NORTH-WESTERN JOURNAL OF ZOOLOGY 16 (2): 117-124
Article No.: e201101

http://biozoojournals.ro/nwjz/index.html

Odonata assemblages as indicators of stream condition – a test from northern Argentina

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Received: 29. November 2019 / Accepted: 25. January 2020 / Available online: 30. January 2020 / Printed: December 2020

Abstract. The increasing consumption of natural resources due to population growth, and the expansion of agricultural activity have a major impact on freshwater ecosystems. The aim of this study was to verify if possible changes in habitat condition and physical-chemical variables due to different land uses are reflected by changes in Odonata assemblages. In order to do that, we evaluated the conservation status of the riparian zone and the physicochemical parameters of stream waters affected by different degrees of anthropogenic impact, and assessed richness and variation in species composition, testing for potential indicator species of habitat quality. The riparian index allowed the differentiation of three habitat condition categories: conserved, intermediate and degraded. No significant differences were found in species richness between the three conservation states, but it was possible to discriminate between the communities present. Four species showed potential as habitat quality indicators that can serve as biomonitors in future strategies of stream management and conservation.

Key words: bioindicator, land use, dragonfly, IndVal, species assemblage.

Introduction

The increasing consumption of natural resources causes fragmentation, habitat loss and has a major impact on freshwater ecosystems by modifying watercourses, altering their hydrological regime and causing decreases in water quality (Bedient et al. 1994, Hooda et al. 2000, Ometo et al. 2000). The different land uses practices usually extend to the margins of the streams, without considering the recommended buffer zones and prohibitions of national and international legislations and policies aiming their conservation. Streams are frequently used as paths to eliminate various types of waste (domestic, sewage, industrial, etc.), resulting in their consequent contamination. In addition, river banks are often affected by the urbanization process and housing developments, causing landscape modifications, including the broadening and diversion of rivers, construction of artificial dams, lagoons or the interruption of channels (Troitiño et al. 2010). The same happens in rural contexts, where the streams are frequently used as a waste sink and by the livestock taken to water, aside from the increased use of pesticides and fertilizers.

The loss of riparian vegetation is a common result of human activities: increasingly larger areas are assigned to agriculture and livestock farming, urban growth and industrial development. It is well known that the riparian zone is effectively protecting the fluvial system (Troitiño et al. 2010). A conserved margin reduces the erosion, diminishes the infiltration of sediments and other pollutants, and contributes to the maintenance of the autochthonous communities acting as a wildlife corridor (Kauffman & Krueger 1984, Zweig & Rabenni 2001, Sparovek et al. 2002). On the other hand, the removal of the riparian vegetation has a negative effect on the inflow of organic matter that constitutes the primary source of energy in rivers food chains (Delong & Brusven 1994, Pozo et al. 1997). All these modifications result, in most cases, in the reduction of diversity, affecting in various ways the biological communities, sometimes leading to the loss of species sensitive to environmental change (Carvalho et al. 2013, da Silva Monteiro et al. 2013, Juen et al. 2014).

The continued growth of agricultural activity and the increase of human population worldwide makes every issue related to the conservation of streams a research priority.

Although physicochemical indicators are widely used in environmental monitoring due to the ease of sampling procedures and standardization, among other things, there are certain limitations related to the high cost of analyses and the increase in the abundance and types of polluting products that may hinder the evaluation (Li et al. 2010, Springer 2010). In this sense, biological indicators emerge as a way to complement physicochemical indicators and to overcome their limitations. Additionally, they provide tools that allow us to understand how the environment and stress-impact factors influence species dynamics (Karr 1981, Heino et al. 2015). This kind of analysis is being implemented with several organisms, however studies are still scarce, taking into account the diverse hydrography and the lack of protection of aquatic ecosystems (Vörösmarty et al. 2010). Research on the use of abiotic indicators and their possible influence on aquatic fauna is an effective measure to foster the management and conservation of streams and adjacent areas (Juen et al. 2016, Calvão et al. 2018).

Odonata species are valuable tools for conservation and monitoring restoration programs; they have proven to be useful bioindicators of environmental quality (Clark & Samways 1996, Simaika & Samways 2009, Monteiro-Júnior et al. 2014, Miguel et al. 2017, Rocha et al. 2019, Suárez-Tovar et al. 2019), and they are being used in many ecological studies (Sahlén & Ekestubbe 2001, Koch et al. 2014, Renner et al. 2016a, May 2019). These insects present a life cycle that makes them suitable to reflect measures of habitat quality in both aquatic and terrestrial environments. In their larval stage, development occurs in water, and after several molts, an adult capable of flying emerges (Corbet 1999). The as-

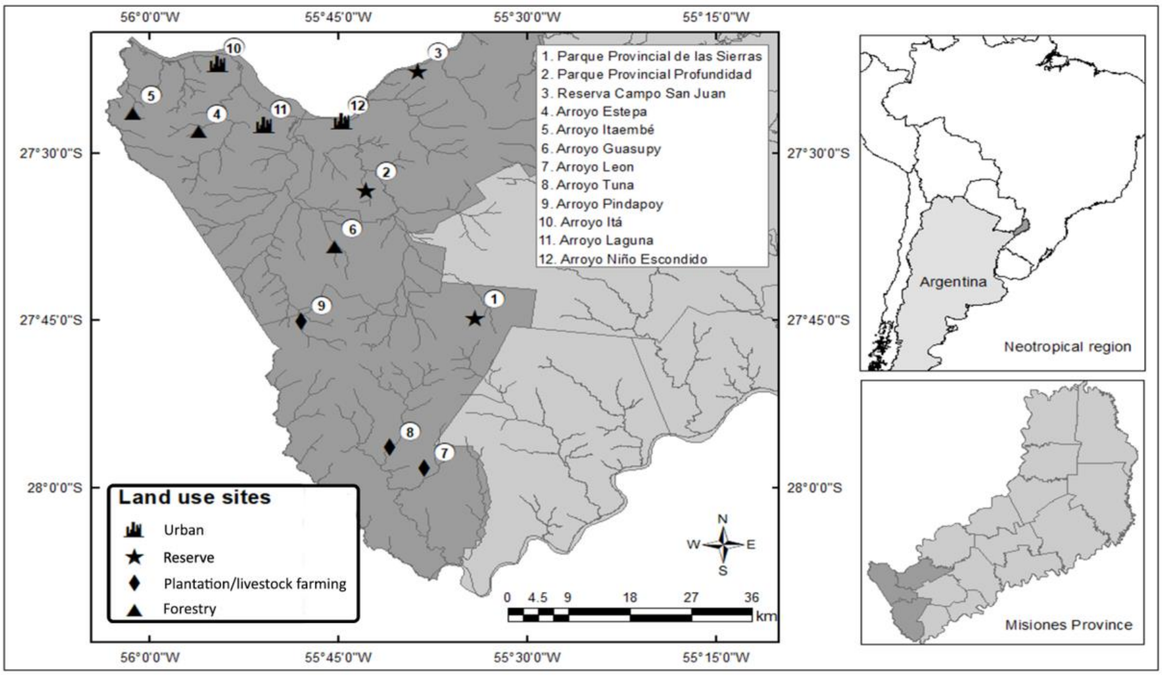

Figure 1. Study area and sampling sites evaluated in southern Misiones, Argentina, 2016-2017.

sembly of adult odonates is usually influenced by the physiognomy and vertical stratification of the marginal vegetation and the presence of aquatic plants (Clark & Samways 1996, Hofmann & Mason 2005), since these are parameters related to habitat selection and oviposition sites (Corbet 1999). Marginal vegetation also regulates local microclimatic conditions (Moore et al. 2005, Carvalho et al. 2013, Rodrigues et al. 2016), and sunlight is one of the determining factors in the behavior of the odonates due to their thermoregulation strategies (De Marco & Resende 2002, De Marco et al. 2015).

The order Odonata is represented by two suborders in the Neotropical region, Zygoptera and Anisoptera. Broadly, Zygoptera are small species, mainly classified as thermal conformers (Corbet 1999, Mckay & Herman 2008). Anisoptera on the other hand, are usually medium-to-large size species, classified as heliothermic, although exceptions are common and some are thermal conformers or endothermic species (Corbet 1999, De Marco & Resende 2002). While the limits in this regard are not always clear for all species, the two suborders are usually treated separately in ecological studies. It has been demonstrated that different eco-physiological requirements may determine odonate species distribution (De Marco et al. 2015), and it is expected that larger species replace smaller ones (e.g. zygopterans replaced by anisopterans) when small stream riparian vegetation is altered or degraded (Pereira et al. 2019).

Our objective in this study was to verify if, in different types of land use gradients, possible changes in habitat condition and physical-chemical variables are reflected by Odonata assemblages. Our first hypothesis was that altered streams present higher Anisoptera richness compared to streams in pristine areas, because several species are opportunistic, with thermoregulatory abilities (May 1979, De Marco et al. 2015) and larger body size (De Marco et al. 2015), which make them less sensitive to the riparian vegetation loss than Zygoptera (Clark & Samways 1996, Corbet 1999, Dolný et al. 2012, Oliveira-Junior et al. 2017). We also expected to find bioindicator species of habitat quality that can serve as biomonitors in future stream management and conservation strategies.

Material and Methods

Study area

The study was carried out in the southern range of the Misiones province (Figure 1). This area corresponds to the "Campos y malezales" ecoregion. It is an ecological transition among the limiting ecoregions: Selva Paranaense to the northeast, Esteros del Iberá and Espinal to the southwest (Matteucci 2012). This location, with the influence of different biogeographical areas, favors the presence of a rich fauna including several regional threatened species like manned wolf and pampas deer (IUCN 2015). The landscape is constituted of pastures and grasslands with isolated forests patches. In addition, a dense canopy forest is accompanying the fluvial courses. The climate is subtropical humid, with uniform rainfall throughout the year, between 1500-1700 mm annually (Cabrera 1994, Matteucci 2012). The literature dealing with this region reports a great floristic diversity due to its peculiar condition of humidity and temperature (Cabrera 1994). Despite this, it is the least protected region of the country (Chebez 2006) and at the same time one of the most threatened because of its small area, increasing forestation with exotic species (mostly *Pinus sp*.) and agriculture.

For our study, we selected the most typical land use types of the region: urban, plantation/livestock farming, forestry, and natural reserve areas as pristine sites. Three streams (up to 3 m wide) for each type of land use were selected with the activity ongoing at the site for at least the last 7 years, considering that there was no interference with other activities and access availability. The data obtained from the two assessments (one during spring and one during summer) performed at each site were combined to capture as much of the biodiversity as possible in every site.

Data collection

Species survey: The collection of adult male Odonata was carried out with aerial nets between 9:00 and 15:00 hrs., which correspond to the period of greatest activity (Corbet 1999). Each site was visited once on November of 2016 and on February of 2017. Adult females were not captured since they are difficult to identify and are hardly found on riverside territories that are usually held by the males (Corbet 1999). In order to determine the abundance and species richness, the Odonata were captured at each site, along 10 transects (10m × 1m) parallel to the riverbank (Simaika & Samways 2009). The insects were identified using taxonomic keys (von Elenrieder & Muzon 1999, Costa et al. 2002, Garrison 2006, von Elenrieder & Garrison 2007, Garrison et al. 2010) and reference collections gently provided by Dr. Muzón from "Laboratorio de Biodiversidad y Genética Ambiental (BIOGEA, UNDAV, Avellaneda, Buenos Aires, Argentina)". Those specimens that could not be identified at a species level were morphotyped.

Habitat condition analysis: Stream integrity was measured based on Nessimian Habitat integrity index (HII) (Nessimian et al. 2008) that focuses on the structural characteristics of the environment in riparian zones (Table 1). Each structural variable is composed of 12 items that assess (i) the land use pattern in the area outside the ciliary forest, (ii) the width and (iii) degree of preservation of the ciliary forest, (iv) condition of the riparian forest within a 10 m distance, (v) retention devices, (vi) channel sediments, (vii) bank structure, (viii) undercutting, (ix) stream bed (x) areas of rapids, pools and meanders, (xi) aquatic vegetation and (xii) debris. For the index calculation, the different variables were weighted according to the scale used in each case. The weighted values were used to calculate the final index for the stream that represents the averaged features. The index ranges from 0 to 1 and is proportional to the integrity of the habitat.

Environmental variables were also measured, since they are also altered by the different land use practices (Troitiño et al. 2010) and may affect Odonata larval development (Corbet 1999). Water temperature was determined with a digital thermometer (WT-1), conductivity was recorded using a portable waterproof potentiometer meter (JENCO 6350). A water sample was taken once at each site for turbidity and nitrates determinations. These analyses were performed by "Programa de Efluentes Indutriales y Urbanos" laboratory (FCEQyN-UNaM, Misiones, Argentina).

Data analysis

To perform the ordering and explore for the main components that structure each type of environment a principal component analysis (PCA) was performed with the HII index and environmental parameters. The broken-stick criterion was used to select the number of axes used in the ordination. Environmental parameters were first normalized to mean 0 and variance 1, to allow comparison. The differences in the variables among the conservation states were tested using the axis scores with Kruskal-Wallis test. According to this, the streams classified as conserved in this study have a habitat index above 0.8, intermediate sites are between 0.5 y 0.8 and the degraded ones have an index under 0.5. All analysis were performed using the Past3 software (Hammer et al. 2001).

To evaluate the hypothesis of low diversity in degraded habitats, species richness was determined based on a first-order jackknife estimator resampling in the Software EstimateS (Collwel 2000), using 1000 repetitions to build a rarefaction curve. The Kruskal Wallis test was used to evaluate differences between the habitat condition categories (conserved, intermediate or degraded) for Odonata community and for each suborder separately. The variation in species composition on different conservation states was explored with a principal coordinate analysis (PCoA) from a Log-transformed matrix of species abundance.

In order to test for potential indicator species of the three habitat condition categories (conserved, intermediate and degraded), the Indicator Value method (IndVal) was used (Dufrene & Legendre 1997). This index is calculated by estimating specificity and fidelity of each species to a given habitat condition. Significance values were obtained from a Monte Carlo randomization test, using 10,000 replicates. All analyses were run in the R software (R Development Core Team 2011) using the Species, Vegan and Indicspecies packages (De Caceres & Legendre 2009, Ji-Ping 2011, Oksanen et al. 2012). All analyses were conducted at 5% significance level.

Results

The first PCA component explained 59.15% of the abiotic parameters variation and was negatively correlated with HII index and turbidity, opposite to nitrates concentration and water temperature that were positively correlated (Table 1).

Table 1. HII parameters and environmental variables used for determination of habitat condition and their contribution to the load of the first component of the PCA analysis.

HII and environmental variables	Loadings	
	PC 1	PC 2
HII index	-0.521	0.066
N-nitrates	0.459	-0.009
Turbidity	-0.447	0.444
Water temperature	0.482	-0.041
Conductivity	0.289	0.892
% Eigenvalue	2.958	0.878
% variance	59.152	17.571

Significant differences ($H=8.69$, $p < 0.01$) were found between the habitat condition categories (conserved, intermediate and degraded) and between each pair of categories ($p < 0.05$).

The intermediate condition sites showed greater variability regarding these parameters (Figure 2) since they correspond to rural areas of agricultural, livestock farming or forestry use. This sites present diffuse limits of the riparian zone, with moderate transit on the banks of the stream and vegetation dominated by grasses, shrubs and isolated trees. The scarce aquatic vegetation is represented mainly by *Ponderia cordata, Eryngium paniculatum* and *Scirpus* sp. The conserved habitat condition corresponds to sites within local and national reserves, presenting restricted human activities, little channel widening (minor to no erosion) and natural riverbank with all three layers of vegetation present that provides abundant shady area on the stream, which could be related to the lower water temperature (Table 2). The degraded condition corresponds to urban areas with high human activity, deteriorate margins and widening of the channel due to erosion. River vegetation is almost absent, with pastures (where *Paspalum sp.* predominates) and few trees or shrubs, resulting in higher exposure to sun light. These sites also have a high concentration of nitrates (Table 2).

Forty-two species of odonates were collected during the sampling. Twenty-three species correspond to Zygoptera (430 individuals) and 19 to Anisoptera (85 individuals). There is a small variation in estimated species richness between the three habitat condition states, but no significant differences were found for Odonata richness, nor for each suborder separately (Figure 3). PCoA shows the variation of the odonatan community according to condition states (Figure 4), capturing 52% of the total variance in two coordinates.

The most widely distributed Zygoptera species were *Hetaerina rosea* and *Peristicta aeneovidridis*, both found in ten of

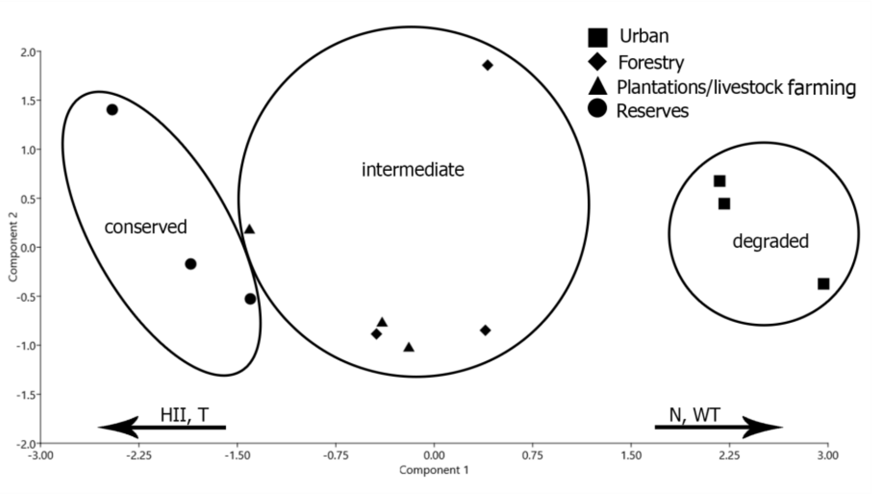

Figure 2. Principal components analysis of the HII and environmental variables considered, representing the sites on the different land uses.

Table 2. Habitat integrity index (HII) and environmental parameters measured in every site.

Conservation state	Land use	Sites	HII index	N-nitrates (mgN/L)	Turbidity (NTU)	Water temperature (ºC)	Conductivity (uS/cm)
Conserved	reserve	1	0.980	0.63	14.00	22.10	38.95
		2	0.922	0.48	29.00	23.80	9.25
		3	0.985	0.58	39.00	21.00	132.80
Intermediate	forestry	4	0.510	0.45	9.90	21.50	32.28
		5	0.623	0.96	11.00	26.20	35.57
		6	0.579	0.34	13.00	23.80	330.50
	plantations/ livestock farming	7	0.556	0.65	10.00	21.30	44.66
		8	0.573	0.65	12.00	24.00	9.27
		9	0.679	0.53	25.00	20.80	73.39
Degraded	urban	10	0.372	1.89	3.10	30.60	145.10
		11	0.345	1.20	7.70	28.00	237.50
		12	0.282	2.40	14.00	24.70	178.70

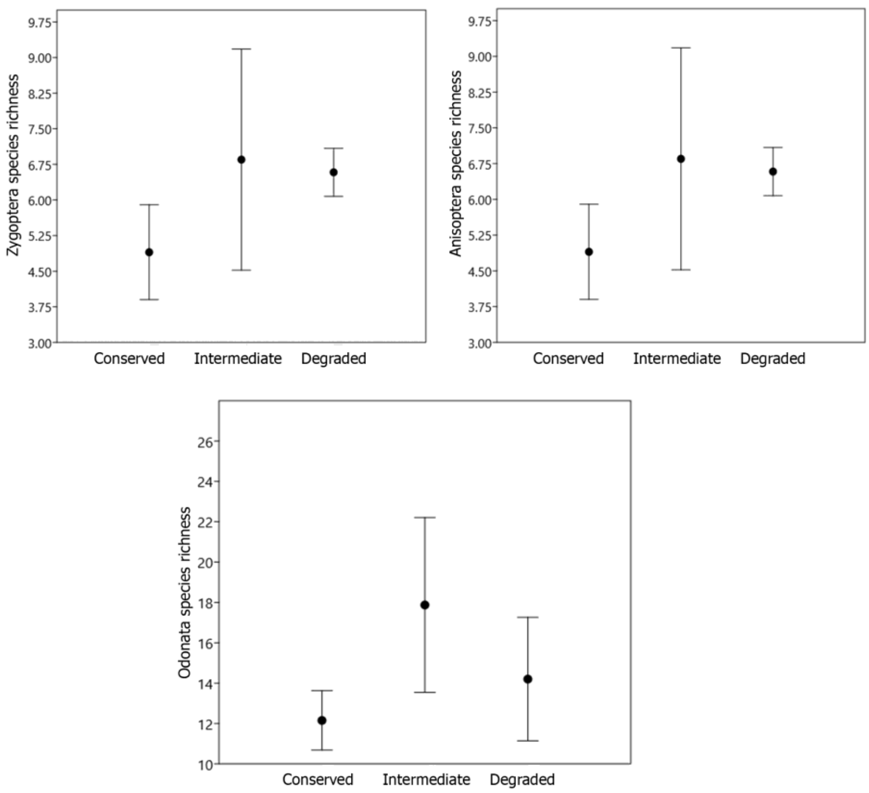

Figure 3. Estimated species richness by first-order jackknife estimator, representing the determined conservation states of streams.

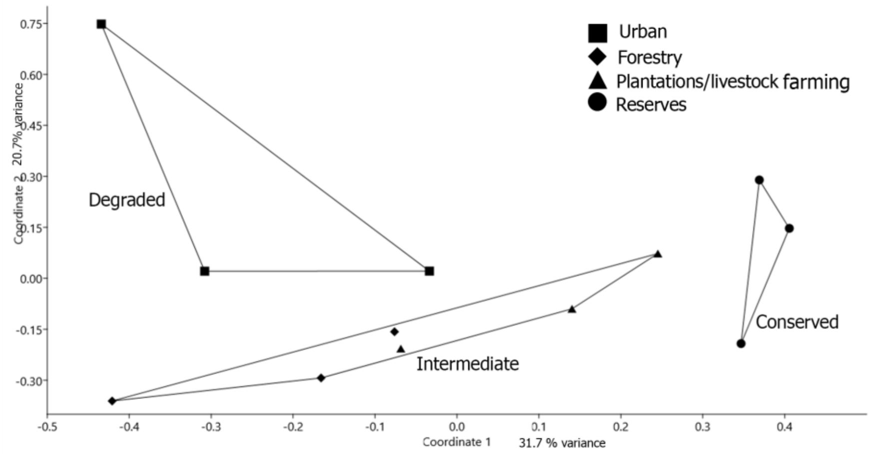

Figure 4. Principal coordinates analysis of odonata species collected in streams affected by different land uses. Eigenvalue first and second coordinate: 0.8 and 0.52 respectively.

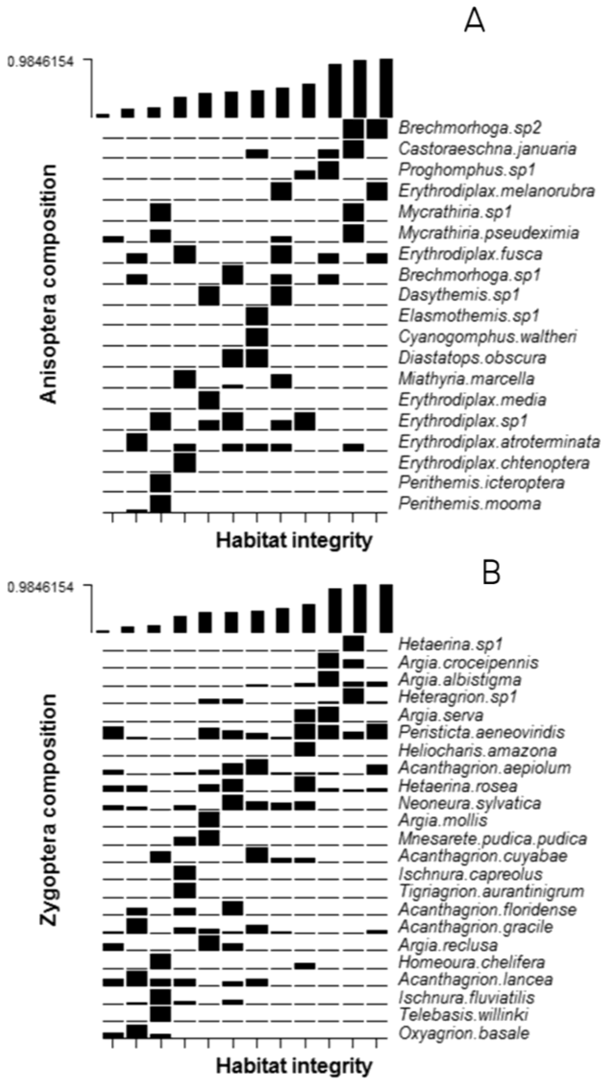

Figure 5. Relative abundance of Anisoptera (A) and Zygoptera (B) species according to habitat condition of the evaluated streams.

the twelve sites evaluated, in all conservation classes, while the most widely distributed Anisoptera species was *Erythrodiplax atroterminata*, collected in six sites and all conservation classes. On the other hand, *Telebasis willinki, Perithemis mooma* and *P. icteroptera* were found exclusively in the degraded environment. *Hetaerina* sp1 and *Brechmorhoga* sp2, were exclusive of conserved environments (Figure 5). Four species of Zygoptera were classified as potential indicators of habitat condition. *Argia croceipennis* and *A. albistigma* were characteristic of conserved streams. *Oxyagrion basale* and *Acanthagrion lancea* for degraded sites (Table 3).

Table 3. Indicator values (IndVal) for Odonata species collected in the streams.

Species	habitat condition	IndVal	pvalue
Argia croceipennis	conserved	0.980	0.021
Argia albistigma	conserved	0.933	0.005
Oxyagrion basale	degraded	0.932	0.007
Acanthagrion lancea	degraded	0.762	0.017

Discussion

Three habitat conservation states were discriminated according to the habitat integrity index HII and the environmental parameters, consistent with the degree of anthropogenic alteration. The main differences between these states were given by HII so the land uses have a great influence on riparian zone conservation. This has direct impact on the physicochemical variables of the water, such is the temperature, which also differed between the condition states. These differences can affect the species assembly due to the fact that the odonates respond differently to stream physiognomy and vertical stratification of marginal vegetation, as both oviposition and perching sites requirements are associated with microclimatic conditions (Corbet 1999, Carvalho et al. 2013, Rodrigues et al. 2016). Habitats in conserved state present detritus consisting of leaves and wood due to the abundant riparian vegetation, which may explain the elevated turbidity values of these sites (Li & Liu 2018). On the other hand, in the degraded habitats there is no riparian forest, but only mixed grasses and sparse pioneer trees present, and the main feature is the high concentration of nitrates due to urban discharges. For rural environments, there is a greater variation between the sites because of the different intensity of agricultural activity: some degree of riparian cover, different grazing intensity, etc., but all of them have intermediate characteristics to those described above.

Species richness did not differ between habitat categories in our study. This may be caused by the fact that several odonate species are good dispersers and usually have a generalist distribution pattern (Nobrega & De Marco Junior 2011, Renner et al. 2016b, Calvão et al. 2018, Šigutová et al. 2019). Our study area is located in the ecoregion of "campos y malezales" and the canopy forest on the streams continues with grassland areas, typically inhabited by Anisoptera. So despite the variation of environmental conditions, the similarity in Anisoptera richness in degraded and their presence also in conserved environments could be explained due to this habitat heterogeneity and the dispersal capacity of these individuals. In fact, the number of Anisoptera species typical of forested habitats (e.g. Castoraeschna) was low compared to species that showed wider habitat preferences. The differences between conservation states were evident in terms of the community composition, and four species showed potential as indicators of habitat quality: *Argia croceipennis*, *A. albistigma*, *Oxyagrion basale* and *Acanthagrion lancea* (Table 3). *Argia croceipennis* and *A. albistigma* were indicators of habitats in conserved condition, these species share habitat feature requirements such as rocks and submerged vegetation among which the larva lives; wooded riverbank with rocks and logs on which the adult perches, and aquatic vegetation in which the female oviposit (Garrison et al. 2010). It is expected of Zygoptera species to be indicators of conserved environments, since they are known to be more sensitive to microhabitat requirements (Carvalho et al. 2013, De Marco et al. 2015), to the characteristics of streams (Monteiro Júnior et al. 2015, Oliveira-Junior et al. 2015) and to the presence of plant structures for endophytic oviposition (De Marco & Resende 2002, Resende & De Marco Jr. 2010). However, there are some Zygoptera species that do not require the protection provided by the canopy cover, as is the case of *Acanthagrion lancea* and *Oxyagrion basale*. In our study, these species had great fidelity and specificity to degraded habitat conditions, and species of these genera establish themselves at streams with slow current (de Assis et al. 2004), marginal vegetation composed of grasses on which the adult settles, and floating plants or masses of algae where the female oviposit (Fulan & Henry 2007, Garrison et al. 2010, Dutra & De Marco 2015). These features are present in degraded environments (Bleich et al. 2015) and therefore, they may have taken advantage of the changes provoked by the urbanization process. This has been proposed before in a study of urban impacts where species of the genus *Erythrodiplax*, typical of lentic systems, appear as bioindicator of disturbed habitats (Monteiro Júnior et al. 2015). In terms of intermediate environments, there are no specific indicators, but rather a mixture of the species present in the communities of the two extremes (degraded and conserved), and species that have some tolerance to anthropogenic alterations or a wider niche, such as *Hetaerina rosea, Erythrodiplax fusca, Acanthagrion gracile* (Dutra & De Marco 2015, Calvão et al. 2018). Although we found exclusive species of intermediate environments (see Figure 4), they were found in low numbers and only in some sites, so they do not match an indicator species.

Our data show coincidences with other works carried out in the subtropical region. For example, it has been reported that *Acanthagrion* and *Oxyagrion* are good indicators of impacted areas and streams with no shading (Dutra & De Marco 2015, Calvão et al. 2018). *Argia reclusa* has also been associated with impacted environments, and in our study it has been found only in a degraded environment (Dutra & De Marco 2015). *Erythrodiplax fusca* was found as indicator of degraded environments on several occasions (Dutra & De Marco 2015, Monteiro Júnior et al. 2015, Oliveira-Junior et al. 2015, Calvão et al. 2018); in our case, this species presents a wide distribution including the conserved environments. *Heteragrion* was indicator of conserved habitat conditions (Monteiro Júnior et al. 2015, Oliveira-Junior et al. 2015) but we also found it in some places affected by agriculture that had, nevertheless, abundant shaded areas. *Argia mollis* was not found in our conserved condition habitats, besides it has been associated to this type of habitat before (Calvão et al. 2018) and was found also in other habitat conditions in this study. Finally, coincident with our study, Monteiro Junior (Monteiro Júnior et al. 2015) detected an *Argia* species as indicator of conserved environments.

There are some advantages for the use of Odonata as bioindicators, such as the simplicity to evaluate a single or several sites very quickly. Unlike water analyzes, Odonata surveys are inexpensive and do not require special treatment or care when transporting samples to the laboratory. In fact, with a little training, most of the identification can be performed in the field. This is also one of the advantages of using adults for the study. The capture of larvae is usually more laborious and the identification is difficult, and even though generic keys for the Neotropical region are now available (e.g. Neiss & Hamada 2014, Neiss et al. 2018), only about 75% of the genera and a much lower percentage of species have been described, and the identification of early stages is almost impossible (Pessacq et al. 2018). Moreover, the correspondence between larvae and adult communities has already been proved significant in other studies (Valente Neto et al. 2015, Mendes et al. 2017). The analysis of the adult Odonata community combined with riparian analysis is an effective and low cost tool for determining habitat quality. Nevertheless, it should be noted that not all parameters used as indicators were useful in this area. Unlike other works (Monteiro Júnior et al. 2015, Miguel et al. 2017, Calvão et al. 2018) species richness did not show significant differences between condition states. This suggest that a previous study in every region is necessary to understand the degree of discrimination that the Odonata community can reach. We are aware that the number of specimens and sites is still low to make a complete analysis about community structure in different land uses and habitat quality, but this data could be considered as a preliminary evaluation for this ecoregion.

Our data reinforces the concept that human disturbance alters riparian vegetation and leads to a loss of environmental quality, consequently altering the Odonata community. It also contributes to the knowledge of the diversity of Odonata in the "campos y malezales" ecoregion. The recovery and protection of these ecosystems is a priority due to the expansion of economic activities in an ecoregion of limited extension. Degradation of aquatic habitats may be reduced by the maintenance of riparian vegetation and urban planning to avoid unregulated urbanization, and thus prevent local extinctions of Odonata species.

Acknowledgement. We would like to thank to Dr. J. Muzón, Dr. R. Garrison and co-workers for the collaboration in the taxonomic identification, to Dr. L. Juen, Dra. C. Brand and Dr. A. Ramírez for the suggestions to the manuscript, to the Ministerio de Ecología y Recursos Naturales de Misiones for authorization to conduct the study in protected areas and to the Entidad Binacional Yacyretá for water analysis financing. This study was supported by the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) through a doctoral scholarship.

References

Assis, J.C.F., Carvalho, A.L., Nessimian, J.L. (2004): Composição e preferência por microhábitat de imaturos de Odonata (Insecta) em um trecho de baixada do Rio Ubatiba, Maricá-RJ, Brasil. Revista Brasileira de Entomologia 48: 273–282.

Bedient, P.B., Rifai, H.S., Newell, C.J. (1994): Ground Water Contamination: Transport and Remediation. Prentice-Hall International, Inc., Englewood Cliffs, USA.

Bleich, M.E., Piedade, M.T.F., Mortati, A.F., André, T. (2015): Autochthonous primary production in southern Amazon headwater streams: Novel indicators of altered environmental integrity. Ecological Indicators 53: 154–161.

Cabrera, A.L. (1994): Regiones Fitogeográficas Argentinas. Enciclopedia Argentina de Agricultura y Jardinería. ACME S.A.C.I., Buenos Aires, Argentina.

Calvão, L.B., Juen, L., de Oliveira Junior, J.M.B., Batista, J.D., De Marco Júnior, P. (2018): Land use modifies Odonata diversity in streams of the Brazilian Cerrado. Journal of Insect Conservation 22: 675–685.

Carvalho, F.G. de, Pinto, N.S., Oliveira Júnior, J.M.B. de, Juen, L. (2013): Effects of marginal vegetation removal on Odonata communities. Acta Limnologica Brasiliensia 25: 10–18.

Chebez, J.C. (2006): Guia de Reservas Naturales de La Argentina, 1 edicion. Latin grafica SRL, Camora, Buenos Aires, pp. 34–100.

Clark, T.E., Samways, M.J. (1996): Dragonflies (Odonata) as Indicators of Biotope Quality in the Kruger National Park, South Africa. Journal of Applied Ecology 33: 1001–1012.

Collwel, R.K. (2000): Estimates: statistical estimation of species richness and shared species from samples version 7.5. Software and User's Guide. <http://viceroy.eeb.uconn.edu/estimates/>. Accessed at: 2018.11.30.

Corbet, P.S. (1999): Dragonflies: Behavior and Ecology of Odonata. Comstock Pub Assoc, Ithaca, New York.

Costa, J.M., Lourenço, A.N., Vieira, L.P. (2002): Micrathyria pseudhypodidyma sp. n. (Odonata: Libellulidae), com Chave das Espécies do Gênero que Ocorrem no Estado do Rio de Janeiro. Neotropical Entomology 31: 377–389.

De Caceres, M., Legendre, P. (2009): Associations between species and groups of sites: indices and statistical inference. Ecology 90: 3566–3574.

De Marco, P.Jr., Resende, D.C. (2002): Activity patterns and thermoregulation in a tropical dragonfly assemblage. Odonatologica 2: 129–138.

De Marco, P.Jr., Batista, J.D., Cabette, H.S.R. (2015): Community Assembly of Adult Odonates in Tropical Streams: An Ecophysiological Hypothesis. PLOS ONE 10: e0123023.

Delong, M.D., Brusven, M.A. (1994): Allochthonous input of organic matter from different riparian habitats of an agriculturally impacted stream. Environmental Management 18: 59–71.

Dolný, A., Harabiš, F., Bárta, D., Lhota, S., Drozd, P. (2012): Aquatic insects indicate terrestrial habitat degradation: changes in taxonomical structure and functional diversity of dragonflies in tropical rainforest of East Kalimantan. Tropical Zoology 25: 141–157.

Dufrene, M., Legendre, P. (1997): Species Assemblages and Indicator Species: The Need for a Flexible Asymmetrical Approach. Ecological Monographs 67: 345–366.

Dutra, S., De Marco, P. (2015): Bionomic differences in odonates and their influence on the efficiency of indicator species of environmental quality. Ecological Indicators 49: 132–142.

von Elenrieder, N., Muzon, J. (1999): The Argentinean species of the genus Perithemis Hagen (Anisoptera: Libellulidae). Odonatologica 28: 385–398.

von Elenrieder, N., Garrison, R.W. (2007): Dragonflies and Damselflies (Insecta: Odonata) of the Argentine Yungas: Species composition and identification. Scientific Reports, Società Zoologica 'La Torbiera', Italy 7: 1–13.

Fulan, J.Â., Henry, R. (2007): Distribuição temporal de imaturos de Odonata (Insecta) associados a Eichhornia azurea (Kunth) na Lagoa do Camargo, Rio Paranapanema, São Paulo. Revista Brasileira de Entomologia 51: 224–227.

Garrison, R.W. (2006): A synopsis of the genera Mnesarete Cowley, *Bryoplathanon* Gen. Nov., and *Ormenoplebia* Gen. Nov. (Odonata: Calopterygidae). Contributions in Science 506: 1–84.

Garrison, R.W., von Ellenrieder, N., Louton, J.A. (2010): Dragonfly Genera of the New World: An Illustrated and Annotated Key to the Anisoptera, The Johns Hopkins University Press. Baltimore, USA.

Hammer, Ø., Harper, D.A.T., Ryan, P.D. (2001): PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica 4: 1–9.

Heino, J., Soininen, J., Alahuhta, J., Lappalainen, J., Virtanen, R. (2015): A comparative analysis of metacommunity types in the freshwater realm. Ecology and Evolution 5: 1525–1537.

Hofmann, T.A., Mason, C.F. (2005): Habitat characteristics and the distribution of Odonata in a lowland river catchment in eastern England. Hydrobiologia 539: 137–147.

Hooda, P.S., Edwards, A.C., Anderson, H.A., Miller, A. (2000): A review of water quality concerns in livestock farming areas. Science of The Total Environment 250: 143–167.

Ji-Ping, W. (2011): SPECIES: An R Package for Species Richness Estimation. Journal of Statistical Software 40: 1–15.

Juen, L., Oliveira-Junior, J.M.B. de, Shimano, Y., Mendes, T.P., Cabette, H.S.R. (2014): Composição e riqueza de Odonata (Insecta) em riachos com diferentes níveis de conservação em um ecótone Cerrado-Floresta Amazônica. Acta Amazonica 44: 223–233.

Juen, L., Cunha, E., Carvalho, F., Ferreira, M., Begot, T., Andrade, A., Shimano, Y., Sousa, H., Pompeu, P., Montag, L. (2016): Effects of Oil Palm Plantations on the Habitat Structure and Biota of Streams in Eastern Amazon: Effect of Oil Palm on the Structure of Stream. River Research and Applications 32: 2081–2094.

Karr, J.R. (1981): Assessment of Biotic Integrity Using Fish Communities. Fisheries 6: 21–27.

Kauffman, J.B., Krueger, W.C. (1984): Livestock impacts on riparian ecosystems and streamside management implications...a review. Rangeland Ecology & Management / Journal of Range Management Archives 37: 430–438.

Koch, K., Wagner, C., Sahlén, G. (2014): Farmland versus forest: comparing changes in Odonata species composition in western and eastern Sweden. Insect Conservation and Diversity 7: 22–31.

Li, D., Liu, S. (2018): Water Quality Monitoring and Management: Basis, Technology and Case Studies. Academic Press.

Li, L., Zheng, B., Liu, L. (2010): Biomonitoring and Bioindicators Used for River Ecosystems: Definitions, Approaches and Trends. Procedia Environmental Sciences 2:1510–1524.

Matteucci, S.D. (2012): Ecorregión Campos y Malezales. pp. 247–263. In: J. Morello, S.D. Matteucci, A. Rodriguez, M. Silva. Ecorregiones y Complejos Ecosistémicos Argentinos, Orientación Gráfica Editora S.R.L.

May, M.L. (1979): Energy Metabolism of Dragonflies (Odonata: Anisoptera) at Rest and During Endothermic Warm-Up. Journal of Experimental Biology 83: 79–94.

May, M.L. (2019): Odonata: Who They Are and What They Have Done for Us Lately: Classification and Ecosystem Services of Dragonflies. Insects 10(3): art.62.

Mckay, T., Herman, T. (2008): Thermoregulatory constraints on behavior: patterns in a neotropical dragonfly assemblage. Odonatologica 27: 29–39.

Mendes, T.P., Oliveira-Junior, J.M.B., Cabette, H.S.R., Batista, J.D., Juen, L. (2017): Congruence and the Biomonitoring of Aquatic Ecosystems: Are Odonate Larvae or Adults the Most Effective for the Evaluation of Impacts. Neotropical Entomology 46: 631–641.

Miguel, T.B., Oliveira-Junior, J.M.B., Ligeiro, R., Juen, L. (2017): Odonata (Insecta) as a tool for the biomonitoring of environmental quality. Ecological Indicators 81: 555–566.

Monteiro Júnior, C. da S., Juen, L., Hamada, N. (2015): Analysis of urban impacts on aquatic habitats in the central Amazon basin: Adult odonates as bioindicators of environmental quality. Ecological Indicators 48: 303–311.

Monteiro-Júnior, C.S., Juen, L., Hamada, N. (2014): Effects of urbanization on stream habitats and associated adult dragonfly and damselfly communities in central Brazilian Amazonia. Landscape and Urban Planning 127: 28–40.

Moore, R.D., Spittlehouse, D.L., Story, A. (2005): Riparian Microclimate and Stream Temperature Response to Forest Harvesting: A Review. Journal of the American Water Resources Association 41: 813–834.

Neiss, U., Fleck, G., Pessacq, P., Tennessen, K. (2018): Odonata: Superfamily Libelluloidea. pp. 399-447. In: Hamada, N., Thorp, J.H., Rogers, C. Thorp and Covich's Freshwater Invertebrates: Volume 3: Keys to Neotropical Hexapoda, Academic Press, San Diego, USA.

Neiss, U.G., Hamada, N. (2014): Ordem Odonata (Capitulo 14). pp. 217 284. In: Hamada, N., J.L. Nessimian & R.B. Querino (Eds.). Insetos Aquaticos Na Amazonia Brasileira: Taxonomia, Biologia e Ecologia. Editora do INPA, Manaus.

Nessimian, J.L., Venticinque, E.M., Zuanon, J., De Marco, P.Jr., Gordo, M., Fidelis, L. (2008): Land use, habitat integrity, and aquatic insect assemblages in Central Amazonian streams. Hydrobiologia 614: art.117.

Nobrega, C.C., De Marco Junior, P. (2011): Unprotecting the rare species: a niche-based gap analysis for odonates in a core Cerrado area. Diversity and Distributions 17:491–505.

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P., O'Hara, R., Simpson, G., Solymos, P., Stevenes, M., Wagner, H. (2012): Vegan: Community Ecology Package. R package version 2.0-2.

Oliveira-Junior, J.M.B. de, Shimano, Y., Gardner, T.A., Hughes, R.M., Júnior, P. de M., Juen, L. (2015): Neotropical dragonflies (Insecta: Odonata) as indicators of ecological condition of small streams in the eastern Amazon. Austral Ecology 40: 733–744.

Oliveira-Junior, J.M.B. de, De Marco, P., Dias-Silva, K., Leitão, R.P., Leal, C.G., Pompeu, P.S., Gardner, T.A., Hughes, R.M., Juen, L. (2017): Effects of human disturbance and riparian conditions on Odonata (Insecta) assemblages in eastern Amazon basin streams. Limnologica 66: 31–39.

Ometo, J.P.H.B., Martinelli, L.A., Ballester, M.V., Gessner, A., Krusche, A.V., Victoria, R.L., Williams, M. (2000): Effects of land use on water chemistry and macroinvertebrates in two streams of the Piracicaba river basin, south-east Brazil. Freshwater Biology 44: 327–337.

Pereira, D.F.G., de Oliveira Junior, J.M.B., Juen, L. (2019): Environmental changes promote larger species of Odonata (Insecta) in Amazonian streams. Ecological Indicators 98: 179–192.

Pessacq, P., Muzon, J., Neiss, U.G. (2018): Order Odonata. pp. 838. In: Hamada, N., Thorp, J.H., Thorp, R.C. (eds), Covich's Freshwater Invertebrates: Volume 3: Keys to Neotropical Hexapoda. Academic Press.

Pozo, J., González, E., Diez, J.R., Molinero Ortiz, J., Elosegi, A. (1997): Inputs of Particulate Organic Matter to Streams with Different Riparian Vegetation. Journal of the North American Benthological Society 16: 602–611.

R Development Core Team. (2011): R: a language and environment for statistical computing. R Foundation for statistical Computing, Vienna.

Renner, S., Sahlén, G., Périco, E. (2016a): Testing Dragonflies as Species Richness Indicators in a Fragmented Subtropical Atlantic Forest Environment. Neotropical Entomology 45: 231–239.

Renner, S., Périco, E., Sahlén, G. (2016b): Effects of exotic tree plantations on the richness of dragonflies (Odonata) in Atlantic Forest, Rio Grande do Sul, Brazil. International Journal of Odonatology 19: 207–219.

Resende, D.C., De Marco Jr., P. (2010): First description of reproductive behavior of the Amazonian damselfly *Chalcopteryx rutilans* (Rambur) (Odonata, Polythoridae). Revista Brasileira de Entomologia 54: 436–440.

Rocha, M., Rodríguez, P., Córdoba-Aguilar, A. (2019): Spatial and temporal effects of land use change as potential drivers of odonate community composition but not species richness. Biodiversity and Conservation 28: 451–466.

Rodrigues, M.E., de Oliveira Roque, F., Quintero, J.M.O., de Castro Pena, J.C., de Sousa, D.C., De Marco Junior, P. (2016): Nonlinear responses in damselfly community along a gradient of habitat loss in a savanna landscape. Biological Conservation 194: 113–120.

Sahlén, G., Ekestubbe, K. (2001): Identification of dragonflies (Odonata) as indicators of general species richness in boreal forest lakes. Biodiversity & Conservation 10: 673–690.

Šigutová, H., Šipoš, J., Dolný, A. (2019): A novel approach involving the use of Odonata as indicators of tropical forest degradation: When family matters. Ecological Indicators 104: 229–236.

da Silva Monteiro, C.J., Couceiro, S.R.M., Hamada, N., Juen, L. (2013): Effect of vegetation removal for road building on richness and composition of Odonata communities in Amazonia, Brazil. International Journal of Odonatology 16: 135–144.

Simaika, J.P., Samways, M.J. (2009): Reserve selection using Red Listed taxa in three global biodiversity hotspots: Dragonflies in South Africa. Biological Conservation 142: 638–651.

Sparovek, G., Beatriz Lima Ranieri, S., Gassner, A., Clerice De Maria, I., Schnug, E., Ferreira dos Santos, R., Joubert, A. (2002): A conceptual framework for the definition of the optimal width of riparian forests. Agriculture, Ecosystems & Environment 90: 169–175.

Springer, M. (2010): Biomonitoreo acuático. Revista de Biología Tropical 58: 53–59.

Suárez-Tovar, C.M., Rocha-Ortega, M., González-Voyer, A., González-Tokman, D., Córdoba-Aguilar, A. (2019): The larger the damselfly, the more likely to be threatened: a sexual selection approach. Journal of Insect Conservation 23: 535–545.

Troitiño, E., Costa, M.C., Ferrari, L., Giorgi, A. (2010): La conservación de las zonas ribereñas de arroyos pampeanos. Actas Del Congreso de Hidrología de Llanuras 2010: 1256–1263.

Valente Neto, F., De Olvera Roque, F., Rodrigues, M.E., Juen, L. (2015): Toward a practical use of Neotropical odonates as bioindicators: Testing congruence across taxonomic resolution and life stages. Ecological Indicators 62: 952–959.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R., Davies, P.M. (2010): Global threats to human water security and river biodiversity. Nature 467: 555–561.

Zweig, L.D., Rabenni, C.F. (2001): Biomonitoring for deposited sediment using benthic invertebrates: A test on 4 Missouri streams. Journal of the North American Benthological Society 20: 643–657.