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Distribution patterns of riodinid butterflies (Lepidoptera: Riodinidae) from southern Brazil

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Abstract

Background: The aim of this study was to synthesize the knowledge of Riodinidae butterflies (Lepidoptera: Papilionoidea) in Rio Grande do Sul state (RS), southern Brazil, evaluating the role of climatic, topographic, and vegetational variables on the observed patterns of occurrence and distribution of these butterflies in the Pampa and Atlantic Forest biomes. The records of riodinid butterflies in RS were collected from published studies and the examination of museum collections in Brazil.

Results: A total of 97 taxa of Riodinidae were recorded, distributed in 92 municipalities. The NMDS analysis and the Constrained Analysis of Principal Coordinates grouped the municipalities according to the phytogeographic regions and biomes - Pampa and Atlantic Forest domains - in which the species records were made. Distance from the ocean, precipitation and temperature were the environmental variables which most contributed to explain the distribution patterns of these butterflies. The multivariate Mantel correlogram suggests that over short distances, the composition of species shows significant levels of spatial autocorrelation, and as geographic distance increases, these levels tend to present negative values.

Conclusions: The results suggest that the observed distribution pattern of Riodinidae in the different biomes and phytogeographic regions in the extreme southern Brazil could be explained by climatic, environmental variables and geographic distance.

Keywords: Atlantic forest; Occurrence; Pampa; Spatial autocorrelation

Background

The distribution of insects is highly influenced by a combination of factors, such as climate, vegetation and topography (Wolda 1988; Goldsmith 2007; Bonebrake and Deutsch 2012). Environmental heterogeneity can derive from the variation of the abovementioned factors across time and space, shaping the patterns of occurrence and diversity of these organisms. Butterflies are closely associated with a variety of biotic and abiotic variables, being a useful group for environmental diagnosis and identification of priority areas for conservation (Brown and Freitas 2000a). Moreover, butterflies are reasonably easy to sample, some taxa have relatively well-known taxonomy and may be considered a charismatic group. For all these features, some butterfly groups can be used as flagships in biodiversity conservation (New 1997; Brown and Freitas 1999; Freitas 2010). However, there is a paucity of knowledge and a lack of studies concerning general patterns of distribution in tropical butterflies on large scales, especially in Brazil (see Bonebrake et al. 2010 for more details).

Riodinid richness is highly concentrated in the neotropics, with 95% of the species (c.a. 1,300) occurring in this region (DeVries 1997; Hall 2002). These butterflies are generally associated in restricted to specific microhabitats and may be spatially rare with low population densities, even if showing, in some cases, wide distributions (Callaghan 1978; Brown 1992; DeVries 1997). For example, the genus *Seco* Hall and Harvey 2002 is restricted to xeric habitats (Hall and Harvey 2002a), while some species from *Euselasia* only occur in wet environments (e.g. Nishida 2010) and most *Aricoris* species are linked to grasslands habitats in vast areas of South America. Despite being the second most diverse family (after the Nymphalidae), Riodinidae is a poorly studied

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group among the butterflies (Hall and Harvey 2002b). Natural history and basic aspects of its biology, such as life history and morphology, are unknown for most species (85% to 87%, Hall et al. 2004; Kaminski 2008). The little knowledge available, however, points to a high habitat specificity of the riodinid butterflies and the sheer number of species present in a given site may be a good indicator of environmental health.

Brazil is one of the three countries with the largest richness of Neotropical butterflies, with more than 3,200 estimated species (Brown and Freitas 1999). However, there is a lack of inventories, especially taking into account its great diversity of biomes. Most of the surveys are concentrated in the Atlantic Forest domain, and many regions of the Brazilian territory still require much sampling effort (Marini-Filho and Freitas 2011). When compared to other Brazilian states, the butterfly fauna of Rio Grande do Sul, the southernmost state of Brazil, is relatively well known and studied (Santos et al. 2008). In particular, few other parts of the country were ever surveyed since as early as the end of the 19th and beginning of the 20th centuries. Most recently published inventories are related to Atlantic Forest habitats (Teston and Corseuil 1999, 2000, 2002; Corseuil et al. 2004; Iserhard and Romanowski 2004; Giovenardi et al. 2008; Grazia et al. 2008; Bonfantti et al. 2009; Romanowski et al. 2009; Iserhard et al. 2010; Pedrotti et al. 2011; Ritter et al. 2011; Santos et al. 2011; Bellaver et al. 2012; Morais et al. 2012), and the major gaps of information concern the Pampa (native grasslands), a biome restricted in Brazil to its extreme south and which covers about 2% of its surface, extending through Uruguay and northwest Argentina (Bencke 2009; Pillar et al. 2009), exclusive to austral South America.

This study aimed (1) to compile and upgrade a species list of riodinid of this extreme southern Brazilian state, (2) to identify environmental variables that shape the patterns of occurrence and distribution of Riodinidae in this region, and (3) to compare the species composition of these butterflies among the different phytogeographic regions in Atlantic Forest and Pampa from southern Brazil.

Methods

Study area

Rio Grande do Sul state (RS), located in extreme southern Brazil, has an area of 281,748,538 km^2 and borders on Uruguay and Argentina (IBGE 2004). The northeast of RS (36%) is part of the Atlantic Forest biome, the second most endangered forest in the world, with different ecosystems such as Mixed and Dense Ombrophilous Forests and Seasonal Deciduous and Semideciduous Forests (Figure 1). The remainder of the area (64%) is included in the Pampa biome, comprising the native grasslands of South America and associated ecosystems (Pillar et al. 2009). The climate in RS is subtropical and according to Köppen's classification, is Cfb in the northeast highland region and in the higher portions of Basaltic Plateau and Serra do Sudeste and Cfa in other regions (Kuinchtner and Buriol 2001).

Data collection

The records of riodinid butterflies were collected from published studies (Mabilde 1896; Azzará 1978; Biezanko et al. 1978; Ruszczyk 1986; Hall and Harvey 2001, 2002a; Krüger and Silva 2003; Iserhard and Romanowski 2004; Marchiori and Romanowski 2006a, b; Dessuy and Morais 2007; Sackis and Morais 2008; Giovenardi et al. 2008; Bonfantti et al. 2009; Iserhard et al. 2010; Siewert et al. 2010, 2014; Fronza et al. 2011; Ritter et al. 2011; Rosa et al. 2011; Morais et al. 2012; Bellaver et al. 2012; Dolibaina et al. 2013; Dias et al. 2013) and the examination of museum collections in Brazil, as follows: Centro de Pesquisa Agropecuária Clima Temperado da Embrapa (CAMB), Museu de História Natural da Universidade Católica de Pelotas (MUCP), Museu de Ciências Naturais Carlos Ritter (MNCR), and Museu Entomológico Ceslau Biezanko (MECB), in Pelotas, Museu Anchieta de Porto Alegre (MAPA), Museu de Ciências e Tecnologia da Pontifícia Universidade Católica do Rio Grande do Sul (MCTP), Museu de Ciências Naturais da Fundação Zoobotânica do Rio Grande do Sul (MCNZ), Museu Ramiro Gomes Costa da Fundação Estadual de Pesquisa Agropecuária (MRGC) and Coleção de Lepidoptera do Departamento de Zoologia da Universidade Federal do Rio Grande do Sul (CLDZ), in Porto Alegre, Coleção de Lepidoptera Alfred Moser (CLAM), in São Leopoldo, Museu e Arquivo Histórico Professor Hermann Wegermann (MAHP) in Panambi, and Departamento de Zoologia da Universidade Federal do Paraná (DZUP), in Curitiba. The collections of Museu de Zoologia da Universidade Federal de São Paulo, in São Paulo (MZSP), Museu Nacional da Universidade Federal do Rio de Janeiro, in Rio de Janeiro (MNRJ), and Coleção de Lepidoptera do Museu de Zoologia da Universidade Estadual de Campinas, in Campinas (ZUEC), were also consulted but there were no Riodinidae from RS in any of them.

All identifications and nomenclature of museum specimens were checked and revised, and for each specimen, the municipality, geographical coordinates, and reference collection were recorded. As reported by Ferro and Melo (2011), geographical coordinates were not available for most museum specimens, and thus, we used geographical coordinates from the municipality nearest to the point in which the specimen was collected, obtained by the GeoLoc tool for the information system 'splink', available from the Reference Center on Environmental Information (http://splink.cria.org.br/geoloc). The specimens were identified from D'Abrera (1994), comparison

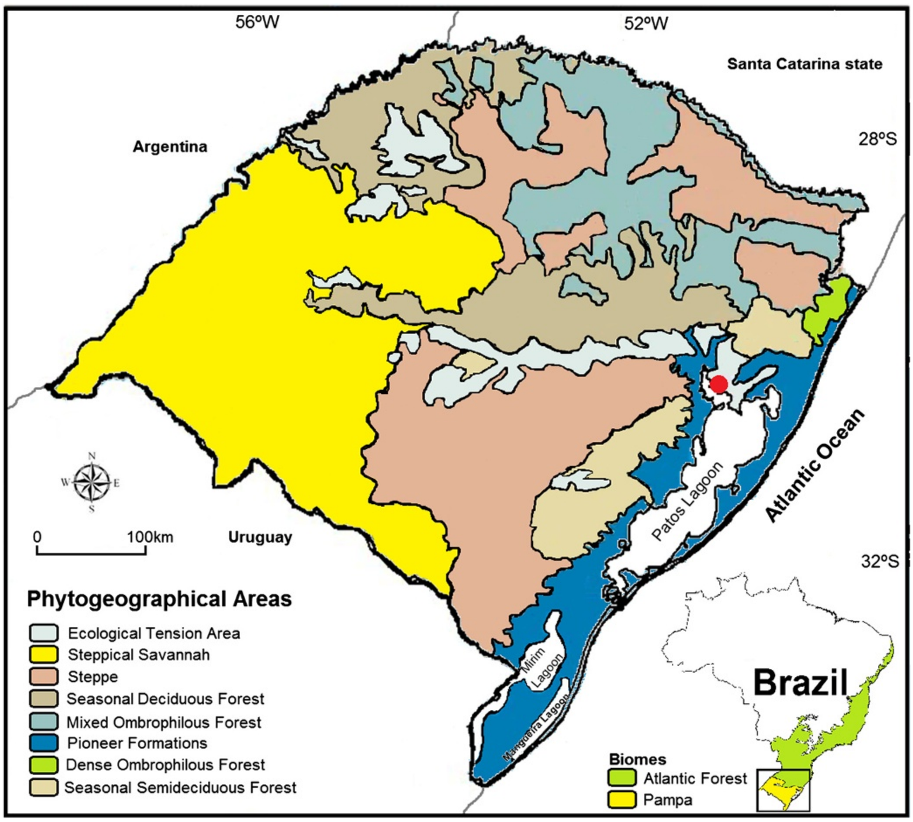

Figure 1 Rio Grande do Sul State and recognized phytogeographical regions. Red spot indicates Porto Alegre, the capital of the State. Phytogeographical regions follow Cordeiro and Hasenack (2009).

with types from the Butterflies of America project (http://www.butterfliesofamerica.com/L/Neotropical.htm) and by specialists. The nomenclature follows Callaghan and Lamas (2004).

Data analysis

The dataset used was plotted in cells of 27 × 27 km using the Diva-GIS 7.5 software (Hijmans et al. 2001), so that the spatial patterns of species richness through RS could be determined. To verify if the species richness per cell was correlated with the number of sites sampled on a cell, a Spearman correlation was performed.

To reduce the noise in the statistical analysis, we selected the 25 best-sampled municipalities for assessing all the eight phytogeographic regions (according to Cordeiro and Hasenack 2009) and its climatic and geographical combined factors. The similarities in riodinid species composition among the phytogeographic regions were performed through a non-metric multidimensional scaling (NMDS, Clarke 1993), in which the sampling units were the municipalities. The data matrix generated was calculated using the Simpson beta-diversity index (β_{sim}), which takes into account only the difference in species composition among samples, reducing any variation in sampling effort in different sites (Koleff et al. 2003). To test for differences in riodinid species composition, an analysis of similarities (ANOSIM) based in 10,000 permutations was used (Clarke and Warwick 1994).

To evaluate the effect of climatic and geographical factors on riodinid species composition, five environmental variables were included: (1) average monthly temperature, (2) daily range of temperature, (3) annual precipitation, (4) altitude, and (5) distance from the ocean (a measure of continentality). We choose these variables based on their importance to the description of the structure of lepidopteran assemblages in the Neotropical region (e.g., Brown and Freitas 2000a, b; Ferro and Melo 2011). The climatic variables were selected from the WorldClim database (Hijmans et al. 2005) in a resolution of 2.5 arc min (approximately 5 km). The distance to the ocean was obtained through the minimum distance between the coast and the municipalities. A Constrained Analysis of Principal Coordinates (CAPC, Anderson and Willis 2003) was used based on a dissimilarity matrix employing the Simpson beta-diversity index. The significance of the axes generated by CAPC was tested by an ANOVA based in 10,000 permutations (Legendre and Legendre 1998).

The spatial autocorrelation between sampling sites was assessed using a multivariate Mantel correlogram (Legendre and Legendre 1998; Borcard and Legendre 2012). A matrix based on species composition of each municipality using the Sørensen index as a measure of distance was built. This matrix was evaluated in relation to a geographic distance matrix in which for each municipality, eight distance classes were quantified, and a respective value of Pearson's R statistic was assigned. This analysis was performed to determine whether closest locations were more similar in species composition of Riodinidae, showing a positive autocorrelation, or less similar, showing a negative autocorrelation (Legendre and Legendre 1998). The significance of the correlogram was tested with 10,000 permutations.

The Mantel correlogram was computed with the software Spatial Analysis in Macroecology (SAM) version 4.0 (Rangel et al. 2010), other analyses were performed using the 'vegan' package (Oksanen et al. 2008) on the software R version 2.15 (R Development Core Team 2012).

Results

A total of 97 taxa (Additional file 1) of Riodinidae recorded from 92 municipalities on RS were gathered (Additional file 2), belonging to Euselasiini (6 spp), Eurybiini (3 spp), Helicopini (1 spp), Mesosemiini (5 spp), Nymphidiini (31 spp), Riodinini (29 spp), Symmachiini (11 spp), and Incertae Sedis (11 spp). Fourteen species are unpublished records, and for each municipality, the richness ranged from 1 to 37 species.

From the total 483 cells (27 × 27 km), formed by the grid generated over the area of RS, only 69 presented records of Riodinidae species, highlighting the lack of uniformity in sampling effort (Figure 2). The three richest cells were located in (1) southern (Pelotas and surroundings) belonging to Pampa, and in northeast RS in (2) Maquiné (representing the Atlantic Forest *stricto sensu* region) and (3) Porto Alegre, São Leopoldo and Viamão in the ecotone of both biomes. Cells in the west and southeast had few records. The observed species richness per cell was correlated with the number of the sampled municipalities ($r_s = 0.52$, $p < 0.01$).

The faunal composition in areas from the Pampa biome differed from Atlantic Forest sites (Figure 3), grouping Riodinidae according to the phytogeographic regions, especially in Pampa. This difference in species composition is statistically significant ($r = 0.56$, $p < 0.01$). Some exclusive species to native grasslands were recorded, such as *Aricoris gauchoana*, *Seco aphanis*, *Stichelia dukinfieldia* and *Zabuella tenellus*, *Barbicornis basilis ephippium* and *Stichelia pelotensis* were also recorded and are endemic to RS.

Similar results were obtained in the CAPC, which segregates the municipalities between the two biomes and the phytogeographic regions evaluated (Figure 4). The first three axes of the CAPC explained 82% of the variation on the species composition according to the environmental variables ($p < 0.05$; Table 1). Municipalities in the Dense and Mixed Ombrophilous Forests and Seasonal Semideciduous Forest were positively associated with precipitation. Sites with high altitudes were grouped. Distance from the ocean and temperature were

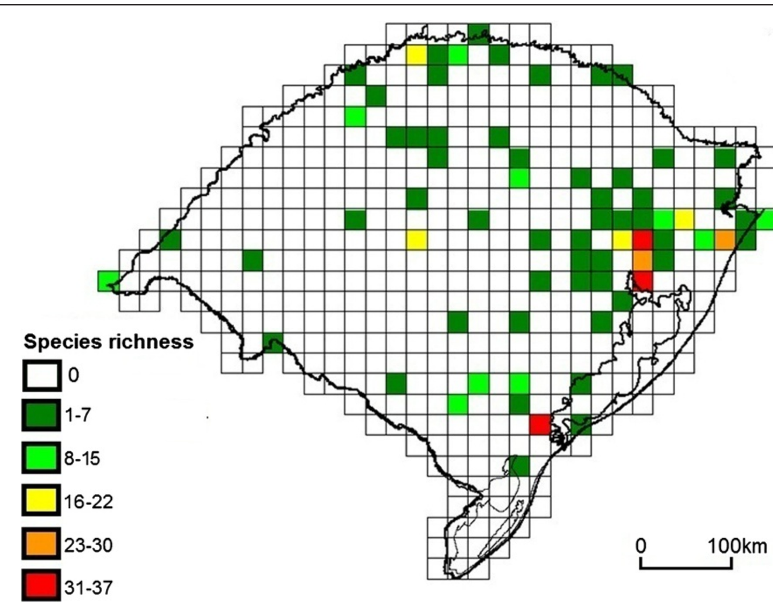

Figure 2 Spatial pattern of Riodinidae species richness recorded in Rio Grande do Sul State, Brazil.

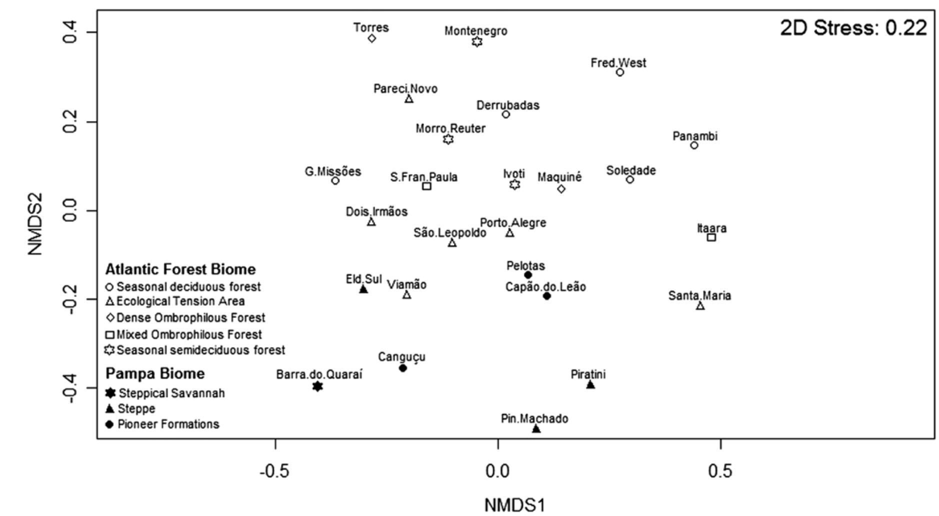

Figure 3 Non-metric multidimensional scaling (NMDS). Based on Simpson beta-diversity index (β_{sim}) for the Riodinidae species sampled in 25 municipalities in Rio Grande do Sul state, southern Brazil.

opposite to precipitation and altitude, while daily range of temperature was positively associated with grassland habitats and negatively associated with the other variables.

The multivariate Mantel correlogram indicates that species composition and geographical distance were correlated even if not strongly so ($r_M = 0.40$, $p < 0.01$). Small distances between sites (approximately 90 km) have positive values of autocorrelation ($p < 0.01$), followed by a decrease on these values, quickly at first, after stabilizing and then having slightly negative values (Figure 5). This spatial pattern indicates that nearest municipalities have more similar composition of Riodinidae and as the geographical distance grows, an increasing dissimilarity in species composition is observed.

Discussion

The distribution pattern of Riodinidae in the different biomes and phytogeographic regions in the extreme southern Brazil observed could be explained by climatic, environmental variables and geographic distance. The richness of Riodinidae recorded in this study represents 12.8% from the estimated total of this butterfly family in Brazil (Brown and Freitas 1999), 7.9% in the Neotropical region, and 7.5% in the global fauna (Hall 2002). The

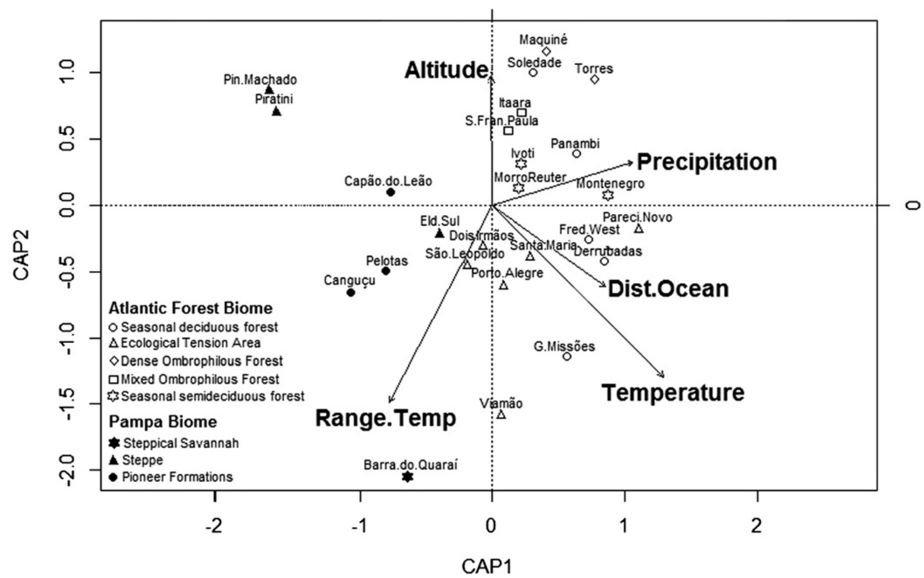

Figure 4 Constrained Analysis of Principal Coordinates (CAPC). Based on Simpson beta-diversity index (β_{sim}) for the Riodinidae species sampled in 25 municipalities in Rio Grande do Sul state, southern Brazil.

Table 1 Environmental variables and its correlations in the Constrained Analysis of Principal Coordinates

Variable	Axis 1	Axis 2	Axis 3
Altitude	−0.005	0.44	−0.43
Distance from ocean	0.39	−0.28	−0.84
Annual precipitation	0.48	0.14	−0.52
Daily range of temperature	−0.35	−0.67	−0.65
Average monthly temperature	0.58	−0.58	0.04

high number of unpublished records (approximately 18%) for the extreme southern region in Brazil corroborates the study developed by Morais et al. (2007) with butterflies in austral South America, in which Riodinidae, Lycaenidae, and Hesperiidae are the families which take longer to reach sampling sufficiency. Thus, these are likely to have the larger number of new occurrences to be registered in southern Brazil, and in the Neotropical region as a whole.

The grids which contained the higher number of species richness were located on the Atlantic Forest domain and in the ecotone between this biome and Pampa. On the other hand, the records of Riodinidae in Pampa are quite sparse, leaving significant gaps to be investigated. In general, this scenario is common for all butterfly families present in Pampa (Rosa et al. 2011). An important aspect should be considered: the well-sampled sites are reported in areas with an amount of researchers and established research institutions (mainly represented by universities) near the state capital (Porto Alegre) or their main research project sites (Iserhard and Romanowski 2004; Marchiori and Romanowski 2006a, b; Iserhard et al. 2010; Bellaver et al. 2012). In Brazil, this pattern is similar for all butterfly fauna, in which the counties that contain more inventories and higher values of species richness are located in areas surrounding important research centers, greatly limiting the access and exploitation to few and limited areas (Santos et al. 2008).

The NMDS result showed similar patterns to those found by Ferro and Teston (2009) for the Arctiidae assemblages in the same region in southern Brazil, but in a more restricted scale: grassland environments had a distinct fauna than that occurring in forested areas. In fact, the composition and occurrence of Lepidoptera are strongly associated with gradients of vegetation (e.g., Brown and Gifford 2002; Summerville et al. 2001); although, in this study, most records were concentrated in regions of Atlantic Forest, it was possible to observe differences on the composition of riodinid between Pampa and Atlantic Forest sites. This result is not surprising given that, when compared, these two biomes have very distinct habitats and formations, floristic composition, and structure and architecture of vegetation and suffer influences of different subsets of abiotic factors segregating, in this way, the riodinid fauna.

The riodinid species composition grouped by phytogeographic regions in areas of the Atlantic Forest domain were not well defined, except for sites located on the ecological tension area. The lack of sampling effort in sites on the Seasonal Semideciduous Forests and the occurrence of the most frequent Riodinidae species in all phytogeographic forested regions (not helping to recognize differences in vegetation in this scale of evaluation) are possible explanations for these patterns. In this study, two common riodinid species whose presence indicates an especially rich environment were recorded for the first time in the Atlantic Forest of this Brazilian region: *Euselasia zara* and *Symmachia arion* (Brown

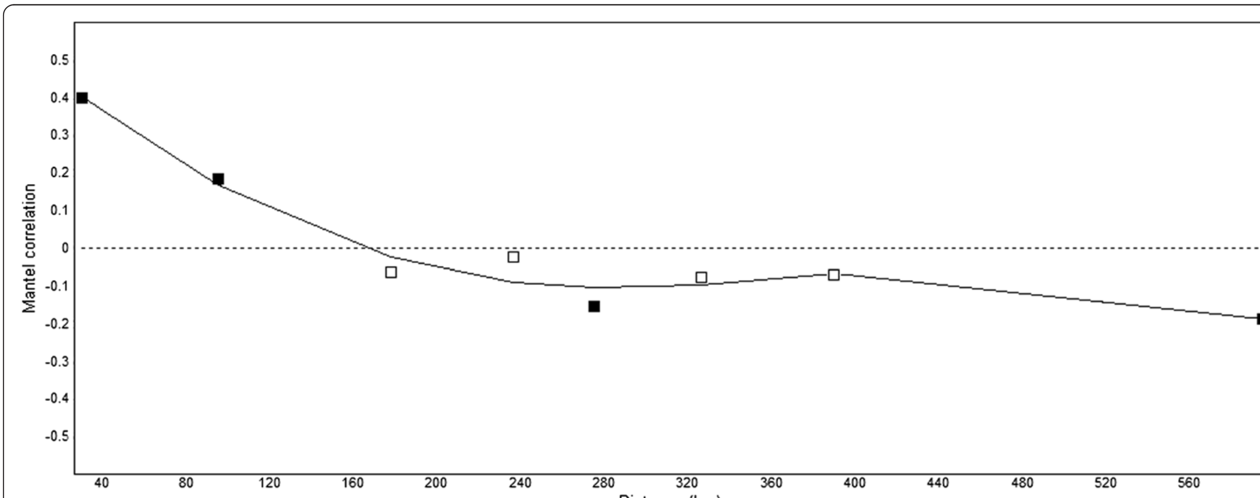

Figure 5 Multivariate Mantel correlogram. Based on the Sørensen index for spatial autocorrelation in Riodinidae assemblages in Rio Grande do Sul state, southern Brazil. Significant values ($p < 0.05$) are represented by dark squares.

and Freitas 2000b). The Atlantic Forest domain is a highly threatened biome due to changes and depletion of their native habitats over time, and actually less than 7.5% of their original extension remains, broken into small and sparse fragments (Myers et al. 2000; Ribeiro et al. 2009). Brown and Freitas (2000a) recorded 368 species of Riodinidae for the Brazilian Atlantic Forest, and about 40% are endemic to this biome, emphasizing the importance of conserving these remaining fragments to the maintenance of biological diversity. On the other hand, the grouping of butterflies according to the phytogeographic regions present in the Pampa indicate a peculiar composition related to each open grassland habitat and to the endemism of some species found in the present study. These results reinforce the fact that different Pampa habitat types are unique and diverse with large levels of endemism and biodiversity (Pillar et al. 2009).

Emphasizing the abovementioned results, an important record related to an endemic species in the Rio Grande do Sul was found: *Stichelia pelotensis* was collected only twice, through a historical record in the extreme southern region of this state, near the boundaries with Uruguay in the 1950s and one recent collection (in 2001) from the vicinities of the state capital in a protected area in the Rio Grande do Sul east region, located in the Coastal Plain. Probably, this species is distributed only in this region in Brazil, since records were made in a narrow range concerning the extreme southern Brazilian Coastal Plain in 'Restinga' forest and 'Butiazal' formation, the latter being a peculiar and exclusive physiognomy in this region. These environments have been suffering intense modification due to irregular settlements and building, so their depletion and fragmentation can bring irreversible consequences to riodinid butterflies.

Several species of Riodinidae present a restricted spatial distribution given their population rates being lower than other butterflies and tending to high fluctuations, which make them easily threatened by the loss of native areas (New 1993). In addition, they are difficult to sample in short periods of time. In southern Brazil, the natural grasslands are being increasingly converted into areas for agriculture, silviculture, and livestock grazing. The Pampa biome has less than 0.5% of its area included in protected areas (Overbeck et al. 2007). Thus, not only Riodinidae but also all butterflies in close association with this vegetation may be threatened, and the first step to their conservation ought to be the creation of new legal protected areas (Overbeck et al. 2007; Dolibaina et al. 2011).

Climatic and geographical factors are important to describe patterns of structure of butterfly communities (Brown and Freitas 2000a). In our study, distance from the ocean, precipitation, and temperature were the most important variables which explain the variation of the riodinid assemblages in the Atlantic Forest. Altitude was another important factor, grouping sites characterized by the presence of the Mixed Ombrophilous Forest (*Araucaria angustifolia* Forest), a type of vegetation exclusive of the south Brazilian region. In Atlantic Forest, the montane forests, such as *Araucaria* Forest sites, seem to present a higher similarity on its floristic composition (e.g., Oliveira-Filho and Fontes 2000; Garcia et al. 2009; Urbanetz et al. 2010), which may be influencing the patterns of occurrence of some lepidopteran species (e.g., Brown and Freitas 2000a; Ferro and Melo 2011).

All municipalities in the Pampa biome, in the southern portion of the south region, were associated with the range of temperature. In fact, areas further from the equator present wide ranges of temperature, reflecting a decrease in species along a latitudinal gradient (see Hillebrand 2004). The study area lies in a transition zone between tropical and temperate climate (Overbeck et al. 2007), showing marked seasonality with four defined seasons. The richness of Riodinidae seemed to be correlated with warmer temperatures, presenting high values in Amazonia and in areas of Atlantic Forest in southeast Brazil (Brown 2005). Thus, the lower richness of Riodinidae in Pampa when compared with other sites near the equator, may be associated, beyond the lack of specific inventories, to the influence of a latitudinal gradient.

As geographical distance increases, the similarity in environmental factors decays across landscapes and the species composition of Riodinidae as well (e.g., Nekola and White 1999). The overall shape of the correlogram could be attributed either to a species gradient or to environmental factors (Legendre and Fortin 1989), corroborating the previous multivariate analysis.

It is important to note that our database was constructed mainly with museum data, and in many cases, its use should be carefully interpreted because of the bias regarding the different sampling efforts (Ponder et al. 2001; Graham et al. 2004; Moerman and Estabrook 2006). Similarly, Ferro and Melo (2011) also used museum data to describe the diversity of tiger moths in the Brazilian Atlantic Forest and discussed this aspect. Even so, both their results and ours seem quite robust. The information yielded indicates a structure for the riodinid assemblages of southern Brazil similar to that described for the tropical lepidopteran fauna (e.g., Brown and Freitas 2000b).

Conclusions

Despite the fact that the extreme southern Brazil has been considered one of the better sampled regions for butterfly surveys (Santos et al. 2008), it is important to emphasize the need to intensify specific and well-sampled inventories. Thus, it is possible to more accurately evaluate patterns of structure, distribution, and composition of butterflies, to generate data for larger scales of evaluation in the Neotropical region, reaching the level of macroecology. This study may be seen as reflecting the current knowledge on the Riodinidae fauna in an austral South American region, and we suggest these same variables may also affect the distribution of the taxon in other parts of the neotropics as well. The data on Riodinidae species distribution show variable degrees of endemism in unprotected areas, providing subsidies to a better assessment directed towards conservation schemes and public policies to justify the maintenance of protected areas and, mainly, the proposal and creation of others.

Additional files

Additional file 1: Riodinidae species list from Rio Grande do Sul state, southern Brazil. * See Additional file 2 for municipality codes. ** Reference sources: [a]Azzará 1978, [b]Bellaver et al. 2012, [c]Biezanko et al. 1978, [d]Bonfantti et al. 2009, [e]Dessuy and Morais 2007, [f]Giovenardi et al. 2008, [g]Hall and Harvey 2001, [h]Hall and Harvey 2002a, [i]Iserhard and Romanowski 2004, [j]Iserhard et al. 2010, [k]Krüger and Silva 2003, [l]Marchiori and Romanowski 2006a, [m]Marchiori and Romanowski 2006b, [n]Morais et al. 2012, [o]Ritter et al. 2011, [p]Sackis and Morais 2008, [q]Rosa et al. 2011, [r]Dolibaina et al. 2013, [s]Dias et al. 2013, [t]Siewert et al. 2014. *** See text for museum acronyms. # Unpublished records for Rio Grande do Sul state.

Additional file 2: Municipalities, phytogeographic region and geographical coordinates from Rio Grande do Sul state, southern Brazil. *According to Cordeiro and Hasenack (2009). P, Pampa Biome; AF, Atlantic Forest Biome.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
RS carried out the design of the study and performed the data collection, identification of all material, the statistical analyses, and drafting of the manuscript. CI contributed in the statistical analyses and drafting of the manuscript. HR helped in several aspects along this work, as well as acting in the coordination. CC participated in the identification of the material, data collection, and discussion. AM participated in the data collection. All authors read and approved the final manuscript.

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