Environ Monit Assess (2020) 192: 194
https://doi.org/10.1007/s10661-020-8147-z

Aquatic insects and their environmental predictors: a scientometric study focused on environmental monitoring in lotic environmental

Leandro Schlemmer Brasil · **Ana Luiza-Andrade** · **Lenize Batista Calvão** ·
Karina Dias-Silva · **Ana Paula Justino Faria** · **Yulie Shimano** ·
José Max Barbosa Oliveira-Junior · **Mylena Neves Cardoso** · **Leandro Juen**

Received: 4 September 2019 / Accepted: 5 February 2020 / Published online: 21 February 2020

Abstract Since early studies about aquatic ecology, it has been found that changes in environmental conditions alter aquatic insect communities. Based on this, the combined study of environmental conditions and aquatic insect communities has become an important tool to monitor and manage freshwater systems. However, there is no consensus about which environmental predictors and facets of diversity are more useful for environmental monitoring. The objective of this work was to conduct a scientometric analysis to identify the main environmental predictors and biological groups used to monitor and manage lotic freshwater systems. We conducted a scientometric study on the Web of Science platform using the following words: stream, river, aquatic insect, Ephemeroptera, Plecoptera, Trichoptera, Odonata, Heteroptera, Chironomidae, bioindicator, environmental change, anthropic, and land use. Although most of the environmental predictors employed are local, intrinsic of freshwater systems using local environmental and associated landscape variables is a better strategy to predict aquatic insect communities. The facets of diversity most used are composition and richness of species and genera, which are not efficient at measuring the loss of ecosystem services and extinction of phylogenetic lineages. Although very important, these functional

---

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10661-020-8147-z) contains supplementary material, which is available to authorized users.

L. S. Brasil (✉) · A. Luiza-Andrade · L. B. Calvão ·
M. N. Cardoso · L. Juen
Programa de Pós-Graduação em Zoologia, UFPA/MPEG,
Instituto de Ciências Biológicas, Universidade Federal do Pará,
Rua Augusto Corrêa, N° 1, Bairro Guamá, Belém, Pará CEP
66075-110, Brazil
e-mail: brasil_biologia@hotmail.com

K. Dias-Silva
campus de Altamira, Programa de Pós-Graduação em
Biodiversidade e Conservação-PPGBC, Faculdade de Ciências
Biológicas, Universidade Federal do Pará-UFPA, Altamira, Pará,
Brazil

L. B. Calvão · A. P. J. Faria · J. M. B. Oliveira-Junior
Programa de Pós-Graduação em Ecologia-PPGECO, Instituto de
Ciências Biológicas, Universidade Federal do Pará, Rua Augusto
Corrêa, N° 1, Bairro Guamá, Belém, Pará CEP 66075-110, Brazil

Y. Shimano
Instituto Nacional de Pesquisa do Pantanal, campus avançado do
Museu Paraense Emílio Goeldi, INPP/MPEG, Av. Fernando
Corrêa da Costa, n° 2367-,Bairro Boa Esperança, Cuiabá, Mato
Grosso CEP 78060-900, Brazil

J. M. B. Oliveira-Junior
Instituto de Ciências e Tecnologia das Águas (ICTA), Rua Vera
Paz, s/n (Unidade Tapajós) Bairro, Universidade Federal do Oeste
do Pará (UFOPA), Av. Fernando Corrêa da Costa, n° 2367-, Bairro
Boa Esperança, Salé, Santarém 68040-255, Brazil

and phylogenetic facets are poorly explored for this purpose. Even though tropical regions are the most diverse globally and are experiencing major losses of native vegetation, these ecosystems are the least studied, a knowledge gap that needs addressing to better understand the effect of anthropogenic activities on the diversity of aquatic insects.

Keywords Environmental change · EPT · Land use · Spatial scale

Introduction

It has been well documented that local physical environmental conditions, or environmental factors of a particular area, affect the diversity of natural communities (Ricklefs 1987). Ecological proposals, such as the River Continuum Concept (Vannote et al. 1980) and Flood Pulse Concept (Junk et al. 1989), indicate that local environmental variables (e.g., allochthonous and autochthonous energy, width of water bodies, amount of vegetation cover, rainfall, productivity, and flow) directly influence the distribution of aquatic organisms. Thus, it can be affirmed that natural characteristics of a region can lead to different mechanisms that influence the distribution patterns of aquatic biota (Heino et al. 2018).

In addition to the various natural factors that limit the distribution of aquatic insects, anthropogenic disturbances also affect these communities, mainly because they modify the environmental conditions of an ecosystem (Malmqvist 2002). The main anthropic actions that directly use hydric resources are related to agriculture, urbanization, and industrialization, such as the construction of dams and canals, exploration for subterranean water, direct water collection (Sabater et al. 2018), and accessing more fertile soil. At the end of the 1950s, Hutchinson (1959) reported difficulties in finding aquatic insect species in regions changed by agricultural activities. However, at this time, he did not know that with the exponential growth of the human population, natural areas would be gradually suppressed (Song et al. 2018) and that his observations would become one the main lines of research in aquatic ecology.

To summarize all this theoretical framework about community ecology and insert in a landscape context, the theory of metacommunities emerged (Leibold et al. 2004). A metacommunity is a biogeographic unit formed by a set of communities that has the ability of exchange species for dispersal (Grönroos et al. 2013). This theory can be summarized by four paradigms: Path-dynamic paradigm predicts that the occurrence of path where there were extinctions is affected by interspecific interactions that are neutralized by dispersion processes. Species-sorting paradigm considers that environmental filters select species along environmental gradients. Mass-effects paradigm says that dispersal variations affect species distribution at different spatial scales and act at different time scales. Neutral paradigm predicts that dispersion and use characteristics of the species intrinsic habitat are irrelevant. Therefore, neutral paradigm is considered a null hypothesis for the other three paradigms above. In practical terms, considering the randomness of dispersion, extinction, and local speciation, it is possible to find patterns of diversity structured by spatial autocorrelation.

Today, the responses of aquatic insect communities to anthropogenic environmental changes started to be used as a tool to monitor freshwater environments (Resh and Unzicker 1975). Biodiversity can be assessed from taxonomic, functional, and phylogenetic diversity; however, most of the works is focused on taxonomic facet. Changes in community structure caused by anthropogenic actions have been observed in several facets of diversity, such as richness (e.g., Astorga et al. 2011; Ligeiro et al. 2013; Cunha et al. 2015; Brasil et al. 2019), species composition (e.g., Faria et al. 2017), abundance of individuals (e.g., Paiva et al. 2017), beta diversity (e.g., Cunha and Juen 2017; Brasil et al. 2017), and functional diversity (e.g., Péru and Dolédec 2010).

In addition to the community level approach, it is possible to diagnose the conditions of an environment based on one or some species at the population level because, depending on the group studied, diversity measures can exhibit different responses. However, although some groups, such as Ephemeroptera, Plecoptera, and Trichoptera (EPT), lose species and individuals in altered environments (Siegloch et al. 2017), other groups, such as Oligochaeta, benefit from these changes and increase in number of species and individuals (Martins et al. 2017). Thus, it is important to identify which environmental factors can affect or benefit aquatic insects, since environmental monitoring programs are based on the distribution of species and how they respond to different environmental conditions (Roque et al. 2008).

In Amazonia, for example, there are some dragonfly species (Order Odonata) that live most of their lives in the marginal vegetation along small streams that are ectotherms and depend on the microclimatic condition of the forest to survive (Carvalho et al. 2018). Further, when a forest is converted to agrosystems, some species, such as *Heteragrion aurantiacum* Selys, 1862, and *Protoneura tenuis* Selys, 1860, decrease until they become locally extinct (Oliveira-Junior et al. 2015; Miguel et al. 2017). Other taxa, such as *Zelusia* (Ephemeroptera) and *Kempnyia* (Plecoptera), are bioindicators of streams that are more environmentally complex, while *Farrodes* and *Miroculis* (Ephemeroptera) are more tolerant and survive in forested areas of intermediate complexity (Polegatto and Froehlich 2003; Siegloch et al. 2017).

The scale at which anthropogenic environmental changes occur can also influence changes in aquatic insect communities. Three scales are notable: (i) impacts at the regional scale, which are related to changes in land use in a region that drains into an freshwater system, for example, a hydrographic microbasin that drains into a stream (Allan et al. 1997; Allan 2004); (ii) impacts in a riparian zone, which are environmental changes along the margins of freshwater systems (Naiman and Decamps 1997), for example, when riparian vegetation around rivers or streams is removed (Rodrigues et al. 2016); and (iii) impacts that occur within freshwater systems, for example, sewage disposal in a lake, river, or stream (Martins et al. 2017). Individually or acting in synergy, environmental changes at these three scales cause significant changes in aquatic biota and, consequently, in ecosystem services (Allan 2004).

However, considering all the important aspects of studying the influence of environmental changes on the ecology of aquatic insects (variations in soil use, scale of change, diversity metrics, and taxonomic groups), it is difficult to have a wide vision of the real effects of anthropization. Although there is a lot of research about this area, the accumulation of information about different taxonomic groups, geographic areas, and type of change can go unnoticed depending on the focus of the study. For this reason, scientometric studies can be important to synthesize the amount of excessive information. According to Mingers and Leydesdorff (2015), scientometrics is the field of study that is most directly related to the evaluation and exploration of scientific research.

Thus, the objective of this work was to conduct scientometric study to identify the main environmental predictors and efficient biological groups for monitoring and managing lotic freshwater systems. Although meta-analyzes already exist on the effect of local and spatial environmental variables on biodiversity (Soininen 2014; Gál et al. 2019), this has never been done on a large scale focused on environmental monitoring. Therefore, this scientometric review brings a degree of innovation by compiling this information and discussing it for environmental monitoring purposes using aquatic insect communities.

Material and methods

Quantitative aspects were collected from scientific articles published in English, Spanish, and Portuguese from 1994 to 2017. The articles were compiled based on the indexed data on the ISI Web of Knowledge (Thomson Reuters) site, using the following keywords: “Stream*” OR ”river*” AND “Aquatic insect*” OR “Ephemeroptera*” OR “Plecoptera*” OR “Trichoptera*” OR “Odonata*” OR “Heteroptera*” OR “Chironomid*” AND “Bioindicator*” OR “environmental change*” OR “anthropic*” OR “land use*” in titles, abstracts, and keywords. The database was accessed in April of 2018 using the Portal de Periódicos da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-CAPES do Brasil (http://apps-webofknowledge.ez3.periodicos.capes.gov.br). For years, the ISI Web of Knowledge (Thomson Reuters) database has been an available tool for indexing scientific literature and is internationally recognized for providing important data about different areas of research related to science and technology and is effective for both recent and old articles.

Only articles that tested a hypothesis related to aquatic insect communities and environmental predictors were included; descriptive, review, and distribution model articles were excluded. All of the works were tabulated in an electronic matrix with the following information: i) climate region (tropical or temperate); ii) local (e.g., physicochemical variables of the water, channel structure), and regional (e.g., land use in microbasin, vegetation cover in riparian zone) environmental predictors; iii) group (e.g., Ephemeroptera, Odonata, Diptera); and iv) facet of diversity (e.g., species richness, abundance of individuals). Those results were expressed in percentage graphs. The database search resulted in 533 articles, among which 355 fit the mentioned criteria.

Results and discussion

Of the 355 articles, almost 80% were conducted in temperate regions comparing with tropical regions. For the type of environment, little has been published that

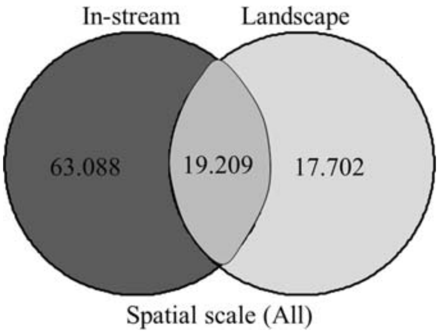
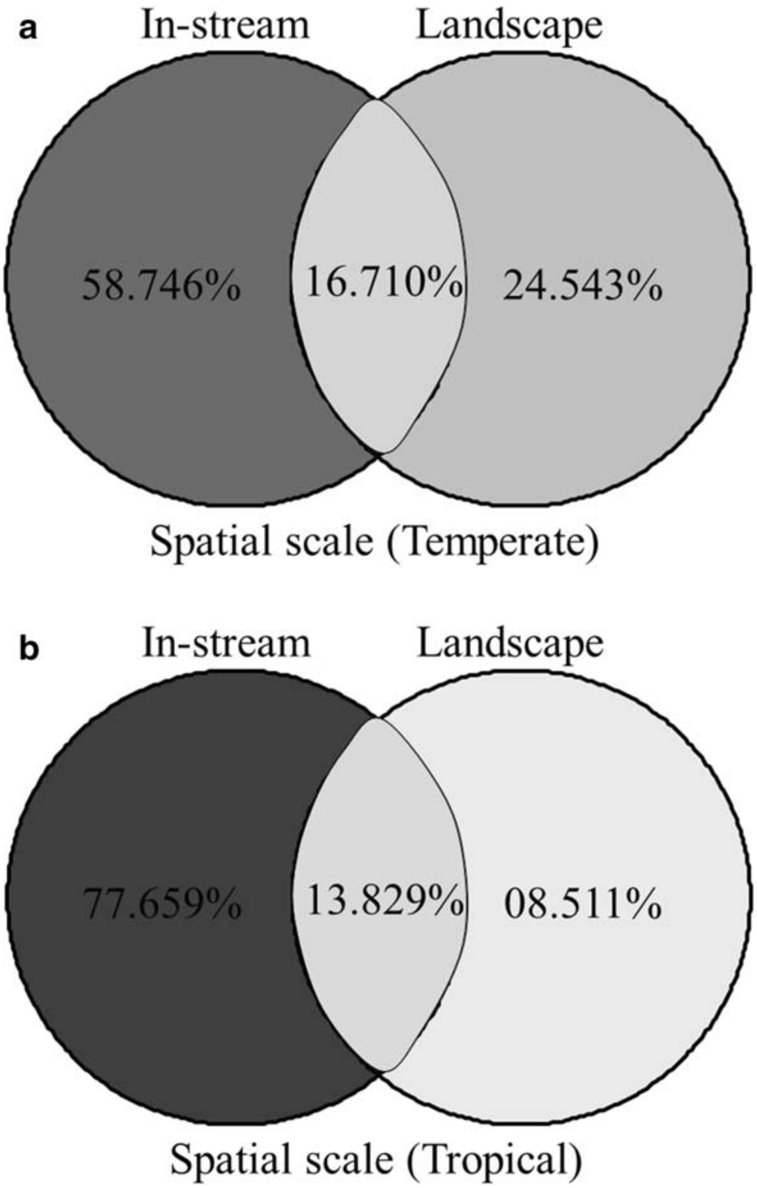


Fig. 1 Number of articles that use in-stream and landscape predictors alone or in combination for study aquatic insect communities

compares science developed in temperate and tropical regions. Evidently, freshwater environments in the tropics differ ecologically from those in temperate zones in their physical, chemical, and biological attributes (Kwok et al. 2007). However, many countries in the subtropics and tropics are still developing and lack financing, infrastructure, and other resources (Kwok et al. 2007) that could help in advancing research related to freshwater systems. Many areas of these regions have become densely populated and rapidly industrialized and their freshwater systems may be under threat due to degradation. Thus, there is an urgent need to establish

Fig. 2 Number of articles that use in-stream and landscape predictors alone or in combination to study aquatic insect communities in temperate and tropical regions



public policies to encourage research and safeguard the biodiversity in these areas.

Even though about 75% of global biodiversity is found in tropical ecosystems (e.g., wetland, freshwater, and marine) (Kwok et al. 2007) and the tropical basin encompasses the largest area of climate zones on Earth (Wantzen et al. 2006), there is a need for broader and more representative studies of systems in tropical zones to standardize patterns so they can be compared with studies conducted in temperate zones. Thus, the scenario that the gradients of diversity in freshwater environments receive less attention than marine and terrestrial environments (Boyero 2002) should be changed.

Which environmental predictors are used the most for aquatic insect communities?

The predictor variables were grouped into in-stream variables, which represent local predictors and encompass all the physicochemical variables of the water and channel morphology and landscape variables, which represent regional predictors and encompass land use and the riparian zone. As a result, 63% of the works used in-stream predictors, 18% used landscape predictors, and 19% used both in-stream and landscape predictors (Fig. 1).

The discrepancy observed between the use of local and regional predictors is even larger when we separate the climate regions. In temperate environments, the difference is subtle. On the other hand, tropical environments show a high difference between landscape predictors, in-stream predictors, and both landscape and in-stream (Fig. 2).

Kim et al. (2016) conducted a scientometric study with limnological works and showed that the number of studies at the landscape level seems to have increased starting in 2010 and that these works have been more frequently related to the keywords “soil use” and “drainage basin.” Thus, we can infer that local studies are more numerous due to the difficulty of obtaining financial resources, human resources, and the limitations of techniques used for landscape analyses. This picture is even clearer when we observe the difference between studies conducted in tropical areas, where there are more developing countries, and temperate areas, where there are more developed countries that have a better structured scientific body. In the coming years, we will probably see an increase in the number of studies at the landscape level, within and outside tropical regions, considering the greater availability of published data and technological advancements related to the internet and techniques used to analyze and compare data from different sites and collection methods.

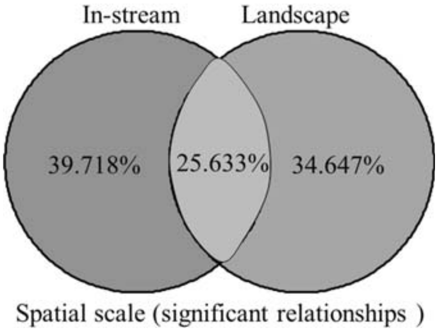


Fig. 3 Number of articles that used in-stream and landscape predictors alone or in combination that have significant relationships to predict aquatic insect communities

Among the environmental predictors used, which are the most important for aquatic insect communities?

When analyzing the absolute values of the relation of the environmental predictors with the communities of aquatic insects, most part of the articles had significant relationships only for the in-stream variables, following by only for the landscape variables, and for both the in-stream and landscape variables (Fig. 3).

However, the number of articles that used in-stream predictors and the number of articles that used landscape predictors are not comparable (see Fig. 2). Therefore, when analyzing the number of articles, 74.936% of the studies with a combination of in-stream and landscape variables found significant relationships with aquatic insect communities, as opposed to 39.718% when only

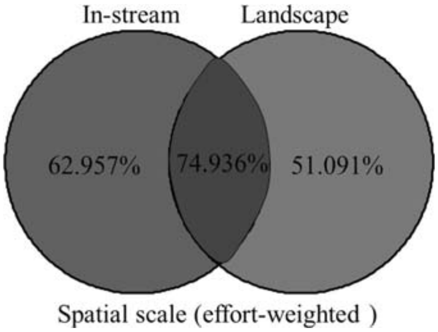


Fig. 4 Number of articles that used in-stream and landscape predictors alone and in combination with significant results for the predictors of aquatic insect communities. For each group of predictors (in-stream and/or landscape), the proportions refer to the number of articles that found significant results in relation to the number of times each group of predictors was used

in-stream predictors were used and 34.647% when only landscape predictors were used (Fig. 4). Thus, a combined analysis of predictors at a local and regional scale (in-stream and landscape) seems to be more efficient at explaining how the environmental predictors relate to aquatic insect communities. The influence of the landscape and stream characteristics on aquatic communities has been discussed for some time; landscape characteristics (width of riparian vegetation, relief and type) affect the conditions and, consequently, the organisms in a stream (Allan and Johnson 1997; Steinman and Denning 2005).

Considering only the in-stream environmental predictors with significant relationships with aquatic insect communities, 43.971% were physicochemical variables of the water, 36.170% referred to channel morphology, and 19.858% included both the water and channel morphology variables. Considering only the landscape environmental predictors with significant relationships with the aquatic insect communities, 76.422% were exclusive to land-use change, 16.260% were exclusive to riparian zone, and 7.312% included both land-use change and riparian zone (Fig. 5, Table 1).

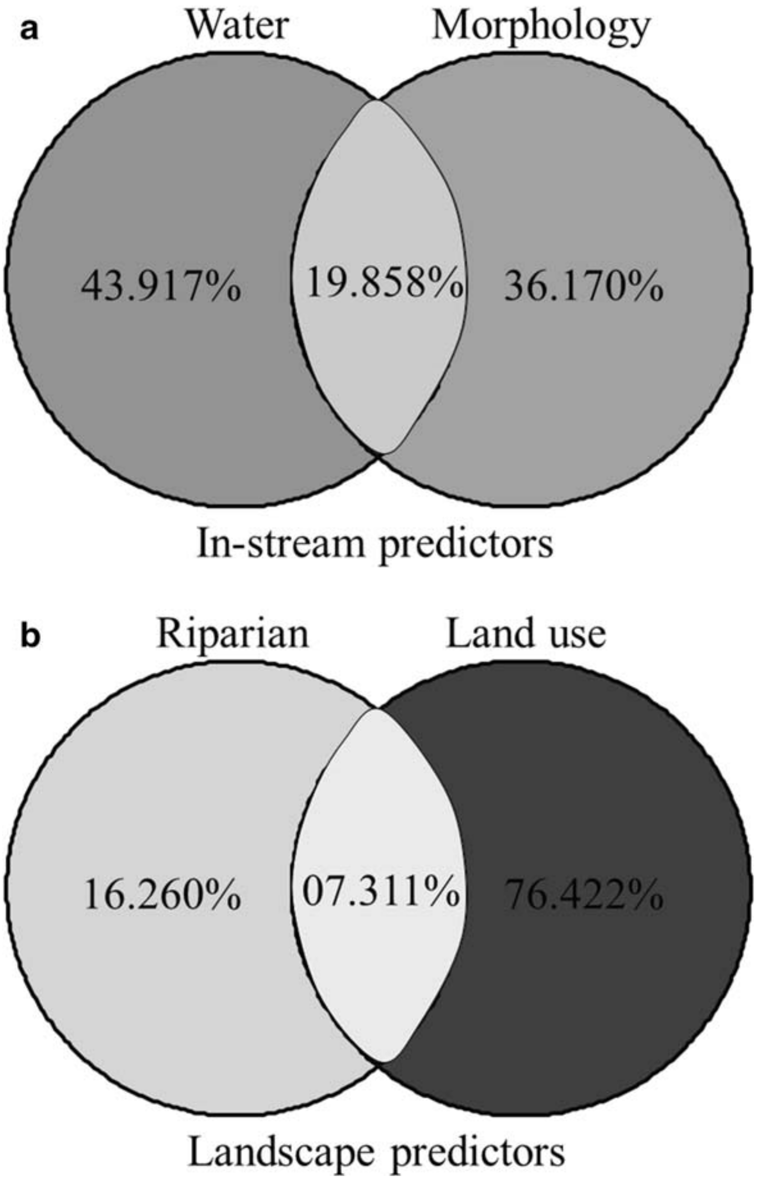


Fig. 5 Detailed description of the articles that used in-stream and landscape predictors to evaluate aquatic insect communities

Table 1 Relation of the ten in-stream and ten landscape environmental predictors for aquatic insect communities

Main in-stream predictors	Main landscape predictors
1 Nutrients (12.862%)	1 Land use (45.914%)
2 Substrate type (09.963%)	2 Canopy cover (20.622%)
3 Dissolved oxygen (08.152%)	3 Vegetation type (07.782%)
4 Electrical conductivity (07.789%)	4 Catchment size (07.003%)
5 Water temperature (07.608%)	5 Altitude (06.614%)
6 pH (06.702%)	6 Connectivity (02.334%)
7 Habitat structure (05.615%)	7 Precipitation (01.945%)
8 Average depth (03.623%)	8 Geographic position (01.945%)
9 Average width (03.442%)	9 Air temperature (01.556%)
10 Average velocity (03.079%)	10 Width of riparian forest (01.167%)
Other predictors (31.165%)	Other predictors (03.180%)

While land use seems to be closely related to large-scale patterns, local effects appear to be more represented by the chemistry of the water influencing aquatic communities. Forest loss at the landscape level negatively impacts ecosystems at the local scale, mainly due to the loss of environmental integrity (Macedo et al. 2013). The environmental consequences for freshwater ecosystems include changes in the concentrations of nutrients, increase in water temperature, degradation of riparian forest, and an increase in the flow rate of sediment (Macedo et al. 2013).

Which taxonomic groups are used the most in response to variations in environmental conditions?

When conducting studies that relate aquatic insect communities to environmental predictors, an important factor is selecting the taxonomic group that will be the response variable. For this, the entire community, only one taxon, or various taxonomic groups can be used, considering their specificities in relation to the environmental conditions. Here, it was verified that most of the articles that report a significant relation between aquatic insects and environmental predictors used the entire community of aquatic insects as the response variable. This represented 60.037% of the total, followed by the combined or separate use of the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT), and then Diptera, Odonata, Coleoptera, and Heteroptera (1.983%). The remaining taxa accounted for less than 1% of the articles (Fig. 6).

The response of communities to environmental predictors is intrinsically related to the specificity of the sensitivity, tolerance, and resistance of organisms to environmental variations, which vary based

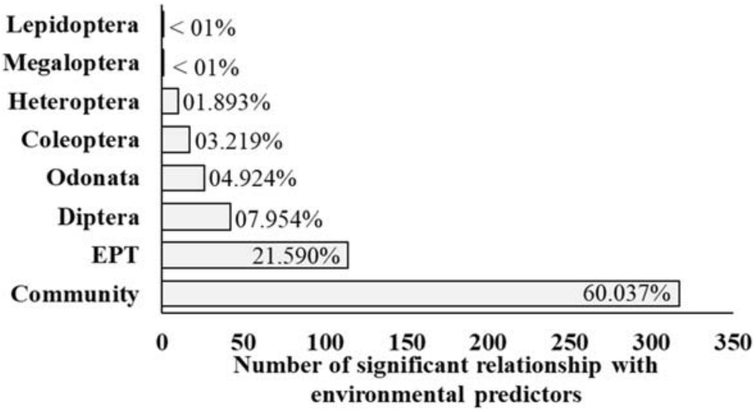


Fig. 6 Most used taxonomic groups in the articles that evaluate the importance of environmental predictors of aquatic insect communities. EPT = Ephemeroptera, Plecoptera, and Trichoptera

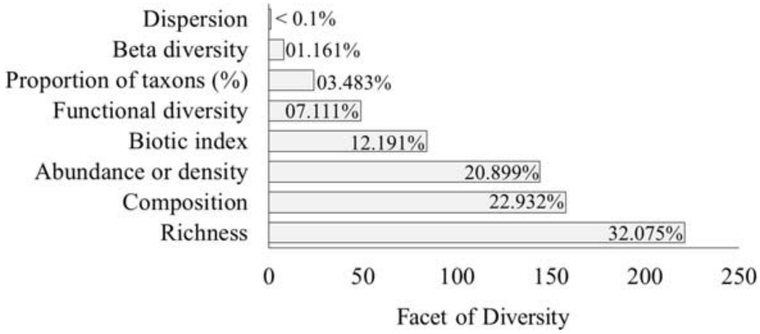


Fig. 7 Most used facets of diversity in the articles that evaluate the importance of environmental predictors for aquatic insect communities

on the environmental conditions (Martins et al. 2017). However, to investigate this in a more specific way, only one taxonomic group in the community in commonly used, such as Odonata (Oliveira-Junior et al. 2015), EPT (Faria et al. 2017), or Heteroptera (Dias-Silva et al. 2010).

Among these groups, Ephemeroptera, Plecoptera, and Trichoptera (EPT) are used the most (Vinson and Hawkins 2003). The high representativeness of these studies could be related to the wide distribution of these taxa and is undoubtedly due to the important role EPT play as bioindicators of lotic freshwater systems. Trichoptera are sensitive to pollutants in freshwater environments and, thus, have been used as crucial indicators in determining environmental quality. Worldwide, studies have demonstrated that anthropogenic activities exert a significant effect on the diversity of EPT (Mehari et al. 2014; Chi et al. 2017).

Which metrics of diversity are most affected by variations in environmental predictors?

In addition to evaluating which taxa are used the most in works, it is also important to define which facet of diversity has been studied the most. For the articles that reported a significant relation between aquatic insects and environmental predictors, the highest percentage used richness of genera or species, followed by composition of species or genera, abundance or density of individuals, biotic indices, functional diversity, and proportion between taxa, beta diversity, and dispersion (Fig. 7).

Similarly, Miller et al. (2010) conducted a meta-analysis to verify the response of macroinvertebrates to environmental restoration and found that species richness is positively affected when trying to restore disturbed areas. Thus, considering our results and the evidence found by Miller et al. (2010), it is evident that the richness of species or genera of aquatic insects is often affected by variations in environmental conditions.

Conclusion

To understand the direct relationship between aquatic insect communities and environmental predictors, it is important to conduct a multi-scale analysis between the lotic freshwater systems, riparian zone, and regional landscape. Traditional metrics of diversity are the most explored (richness and composition of species and genera and abundance or density of individuals).

Functional and phylogenetic diversity, which can be used to measure changes in ecosystem services and loss of evolutionary lineages, respectively, are still poorly explored aspects for aquatic invertebrates. We emphasize that even though tropical environments are more diverse and contain native vegetation that is being suppressed by diverse anthropic activities, these regions are less studied, and the studies are less comprehensive compared with those conducted in temperate environments.

Finally, understanding this dynamic is of great relevance in determining priorities and gaps in research areas and helps explain the effect of anthropic activities on the diversity of aquatic insects in various parts of the world. We hope that this study contributes to a better understanding of these gaps.

Acknowledgements L.S.B. thanks to "Coordenação de Aperfeiçoamento de Pessoal de Nível Superior" (CAPES) for the Postdoctoral Scholarship (Process 086/2013). L.J. receives continuous research support from "Conselho Nacional de Desenvolvimento Científico e Tecnológico" (CNPq) productivity grants (Process 304710/2019-9). A.L.A. thanks to "CNPq" for the

Doctoral Scholarship (141991/2016-0). L.B.C. and A.P.J.F. thank BRC consortium and Norsk Hydro for financial support and L.B.C. the CNPq Postdoctoral Scholarship (process 154761/2018-4). J.M.B.O.J. thanks Universidade Federal do Oeste do Pará (Ufopa) for his authorization toleave the country to participate in the Postdoctoral Internship at the Universidade do Algarve/CCMAR, Portugal (Ordinance No. 708/GR-Ufopa of 27 November 2018, rectified by No. 178, of 4 April 2019).

References

Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution, and Systematics*. https://doi.org/10.1146/annurev.ecolsys.35.120202.110122.

Allan, J., & Johnson, L. (1997). Catchment-scale analysis of aquatic ecosystems. *Freshwater Biology*. https://doi.org/10.1046/j.1365-2427.1997.00155.x.

Allan, D., Erickson, D., & Fay, J. (1997). The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology, 37*(1), 149–161.

Astorga, A., Heino, J., Luoto, M., & Muotka, T. (2011). Freshwater biodiversity at regional extent: determinants of macroinvertebrate taxonomic richness in headwater streams. *Ecography*. https://doi.org/10.1111/j.1600-0587.2010.06427.x.

Boyero, L. (2002). Insect biodiversity in freshwater ecosystems: is there any latitudinal gradient? *Marine and Freshwater Research*. https://doi.org/10.1071/MF01232.

Brasil, L. S., Vieira, T. B., de Oliveira-Junior, J. M. B., Dias-Silva, K., & Juen, L. (2017). Elements of metacommunity structure in Amazonian Zygoptera among streams under different spatial scales and environmental conditions. *Ecology and Evolution*. https://doi.org/10.1002/ece3.2849.

Brasil, L. S., Silverio, D. V., Cabette, H. S. R., Batista, J. D., Vieira, T. B., Dias-Silva, K., & Juen, L. (2019). Net primary productivity and seasonality of temperature and precipitation are predictors of the species richness of the Damselflies in the Amazon. *Basic and Applied Ecology*. https://doi.org/10.1016/j.baae.2019.01.001.

Carvalho, F. G., de Oliveira Roque, F., Barbosa, L., de Assis Montag, L. F., & Juen, L. (2018). Oil palm plantation is not a suitable environment for most forest specialist species of Odonata in Amazonia. *Animal Conservation*. https://doi.org/10.1111/acv.12427.

Chi, S., Li, S., Chen, S., Chen, M., Zheng, J., & Hu, J. (2017). Temporal variations in macroinvertebrate communities from the tributaries in the Three Gorges Reservoir Catchment, China. *Revista Chilena de Historia Natural, 90*, 1–11. https://doi.org/10.1186/s40693-017-0069-y.

Cunha, E. J., & Juen, L. (2017). Impacts of oil palm plantations on changes in environmental heterogeneity and Heteroptera (Gerromorpha and Nepomorpha) diversity. *Journal of Insect Conservation, 21*, 111–119. https://doi.org/10.1007/s10841-017-9959-1.

Cunha, E. J., Montag, L. F. A., & Juen, L. (2015). Oil palm crops effects on environmental integrity of Amazonian streams and Heteropteran (Hemiptera) species diversity. *Ecological Indicators*. https://doi.org/10.1016/j.ecolind.2014.12.024.

Dias-Silva, K., Cabette, H. S., Juen, L., & De Marco Jr, P. (2010). The influence of habitat integrity and physical-chemical water variables on the structure of aquatic and semi-aquatic Heteroptera. *Zoologia*. https://doi.org/10.1590/s1984-46702010000600013.

Faria, A. P. J., Ligeiro, R., Callisto, M., & Juen, L. (2017). Response of aquatic insect assemblages to the activities of traditional populations in eastern Amazonia. *Hydrobiologia, 802*, 39–51. https://doi.org/10.1007/s10750-017-3238-8.

Gál, B., Szivák, I., Heino, J., & Schmera, D. (2019). The effect of urbanization on freshwater macroinvertebrates–knowledge gaps and future research directions. *Ecological Indicators, 104*, 357–364. https://doi.org/10.1016/j.ecolind.2019.05.012.

Grönroos, M., Heino, J., Siqueira, T., Landeiro, V. L., Kotanen, J., & Bini, L. M. (2013). Metacommunity structuring in stream networks: roles of dispersal mode, distance type, and regional environmental context. *Ecology and Evolution, 3*(13), 4473–4487. https://doi.org/10.1002/ece3.834.

Heino, J., Melo, A. S., Jyrkänkallio-Mikkola, J., Petsch, D. K., Saito, V. S., Tolonen, K. T., et al. (2018). Subtropical streams harbour higher genus richness and lower abundance of insects compared to boreal streams, but scale matters. *Journal of Biogeography*. https://doi.org/10.1111/jbi.13400.

Hutchinson, G. E. (1959). Homage to Santa Rosalia or why are there so many kinds of animals? *The American Naturalist, 93*(870), 145–159.

Junk, W. J., Bayley, P. B., & Sparks, R. E. (1989). The flood pulse concept in river-floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences, 106*(1), 110–127.

Kim, J. Y., Joo, G. J., Kim, H. W., Kim, G. Y., & Do, Y. (2016). A scientometric study of the limnological societies: inferences of research collaboration and core topics based on publication networks. *Inland Waters*. https://doi.org/10.1080/IW-6.3.849.

Kwok, K. W., Leung, K. M., Lui, G. S., Chu, V. K., Lam, P. K., Morritt, D., et al. (2007). Comparison of tropical and temperate freshwater animal species' acute sensitivities to chemicals: implications for deriving safe extrapolation factors. *Integrated Environmental Assessment and Management: An International Journal*. https://doi.org/10.1002/ieam.5630030105.

Leibold, M. A., Holyoak, M., Mouquet, N., Amarasekare, P., Chase, J. M., Hoopes, M. F., ... & Loreau, M. (2004). The metacommunity concept: a framework for multi-scale community ecology. *Ecology Letters, 7*(7), 601–613. https://doi.org/10.1111/j.1461-0248.2004.00608.x.

Ligeiro, R., Hughes, R. M., Kaufmann, P. R., Macedo, D. R., Firmiano, K. R., Ferreira, W. R., Oliveira, D., et al. (2013). Defining quantitative stream disturbance gradients and the additive role of habitat variation to explain macroinvertebrate taxa richness. *Ecological Indicators*. https://doi.org/10.1016/j.ecolind.2012.09.004.

Macedo, M. N., Coe, M. T., DeFries, R., Uriarte, M., Brando, P. M., Neill, C., & Walker, W. S. (2013). Land-use-driven stream warming in southeastern Amazonia. *Philosophical*

Transactions of the Royal Society, B: Biological Sciences. https://doi.org/10.1098/rstb.2012.0153.

Malmqvist, B. (2002). Aquatic invertebrates in riverine landscapes. *Freshwater Biology*. https://doi.org/10.1046/j.1365-2427.2002.00895.x.

Martins, R. T., Couceiro, S. R., Melo, A. S., Moreira, M. P., & Hamada, N. (2017). Effects of urbanization on stream benthic invertebrate communities in Central Amazon. *Ecological Indicators*. https://doi.org/10.1016/j.ecolind.2016.10.013.

Mehari, A. K., Wondie, A., Mingist, M., & Vijverberg, J. (2014). Spatial and seasonal variation in the macro-invertebrates and physico-chemical parameters of the Enfranz River, Lake Tana sub-basin (Ethiopia). *Ecohydrology & Hydrobiology*. https://doi.org/10.1016/j.ecohyd.2014.07.004.

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*. https://doi.org/10.1016/j.ecolind.2017.06.010.

Miller, S. W., Budy, P., & Schmidt, J. C. (2010). Quantifying macroinvertebrates responses to in-stream habitat restorarion: applications of meta-analysis to river restorarion. *Restoration Ecology*. https://doi.org/10.1111/j.1526-100X.2009.00605.x.

Mingers, J., & Leydesdorff, L. (2015). A review of theory and practice in scientometrics. *European Journal of Operational Research*. https://doi.org/10.1016/j.ejor.2015.04.002.

Naiman, R. J., & Decamps, H. (1997). The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics, 28*(1), 621–658.

Oliveira-Junior, J. M. B., Shimano, Y., Gardner, T. A., Hughes, R. M., de Marco Júnior, P., & Juen, L. (2015). Neotropical dragonflies (Insecta: Odonata) as indicators of ecological condition of small streams in the eastern Amazon. *Austral Ecology*. https://doi.org/10.1111/aec.12242.

Paiva, C. K. S., Faria, A. P. J., Calvão, L. B., & Juen, L. (2017). Effect of oil palm on the Plecoptera and Trichoptera (Insecta) assemblages in streams of eastern Amazon. *Environmental Monitoring and Assessment, 189*, 1–9. https://doi.org/10.1007/s10661-017-6116-y.

Péru, N., & Dolédec, S. (2010). From compositional to functional biodiversity metrics in bioassessment: a case study using stream macroinvertebrate communities. *Ecological Indicators*. https://doi.org/10.1016/j.ecolind.2010.02.011.

Polegatto, C. M., & Froehlich, C. P. (2003). Feeding strategies. In E. Gaino (Ed.), *Atalophlebiinae (Ephemeroptera: Leptophlebiidae), with considerations on scraping and filtering. Research Update on Ephemeroptera & Plecoptera* (pp. 55–61). Perugia: University of Perugia.

Resh, V. H., & Unzicker, J. D. (1975). Water quality monitoring and aquatic organisms: the importance of species identification. *Journal - Water Pollution Control Federation*, 9–19.

Ricklefs, R. E. (1987). Community diversity: relative roles of local and regional processes. *Science, 235*, 167–171.

Rodrigues, M. E., de Oliveira Roque, F., Quintero, J. M. O., de Castro Pena, J. C., de Sousa, D. C., & Junior, P. D. M. (2016). Nonlinear responses in damselfly community along a gradient of habitat loss in a savanna landscape. *Biological Conservation*. https://doi.org/10.1016/j.biocon.2015.12.001.

Roque, F. O., Lecci, L. S., Siqueira, T., & Froehlich, C. G. (2008). Using environmental and spatial filters to explain stonefly occurrences in southeastern Brazilian streams: implications for biomonitoring. *Acta Limnologica Brasiliensia, 20*(1), 117–130.

Sabater, S., Bregoli, F., Acuña, V., Barcelo, D., Elosegi, A., Ginebreda, A., Marcé, R., Muñoz, I., Sabater-Liesa, L., & Ferreira, V. (2018). Effect of human-driven water stress on river ecosystems: a meta-analysis. *Nature, 8*, 1–11. https://doi.org/10.1038/s41598-018-29807-7.

Siegloch, A. E., Schmitt, R., Spies, M., Petrucio, M., & Hernández, M. I. M. (2017). Effects of small changes in riparian forest complexity on aquatic insect bioindicators in Brazilian subtropical streams. *Marine and Freshwater Research*. https://doi.org/10.1071/MF15162.

Soininen, J. (2014). A quantitative analysis of species sorting across organisms and ecosystems. *Ecology, 95*(12), 3284–3292. https://doi.org/10.1890/13-2228.1.

Song, X. P., Hansen, M. C., Stehman, S. V., Potapov, P. V., Tyukavina, A., Vermote, E. F., & Townshend, J. R. (2018). Global land change from 1982 to 2016. *Nature*. https://doi.org/10.1038/s41586-018-0411-9.

Steinman, D., & Denning, R. (2005). The role of spatial heterogeneity in the management of freshwater resources. In G. M. Lovett, C. G. Jones, M. G. Turner, & K. C. Weathers (Eds.), *Ecosystem function in heterogeneous landscapes* (pp. 367–387). New York: Springer.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., & Cushing, C. E. (1980). The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences, 37*(1), 130–137.

Vinson, M. R., & Hawkins, C. P. (2003). Broad-scale geographical patterns in local stream insect genera richness. *Ecography, 26*, 751–767.

Wantzen, K. M., Ramírez, A., & Winemiller, K. O. (2006). New vistas in Neotropical stream ecology-preface. *Journal of the North American Benthological Society, 25*, 61–65.