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ORIGINAL PAPER

The conservation status of southern South American aquatic insects in the literature

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Abstract We provide a comprehensive review of publications regarding the conservation of aquatic and terrestrial insects at a global scale and with an emphasis on southern South America. We reviewed three prominent conservation journals (*Conservation Biology*, *Biodiversity and Conservation*, and *Biological Conservation*) and found that only 5 % of all the works published between 1995 and 2008 focus on the conservation of aquatic insects. The highest percentage of publications on the conservation of aquatic insects comes from Europe (2.3 %), while the lowest percentage comes from South America (0.1 %). To assess the trends of aquatic insect research in southern South America, we conducted a literature search using *Zoological Records, Biological Abstracts*, and *Current Contents*. We conclude that there is a gap in research regarding the conservation of freshwater and terrestrial insects, as reflected by the low amount of publications that specifically focus on the description and identification of new insect species and their conservation. In order to help overcome this gap in conservation research, we propose three ideas that could help enhance the research and conservation initiatives regarding these organisms: (1) focus research on understudied

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regions of the world, such as the Magellanic sub-Antarctic ecoregion, (2) increase the amount of funding available for taxonomic research focused on the description and identification of new aquatic and terrestrial insect species, and (3) increase the amount of public education programs which focus on field experiences and direct encounters with aquatic insect biodiversity and their habitats.

Keywords Aquatic insects · Chile · South America · Subpolar · Literature review · Conservation literature

Introduction

Despite the extraordinary richness, uniqueness, and economic importance of freshwater ecosystems and their fauna, they are highly underrepresented in high-priority conservation initiatives (Olson et al. 1998). Additionally, freshwater habitats are being subjected to unprecedented levels of human disturbance (Saunders et al. 2002), and around the world these habitats are more imperiled than their terrestrial counterparts (Abell 2002). Various studies demonstrate growing rates of extinctions in freshwater fauna (Ricciardi and Rasmussen 1999), with at least 20 % of the world's freshwater fish and 72 % of freshwater mussel species in North America listed as endangered, vulnerable, or extinct under the World Conservation Union criteria (Polhemus 1993; Saunders et al. 2002).

Amongst the freshwater fauna, aquatic insects play key ecological roles, being indispensable in food webs and nutrient cycling (Morse 2009). They are of special importance in terms of conservation and protection of freshwater ecosystems because of their high sensitivity to environmental stress and/or ability to withstand harsh changes in the environmental conditions. Many methods have been developed to assess stream quality using aquatic insects, ranging from assessing physiological and morphological changes of individuals to various measures of community structure (Wallace 1996). Moreover, aquatic insects have been used extensively as indicators of the level of pollution in the waters that we drink, use for recreation, and other practical uses (Hynes 1970; Hellawell 1978; Abellán et al. 2005).

Nonetheless, aquatic insect diversity has been incompletely catalogued, and until recently, little was known about freshwater invertebrates in virtually all taxonomic groups and regions (Allan and Flecker 1993). Although some surveys indicate that aquatic insect species make up almost 20 % of all species of insects described (Morse 2009), many species remain unknown to science (Balian et al. 2007; Morse 2009) and little is known about their levels of imperilment. Invertebrate research is highly underrepresented over vertebrate research; the latter is highly overrepresented in conservation and research literature in terms relative to the number of vertebrate species described, as compared to the number of invertebrate species (Clark and May 2002). Additionally, although some of the leading causes of aquatic insect diversity include habitat destruction, displacement by introduced species, and water impoundments (sensu Black and Vaughan 2003), it is estimated that 100,000 of every million species of insects could be extinct by 2050 due to habitat loss, yet insect conservation remains the awkward "kid sister" to vertebrate conservation (Dunn 2005). Additionally, within the Neotropics, southern South America freshwater ecosystems, have received less attention in global conservation than the highly diverse Amazon (Olson et al. 1998). Recently, Pérez-Losada et al. (2009) have called attention to the fact that at a continental scale the southern ecoregions of Central Chile and Chilean Lakes (sensu Abell et al. 2008) stand out for its phylogenetically distinctiveness for freshwater crab species (*Aegla* sp.), and its high degrees of threat.

Pérez-Losada et al. (2009) used the classification of freshwater ecoregions developed by Abell et al. (2008), which defines Patagonia as the southernmost ecoregion of South America. This can represent a limitation for studies conducted in southern South America, because the Patagonian ecoregion includes in it two very contrasting zones: an arid zone east of the Andean cordillera, and a hyperhumid zone west of this mountain range. The latter zone has been identified by Conservation International as the "Magellanic subpolar rainforest" ecoregion (Mittermeier et al. 2003), also called "Magellanic sub-Antarctic ecoregion" (Rozzi et al. 2006), and is understudied with regard to biodiversity but also regarding long-term ecological research (Rozzi et al. 2012).

In lights of the current biodiversity crisis, which is undeniably an insect biodiversity crisis (Dunn 2005), we provide a comprehensive review of publications regarding the conservation of aquatic and terrestrial insects at a global and continental scale to determine whether there are significant differences across continents in terms of conservation research regarding these organisms, as expressed in conservation literature. We reviewed three prominent conservation journals (*Conservation Biology*, *Biodiversity and Conservation*, and *Biological Conservation*). We recorded the number of articles published from 1995 to 2008 regarding aquatic and terrestrial insects and focused on the status of research in South America, as the percentage of articles published was the lowest for all areas of the world investigated. In the final part of our work, we focus on southwestern South America, in order to help overcome a geographical bias that has largely overlooked this remote region.

Methods

Global conservation of aquatic and terrestrial insects

To evaluate the conservation status of aquatic and terrestrial insects in the literature, we collected data from three international conservation journals: *Conservation Biology* (CB), *Biodiversity and Conservation* (B&C), and *Biological Conservation* (BC). We selected these journals because of their high 2009 impact factor (ISI Web of Knowledge: CB = 4.6, B&C = 2.0 and BC = 3.9) their long standing in conservation research, their involvement in the promotion of conservation biology, and because they provide a good representation of the global scientific literature in conservation biology (Fazey et al. 2005). We surveyed all reviews, letters, contributed papers, and short notes from 1995 to 2008 for the selected journals. We examined and catalogued articles, published in both, English and Spanish, in search for a focus on aquatic and terrestrial insect conservation and selected them based on their title, keywords, and abstract (total $n = 7780$; comprised of CB = 3,060, B&C = 1,696, and BC = 3,024 articles). After selecting the articles, we organized them into the following world regions: *Africa, Asia & Middle East, Europe, South America,* and *North America*. In order to assess global conservation trends, we conducted a one-way Analysis of Variance (ANOVA) and a Student–Newman–Keuls (SNK) test (α 0.05) (R Development Core Team 2010).

Research trends in southern South America

We defined southern South America as the area that includes the Patagonian and Valdivian Lakes, Central Chile (the southern tip of it), and Patagonia ecoregions (sensu Abell et al. 2008), (i.e. the area south of 35°S from the Atlantic to the Pacific coast at 55°S)

(sensu Arroyo et al. 1996). We conducted a literature search using *Zoological Records, Biological Abstracts*, and *Current Contents*. We examined 747 articles, reviews, letters, and short notes published from 1975 to 2010. To assess the research trends regarding aquatic insects in South America, we focused on the Orders Ephemeroptera, Plecoptera, Trichoptera, Odonata, and Diptera (Chironomidae). The Family Chironomidae was emphasized amongst other dipterans because its members play an important role in energy transfers in ecosystems and constitute a major food source for many organisms (Engel 1988;, Balci and Kennedy 2002). All literature searches were conducted in both, English and Spanish, as some of the main journals published in South America are published mainly in Spanish, but may include titles, subtitles, and abstracts in English (as in the case of Revista Chilena de Historia Natural). After selecting the articles, we organized them into decades (according to publication year) and into the categories of *taxonomy, ecological processes, biogeography, and bioassessment*. To examine differences between research trends and decades, we used R software (2010) to conduct ANOVA and SNK test (α 0.05).

Results

Global conservation of aquatic and terrestrial insects

Overall, the percentage of works published regarding the conservation of aquatic and terrestrial insects, compared to the total amount of publications reviewed, was low for the three journals selected (5 and 27 % respectively). The highest percentages of articles published for both, aquatic and terrestrial insects, were 17 and 2.6 % for the journal *Biodiversity and Conservation*, while the lowest percentages were 0.2 and 4 % for the journal *Conservation Biology* (Fig. 1).

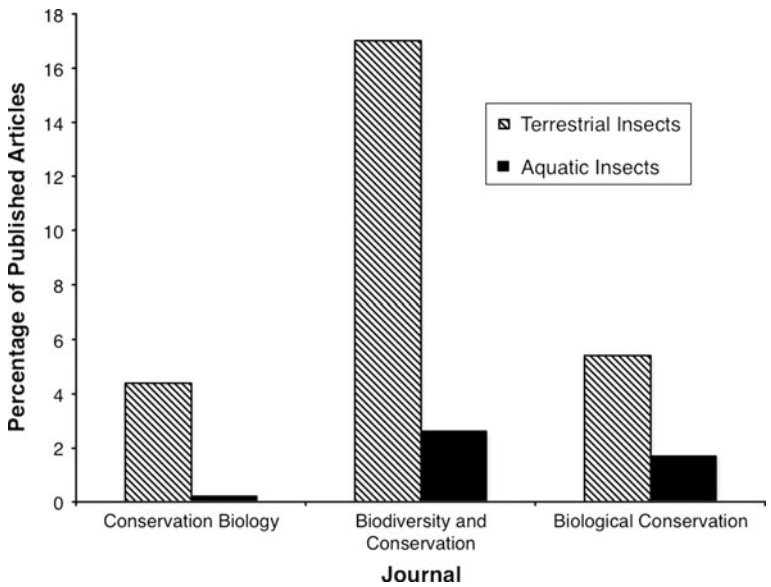

Fig. 1 Percentage of articles regarding the conservation of freshwater and terrestrial insects published between 1995 and 2008 in the journals Conservation Biology, Biodiversity and Conservation, and Biological Conservation

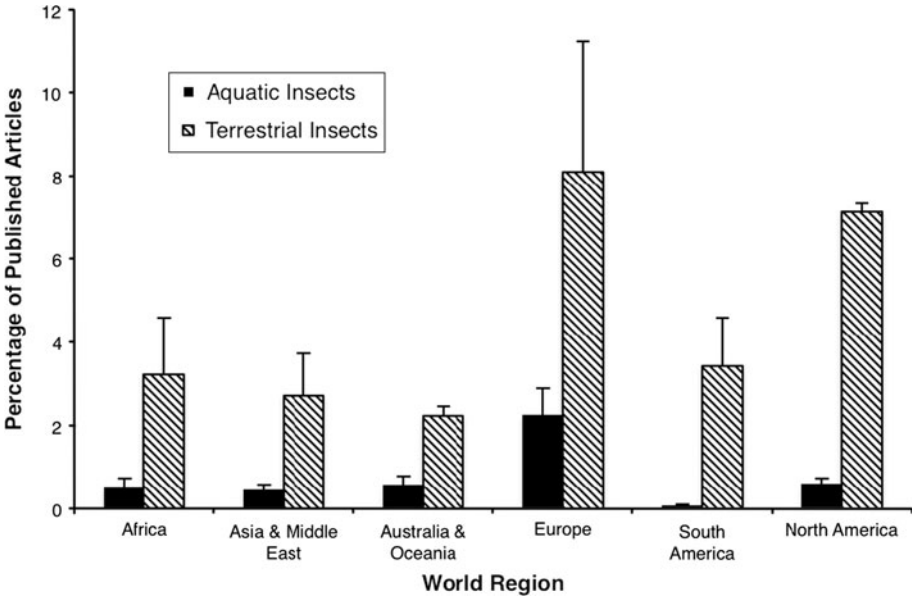

Fig. 2 Average percentage (±1 SD) of freshwater and terrestrial insect articles related to conservation, published between the years 1995 and 2008 in the journals Conservation Biology, Biodiversity and Conservation, and Biological Conservation. The percentage of works published in Europe is significantly higher than other regions of the world, while the percentage of works published in South America is significantly lower (One-way parametric ANOVA with SNK analysis, $p = 0.03$, $\alpha = 0.05$)

At a global scale, the percentage of publications in relation to the conservation of aquatic insects is significantly higher in Europe (2.3 %) (One-way parametric ANOVA, $p = 0.03$; SNK test, α 0.05), while Africa, Asia and the Middle East, Australia and Oceania, and North America, range from 0.5 to 0.6 %. The percentage of articles published in South America is significantly lower (SNK test, α 0.05) than other regions of the world, with only 0.1 % of all of the publications focusing on the conservation of aquatic insects (Fig. 2). Terrestrial insects are significantly better represented than aquatic insects in all continents. Although, there are no significant differences between the different regions of the world (One-way parametric ANOVA, $p = 0.15$, α 0.1), the highest percentage of publications is observed for Europe and North America (8 and 7 % respectively).

Africa, Asia and the Middle East, Australia and Oceania, and South America range from 2.2 to 3.4 % of publications regarding the conservation of terrestrial insects (Fig. 2). Regarding insect Orders, Coleoptera and Lepidoptera are the most represented in the conservation literature, as 58 % of all of the articles focus on the conservation of these organisms.

Research trends in southern South America

In general, there has been a significant increase in the number of publications in the orders Ephemeroptera, Plecoptera, and Trichoptera since 1975. The highest number of publications has been related to the orders Odonata and Diptera (Chironomidae), with a total of 95 and 90 publications respectively (Fig. 3).

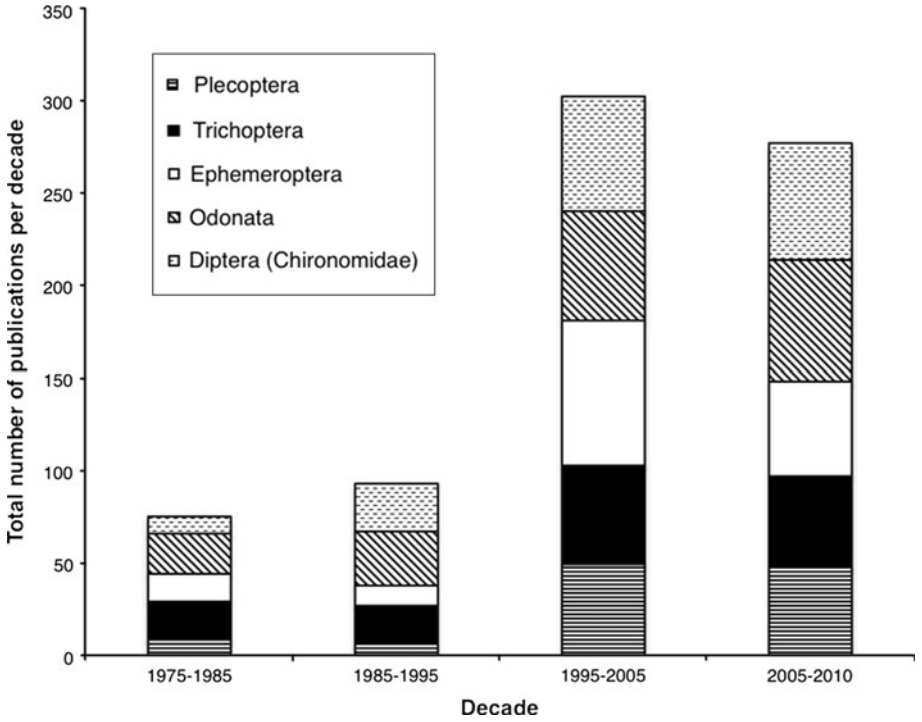

Fig. 3 Total number of publications about the orders Plecoptera, Trichoptera, Ephemeroptera, Odonata, and Diptera (Chironomidae), published between the years 1975 and 2010 in southern South America

The percentage of publications related to the taxonomy and ecological processes of the Orders under study are significantly higher than other research trends (Fig. 4, One-way parametric ANOVA, $p < 0.0001$, α 0.05), and the majority of the works have been published in the journals *Aquatic Insects*, *Gayana, Odontologica, Revista de la Sociedad Entomológica Argentina, Studies on Neotropical Fauna and Environment*, and *Zootaxa*.

Discussion

Insects as a group receive only minimal legislative protection, presumably because of their small size and distant evolutionary relationship to humans (Metrick and Weistzman 1996;, Bossart and Carlton 2002). Additionally, invertebrate research is highly underrepresented (Clark and May 2002). By reviewing three of the most prominent conservation journals, we were able to identify both, taxonomic and geographical biases: (1) aquatic insects are underrepresented in conservation literature and (2) at a global scale, Europe presents the highest percentage of publications related to the conservation of aquatic insects (2.3 %), while the percentage of publications for South America is the lowest (0.1 %) in the world.

These results suggest that there is a gap in conservation research regarding freshwater and terrestrial insects. Various authors have established that vertebrates, especially endotherms, are over-represented in relation to the number of species described (Bonnet et al. 2002; Clark and May 2002). According to the International Union for the Conservation of

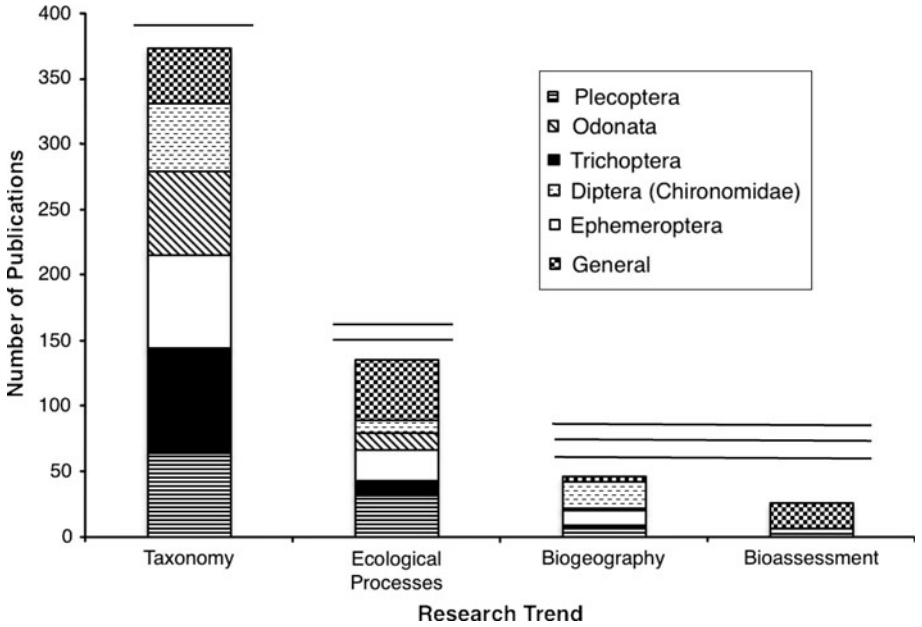

Fig. 4 Number of publications related to taxonomy, ecological processes, biogeography, and bioassessment in southern South America. Lines above stacked bars represent significantly different number of publications for each research trend (One-way parametric ANOVA, $p < 0.0001$). A SNK analysis indicated that publications related to taxonomy were significantly higher than publications involving ecological processes, while publications related to biogeography and bioassessments were not significantly different from each other (α 0.05)

Nature and Natural Resources (IUCN) 2010 Red List, 0.1 % of 1 million of species of insects described, are cataloged as threatened (Adler and Footit 2009; IUCN 2010). However, insects appear to be specially sensitive to human transformation of habitat, resulting in a fast decrease in their number of species, declining faster than birds or vascular plants (Travis 2003; Samways 2009). We propose the low percentage of insects included at IUCN and other red lists, is the direct result of the low amount of publications that specifically focus on the description and identification of new insect species and their conservation.

Europe, and specially England, has been the epicenter where the majority and most sophisticated ecological studies applied to insect conservation problems have been developed (Pyle et al. 1981). In 1925, the Insect Protection Committee of the Royal Entomological Society of London came into being and it issued its first endangered species list in 1946 (Pyle et al. 1981). Furthermore, during the 1960s and 1970s, insect conservation gained a firmer footing and scientists of the British Nature Conservancy held a symposium on invertebrate conservation (Pyle et al. 1981).

Although the percentage of works published in South America regarding the conservation of aquatic insects is significantly lower than other areas of the world, as reflected by the percentage of publications in the sources searched in this article, it is important to emphasize that highly comprehensive taxonomic works available for South America have been compiled by distinguished authors in the field. For example, Hurlbert (1977), published a bibliography for southern South America (entitled *Biota acuática de Sudamérica*

Austral) with sections written by recognized taxonomic experts, providing a comprehensive compendium for the works published through the mid 1970′s. Furthermore, recent compilations of taxonomic keys have been published in the form of books or encyclopedias, such as *Macroinvertebrados Bentónicos Sudamericanos- Sistemática y Biologíá* (Domínguez and Fernández 2009), in addition to a series of encyclopedia volumes published by Charles Heckman on the aquatic insects of South America. Although we did not include these compilations in the analysis, as we focused on the literature published in the form of peer-reviewed articles (as explained in the methodology), they represent some of the most important sources used today by freshwater ecologists for the identification of South American freshwater insects.

In this context, a considerable number of taxonomic and ecological works have been published since S. H. Hurlbert's *Biota acuática de Sudamérica Austral*. By reviewing the literature from 1975 to 2010 of the works conducted in southern South America (Patagonia, sub-Antarctic ecorregion), we were able to determine that the majority of research carried out today is related to the taxonomy and systematics of aquatic insects. This is very important, as before we can protect insects and other invertebrates we need to know, at least, what species are present, if populations are stable or declining, and the habitat needs of these populations (Black and Vaughan 2003). Although the amount of taxonomic works is increasing in southern South America, particularly in Chile and Argentina, the percentage of authors who focus in the study of invertebrates is low. According to a study about the taxonomists currently working in Chile, there is a significant mismatch between biological diversity and the number of taxonomists per group (Simonetti 1997). Additionally, the Patagonian ecoregion as defined by Abell et al. (2008) and Arroyo et al. (1996) encompasses the whole territory included between the Atlantic and Pacific coasts of South America south of 35°S–55°S. This classification overlooks the sharp contrast between Eastern and Western Patagonia. The latter includes the per-humid Magellanic sub-Antarctic ecoregion subject to the continuous rainfall brought by the westerlies, while the Eastern slopes is subject to the rainshadow effect of the Andean Cordillera and includes mostly the rivers that cross the arid Patagonian steppe (Pisano 1981; Rozzi et al. 2012).

In the long run, more emphasis needs to be placed on the particularities of contrasting zones within defined ecoregions, and on invertebrate surveys, systematics, taxonomy, and population ecology in these diverse ecoregions. This will enable that freshwater species can be identified, catalogued, and their life histories understood not only by biologists, but also by decision makers, educators, and the general public (Black and Vaughan 2003). It is necessary to concentrate biological research and public education on flagship species when these are available in threatened habitats, in the manner that has proved so successful in vertebrate conservation (Wilson 1987). This has already been put into practice by using insects that have been catalogued as charismatic or umbrella species. Terrestrial insects such as butterflies, dragonflies and beetles have been widely studied and are appealing to the general public. Most scientists would agree that lepidopterans and odonates are considered more charismatic than other Orders, and taxonomic representations on conservation tracking lists are closely linked with these broad designations of relative charisma (Bossart and Carlton 2002). These designations promote dramatic discrepancies on conservation initiatives. For example, large and showy dragonflies and damselflies, which have a long established, significant professional and amateur following, occur on tracking lists at a frequency of 26 times greater than that expected by their number of species, whereas Diptera are 13 times less likely to be listed as a species of concern (Bossart and Carlton 2002). Furthermore, several Invertebrate Specialist Groups have been established within the IUCN's Survival Service commission, including Lepidoptera, Odonata, and

cave invertebrates (Pyle et al. 1981). A similar effort has not yet been developed for orders of aquatic insects such as Hemiptera, Trichoptera, Ephemeroptera, or Plecoptera.

To help overcome this gap in conservation research, we propose three ideas that could help increase the number of publications and conservation initiatives regarding aquatic insects:

(a) *Focus research on "understudied" regions of the world, such as southern South America*—as shown in the results of this article, research has been highly underrepresented in the Southern Hemisphere. If we concentrate our efforts in studying regions of the world such as southwestern South America, the number of aquatic insect species described would dramatically increase. For example, Chile's Magallenic Sub-Antarctic Archipelago has been catalogued as one of the 24 most pristine areas left in the world (Mittermeier et al. 2003). Furthermore, the central and southern regions of Chile have been reported as a hotspot of biodiversity for freshwater invertebrates (CONAMA 2008). This region is clearly isolated from the rest of South America by a series of geographic barriers, allowing for a great level of endemism and diversity at the species level. Moreover, because southwestern South America is positioned outside of air streams carrying industrial pollutants and receives rainstorms that originated over the southern Pacific Ocean, the austral forests and associated ecosystems are to a large extent free of atmospheric pollution (Hedin et al. 1995). Precipitation chemistry in this region reveals one of the lowest concentrations of nitrate ever recorded (Likens 1991, Weathers et al. 2000). Additionally, southwestern South America contains vast areas of continental ice: 4,200 km^2 in the Northern Patagonian Icefield, 13,000 km^2 in the Southern Patagonian Ice field, and 2,300 km^2 in the extensive glacier systems of the Darwin Cordillera on Tierra del Fuego and the neighboring archipelagoes (Porter and Santana 2003). Together, these glaciers are (a) the largest ice masses in the Southern Hemisphere, aside from those in Antarctica; and (b) immense reservoirs of freshwater (Rozzi et al. 2012). Additionally, the strong biogeographic isolation of southern temperate forests, occurring between 35°S and 55°S, eliminates the possibility that forests outside the region may act as sources of recolonization after habitat destruction or sudden climate change, therefore acting as the only long-term reservoir of temperate forest biodiversity in South America (Armesto et al. 1998). Thus, increasing the amount of research that focuses on freshwater insects in this region of the world, would allow for the development of conservation initiatives that would ensure the protection of one the greatest sources of freshwater in the planet and one of the last pristine areas left in the world.

(b) *Increase the amount of funding available for taxonomical research focused on the description and identification of new aquatic insect species*—Taxonomical studies should be emphasized, as one of the biggest problem in determining candidate insects and other related arthropods for endangered status is our lack of knowledge of the biodiversity, distribution, habits, and abundance of endemic insects (Primack et al. 2001; Bailan et al. 2007; Olson et al. 1998). Taxonomic and conservation research helps identifying flagship aquatic insect species as targets for conservation, and determine the level of imperilment of other species of the community that could be at risk. Identification of both endangered species and candidates for charismatic freshwater species assist the implementation of conservation initiatives, and legislations that contribute to the protection of ecosystems and watersheds.

(c) *Increase the amount of public education programs which focus on field experiences and direct encounters with aquatic insect biodiversity and their habitats*—Today, direct encounters with nature are becoming increasingly rare, due to that a large portion of our knowledge about nature is mediated by mathematical equations and models, technology,

and established ecological theory (Rozzi et al. 2005). An effective way to resolve this problem is through educational activities that include field experiences and "direct encounters" ("face-to-face" interactions) with aquatic insects in their habitats. Field experiences also work effectively at the pre-school and elementary school levels and help children to better understand regional cultural, ecological, and the spiritual values (sensu Hargrove 2008) linked to freshwater fauna and ecosystems.

Efforts to overcome the conservation research gap on aquatic insect biodiversity in southwestern South America: The Omora Ethnobotanical Park LTSER site in Cape Horn

Although the percentage of publications regarding the conservation of aquatic insects in southern South America is low, an initiative to research the ecology and natural history of these organisms and to promote their conservation through education and ecotourism activities was launched by scientists, philosophers and artists at the Omora Ethnobotanical Park (OEP) on Navarino Island (55°S), Chile, at the southwestern end of the Americas in 1999 (Rozzi et al. 2010). The OEP is a long-term socio-ecological research (LTSER) site in the Cape Horn biosphere reserve (CHBR). The biological richness of the Cape Horn archipelago and the Magellanic sub-Antarctic eco-region has remained underestimated, because the majority of the biodiversity studies conducted in the region have focused on vertebrates and vascular plants (Rozzi et al. 2000, 2008). However, one of OEP's national and international research programs focused on non-vascular plants, and recently demonstrated that the Magellanic sub-Antarctic ecoregion holds more than 5 % of the world's bryophyte species on less than 0.01 % of the Earth's land surface (Rozzi et al. 2008). This information provided strong support for the creation of the Cape Horn Biosphere Reserve in 2005, and showed how less conspicuous taxonomic groups, such as bryophytes, can motivate the protection of whole ecosystems (Rozzi et al. 2008). In order to make "underperceived taxonomic groups" more visible to decision makers, educators, and the general public, OEP research team has developed a methodology called Field Environmental Philosophy (FEP), which integrates ecological and philosophical research into education, ecotosurism, and biocultural conservation (Rozzi et al. 2012). This methodology includes a 4-step cycle consisting of: (1) interdisciplinary ecological and philosophical research; (2) composition of metaphors and communication of simple narratives; (3) design of field activities with an ecological and ethical orientation; and (4) implementation of in situ conservation areas (Rozzi et al. 2010; Contador 2011). Although various authors have established that southern South American freshwater invertebrates present a high degree of endemism and speciation (Miserendino and Pizzolon 2000) and play important ecological roles in the CHBR ecosystems (Anderson et al. 2006), as evidenced by this research, they have not been the targets of research within the Sub-Antarctic ecoregion.

To help overcome this gap in freshwater invertebrate conservation research in southwestern South America, in 2007 we initiated long-term studies on aquatic insects at OEP using the FEP methodology. The praxis of this methodology has allowed us to integrate new educational experiences with children, their parents, educators, tourism operators and decision makers, who learn about freshwater biodiversity and its importance for the conservation of whole watersheds (Contador et al. in preparation). These activities are leading to the development of long-term studies that are revealing that not only the composition of the freshwater biodiversity is unique in the austral ecoregion, but also the life histories of the aquatic insects (Contador 2011).

The Northern and Southern Hemispheres contrast markedly in their land:ocean ratios, generating sharp inter-hemispheric climatic and biotic differences in temperate and subpolar latitudes. At the 40°–60° latitudinal range, land surface prevails with a 54 % over a 46 % of oceanic surface in the Northern Hemisphere, whereas in the Southern Hemisphere, 98 % of the surface is oceanic and only 2 % is terrestrial (Rozzi et al. 2012). Consequently, Northern Hemisphere high-latitude ecosystems are characterized by a strongly continental climate (freezing winters and contrastingly warm summers), whereas the Southern Hemisphere temperate and subpolar ecosystems are modulated by a largely oceanic climate (mild winters and rather cool summers) (Arroyo et al. 1996; Lawford et al. 1996). The oceanic conditions in the Magellanic sub-Antarctic ecoregion can explain unexpected phenomena, such as multivoltine life histories of Diptera species at the high latitudes of southern South America (Contador 2011). There is still much to be discovered about the compositional, structural, and functional freshwater biodiversity of this remote austral region. At the same time, development pressures and threats to biodiversity are rapidly growing in the Magellanic sub-Antarctic ecoregion (Rozzi et al. 2012). Our analyses aim, first, to raise awareness about the need of conservation research in freshwater biodiversity at the southern end of the Americas. Second, in the context of global environmental change, national and international collaborations are essential to effectively protect biodiversity at local and regional scales. To address this challenge in southwestern South America, we invite ecologists, taxonomists, and other scientists to conduct research at OEP-LTSER site in the CHBR. Third, the FEP's methodology developed at OEP could be adapted to better understand and value the freshwater biodiversity in other regions of the world.

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