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A scientometric study of the order Odonata with special attention to Brazil

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The insects of the order Odonata have an aquatic larval stage and land-dwelling adults. These insects play an important role in aquatic ecosystems and are excellent bioindicators. The present study was based on a scientometric analysis of the research available on the Odonata, which aimed to identify the principal trends and gaps in the database on these organisms, compiled online from databases of the Institute for Scientific Information – ISI, Scielo and journals *Odonatologica* and *International Journal of Odonatology*. A total of 2317 papers were analyzed, permitting the detection of the following tendencies: a gradual increase in the number of papers occurred over time, most of the papers had an ecological perspective, most focused primarily on the adult stage and species level, and 49 studies focused on bio-indication by examining variation in the composition of the community, fluctuating asymmetry, bioaccumulation, species richness and abundance, and odonate habitat index (OHI). The increase in the ecological studies of odonates may reflect the dynamic characteristics of this order, and its relatively well-defined systematics, principally in the case of the adults. Despite the increase in the number of publications, there are still many gaps, such as biogeography, parasitism, competition within and among species, evolutionary and phylogenetic relationships, as well as studies of the larval stages of these organisms. Given the sensitivity of the members of this order to environmental variables, they may be used for the evaluation of aquatic systems, given their roles as detectors, exploiters or accumulators, depending on the type of response to environmental modifications.

Keywords: scientific production; knowledge gaps; indexation; literature review; bioindicators; Anisoptera; Zygoptera; dragonfly

Introduction

The insects of the order Odonata, known popularly as dragonflies and damselflies, form a group of approximately seven thousand species (Kalkman et al., 2008). These insects have long attracted the interest of scientists, due to the importance of their roles in both aquatic and terrestrial ecosystems (Corbet, 1999). Odonates are found throughout the world, constituting one of the most important groups of predator insects, found primarily in association with aquatic environments (Samways & Steytler, 1996). In the immature phase, odonates may be associated

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with aquatic plants or the bottom substrates of watercourses (Corbet, 1999; Juen, Cabette, & De Marco, 2007), and as adults (terrestrial or aerial forms), they need bodies of water in which to reproduce (Corbet, 1999). They play an active role in the transfer of energy, through their predatory habits in aquatic systems and in particular, the interface between aquatic and terrestrial ecosystems (Knight, McCoy, Chase, McCoy, & Holt, 2005).

Odonata are attractive to the general public due to their large size, coloration, charisma, and because most species are easy to observe (Carle, 1979; De Marco & Vianna, 2005). These insects are also sensitive to environmental change in riparian vegetation (Carvalho, Pinto, Oliveira Junior, & Juen, 2013; Monteiro Júnior, Couceiro, Hamada, & Juen, 2013; Oertli, 2008; Pinto, Juen, Cabette, & De Marco, 2012), due to the fact that many species are specialists and require very specific conditions (Oertli, 2008). On the other hand, some species may thrive in naturally modified environments (Samways & Grant, 2008) and in anthropogenic habitats (Simaika, Samways, & Frenzel, 2016). Odonata as a group has shown a very complex response to environmental factors covering a wide range of tolerances. Thus, to assess the response of these species to different disturbances and their intensities, some authors have applied the Dragonfly Biotic Index. This has been very useful for conservation policy measures but it is still necessary to be cautious in its use (Simaika & Samways, 2012).

Odonates have a very close relationship with the environment in which they occur, responding rapidly to anthropogenic or natural alterations, making them appropriate for biomonitoring studies of their habitats (Oliveira Júnior et al., 2015; Pinto et al., 2012; Silva, De Marco, & Resende, 2010). Given all these characteristics, odonates have considerable potential as flagship species for conservation activities, and there are even tourism programs that involve the observation and identification of dragonflies in their natural habitats (Clausnitzer et al., 2009).

The Odonata represent an ancient lineage, which first appeared in the Lower Permian, approximately 250 million years ago (Grimaldi & Engel, 2005). Odonates are divided into three suborders: the Anisoptera, or dragonflies, the Zygoptera, or damselflies, and the Anisozygoptera, which has some characteristics similar to the Zygoptera, but is currently combined with Anisoptera to form the infraorder Epiprocta (Dijkstra et al., 2014; Kalkman et al., 2008). In this infraorder, the Epiophlebioptera ($=$ Anisozygoptera) are found only in Japan (Asahina, 1954), China (Li et al., 2012), and the Himalayas (Asahina, 1961, 1963; Brockhaus & Hartmann, 2009; Tillyard, 1921), with only three known species. It is estimated that the number of known Odonata species in the world is around 5400, of which about 1500 occur in the Neotropics. The number of known species in Brazil is about 828, but there are indications that this number may be much higher, considering that there has been an increase in the number of descriptions of new species in recent years (Garrison & von Ellenrieder, 2015; Lencioni, 2009, 2013; Machado & Bedê, 2015; Pessacq & Costa, 2010; Pinto & Almeida, 2016; Pinto & Lamas, 2011; Souza, Costa, & Oldrini, 2007; von Ellenrieder, 2012, 2013), and that many areas have not been adequately sampled (De Marco & Vianna, 2005).

In the twentieth century, a number of classic studies and reviews were published that had a major influence on the research on odonates, and continue to influence the field in the present day. Robin Tillyard's *The Biology of Dragonflies* (1917) brought together the scant knowledge available at the time on the order, with emphasis on anatomy, ontogeny, physiology, and ecology. Almost half a century later, Philip Corbet (1962) wrote *A biology of dragonflies*, published in 1963 and re-edited in 1983. This book complemented Tillyard's seminal work, in particular in the field of behavior, while also identifying lines of research and questions that required more systematic investigation. Corbet subsequently published a new book, *Dragonflies: Behaviour and ecology of Odonata* (1999), which amplified the perspectives presented in his previous work (Rowe, 2003), and represents one of the classic studies in the field of odonate research.

Over the past 50 years, the number of studies on the behavior and ecology of the odonates has grown continuously, in line with the enormous volume of data and scientific knowledge

produced worldwide. Odonates are used as model organisms for a variety of types of research in behavioral ecology, genetics, and evolutionary biology (Córdoba-Aguilar, 2008). Over the past 20 years, in particular, there have been an ever growing number of studies on behavior, sexual selection, wing morphology and flight characteristics, the distribution of communities, and the response of different species to environmental impacts. A similar pattern has been observed in Brazil, where the number of studies has grown considerably in recent years, in particular in the northern and southeastern regions of the country, as shown by De Marco & Vianna (2005) in their analysis of sampling effort in the country. Despite this ongoing expansion in research, little attention has been paid to the characteristics of this process, in particular with regard to the identification of lacunas or the prioritization of fields of research or strategies of investigation, in order to best exploit the characteristics of the order in different types of study (Córdoba-Aguilar, 2008)

Given these considerations, the present study is based on a scientometric analysis of the literature available on this insect order, with the aim of identifying the principal research themes and existing lacunas, with emphasis on the use of odonates as indicators of environmental quality, and the experimental procedures used in these studies. The principal questions analyzed in the present study were: (i) What is the rate of growth in the production of scientific papers on the order Odonata in Brazil and worldwide over the past 20 years? (ii) In which countries or Brazilian states/regions are these studies being conducted? (iii) Which authors most contribute to the literature on the order, and in which journals are the studies being published? (iv) Are these studies being cited by other authors? (v) Which groups (infraorder or suborders) are most studied? (vi) What are the principal characteristics and lacunas in this scientific literature? (vii) What is the focus of these studies – taxonomy or ecology? (viii) Are the adults and larvae represented equally in terms of the number of studies and fields of research? (ix) What is the taxonomic resolution normally used in the studies (family, genus, morphospecies or species)? (x) How many biomonitoring studies involve odonates and what type of response do they obtain? This analysis provides important insights into the progress of research on the Odonata, as well as the scientific lacunas, both worldwide, and specifically in Brazil. It is hoped that this review can be used to bring attention to the fields of investigation that demand most consideration, and to provide incentives for further research in areas of major interest, but which still lack a solid database.

Material and methods

The data were compiled from the websites "Thomson-Reuters Web of Knowledge" and "Scielo", focusing on the studies published between 1992 and 2013. Papers were searched for the presence of the terms "Odonata*" "Anisoptera*", "Zygoptera*", "Dragonflies*" and "Damselflies*" in their title, abstract or key words. When information on the type of study, the region in which it was conducted, and the taxonomic group analyzed were not apparent from the title or abstract, the text of the manuscript was examined in detail. In order to avoid the duplication of results containing only the term "Odonata", all searches compared this term with all the other key words. In addition to this general literature search, the two journals that specialize in research on this order (*Odonatologica* and the *International Journal of Odonatology*) were also examined in detail.

For each paper located, a series of different types of information was obtained, including the year of publication, the name of the journal, the number of citations per year, authors, country(ies) and/or Brazilian state(s) in which the data were collected, the spatial scale of the study, and the taxonomic groups analyzed. Studies that involved two or more different geographic regions were counted only once for each region or state.

Papers with more than one author were recorded for all the authors, independently of their position in the author list. The information on taxonomic resolution, organization level, type of study, and the life stages analyzed were classified as below:

- **Taxonomic resolution:** (i) species; (ii) morphospecies; (iii), genus; (iv) family.
- **Type of study:** (i) ecological – studies involving theoretical approaches, modeling, macroecology or intra/interspecific relationships; (ii) taxonomic – studies that present a description or redescription of species, identification keys or inventories; (iii) phylogenetic – studies that emphasize the relationships among taxa; (iv) morphometric – studies that emphasize the description of bodily structures in larvae and adults; (v) teaching – studies that emphasize teaching activities. Papers that incorporated two or more of these approaches were counted separately for each type of study.
- **Life stage:** (i) larval (immature); or (ii) adult.
- **Biomonitoring:** studies involving this approach were classified according to the types of response presented by the odonate community: (i) changes in the composition of the community; (ii) changes in species richness and/or individual abundance; (iii) bioindicator species; (iv) bio-indication through fluctuating asymmetry and (v) bioaccumulation. All were related to some kind of environmental impact.

Results

A total of 2317 publications on the Odonata were identified during the present study. Of these, 553 (23.73%) were published between 1992 and 2000, and 1764 (76.27%) between 2001 and 2013 (Figure 1A). In Brazil (Figure 1B), 15 (12.29% of the total for this country) studies were published in 1995, 1998, 1999, and 2000, whereas 107 (87.70%) were published between 2001 and 2013.

On a continental scale (Figure 2), the countries with the most publications in Europe were UK, with 43, and Germany, with 29, corresponding to 25.9% of the total number of publications recorded for the continent. In the Americas, the USA (155 studies), Brazil (122), and Argentina (38) together accounted for 63% of the total production of papers. In Asia, the top countries were China, with 96 publications, and Malaysia, with 29, which together corresponded to 42% of the total for the continent. In Africa, South Africa (23 studies) and Algeria (eight) accounted for 31% of the continent's production. In Oceania, Australia (22 studies) and Papua New Guinea (16) produced 76% of the total for the continent. In the case of oceanic islands and archipelagos, Hawaii, with eight studies, and the Azores, with four, accounted for 63.15% of the total

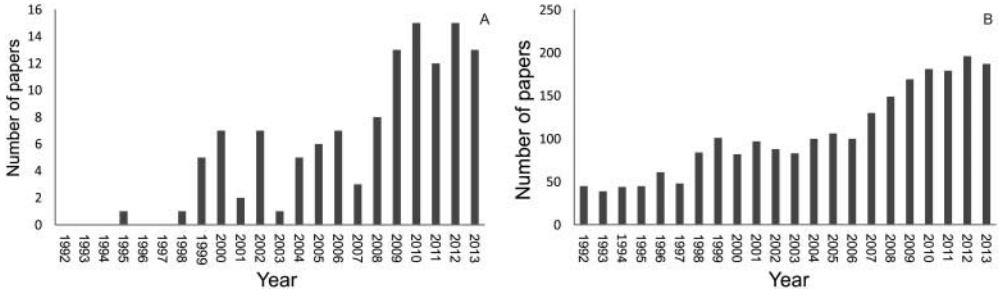

Figure 1. Growth in scientific literature involving the order Odonata between 1992 and 2013: (A) Global and (B) Brazilian.

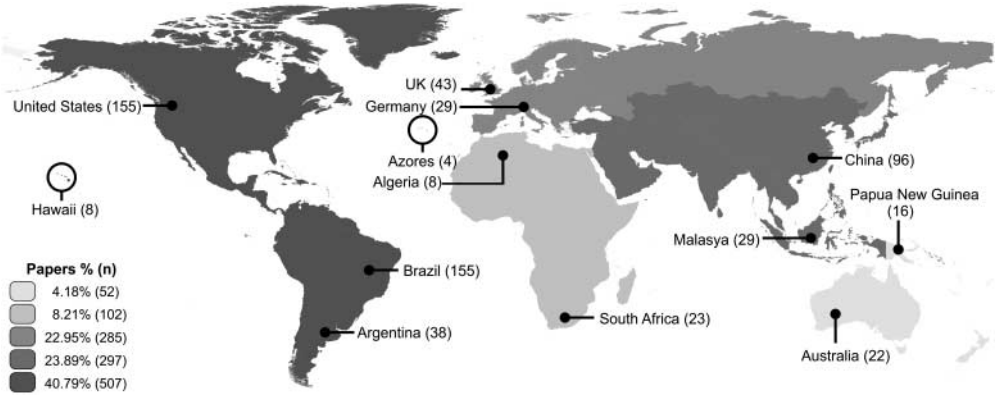

Figure 2. Global production of scientific papers on the Odonata. The different shades of gray indicate the relative contribution of the different regions to the literature. The arrows indicate the countries responsible for the largest number of papers produced in each region.

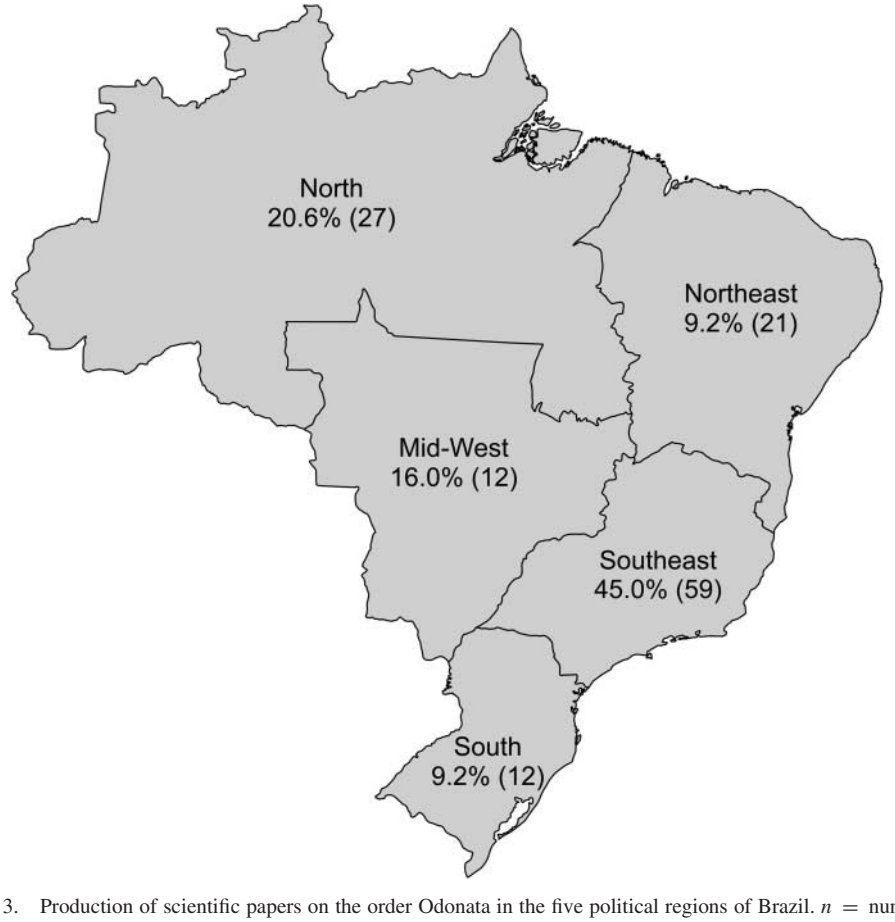

Figure 3. Production of scientific papers on the order Odonata in the five political regions of Brazil. n = number of papers.

production. A further 101 studies did not provide information on the region or country in which they were conducted, and were thus classified only in terms of the continent of origin.

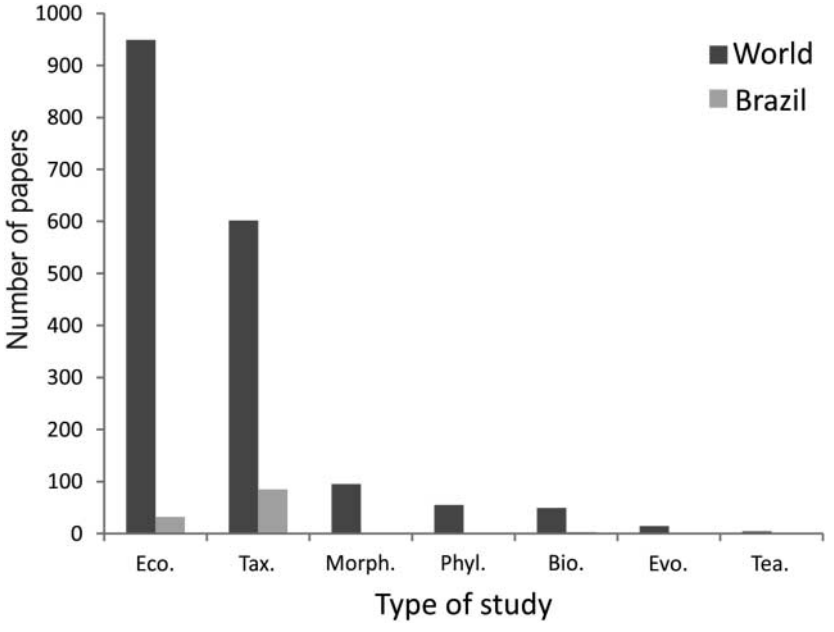

Figure 4. Contribution of the different types of study to the papers published on the order Odonata between 1992 and 2013. Eco. = ecological and behavioral, Tax. = taxonomic and/or descriptive, Morph = morphometric, Phyl. = phylogenetic, Bio. = biomonitoring, Evo. = evolutionary, Tea. = teaching.

In Brazil (Figure 3), the majority of the studies (86) were conducted in the southeastern and northern regions. The states that contributed most to the inventory were Minas Gerais, with 27 studies, followed by Amazonas, with 18, Rio de Janeiro (13), and São Paulo, with 12.

In relation to the type of study (Figure 4), the principal category ($n = 949$, 53.67%) was ecology, followed by taxonomy ($n = 602$, 34.04%). A further 95 papers (5.37%) presented morphological or morphometric studies, 55 (3.11%) phylogenetic analyses, 49 (2.77%) the results of biomonitoring studies, 14 (0.79) evolutionary analyses, and four (0.22%) presented teaching activities. In Brazil, by contrast, the majority of the papers (70.24%; $n = 85$) involved a taxonomic approach, while 26.44% ($n = 32$) were ecological, 2.47% ($n = 3$) focused on biomonitoring, and one study (0.82%) was morphometric. No phylogenetic or evolutionary studies were conducted in Brazil (Figure 4).

The authors who most contributed to the body of work published on the Odonata are from Europe – A. Nel from France, with 75 publications, and R. Stoks from Belgium, with 68 (Table 1). These researchers are followed by two Mexicans, A. Cordoba-Aguilar, with 52 papers, and R. Novelo-Gutierrez, with 41, and a South African, M.J. Samways, with 44 papers. In Brazil, the authors with the most publications were A.B.M. Machado, with 23 papers, J.M. Costa, with 15, and three researchers – A.L. Carvalho, P. De Marco Jr, and F.A.A. Lencioni, with eight each.

Few of the papers worldwide, including those based on research in Brazil, had a high citation index, and only 11 (0.47% of the total) have been cited more than 100 times (Figure 5). On the other hand, 1383 studies (59.69%) were cited between three and 100 times, while the remaining 923 (39.84%) were cited no more than twice.

Of the papers with more than 100 citations, four report on experimental analyses of the capacity of larvae to detect and respond to the presence of predators and their chemical signals (Table 2). These studies included four approaches – (i) the capacity of odonates to detect and respond to chemical stimuli reflecting predation risks (2); (ii) experimental trials showing morphological changes in tadpoles in the presence of larval predators (6); (iii) trials relating life

Table 1. The authors with the largest number of papers published on odonates in the world (left) and Brazil (right) between 1992 and 2013.

World		Brazil	
Author	Number of papers	Author	Number of papers
Nel, A.	75	Machado, A.B.M.	23
Stoks, R.	68	Costa, J.M.	15
Cordoba-Aguilar, A.	52	Carvalho, A.L.	8
Samways, M.J.	44	De Marco, P. Jr	8
Novelo-Gutierrez, R.	41	Lencioni, F.A.A.	8

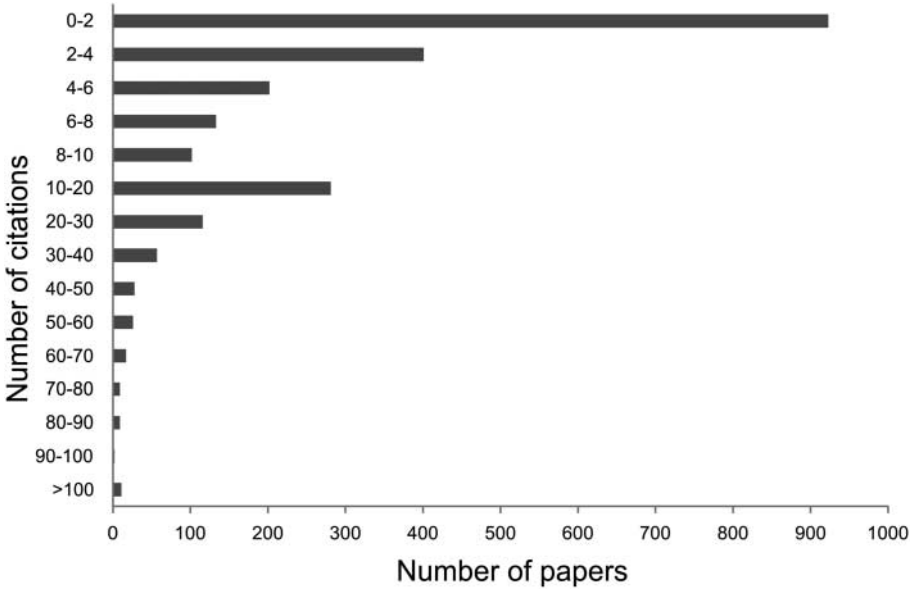

Figure 5. Odonate papers published between 1992 and 2013, ranked by the number of citations.

history traits and behavioral responses to season-related time limitations (11); and (iv) intraguild predation effect on competition among Odonata species (5) (Table 2). Other experiments are: the effects of seasonality on the emergence of individuals (9); whether adults have their immunological capacity reduced following bouts of fighting or egg laying (8); variations in flying behavior related to wing shape and structure (10); and whether the immunological capacity of adult males is related to size of spots on their wings (3). Finally, there is a study on parasitism (4). The other ecological studies (Table 2) included tests showing the shifting of individuals according to climatic fluctuations (7), or investigated territoriality in male adults relating aggressiveness to energy reserves (fat) (1).

The journal with the most papers published on odonates was *Odonatologica*, with a total of 499, followed by the *International Journal of Odonatology*, with 147 and *Zootaxa*, with 123 papers. Other important, but less productive journals included *Animal Behaviour*, which published 42 of the papers identified, *Ecological Entomology*, with 34, the *Journal of Insect Behavior*, with 31, and *Hydrobiologia*, with 30 papers.

Only a single paper was found on the superorder Odonatoidea, while 14 were identified on the suborder Anisozygoptera, 992 involved the Zygoptera, and 1068 the Anisoptera. A further 242 studies involved both Anisoptera and Zygoptera. Most (1727) of the studies focused on the adult stage, 545 on the larvae, 27 on the eggs, and 18 on the exuviae.

Table 2. The 10 most cited Odonata papers published between 1992 and 2013.

Authors	Title	Country	Type of study	Number of citations	Year	*n*
Plaistow and Siva-Jothy	Energetic constraints and male mate-securing tactics in the damselfly *Calopteryx splendens xanthostoma* (Charpentier)	France	Ecological	153	1996	1
Chivers, Wisenden, and Smith	Damselfly larvae learn to recognize predators from chemical cues in the predator's diet	Canada	Experimental	148	1996	2
Rantala, Koskimaki, Taskinen, Tynkkynen, and Suhonen	Immunocompetence, developmental stability and wingspot size in the damselfly *Calopteryx splendens* L.	Finland	Experimental	137	2000	3
Siva-Jothy	A mechanistic link between parasite resistance and expression of a sexually selected trait in a damselfly	France	Parasitism/experimental	137	2000	4
Wissinger and McGrady	Intraguild predation and competition between larval dragonflies – direct and indirect effects on shared prey	USA	Experimental	135	1993	5
McCollum and Leimberger	Predator-induced morphological changes in an amphibian: Predation by dragonflies affects tadpole shape and color	UK	Experimental	127	1997	6
Hickling, Roy, Hill, and Thomas	A northward shift of range margins in British Odonata	UK	Ecological	117	2005	7
Siva-Jothy, Tsubaki, and Hooper	Decreased immune response as a proximate cost of copulation and oviposition in a damselfly	Japan	Experimental	117	1998	8
Johansson and Rowe	Life history and behavioral responses to time constraints in a damselfly	Canada	Experimental	116	1999	9
Wakeling and Ellington	Dragonfly flight.2. Velocities, accelerations and kinematics of flapping flight	UK	Experimental	109	1997	10
Johansson, Stoks, Rowe and De Block	Life history plasticity in a damselfly: Effects of combined time and biotic constraints	Belgium/Switzerland	Experimental	108	2001	11

Table 3. Number of papers published between 1992 and 2013 on the principal odonate families and species.

Principal families	Principal study species	Number of papers published
Coenagrionidae	*Coenagrion mercuriale* (Charpentier, 1840)	457
	Coenagrion puella (Linnaeus, 1758)	
	Enallagma cyathigerum (Charpentier, 1840)	
	Ischnura elegans (Vander Linden, 1820)	
	Ischnura graellsii (Rambur, 1842)	
	Ischnura senegalensis (Rambur, 1842)	
	Ischnura verticalis (Say, 1839)	
	Nehalennia irene (Hagen, 1861)	
Libellulidae	*Libellula depressa* (Linnaeus, 1758)	322
	Pantala flavescens (Fabricius, 1798)	
	Perithemis tenera (Say, 1839)	
Calopterygidae	*Calopteryx haemorrhoidalis* (Vander Linden, 1825)	181
	Calopteryx maculata (Beauvois, 1805)	
	Calopteryx splendens (Harris, 1780)	
	Calopteryx virgo (Linnaeus, 1758)	
	Hetaerina americana (Fabricius, 1798)	
Aeshnidae	*Aeshna cyanea* (Muller, 1764)	153
	Aeshna juncea (Linnaeus, 1758)	
	Anax junius (Drury, 1773)	
Gomphidae	*Onychogomphus uncatus* (Charpentier, 1840)	91
Corduliidae	*Somatochlora alpestris* (Selys,1840)	74
Lestidae	*Lestes sponsa* (Hansemann,1823)	
	Lestes viridis (Vander Linden, 1825)	72
Megapodagrionidae*	*Paraphlebia zoe* (Selys in Hagen, 1861)	54

*Revised by Dijkstra et al. (2014) as Thaumatineuridae.

Most of the papers (1690) identified the study taxon to the species level. These studies include 457 papers on coenagrionids, 322 on libellulids, 181 on calopterygids, 153 on aeshnids, 91 on gomphids, 74 on corduliids, 72 on lestids, and 54 on megapodagrionids s. l. (Table 3). Other studies were based on a broader taxonomic resolution, with 34 focusing on families, four on subfamilies, 70 on genera, one on a subgenus, and two on subspecies.

These studies were distributed differentially in relation to the life stages analyzed. In the 70 papers based on a generic-level taxonomic resolution, for example, 36 focused on the larval stage, and 30 on the adults. By contrast, the family-level studies included 19 that focused on adults, 10 on larvae, and one on eggs. In the case of species-level studies, 972 involved adults, and 343 involved larvae. No information was provided on the life stage analyzed in eight of the papers.

Overall, 39 studies (1.68% of the total) focused on bioindication, using five different approaches: (i) indicator species (17 papers); (ii) species richness/abundance (11 papers); (iii) bioaccumulation (four papers); (iv) fluctuating asymmetry (three papers); and (v) variation in the composition of the community and odonate habitat index (OHI), with three studies. The 17 papers that focus on odonates as bioindicator species indicate that the sensitivity of a given species to environmental impacts will depend on the variation in the quality of the biotopes and the health of the habitats. The 11 studies that focus on species richness found that alterations in the environment lead to the substitution of stenotopic species by eurytopic ones, causing the homogenization of the composition of the community.

Four of the bio-accumulation studies concluded that both adult and larval odonates are good indicators of environmental pollution by heavy metals. Similarly, the three studies that focused on fluctuating asymmetry showed that odonates present a systematic asymmetric reaction in bodily structures, such as the wings, in response to modifications in environmental conditions. Three other studies tested the OHI and variation in the composition of the community related

to habitat preferences, species abundance, and the indicative weight of the Odonata. One of the studies measured the flight dispersal capacity of the individuals as a criterion for the maintenance and dimensions of buffer zones of riparian vegetation in conservation areas.

Discussion

The results of the present study demonstrate a major advance in the scientific literature on the order Odonata, both in Brazil and worldwide. This trend appears to be related to a number of specific characteristics of this group of insects, such as their charisma (Corbet, 1999), well-resolved taxonomic status (Garrison, Ellenrieder, & Louton, 2006, 2010), and the ease with which specimens can be observed and manipulated in the field (De Marco & Vianna, 2005). These characteristics favor the use of these insects in a variety of studies, in fields such as ecology, genetics, conservation biology, and evolutionary and developmental biology, all of which have contributed to the observed increase in the scientific literature.

In particular, odonates have become important model organisms for ecological and evolutionary studies. An additional aspect of the advance in the scientific literature is the number of ecological researchers using odonates as study subjects (Verbeek, Debackere, Luwel, & Zimmermann, 2002), in particular in Brazil, which is considered a developing country, but is at least as productive in terms of the literature on these insects as many other, so-called developed countries. It is important to note that the values recorded in the present study (122 for Brazil) would have been even higher if the study had included papers published prior to the period analyzed or in journals that have yet to be indexed. The increase in the production of scientific papers may be related to the growth in incentives from Brazilian scientific research agencies through their financial support of graduate programs, as well as increased access to journals for the publication of their findings. An additional factor may be the growth in research partnerships and exchange programs with foreign institutions, in particular through the training of graduate students both in Brazil and in other countries (Mugnaini, Jannuzzi, & Quoniam, 2004).

The advance in the production of scientific publications on odonates in Brazil has been accompanied by an increase in the number of authors. Between 1992 and 2000, a total of only 24 Brazilian authors were identified, with a total productivity of approximately two papers per year. Between 2001 and 2013, the number of authors increased to 77, with around nine papers being published per year, on average.

The principal odonate studies worldwide have been conducted in developed countries, and focus primarily on ecological themes. This trend can be accounted for by the longer history of odonate research in these countries, where the earlier, basic taxonomic and morphological studies have enabled more behavioral and ecological research. This transition has also been supported by technological and computational advances, which have facilitated the development of complex statistical approaches and new ecological theories. An additional factor would likely be the reduced diversity of odonates in temperate regions, which would limit the potential for taxonomic studies.

In contrast to research worldwide, Odonata research in Brazil focuses primarily on systematics, whereas ecological studies and research into other aspects of the biology of these organisms is still relatively limited. This tendency for a predominance of studies in taxonomy and systematics is typical of regions in which research programs are still incipient. In other words, it is necessary to first describe the diversity of organisms present within a region before, for example, investigating distribution patterns and testing ecological hypotheses. The enormous diversity of odonates in Brazil emphasizes the need for basic taxonomic studies, although there is a clear tendency for an increasing number of studies on ecological themes. It thus seems likely that, as

the understanding of basic taxonomic questions increases, the number of studies on ecological themes in Brazil will eventually overtake that of the more descriptive research.

Despite the clear increase in the overall number of studies on the Odonata, the research is often concentrated into certain specific regions. In Brazil, for example, extensive data on the geographic distribution of odonates are available for only 29% of the country's total area (De Marco & Vianna, 2005). Ferreira-Peruquetti and Fonseca Gessner (2003) have commented that, while most recent ecological studies have focused primarily on surveys and have produced important data on the distribution of species, the data obtained from taxonomic studies can also be important for the definition of geographic ranges. Given this, many aspects of the ecology or biology of the odonates remain unknown or only superficially understood, reinforcing the need for the careful analysis of the potential discoveries and lacunas still waiting to be covered in this group of aquatic insects. With more and more appropriate information available, it will be possible to develop conservation measures more reliably and more efficiently, in terms of time and resources.

Most studies focus on the adult phase, which is when the animals are most easily identified in the field, given the well-established systematics of these individuals (Garrison et al., 2006, 2010). Identification keys are available for most groups, allowing specimens to be classified to the species level. This is at least partly due to the less well-defined taxonomy of the larvae, in addition to the greater difficulties of collecting, processing (e.g. maintaining and rearing living larvae) these aquatic animals. Independently of these considerations, the larvae of few species have been described adequately.

The Thomson-Reuters Web of Knowledge (ISI) database covers a wide range of high-quality and widely circulated indexed journals that publish papers on the Odonata. The principal journal here is *Odonatologica*, which would be expected given that it is the oldest publication dedicated exclusively to this insect order, being in print since 1972. The other specialist journal is the *International Journal of Odonatology*, which was established in 1998. All the other journals cover much wider scientific fields, such as ecology, behavior, entomology, evolution, conservation biology, taxonomy, insect physiology, and experimental biology.

In addition to the journal in which it is published, another form of evaluating a scientific paper is the frequency with which it is cited in other publications. The number of citations is a direct measure of the impact a study has on its scientific field (Verbeek et al., 2002). Many papers are cited infrequently or not at all due to the limited scope of their content or the fact that they are published in journals with a local or restricted circulation. However, a low citation rate may also be related to the academic status or influence of the authors, who may be unable to attract the interest of their peers, irrespective of the quality of their papers (Lawrence, 2003).

On the other hand, high citation rates in papers generally reflect their intrinsic quality or the presentation of innovative science (Weinstock, 1971). These studies may be characterized as "hot papers", which focus on relatively far-reaching questions, which can be widely generalized. This type of paper tends to reach a high citation rate within a short time of being published, becoming key references in their respective fields of research.

Currently, the most productive odonate researcher is André Nel, who is affiliated with the National Natural History Museum in Paris, and who works primarily on species descriptions, and taxonomic and evolutionary studies. In Brazil, Ângelo B. M. Machado is the most productive author. He was a professor in the Zoology Department at the Federal University of Minas Gerais in Belo Horizonte, and also worked primarily on the taxonomic description of odonate species. It is important to note, however, that productivity is influenced by the ISI database, and that these results might change if other journals were included. Philip Corbet, for example, is not among the principal authors in the study period, which was restricted to the years after 1992, which is when papers were first made universally available in the principal databases. Corbet was, however, among the most active odonate researchers, publishing at least 40 papers

on these insects during his lifetime, according to Dennis Paulson's List of Odonate Literature (http://www.windsofkansas.com/odbib.html).

In Brazil, N. D. Santos, who is also not among the leading authors for the study period, published at least 75 pioneering papers on odonate biology during his lifetime. In addition, this odonate scientist was an active researcher with many foreign contacts and graduate students, who collaborated with most present-day Brazilian specialists. While not appearing prominently in the results, other Brazilian scientists were also important for the advances in odonate biology in this country, such as J. Costa, who described a number of species and contributed actively to the establishment of one of the largest scientific collections of odonates in Brazil, which has contributed in particular to the development of the graduate research of both Brazilian and foreign students (http://www.museunacional.ufrj.br/revistamuseu/libelula.htm).

While the papers not indexed in the ISI database are not widely disseminated, they are certainly important for the researchers who want to investigate the biology of specific organisms. Some of these papers are in fact considered to be classic works for the order Odonata. Files within in our survey period data available in hardcopy, such as books by Philip S. Corbet, or journals (e.g. *Odonatologica*, files were not available on digital platform), can greatly limit the access to readers. Additionally, taxonomy articles are used by a narrow range of researchers. Obviously, the importance of these studies cannot be reduced. They are extremely useful for the development of Odonata studies and provide access to the basic biology of organisms and identification of specimens, serving as the basis for many other fields of scientific research.

The results of the present study emphasize the potential of the odonates for bioindication, although there are no systematic lists of the species involved and what type of impact they are most appropriate for. Most studies focus on the adults, providing insights into different aspects of the "health" of a habitat. In the case of the Odonata, ecological and environmental bioindicators can be divided into different categories according to their response to changes in the environment, such as detectors, exploiters, and accumulators (Gerlach, Samways, & Pryke, 2013).

The results of the present study reinforce this role, indicating a strong link between odonates and environmental integrity, and their capacity to indicate changes in this integrity over time (Butler & de Maynadier, 2007; Carle, 1979; Carvalho et al., 2013; Castella, 1987; Monteiro Junior et al., 2013; Samways & Sharratt, 2010; Samways & Steytler, 1996), as well as the existence of indicator species of preserved and impacted environments (Chovanec, 2000; Chovanec & Waringer, 2001; Clark & Samways, 1996; D'Amico, Darblade, Avignon, Blanc-Manel, & Ormerod, 2004; Samways & Steytler, 1996), fluctuating asymmetry under different levels of environmental pollution (Hardersen, 2000; Hardersen & Frampton, 1999; Palmer & Strobeck, 1986; Pinto et al., 2012), and bio-accumulation in polluted environments (Corbi, Trivinho-Strixino, & Santos, 2008).

Worldwide, ecological studies dominate the papers published in indexed journals, although major lacunas still exist in the scientific understanding of this insect order. To reduce the existing gaps, a good start would be the methodological standardization of samples (larvae, adults, and exuviae) to build a dataset that allows the comparison of Odonata species; this would bring great benefits, making it possible to test hypotheses and theories in different regions or even between continents. Specifically for Brazil, this plan would cover all biomes mainly in the south, midwest, and northeast, which have had lower levels of scientific output. In this scenario, the scope of these studies could also include the transitional areas of these biomes so as to better define the range of populations and to establish clearer links on the distribution pattern of species and their microhabitats.

This dataset would be important to add information on the basic biology of each species, providing details that could eventually enable a classification among specialist species or generalist species habitats, which would fundamentally contribute to better understanding of the ecological requirements of this order. The dataset of ecological or biological traits should offer

the opportunity to identify a large variety of news metrics (Oertli, 2008). The interaction with other areas such as genetics would enable studies on gene flow of species, and it also would help identify how phylogenetic relationships, biological interactions, and functional morphology of Odonata contribute to determining species coexistence patterns, microhabitat selection (De Marco et al., 2015; Okuyama, Samejima, & Tsubaki, 2015), and the limitation in species distribution in different systems managed by human activities.

There is also a lack of assessment of the sampling effort for the standardization of procedures and congruence level in the collection of larval, exuviae, and adult specimens within the same community. Despite the congruence of ecological responses between adults and larvae (Valente-Neto, Roque, Rodrigues, Juen, & Swan, 2016) it is essential to assess whether these responses are similar to exuviae, and whether this pattern is repeated when evaluating the suborders separately. Although some authors suggest that exuviae would be better indicators of the association of species with environmental conditions of streams, the number of studies on exuviae is very limited, accounting for only 1% of the papers analyzed. This result is similar to that found by Bried & Samways (2015), who demonstrate that larvae and adults are more commonly used in studies than exuviae and eggs. We believe that identification is difficult as identification keys are not always available, and also the difficulty in finding exuviae in the environment cause them to be neglected compared to the number of studies on larvae or adults.

Ultimately, the fact that odonates are model organisms for many fields of research means that new studies should be encouraged in areas that have received less attention up until now. In addition to contributing to the scientific understanding of this order, these advances will be fundamental to the development of more efficient conservation strategies, given the considerable sensitivity of these insects to disturbances in the environment.

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