÇÃO MINERAL. Projeto RadamBrasil: levantamento de recursos naturais. Rio de Janeiro: DNPM, v. 8, p. 139-180.

FRANCO GMS & TAKEDA AM. 2002. Spatial and temporal variation of Odonata larvae associated with macrophytes in two floodplain lakes from the upper Paraná River, Brazil. Acta Sci 24: 345-351.

GARRISON RW, VON ELLENRIEDER N & LOUTON JA. 2006. Dragonfly Genera of the New World – An illustrated and annotated key to the Anisoptera. Johns Hopkins University Press, Baltimore, USA, 366 p.

GARRISON RW, VON ELLENRIEDER N & LOUTON JA. 2010. Damselfly Genera of the New World. An Illustrated and Annotated Key to the Zygoptera. The Johns Hopkins University Press, Baltimore, USA, 490 p.

GORHAM CT & VODOPICH DS. 1992. Effects of acidic pH on predation rates and survivorship of damselfly nymphs. Hydrobiologia 242: 51-62.

GOTELLI NJ ET AL. 2009. Patterns and causes of species richness: a general simulation model for macroecology. Ecol Lett 12: 873-886.

GUTIÉRREZ-CÁNOVAS C, MILLÁN A, VELASCO J, VAUGHAN IP & ORMEROD SJ. 2013. Contrasting effects of natural and anthropogenic stressors on beta diversity in river organisms. Glob Ecol Biogeogr 22(7): 796-805.

HEINO J ET AL. 2015. A comparative analysis reveals weak relationships between ecological factors and beta diversity of stream insect metacommunities at two spatial levels. Ecol Evol 5: 1235-1248.

HOFMANN TA & MASON CF. 2005. Habitat characteristics and the distribution of Odonata in a lowland river catchment in eastern England. Hydrobiologia 539: 137-147.

HOLTMANN L, JUCHEM M, BRÜGGESHEMKE J, MÖHLMEYER A & FARTMANN T. 2018. Stormwater ponds promote dragonfly (Odonata) species richness and density in urban areas. Ecol Eng 118: 1-11.

JACOBSEN D & MARÍN R. 2008. Bolivian Altiplano streams with low richness of macroinvertebrates and large diel fluctuations in temperature and dissolved oxygen. Aquat Ecol 42: 643-656.

JUEN L & DE MARCO JR P. 2011. Odonate biodiversity in terra-firme forest streams in Central Amazonia: On the relative effects of neutral and niche drivers at small geographical extents. Insect Conserv Divers 4: 265-274.

LEGENDRE P. 1993. Spatial autocorrelation: Trouble or new paradigm? Ecology 74: 1659-1673.

LEGENDRE P & GALLAGHER ED. 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129(2): 271-280.

LEGENDRE P & LEGENDRE L. 2011. Numerical Ecology. Amsterdam: Elsevier, 853 p.

LEITE GFM, SILVA FTC, NAVARRO FKSP, REZENDE RDS & GONÇALVES JF. 2016. Leaf litter input and electrical conductivity may change density of *Phylloicus* sp. (Trichoptera: Calamoceratidae) in a Brazilian savannah stream. Acta Limnol Bras 28: e12.

LENCIONI FAA. 2005. Damselflies of Brazil - An illustrated identification guide - 1 – Non Coenagrionidae families. All Print Editora, São Paulo, Brasil, 316 p.

LENCIONI FAA. 2006. Damselflies of Brazil - An Illustrated identification guide - 2 - Coenagrionidae. All Print Editora, São Paulo, Brasil, 419 p.

MACHADO ABM, MESQUITA HG & MACHADO PAR. 1995. Contribuição ao conhecimento dos odonatos da estação ecológica de Maracá – Roraima. Acta Amazon 21: 159-173.

MCPEEK MA. 2004. The growth/predation risk trade-off: So what is the mechanism? Am Nat 163: 88-111.

MELIÁN CJ, KŘIVAN V, ALTERMATT F, STARÝ P, PELLISIER L & LAENDER FD. 2015. Dispersal dynamics in food webs. Am Nat 185: 157-168.

MENDES TP, BENONE NL & JUEN L. 2019. To what extent can oil palm plantations in the Amazon support assemblages of Odonata larvae? Insect Conserv Divers 12: 448-458.

MENDES TP, CABETTE HSR & JUEN L. 2015. Setting boundaries: Environmental and spatial effects on Odonata larvae distribution (Insecta). An Acad Bras Cienc 87: 239-248. https://doi.org/10.1590/0001-3765201520130477.

MENDES TP, LUIZA-ANDRADE A, CABETTE HSR & JUEN L. 2018. How does environmental variation affect the distribution of dragonfly larvae (Odonata) in the Amazon-Cerrado transition zone in Central Brazil? Neotrop Entomol 47: 37-45.

MIRANDA IS & ABSY ML. 1997. A Flora Fanerogâmica das Savanas de Roraima. In: Barbosa RI, Ferreira EJG & Castellon EG (Eds), Homem, Ambiente e Ecologia no estado de Roraima. Manaus: INPA, p. 445-453.

MIRANDA IS & ABSY ML. 2000. Fisionomia das savanas de Roraima, Brasil. Acta Amazon 30: 423-440.

MONTEIRO JR CS, JUEN L & HAMADA N. 2015. Analysis of urban impacts on aquatic habitats in the central Amazon basin: Adult odonates as bioindicators of environmental quality. Ecol Indic 48: 303-311.

NEEDHAM JC, WESTFALL MJ & MAY ML. 2000. Dragonflies of North America. Revised edition. Scientific Publishers, Gainesville, 939 p.

OERTLI B, BIGGS J, CÉRÉGHINO R, DECLERCK S, HULL A & MIRACLE MR. 2010. Pond conservation in Europe. Dordrecht: Springer.

OERTLI B, BIGGS J, CÉRÉGHINO R, GRILLAS P, JOLY P & LACHAVANNE J. 2005. Conservation and monitoring of pond biodiversity: introduction. Aquat Conserv Mar Freshw Ecosyst 15: 535-540.

OLIVEIRA JR JMB & JUEN L. 2019. Structuring of dragonfly communities (Insecta: Odonata) in eastern Amazon: Effects of environmental and spatial factors in preserved and altered streams. Insects 10: 322.

OLIVEIRA JR JMB, DIAS-SILVA K, TEODÓSIO MA & JUEN L. 2019. The response of Neotropical dragonflies (Insecta: Odonata) to local and regional abiotic factors in small streams of the Amazon. Insects 10: 446.

PERRON MA, RICHMOND I & PICK FR. 2021. Plants, water quality and land cover as drivers of Odonata assemblages in urban ponds. Sci Total Environ 773: 145467.

PIRES MM, STENERT C & MALTCHIK L. 2018. Drivers of beta diversity of Odonata along a forest–grassland transition in southern Brazilian coastal ponds. Freshw Sci 37: 357-366.

PRANCE GT. 1996. Islands in Amazonia. Philos Trans R Soc Lond B Biol Sci 351: 823-833.

R CORE TEAM. 2024. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

REMSBURG AJ & TURNER MG. 2009. Aquatic and terrestrial drivers of dragonfly (Odonata) assemblages within and among north-temperate lakes. J N Am Benthol Soc 28: 44-56.

ROCHA TS, CALVÃO LB, JUEN L & OLIVEIRA-JUNIOR JMB. 2023. Effect of environmental integrity on the functional composition of the Odonata (Insecta) community in streams in the Eastern Amazon. Front Ecol Evol 11: 1166057. DOI 10.3389/fevo.2023.1166057.

RYCHŁA A, BENNDORF J & BUCZYŃSKI P. 2011. Impact of pH and conductivity on species richness and community structure of dragonflies (Odonata) in small mining lakes. Fundam Appl Limnol 179: 41-50.

SANTOS F, NICASIO K, SILVA K, MARTINS J, PERICO E, DALZOCHIO M & CAJAIBA RL. 2021. Can artificial ponds retain dragonfly (Insecta: Odonata) biodiversity? A preliminary study in the Brazilian Amazon. Austral Entomol 60: 698-706.

SGANZERLA C, DALZOCHIO MS, PRASS GDS & PÉRICO E. 2021. Effects of urbanization on the fauna of Odonata on the coast of southern Brazil. Biota Neotrop 21: e20201122.

SONODA KC. 2025. Efeitos dos usos do solo sobre insetos de ambientes aquáticos brasileiros. Brasília, DF: Embrapa.

THALIB YA, RAZALI RS, MOHAMAD S, RAHMAH S, GHAFFAR MA, NHAN HT & LIEW HJ. 2021. Environmental changes affecting physiological responses and growth of hybrid grouper–The interactive impact of low pH and temperature. Environ Pollut 271: 116375.

VELOSO HP, GOES-FILHO L, LEITE PF, BARROS-SILVA S, FERREIRA HC, LOUREIRO RL & TEREZO EFM. 1975. Folha NA.20 Boa Vista e Parte das Folhas NA.21 Tumucumaque, NB.20 Roraima e NB.21. Rio de Janeiro, Projeto Radambrasil: Vegetação, DNPM, p. 307-406.

VILLALOBOS-JIMÉNEZ G, DUNN A & HASSALL C. 2016. Dragonflies and damselflies (Odonata) in urban ecosystems: a review. Eur J Entomol 113: 217-232.

VON ELLENRIEDER N & GARRISON RW. 2003. A Synopsis of the Genus Triacanthagyna (Odonata: Aeshnidae). Int J Odonatol 6: 147-184.

ZAR JH. 2010. Biostatistical analysis. Upper Saddle River: Pearson Prentice-Hall.

SUPPLEMENTARY MATERIAL

Figure S1.
Table SI.

How to cite

OLIVE EL, MARTINS RT, DIAS-SILVA K, NEISS UG & HAMADA N. 2025. Effects of geographic distance and abiotic variables on larval Odonata assemblages in western Amazon savannah lakes. An Acad Bras Cienc 97: e20250159. DOI 10.1590/0001-3765202520250159.

Manuscript received on February 12, 2025;
accepted for publication on July 29, 2025

EMILY L. OLIVE[1]
https://orcid.org/0000-0003-1537-186X

RENATO T. MARTINS[2]
https://orcid.org/0000-0003-3464-7905

KARINA DIAS-SILVA[3]
https://orcid.org/0000-0001-5548-4995

ULISSES G. NEISS[4]
https://orcid.org/0000-0002-2844-7061

NEUSA HAMADA[1]
https://orcid.org/0000-0002-3526-5426

[1]Instituto Nacional de Pesquisas da Amazônia (INPA), Coordenação de Biodiversidade (COBio), Av. André Araújo, 2936, Petrópolis, 69067-375 Manaus, AM, Brazil

[2]Fundação Oswaldo Cruz (Fiocruz), Instituto Oswaldo Cruz (IOC), Laboratório de Entomologia (LABE), Av. Brasil, 4365, Manguinhos, 21040-900 Rio de Janeiro, RJ, Brazil

[3]Universidade Federal do Pará (UFPA), Programa de Pós-Graduação em Ecologia (PPGECO), Instituto de Ciências Biológicas, Rua Augusto Correia, 1, Guamá, 66075-110 Belém, PA, Brazil

[4]Instituto de Criminalística, Departamento de Polícia Técnico–Científica (DPTC), Av. Arquiteto José Henriques B. Rodrigues, 3760, Monte das Oliveiras, 69093-149 Manaus, AM, Brazil

Correspondence to: **Renato Tavares Martins**
E-mail: martinsrt@gmail.com

Author contributions

Conceptualization: ELO, RTM, KDS, NH; Data curation: ELO; Methodology: ELO, UGN, KDS; Formal analysis: RTM, KDS; Writing - original draft preparation: ELO, RTM, KDS; Writing - review and editing: ELO, RTM, KDS, UGN, NH.